

**National Capital Region Transportation Planning Board
Metropolitan Washington Council of Governments**

**FY-2009 Development Program for
TPB Travel Forecasting Models**

June 30, 2009

DRAFT

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Abstract: This report describes work activities undertaken during FY-2009 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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Chapter 1 Introduction

The National Capital Region Transportation Planning Board (TPB) maintains a travel modeling capability that supports regional studies conducted by TPB staff as well as project planning studies conducted by state and local transportation agencies. The TPB recognizes that its travel modeling capability must be refined on a continuing basis in order to respond to changing federal requirements, to address new questions being asked by decision makers, and to incorporate advances in the state-of-the practice. The TPB FY-2009 Unified Planning Work Program (UPWP) includes this activity under element 4.C (Models Development). This report describes models development activities undertaken during FY-2009, i.e., from July 1, 2008 to June 30, 2009.

The Models Development program is overseen by the TPB Travel Forecasting Subcommittee (TFS), a subcommittee to the TPB Technical Committee. The TFS is comprised of representatives from state and local transportation agencies in the Washington, D.C. region and the Washington Metropolitan Area Transit Authority (WMATA). Transportation consultants working in the region and various public interest groups are also TFS participants. The TFS meetings occur on a bi-monthly schedule beginning in July.

Implementing travel modeling improvements presents some practical concerns for any MPO. Given that production-ready forecasting procedures are needed to serve regularly scheduled planning activities, there are inherent uncertainties about when proposed improvements will be ready for application. The Models Development program has been designed to manage uncertainty by structuring model improvement activities among five concurrent “tracks”:

- **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 into 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 four-step model or a “next generation” model. The plan is that, at some point, one of the candidate “methods” models would 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 tracks are established to occur over a multi-year period, allowing for longer-term improvements to proceed off-line while the application model is maintained to support immediate planning needs. The longer-term improvements are phased into application only when deemed appropriate by TPB staff, in consultation with the TFS. Specific activities associated with each track are formulated by TPB staff based on recommendations of formal model reviews, emerging study needs, and changes in federal guidance.

1.1 FY-2009 Models Development Program Background

The TPB's currently adopted travel forecasting process is known as the Version 2.2 model¹. Version 2.2 is a conventional "four-step" travel forecasting process, a process commonly employed by most large MPOs in the U.S. The model is applied on a microcomputer using Citilabs TP+/Cube Base software and operates on a 2,191 transportation analysis zone (TAZ) system. During FY-2009, minor refinements to the Version 2.2 model structure were implemented and some model inputs were updated. Especially significant was the release of Round 7.2 and Round 7.2a land activity forecasts by COG's Metropolitan Development Policy Committee. Work activities also included the ongoing development of a more refined model, known as Version 2.3. Version 2.3 is similar to the Version 2.2 model but features several refinements, including a nested-logit mode choice model and updated truck models. The Version 2.3 model was released in draft one year ago,² but still remains in development, due to two decisions taken in FY-2009: 1) to re-calibrate the model using the new 3,700-TAZ zone system, and 2) to re-calibrate the model using several new data sets. Both of these issues are discussed below.

The first issue relates to the development of a more detailed Transportation Analysis Zone (TAZ) system. The revised TAZ system will maintain the same geographic extent as the existing modeled study area, but will be comprised of approximately 3,700 internal zones. This is a substantial increase over 1,972 internal TAZs that comprise the existing study area. The design of the more detailed TAZ system has been influenced by regional activity centers and clusters identified by COG's Metropolitan Development Policy Committee. These are locations of existing and planned concentrations of development along transportation corridors. The activity centers and clusters were intended to be used as a tool to help guide land use and transportation planning decisions. The new zone system is anticipated to be approved at the beginning of FY-2010.

The second issue relates to the development of several new data sets. These include the 2007/2008 Household Travel Survey, the 2007 Metrorail Survey, and the 2008 Regional Bus On-Board Survey. The arrival of new travel survey data is an especially significant event with respect to models development since the previous household travel survey was conducted in

¹ Ronald Milone et al., *TPB Travel Forecasting Model, Version 2.2: Specification, Validation, and User's Guide* (Washington, D.C.: Metropolitan Washington Council of Governments, National Capital Region Transportation Planning Board (COG/TPB), March 1, 2008)

² Ronald Milone et al., *TPB Travel Forecasting Model, Version 2.3: Specification, Validation, and User's Guide*, Draft report (Washington, D.C.: Metropolitan Washington Council of Governments, National Capital Region Transportation Planning Board (COG/TPB), June 30, 2008)

1994. These new data sets will provide the foundation for calibration files to be prepared during FY-2010. The household and Metrorail survey files are currently anticipated to be released for calibration work at the beginning FY-2010. The bus on-board survey will be available later, perhaps during the fall of 2010.

During the first half of FY-2009, TPB staff decided to delay the release of Version 2.3 in order to integrate the new TAZ system and transportation survey data with the Version 2.3 model development. In the mean time, staff focused its development activities on complimentary work efforts, including: 1) sensitivity testing of the draft Version 2.3 model, 2) investigating avenues for reducing the running time of the model, and, 3) investigating refinements to the development of transit fare inputs to the travel model.

As in previous years, TPB continued to retain the services of a transportation consultant (Cambridge Systematics, Inc.) to provide technical support on a task order basis. This contractual arrangement was established primarily to provide for an ongoing assessment of the TPB's travel modeling performance and practices. It also served to provide written guidance on specific models development issues raised by TPB members or TPB staff drawing upon knowledge of travel modeling practices at other MPOs. Receiving this type of independent feedback on the TPB's modeling practices has been useful in formulating the future direction of the models development program. During FY-2009, TPB asked the consultant for written guidance on five areas:

1. Fuel Prices in Travel Models
2. Recommended Approach to Near-Term Model Enhancements
3. Framework for Before-and-After Study of HOV Network Effects Due to New HOT Lanes
4. Improving the Model's Sensitivity to Land Use Policies and Non-Motorized Travel
5. Recommendations on Feedback Convergence Methods

These reports will be compiled and published as a compiled self-standing document, which will be reviewed by both the TPB staff and the TFS.

1.2 Structure of the Report

The following chapters detail the key model development activities that were undertaken during FY-2009. Applications track activities are described in Chapter 2, including refinements made to the currently adopted Version 2.2 model and a description of inputs to the Version 2.2 model that have been recently updated. Chapter 2 also includes a number of developmental activities relating to the Version 2.3 model that were undertaken. Methods Track activities are discussed in Chapter 3, including research on airport ground access modeling and the TPB's plans for migrating towards more advanced modeling procedures. The TPB's efforts to keep abreast of transportation research, and modeling practices at other agencies, are presented in Chapter 4. Transportation activities relating to data-cleaning and preparation are addressed in Chapter 5. Finally, a discussion of the models development program direction in the coming fiscal year (FY-2010) and beyond is discussed in Chapter 6.

Chapter 2 Applications Track

This chapter details the application track activities undertaken during FY-2009. Two subsections are presented. The first section addresses updates to the currently adopted Version 2.2 model. The second section addresses activities supporting the Version 2.3 model currently in development.

2.1 Version 2.2 Model Updates

The Version 2.2 travel model supported the TPB's 2009 CLRP / 2010-2015 TIP Air Quality Conformity Determination, undertaken in the spring of 2009. In preparation for this regional analysis, transportation networks were revisited to reflect the latest plan and 6-year transportation improvement program. In addition, other basic inputs to the model were updated during FY-2009 and minor changes to the model specification were implemented.

2.1.1 Changes to Modeling Inputs

Beyond the update of transportation networks, three changes to modeling inputs were implemented during FY-2009: 1) an updated set of land activity forecasts, known as the Round 7.2 Cooperative Forecasts, was released and prepared for use as an input to the travel model, 2) the Consumer Price Index (CPI) schedule for deflating transportation costs from the present year (2009) to constant/base year (1994) values was refreshed using the latest Bureau of Labor Statistics data, and 3) the latest WMATA fare tariff used to develop transit fare inputs to the mode choice model was updated. These updates are described in greater detail below.

Round 7.2 Land Activity

Round 7.2 Cooperative Forecasts at the TAZ level were released by COG's Metropolitan Development Policy Committee on April 9, 2009.¹ These forecasts consisted of household, population, and employment estimates from 2005 to 2040 in five-year increments. The previous set (Round 7.1) of land activity forecasts were released on August of 2007.²

With the release of new land activity forecasts, procedures have been established to read standard files containing Cooperative Forecasts and to develop year-specific files in the format required by the Version 2.2 model.³ The procedures also include other functions:

- 2000 CTPP-based employment adjustment factors are applied to job forecasts for some non-COG member jurisdictions. The adjustments are necessary to account for definitional differences used by local planning agencies.
- Exogenous travel files, including external person and truck trips, through (X-X) auto driver trips and truck trips, and airport passenger auto driver trips, are prepared. The land use forecasts are combined with the exogenous travel forecasts to ensure that growth assumptions over time are consistent.
- As the Cooperative Forecasting Process develops land activity projections in five-year increments, the processing steps allow for the creation of land use files and exogenous

¹ Paul DesJardin to Michael J. Clifford, "Round 7.2 Cooperative Forecast TAZ file," Memorandum, April 9, 2009.

² Paul DesJardin, "Final Round 7.1 Cooperative Forecast TAZ File," Memorandum, August 24, 2007.

³ Ronald Milone to DTP Technical Staff, "Version 2.2 Travel Model Inputs Based on Round 7.2 Cooperative Forecast," Memorandum, April 17, 2009.

travel files for each individual year, using linear interpolation. Off-year travel simulations are typically needed for air quality conformity determination or for special project planning needs.

It should be noted that the Round 7.2 forecasts for 2020 and beyond underwent some technical corrections (“Round 7.2a”) for a single TAZ in the District of Columbia.⁴ Land activity estimates were revised, but the exogenous trip forecasts developed earlier were maintained. Regional Round 7.2 land activity totals are shown in Table 2-1.

Table 2-1 Round 7.2 Land Activity Forecasts Used for Travel Modeling

Year	HHs	HH_Pop	GQ	Total_Pop	Total_Emp	Ind_Emp	Ret_Emp	Off_Emp	Oth_Emp
2000	2,143,451	5,632,014	116,105	5,748,119	3,441,381	459,906	628,912	1,630,149	722,414
2005	2,340,093	6,156,586	119,674	6,276,260	3,705,269	530,326	648,763	1,752,534	773,646
2010	2,520,189	6,542,999	122,861	6,665,860	3,992,826	562,340	703,827	1,898,797	827,862
2015	2,714,085	6,954,175	126,929	7,081,104	4,312,926	599,227	762,615	2,069,164	881,920
2020	2,895,063	7,365,606	129,376	7,494,982	4,639,392	641,223	817,340	2,246,525	934,304
2025	3,048,186	7,722,614	132,810	7,855,424	4,918,096	676,405	861,863	2,383,043	996,785
2030	3,181,103	8,016,488	136,870	8,153,358	5,159,927	709,852	902,097	2,510,899	1,037,079

Note: -CTPP-based Employment adjustments are used
 -Technical corrections made to TAZ 62 in the District of Columbia

Cost Deflation Updates

Current- and future-year transportation costs such as transit fares and highway tolls must be converted to an earlier “constant” year, typically the year for which the travel model was calibrated. The calibration year of the Version 2.2 model was 1994. The conversion, or deflation, of costs is addressed in the Version 2.2 job stream model using a factor that is developed from a yearly Consumer Price Index (CPI) table (annual CPI data is periodically published by the Bureau of Labor Statistics (BLS) as a generalized measure of price inflation). TPB uses the average annual CPI associated with all urban consumers – U.S. city average (’82-’84=100.0). The deflation factor is computed as the ratio of the CPI for 1994 to the CPI of the year being modeled. The CPI generally increases in magnitude with each successive year. Accordingly the deflation factor of 1994 would equal a value of 1.00, and the deflation factor for years following 1994 would be less than 1.00.

The deflation factor calculation for prior years (1994-2008) is straightforward: one would calculate the ratio using the historical CPI schedule published by the BLS. The deflation factor of the current-year (2009) or of forecast years (2010 and beyond) involves assumptions. TPB’s default assumption for modeling is that travel costs will escalate *directly* with the historical rate of inflation. Table 2-2 shows the historical CPI data and the projected CPI values calculated using the TPB’s assumption. Figure 2-1 shows the same information graphically. The key point regarding Table 2-2 is the average rate of inflation assumed for today and in the future is linked to the actual (and most up-to-date) historical CPI growth observed between 1994 and 2008.

During the application of the Version 2.2 model, a deflation factor is automatically computed in the job stream with the SET_CPI.S script. The script calls a small file (CPI_File.txt), which contains an annualized CPI schedule and which normally resides in the \INPUTS subdirectory. This file

⁴ Ronald Milone to DTP Technical Staff, “Technical Correction of Round 7.2 Cooperative Forecasts,” Memorandum, May 7, 2009.

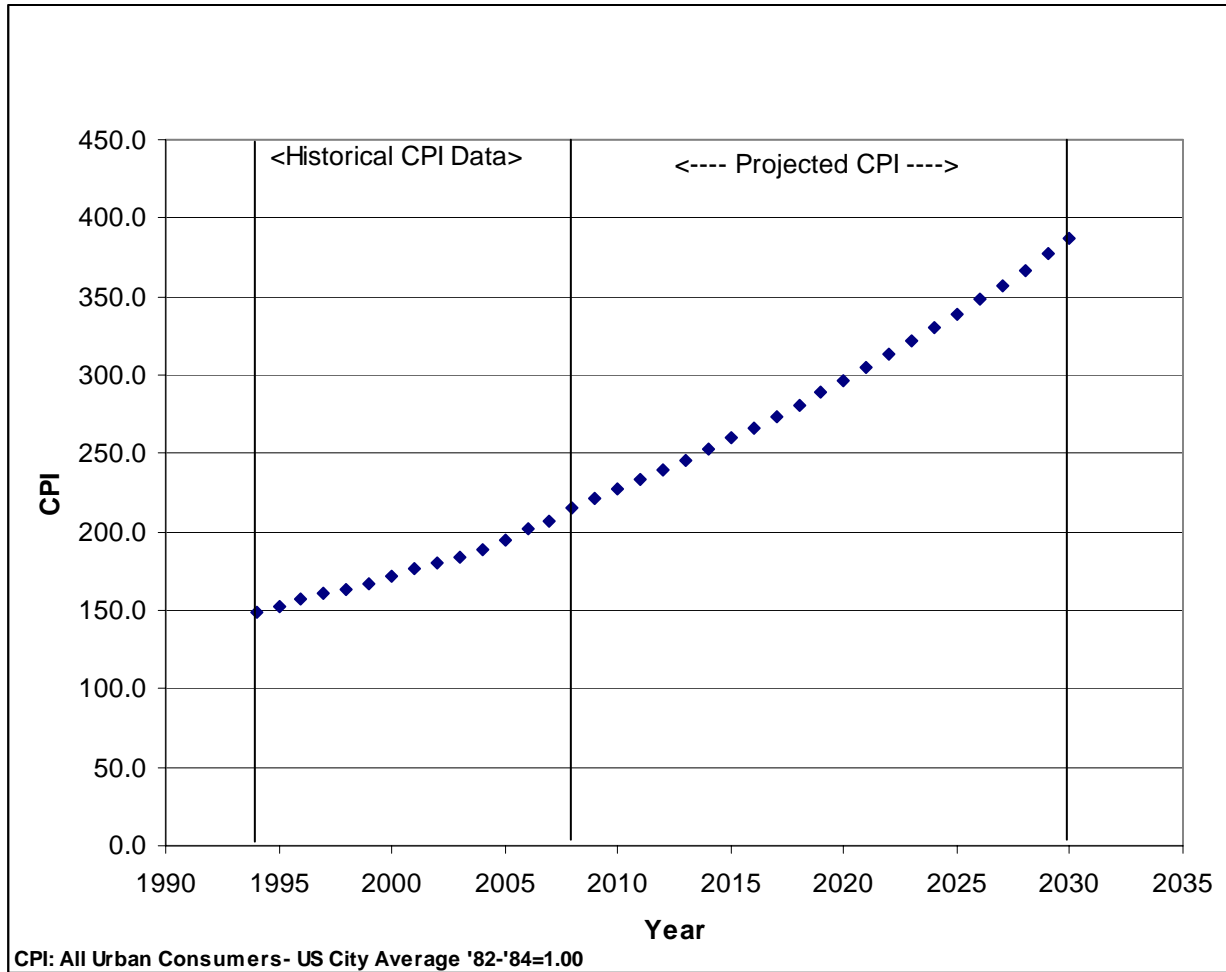
was updated during FY-2009 to reflect the latest BLS CPI schedule. The parameters specified in the CPI_File.txt file are:

- 1) BaseCPIYear=???? – This parameter indicates the “constant-dollar” year used for the model. In our case (as per Version 2.2) the BaseCPIYear is “1994”.
- 2) CurrCPIYear=???? – This parameter indicates the year for which the most recent average annual CPI data exists from the BLS. Presently, the CurrCPIYear is “2008”, as this is the most recent year for which the *complete* average annual CPI information is available.
- 3) The yearly historical CPI schedule – This is a look-up table that reflects pre-existing yearly CPI data. The key point about the schedule is that it needs to supply annual CPI information beginning with the BaseCPIYear and ending with the CurrCPIYear. TPB staff recommends that this file should be updated each year, as new average annual CPI information becomes available.

Table 2-2 Historic and Projected CPI Values – 1994 to 2030

Year	CPI	1994-to-Year CPI Ratio	Avg. Annual CPI Growth (from 1994 to Year)		
1994	148.2	1.00000	-		<--- BaseCPIYear =
1995	152.4	0.97244	2.834%	*	
1996	156.9	0.94455	2.893%		
1997	160.5	0.92336	2.693%	H	
1998	163.0	0.90920	2.408%	I	
1999	166.6	0.88956	2.368%	S	
2000	172.2	0.86063	2.533%	T	
2001	177.1	0.83682	2.578%	O	
2002	179.9	0.82379	2.453%	R	
2003	184.0	0.80543	2.433%	I	
2004	188.9	0.78454	2.456%	C	
2005	195.3	0.75883	2.541%	A	
2006	201.6	0.73512	2.598%	L	
2007	207.3	0.71491	2.615%		
2008	215.3	0.68834	2.704%	*	<--- CurrCPIYear =
2009	221.1	0.67022	2.704%	*	
2010	227.1	0.65258	2.704%		
2011	233.2	0.63540	2.704%		
2012	239.5	0.61867	2.704%		
2013	246.0	0.60239	2.704%		
2014	252.7	0.58653	2.704%		
2015	259.5	0.57109	2.704%	P	
2016	266.5	0.55606	2.704%	R	
2017	273.7	0.54142	2.704%	O	
2018	281.1	0.52717	2.704%	J	
2019	288.7	0.51329	2.704%	E	
2020	296.5	0.49978	2.704%	C	
2021	304.5	0.48662	2.704%	T	
2022	312.8	0.47381	2.704%	E	
2023	321.2	0.46134	2.704%	D	
2024	329.9	0.44920	2.704%		
2025	338.8	0.43737	2.704%		
2026	348.0	0.42586	2.704%		
2027	357.4	0.41465	2.704%		
2028	367.1	0.40373	2.704%		
2029	377.0	0.39311	2.704%		
2030	387.2	0.38276	2.704%	*	

Figure 2-1 Historical & Projected CPI - 1994 to 2030



The SET_CPI.S script combines information specified in CPI_File.txt with the environment variable in RUNALL_?????.bat which specifies the specific year being simulated (set _year_=????), thus producing two small files with consistent deflation factors (Trn_Deflator.txt and Hwy_Deflator.txt). These files are, in turn, called into subsequent scripts that process highway and transit costs. A listing of the updated CPI_file.txt file is shown in Figure 2-2. As an example, using the CPI schedule shown in Figure 2, the deflation factor for 2009 would equal:

$$CPI_{1994} / CPI_{2009} = 148.2 / 221.1 = 0.6702$$

In converting future year tolls to existing (2009) conditions, the factor would be developed using CPI information shown in Table 2-2. For example, a \$1.00 toll in the year 2010 would be converted to 2009 dollars using the conversion factor:

$$CPI_{2009} / CPI_{2010} = 221.1 / 227.1 = 0.9736$$

Therefore, \$1.00 in 2010 is equal to 97 cents in 2009.

Figure 2-2 Example of Updated CPI_File.txt File

```

;; ----- Inflation Parameters -----
;; - RJ Milone - 4/13/2009 - CPI data from BLS / All Urban Consumers (CPI-U) US City Avg. / 1982-84=100

InflationFTR      = 1.0          ; Inflation Assumption (DEFAULT IS 1.0)
Defl_Override     = 0.0          ; Deflation Override (DEFAULT IS 0.0) If Non-zero it is used as deflator
                                ; Used as deflator IF NON-ZERO
BaseCPIYear       = 1994         ; Base year of the CPI Table below
CurrCPIYear       = 2008         ; Current year on CPI table below (Most current year for which CPI data is
available)
;
;=====
; Establish historic CPI table and Deflation Factor =
;=====
;
LOOKUP Name=CPI_Table,
LOOKUP[1] = 1,Result = 2,          ; CPI index (from US BLS)
LOOKUP[2] = 1,Result = 3,          ; Compounded Growth Rate From Base Year
LOOKUP[3] = 1,Result = 4,          ; Deflation Factor
Interpolate = N, FAIL=0,0,list=Y,
;
;;
;;          (1-((YrCPI/BsCPI)^(1/n)))*100      (BsCPI/YrCPI)
;;          Annual_Avg.                        Historic Deflation
;; YEAR    CPI      Growth_Rate                Factor
;; -----
R=' 1994,   148.2,    0.000,          1.00000', ; <--- BaseCPIYear
' 1995,   152.4,    2.834,          0.97244', ;
' 1996,   156.9,    2.893,          0.94455', ;
' 1997,   160.5,    2.693,          0.92336', ;
' 1998,   163.0,    2.408,          0.90920', ;
' 1999,   166.6,    2.368,          0.88956', ;
' 2000,   172.2,    2.533,          0.86063', ;
' 2001,   177.1,    2.578,          0.83682', ;
' 2002,   179.9,    2.453,          0.82379', ;
' 2003,   184.0,    2.433,          0.80543', ;
' 2004,   188.9,    2.456,          0.78454', ;
' 2005,   195.3,    2.541,          0.75883', ;
' 2006,   201.6,    2.598,          0.73512', ;
' 2007,   207.3,    2.615,          0.71491', ;
' 2008,   215.3,    2.704,          0.68834', ; <--- Curr(ent)CPI Year
;
; --- end of CPI File -----

```

WMATA Tariff Update

The Version 2.2 model utilizes a small text file named tariff.txt to specify a number of parameters associated with WMATA transit fare policy for a particular year. The file is accessed by the process that is used to develop station-to-station Metrorail fares and zone-to-zone total transit fares. The file normally resides in the \INPUTS subdirectory. This tariff.txt file specification was updated during FY-2009 and is to be used for model years 2009 (today) and all years beyond (2010-2030). The tariff parameters are consistent with WMATA Tariff #25 (effective January 6, 2008). Two changes have been implemented:

Beginning January 4, 2009, WMATA discontinued the use of paper transfers, which previously discounted rail-to-bus transfers by 90 cents. At present, rail/bus discounts are available *only* to SmartTrip card holders. A 50-cent discount is applied both to bus-to-rail transfers and to rail-to-bus transfers. Therefore the daily rail-to-fare discount parameters (DC_RailBus_Disc, MD_RailBus_Disc, VA1_RailBusDisc, and VA2_RailBusDisc) are specified as \$1.00 as opposed to 90 cents assumed previously. (We will assume for now that all average weekday transit riders are SmartTrip users).

A review of the latest published tariff document indicates slightly revised values for the incremental per-mile rates used to compute the peak Metrorail fare as compared to the values assumed last year. Specifically, the parameter specifying the incremental fare rate for trips beyond 3 miles but less than or equal to 6 miles (Pk_Fare_Rate2) was revised from 27 to 26 cents per mile. The parameter specifying the incremental fare rate for trips beyond 6 miles (Pk_Fare_Rate3) was revised from 24 to 23 cents per mile.

As stated, the updated tariff file above file applies *only* to present and future model years. Note that both of the above changes will effectively *reduce* peak transit fares slightly which, in turn, will result in a small *increase* in the number of modeled HBW transit trips in comparison with last year's results, all other things being equal. A listing of the revised file appears in Figure 2-3.

Figure 2-3 Listing of the updated tariff file (tariff.txt)

```

-----
;;
;; WMATA Tariff #25 effective January 2008 fare structure input to MFARE2.S
;; Note: Beginning Jan 4, 2009 Metro NO LONGER uses paper transfers
;; Rail/Bus transfer discounts etro NO LONGER uses paper transfers
;; (Prepared April 23, 2009/rjm)
;;
-----
;; Peak and OffPeak Metrorail Policy
;
; Fare Increment      Fare Rate in Cents      Trip Distance Increment(in Composite Miles)
; in Cents           per Composite mile:    Associated with Fare Increment/Rate
;-----
Pk_Fare_Incr1 = 165.0  Pk_Fare_Rate1 = 0.0    Pk_Fare_Dist1 = 3.0    ;
Op_Fare_Incr1 = 135.0  Op_Fare_Rate1 = 0.0    Op_Fare_Dist1 = 7.0    ;

Pk_Fare_Incr2 = 0.0    Pk_Fare_Rate2 = 26.0   Pk_Fare_Dist2 = 3.0    ;
Op_Fare_Incr2 = 50.0   Op_Fare_Rate2 = 0.0    Op_Fare_Dist2 = 3.0    ;

Pk_Fare_Incr3 = 0.0    Pk_Fare_Rate3 = 23.0   ;
Op_Fare_Incr3 = 50.0   Op_Fare_Rate3 = 0.0    ;

Pk_Fare_Max    = 450.0    ;
Op_Fare_Max    = 235.0    ;

-----
;;
;; Rail-to-Bus discounts in current year cents based on selected tariff  ;;
;;
;; DC_RailBus_Disc = 100.0 ; Area defined by Jur='0' in the zone file input ;; Discount available to
SmartTrip card holders only
MD_RailBus_Disc = 100.0 ; Area defined by Jur='1' in the zone file input ;; Rail-to-bus discount
is 50 cents
VA1_RailBusDisc = 100.0 ; Area defined by Jur='2' in the zone file input ;; Bus-to-Rail discount
is 50 cents
VA2_RailBusDisc = 100.0 ; Area defined by Jur='3' in the zone file input ;;

```

2.1.2 Refinements to the Version 2.2 Travel Model

The key structural change that was implemented to the Version 2.2 model pertained to the treatment of highway tolls in the trip distribution step. The trip distribution process in Version 2.2 is based on a gravity model formulation. Twenty-seven separate gravity models are applied, corresponding to market segments that are divided among movement type (internal and external travel), mode (auto, commercial vehicle, and truck types), and income strata. The measure of impedance used among residential submarkets is a composite of transit and congested highway time.

The Version 2.2 model captures the effect of highway tolls in trip distribution by converting highway tolls encountered along a path into equivalent minutes which are added to the congested time normally computed with the restrained speed and distance. The development of an equivalent time calculation varies by income strata and mode. In developing the travel time equivalents of tolls, the calculation reflects the assumption that lower income travelers will be more sensitive to highway tolls than higher income travelers. The treatment of tolls using this type of approach was originally developed to affect the *internal* travel markets only. During the course of recent project planning work using Version 2.2, it became apparent that the effect of tolls should be extended beyond internal travel markets to include external travel markets, as well. The trip distribution scripting was updated to ensure that the highway tolls were reflected in the travel time developed for external auto travel. The toll time equivalent applied to external travel is based on an average time valuation.

The Version 2.2 travel model also uses a two-step traffic assignment, which was described in a presentation to the TFS⁵ and other technical documentation.⁶

⁵ Ronald Milone and Mark Moran, "TPB Models Development Status Report" (Presentation at the Travel Forecasting Subcommittee presented at the Travel Forecasting Subcommittee, Washington, D.C., November 21, 2008), 6.

⁶ Metropolitan Washington Council of Governments, National Capital Region Transportation Planning Board (COG/TPB), *Air Quality Conformity Determination of the 2008 Constrained Long-Range Plan and the FY 2009-2014 Transportation Improvement Program for the Washington Metropolitan Region* (Washington, D.C.: Metropolitan Washington Council of Governments, National Capital Region Transportation Planning Board (COG/TPB), November 19, 2008); Michael J. Clifford to Transportation Planning Board, "Air quality conformity assessment for the 2008 update of the Constrained Long Range Plan (CLRP) and FY 2009-2014 Transportation Improvement Program (TIP)," Memorandum, October 8, 2008; Ronald Milone and Meseret Seifu to Files, "Transmittal of Version 2.2 travel model files as per the 2008 CLRP/2009-2014 TIP air quality determination," Memorandum, December 17, 2008; Jinchul Park to Files, "Two Step Traffic Assignment for HOT Lane Modeling in 2008 CLRP," Memorandum, December 2, 2008.

2.2 Version 2.3 Model Development Activities

This section details work on the TPB's Version 2.3 model. The activities consisted of sensitivity testing with respect to transit fares and to highway network changes. TPB staff also investigated a procedure to reflect transit subsidies into the transit fare development. Finally, avenues for hastening travel model executions were explored.

2.2.1 Sensitivity testing of the Version 2.3 travel model

Fare elasticities

Introduction

This section of the chapter discusses a series of sensitivity tests done to determine the fare sensitivity of the COG/TPB nested-logit mode choice (NL MC) model that is part of the Version 2.3 travel model. The NL MC model being tested is the one that was documented in June 2008.⁷ In November 2008, TPB staff conducted over 20 model runs spanning three modeled years: 2002, 2005, and 2030. This section of the report is focused on the 2002 tests, but the other tests are documented in a technical memorandum.⁸ The two main scenarios tested are

- Increased fare by 20%
- Decreased fare by 20%

However, there were sub-scenarios that were also tested that will be explained in this section. The structure of the NL MC model can be seen in Figure 2-4. The model includes 15 choices:

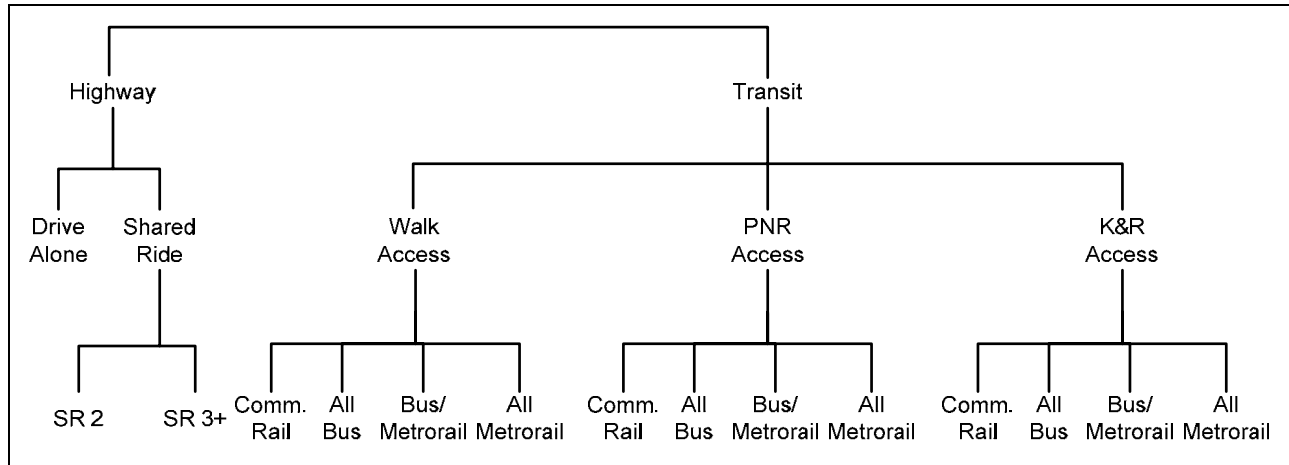
- Three auto modes: Drive alone, shared ride 2, and shared ride 3+
- Four transit modes: Commuter rail, all bus, all Metrorail, and combined bus/Metrorail
- Three modes of access to transit: Park and ride (PNR), kiss and ride (KNR), and walk

The time and cost coefficients in the TPB nested-logit mode choice model (Version 2.3) can be seen in Figure 2-5.

⁷ Ronald Milone et al., *TPB Travel Forecasting Model, Version 2.3: Specification, Validation, and User's Guide*, Draft report (Washington, D.C.: Metropolitan Washington Council of Governments, National Capital Region Transportation Planning Board (COG/TPB), June 30, 2008).

⁸ Mark Moran to Files, "Sensitivity analyses of the Version 2.3 travel model: Fare elasticities," Memorandum, November 16, 2008.

Figure 2-4 Structure of the nested-logit mode choice model



Ref: M:\model_dev\nest_log\NestedChoice_Struct3.vsd

Figure 2-5 Time and cost coefficients in the TPB nested-logit mode choice model

Variable		Trip Purpose (4)			
		HBW	HBS	HBO	NHB
In-vehicle time	ivt	-0.02128	-0.02168	-0.02322	-0.02860
Auto access time	aat	-0.03192	-0.03252	-0.03483	-0.04290
Walk access time	ovtwa	-0.04256	-0.04336	-0.04644	-0.05720
Other out-of-vehicle time*	ovtot	-0.05320	-0.05420	-0.05805	-0.07150
Cost - Income group 1	costinc1	-0.00185	-0.00202	-0.00202	-0.00994
Cost - Income group 2	costinc2	-0.00093	-0.00101	-0.00101	-0.00994
Cost - Income group 3	costinc3	-0.00062	-0.00067	-0.00067	-0.00994
Cost - Income group 4	costinc4	-0.00046	-0.00051	-0.00051	-0.00994

Ref: M:\model_dev\nest_log\NLmcTimeCostCoef4.xls

In terms of modeling the two changes in fares, there are two ways, mechanically, to effect these changes:

- Via the input files
- Via the NL MC control files

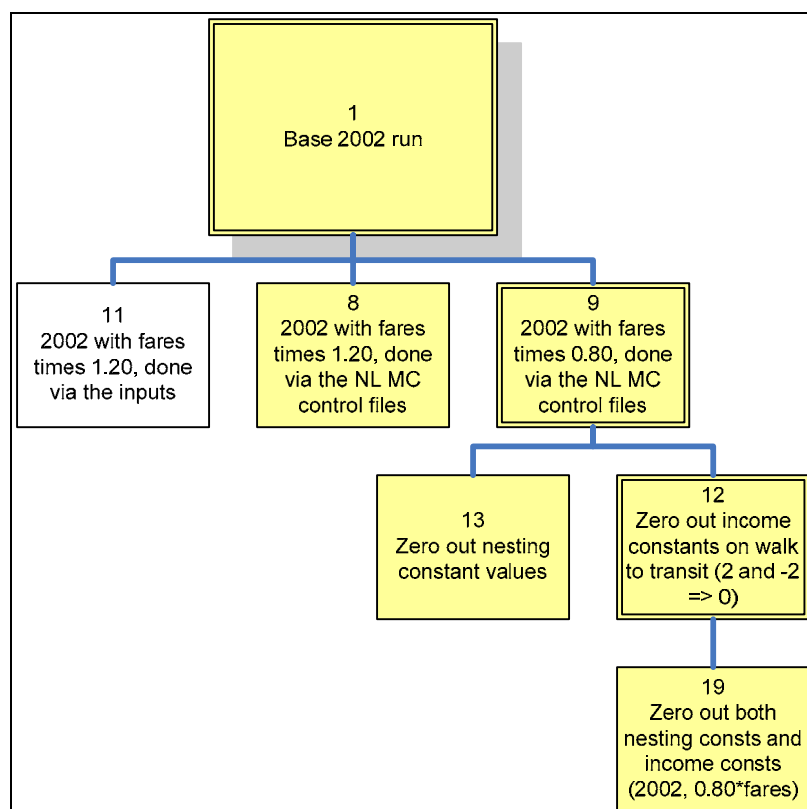
The input files include 1) the Metrorail tariff policy file (TARIFF.TXT), and 2) the “bus” (i.e., non-Metrorail) fare matrices: BUSFARAM.ASC and BUSFAROP.ASC. As for the NL MC control files used by AEMS.EXE,⁹ one can change some of the control statements so that fares are effectively multiplied by 1.20 or 0.80. Both of these methodologies (via the inputs and via the control files) were tried and both resulted in about the same change, which is what we would expect. However, TPB staff found that the preferred way to effect the changes was via the control files, since this is generally easier to implement and more flexible.

⁹ AECOM Consult, Inc., *AECOM Consult Mode Choice Computation Programs, AEMS, Users Guide*, Draft report (Fairfax, Virginia: AECOM Consult, Inc., April 5, 2005).

The full list of scenarios tested and described in this section of the report can be found in Figure 2-6. For the scenario of a 20% reduction in fares (i.e., fares times 0.80), we tested three other sub-scenarios:

- Zeroed out income constants
- Zeroed out nesting constants
- Zeroed out both income and nesting constants

Figure 2-6 Fare sensitivity tests conducted, modeled year 2002



Ref: M:\model_dev\nest_log\sensitivity\Tests7.vsd

The TPB NL MC model uses a set of income constants, which were developed for the AECOM/Wmata NL MC model and retained for use in the TPB model (See Table 2-3). AECOM introduced the income constants to help reduce the high number of modeled boardings in Northwest D.C.¹⁰

¹⁰ AECOM Consult, Inc., “Revised Calibration Results with Additional Revisions to Transit Components of Washington Regional Demand Forecasting Model” (Presentation to the Transit Modeling group, Metropolitan Washington Council of Governments presented at the Transit Modeling group, Washington, D.C., March 2, 2005), 5.

Table 2-3 Income constants used in the TPB Ver. 2.3 NL MC model

Mode	Income stratification		
	Low	Middle	High
All auto modes	0.0	0.0	0.0
Walk to commuter rail	2.0	0.0	-2.0
Walk to all bus	2.0	0.0	-2.0
Walk to bus/Metrorail	2.0	0.0	-2.0
Walk to all Metrorail	2.0	0.0	-2.0
PNR and KNR to transit	0.0	0.0	0.0

Ref: M:\model_dev\nest_log\NLmcTimeCostCoef4.xls

The income constants apply to all trip purposes. “Low income” means income group 1. “Middle income” means income groups 2 and 3. “High income” means income group 4. These income constants have the effect of increasing the probability (due to the +2.0) that low income travelers will choose walk to transit and decreasing the probability (due to the -2.0) that high income travelers will choose walk to transit.

The TPB NL MC model also includes a set of nesting coefficients (a.k.a. logsum parameters or Φ) and nesting constants (NC). The NL MC model is calibrated by estimating the values of the nesting constants (typically via a Fortran program called CALIBMS).¹¹ AECOM developed 20 production/attraction market segments, based on seven superdistricts. TPB staff chose to retain this same geographic market segmentation. There is one nesting constant for each market segment (20), each travel mode (15), and each trip purpose (4). The reasons for including a sub-scenario with no nesting constants will be explained later in this chapter.

Elasticity of demand

In general, the “price elasticity of demand” is the percentage change in the quantity of a commodity demanded, in response to a 1 percent change in the price of the commodity. For our analysis, we have calculated fare elasticities using the most common form for transportation analyses: Arc elasticity (See Equation 2-1).

Equation 2-1 Arc elasticity

$$\eta = \frac{\Delta \log Q}{\Delta \log P} = \frac{\log Q_2 - \log Q_1}{\log P_2 - \log P_1} = \frac{\log Q_2 - \log Q_1}{\log(P_2 / P_1)}$$

The aggregate fare elasticity average for U.S. cities, excluding those with heavy-rail transit, is about -0.4.¹² This value of -0.4 is very close to what would be predicted from the famous Simpson & Curtin formula.¹³ Using Simpson & Curtin and expressing changes on a percentage basis, a 20% increase in transit fares should correspond to a 6.8% drop in ridership. Or, in terms of arc

¹¹ AECOM Consult, Inc., *CALIBMS: Nested Mode Split Model Constant Calibrator for AEMS (AECOM Consult Mode Choice Computation Programs), Users Guide*, Draft report (AECOM Consult, Inc., June 2006).

¹² Brian E. McCollom and Richard H. Pratt, *Chapter 12: Transit Pricing and Fares*, Transit Cooperative Research Program (TCRP) Report 95, Traveler Response to Transportation System Changes (Washington, D.C.: Transportation Research Board (TRB), 2004), 12-8.

¹³ Curtin, 1968, as cited in *Ibid.*, 12-9

elasticity, this would correspond to about -0.39. The Simpson & Curtin formula was derived from a regression analysis of before-and-after results of 77 surface transit (bus and streetcar) fare changes. When making such calculations, it is known that inclusion of systems with heavy rail transit (HRT) tends to lower fare elasticity averages.¹⁴ Consequently, the Simpson & Curtin formula tends to overstate the fare elasticity in cities with HRT, like Washington, D.C.

Based on a 20% drop in fares, the TPB nested-logit mode choice (NL MC) model in the Ver. 2.3 travel model shows a fare elasticity of -0.11. According to Webster and Bly,¹⁵ the most commonly observed range of aggregate fare elasticity values in United States and Europe is from -0.1 to -0.6. Thus, our finding of -0.11 is within the normal range of observed values, though at the lower end of the range. Furthermore, according to a 1980 study which included a sample of U.S. cities both with and without heavy rail systems, the mean fare elasticity was found to be -0.28 ± 0.16 .¹⁶ A standard deviation of ± 0.16 implies that about two-thirds of the elasticity observations lie within the range of -0.12 to -0.44. The lower bound of this range matches approximately what we are finding in the NL MC model of the Version 2.3 travel model.

The fare sensitivity exhibited by a mode choice model is a function of the cost coefficients in the model. As a check on the value of the cost coefficients, we computed the value of time (VOT) using the following formula:

Equation 2-2 Calculating value of time from the time and cost coefficients

$\text{VOT} = 0.60 * (\text{IVTT}/\text{Cost})$

where 0.60 converts cents/min to dollars/hour

There are two main rules of thumb for VOT. First, the work VOT should be between 25% and 50% of prevailing wage rate. Second, the non-work VOT should be between 25% and 50% of the work VOT, which is equivalent to being between 6.25% and 25% of prevailing wage rate. Consequently, the work VOT should be between \$4.44 and \$8.88 (in 1994 \$) and the non-work VOT should be between \$1.11 and \$4.44 (in 1994 \$). As can be seen in Table 2-4, the values of time for the four income groups in the model often fall outside the range predicted by the two rules of thumb. The only implied values of time that fell within the predicted ranges were those for HBW income group 1 and NHB. So, the calibrated model is showing VOTs that are on the high side of what one would expect. This information needs to be considered when the NL MC model is recalibrated in the summer and fall of 2009 as part of the recalibration of the Version 2.3 travel model on the new, 3,700-zone TAZ system.

¹⁴ Ibid., 12-10.

¹⁵ As cited in Ibid.

¹⁶ Mayworm, Lago, and McEnroe, 1980, as cited in Ibid.

Table 2-4 Implied values of time in the current TPB NL MC model

	HBW	HBS	HBO	NHB
Income group 1	\$6.90	\$6.44	\$6.90	\$1.73
Income group 2	\$13.80	\$12.88	\$13.79	\$1.73
Income group 3	\$20.70	\$19.32	\$20.69	\$1.73
Income group 4	\$27.61	\$25.76	\$27.59	\$1.73

Key: Falls outside the general rule of thumb for work
\$x.xx Falls outside the general rule of thumb for non-work

Ref: M:\model_dev\nest_log\NLmcTimeCostCoef4.xls

Given the structure of the NL MC model, we have the ability to stratify fare elasticity by income and transit sub-mode. We would expect to see both an income effect and a transit sub-mode effect. As for the income effect, we would expect that households with lower incomes would exhibit higher fare sensitivities. As for the transit sub-mode effect, we would expect that heavy rail (commuter rail and Metrorail) to have the lowest elasticities and for bus to have the highest elasticities, as shown in Table 2-5.

Table 2-5 Fare elasticities for bus and heavy rail/Metro

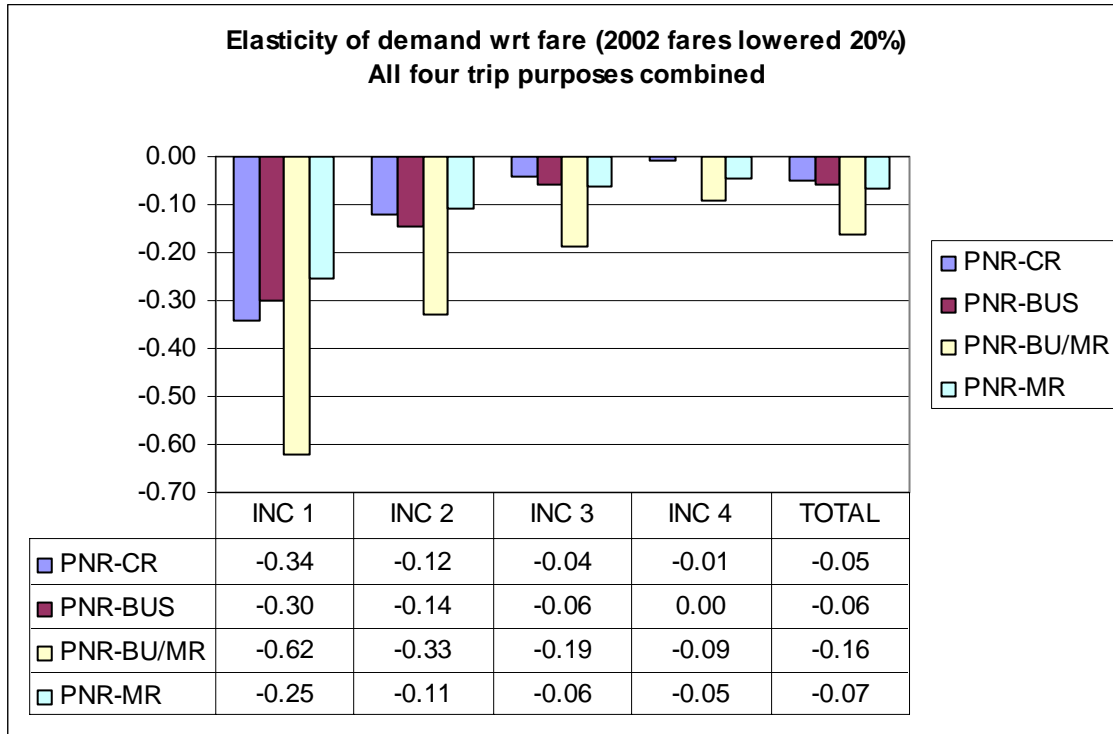
City	Period	Bus	Rail	Source
Chicago ^a	1981–1986	-0.43	-0.18	LTI Consultants, Inc., and E. A. France and Associates (1988)
London	1971–1990	-0.35	-0.17	London Transport (1993)
New York	1948–1977	-0.32	-0.16	Mayworm, Lago and McEnroe (1980)
New York	1970–1995	-0.20 to -0.30	-0.10 to -0.15	Jordan (1998)
New York	1995	-0.36	-0.15	Charles River Associates (1997)
Paris	1971	-0.20	-0.12	Webster and Bly (1980)
San Francisco	1984–1986	—	-0.31	Reinke (1988)

Source: ¹⁷

In the case of park-and-ride (PNR) access to transit, we did see the appropriate income effect, namely lower income households were more sensitive to fare changes (See Figure 2-7). However, we did not see the expected transit sub-mode effect, namely that heavy rail transit (HRT) would be expected to have the lowest elasticities and that bus would be expected to have the highest elasticities. Specifically, in the case of PNR access to transit, 1) bus did not show the highest elasticity values, 2) bus/Metrorail had the highest elasticity values, and 3) HRT elasticities were not as low, relative to the others, as one would have expected. We graphed comparable data for kiss-and-ride (KNR) access to transit and the same trends occurred: income effect was present, but transit sub-mode effect was not what was expected a priori. These results are discussed later in the chapter.

¹⁷ Ibid., 12-11.

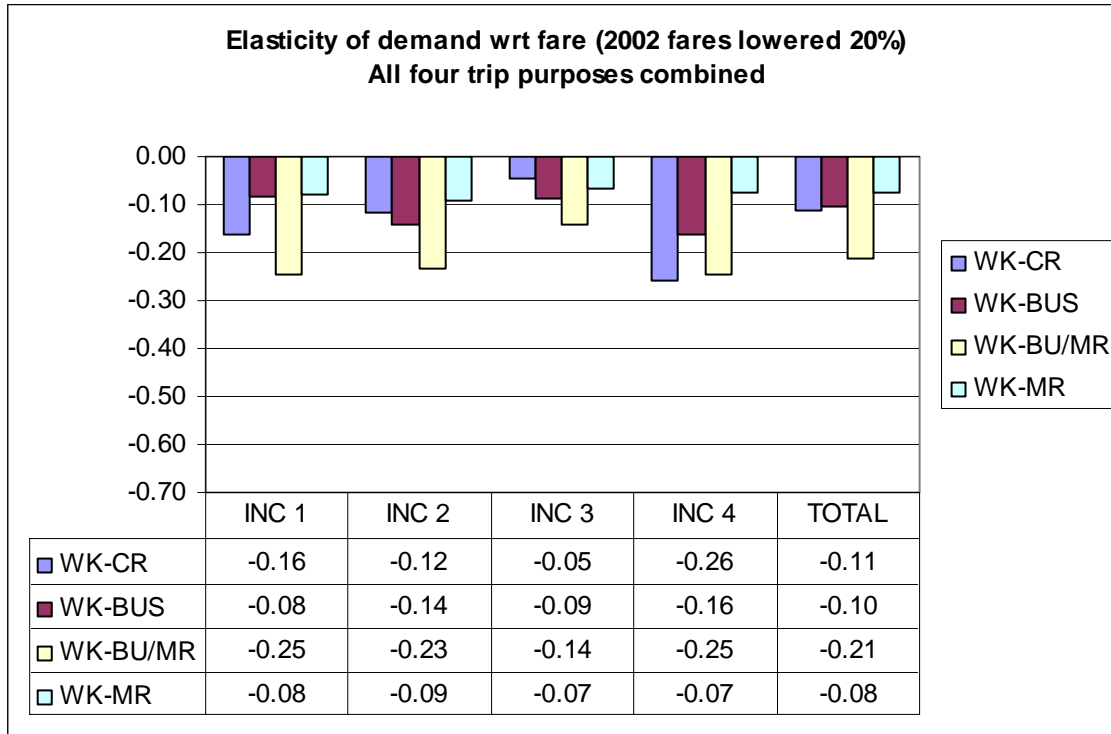
Figure 2-7 Fare elasticity due to a 20% drop in transit fares (year 2002): PNR access to four transit modes



Ref: M:\model_dev\Ver2.3_20080830\Summary\fareSensitivity2.xls tab=2002_fareX0.80c

In Figure 2-8, one can see the fare elasticities for walk-access to transit, due to a 20% drop in transit fares. Now, even the income effect is missing, and the transit sub-mode effect is the same as before: at odds with a priori expectations.

Figure 2-8 Fare elasticity due to a 20% drop in transit fares (year 2002): Walk-access to four transit modes



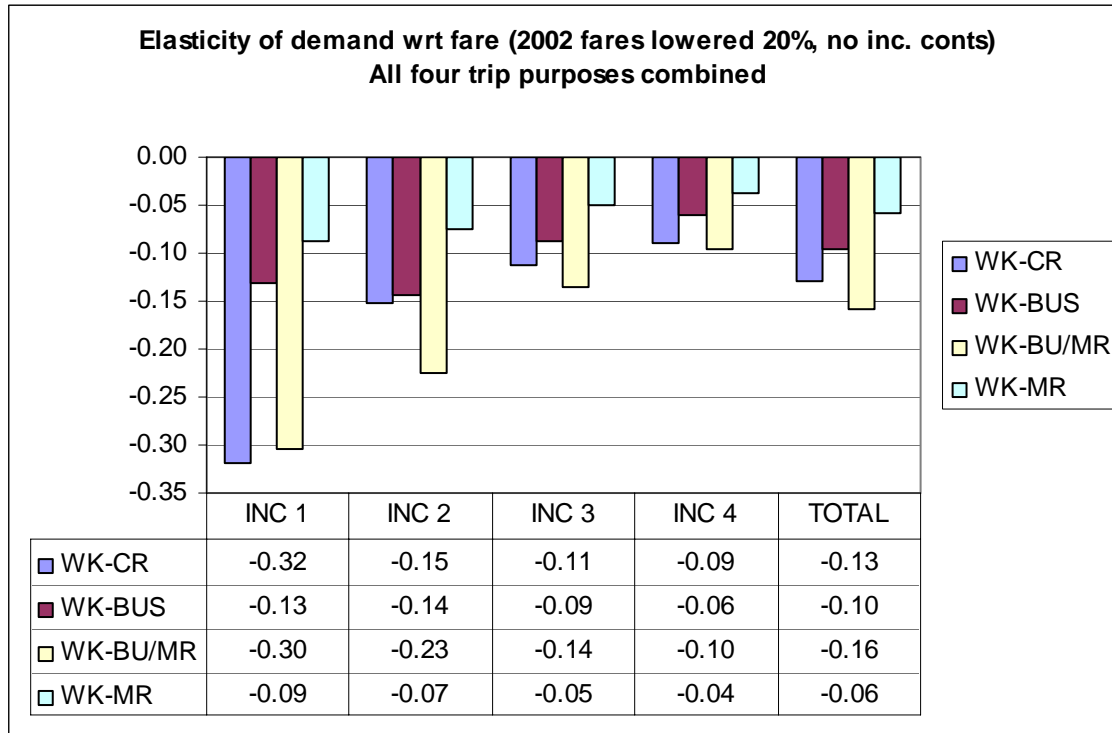
Ref: M:\model_dev\Ver2.3_20080830\Summary\fareSensitivity2.xls tab=2002_fareX0.80c

Concerning the lack of the income effect for walk-access transit trips, one hypothesis is that the income constants added to the NL MC model are adversely affecting the fare elasticity by income group. As we can see from Table 2-3, the income constants apply to all trip *purposes*, but to only one travel *mode* (walk-access transit trips) and to only low and high income travelers. To test this hypothesis, we decided to run the model without the income constants (i.e., setting the income constant values of -2 and +2 to 0). To make a valid comparison, we had to re-run both the base and the test case:

- Zero out the income constants for the 2002 base run
- Zero out the income constants for 2002 transit fares reduced by 20%

As we can see from Figure 2-9, when we zeroed out the income constants, the income effect was restored.

Figure 2-9 Fare elasticity due to a 20% drop in transit fares (year 2002): Walk-access to four transit modes: Income constants set equal to zero



Ref: M:\model_dev\Ver2.3_20080830\Summary\fareSensitivity2.xls, tab= fareX0.80c_noIncConst2

It should be noted that, although this test produced some positive results in terms of restoring the income effect in the fare elasticities, this manual re-setting of income constants means that the model is no longer calibrated. This test simply provides information that can be used when recalibrating the NL MC model this summer and fall.

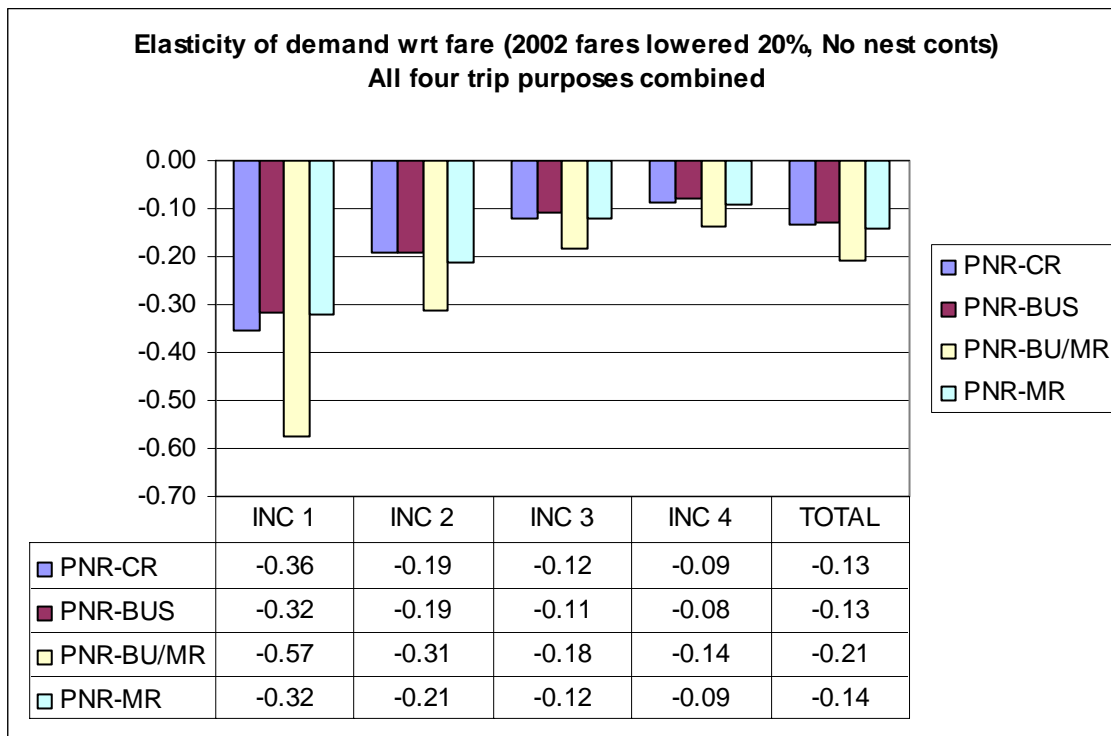
The remainder of this section discusses the counter-intuitive results concerning the transit sub-mode effect. One hypothesis for the disparity between the bus and bus/Metrorail fare elasticities is that there may be a problem with the alternative-specific constants (ASCs). Typically, in logit models, the utility function of each mode, except one, should include an ASC. The ASCs reflects the contribution to the utility of each mode of all that variables that are not in the model, but which, nonetheless, affect mode choice. Typical examples include measures of comfort, convenience, and personal safety. Since there are 15 choices in the NL MC model, we would expect 14 ASCs. However, there are also 20 geographic market segments (based on seven superdistricts, forming 49 interchanges, which are collapsed down to 20 geographic interchanges). So, the actual number of constants in the NL MC model, per purpose, is $14 \times 20 = 280$. These constants are called “nesting constants,” even though they play a dual role. Although 280 constants per model (HBW, HBS, HBO, and NHB) seem like a lot of constants, the mode choice model used in the Version 2.2 travel model (and earlier travel models) has 800 adjustment factors per model (400 transit percent adjustment factors and 400 car occupancy adjustment factors). So, the 280 constants is actually a reduction from current levels.

The nesting constants are estimated using an automated calibration routine, known as CALIBMS. For a number of reasons, it is possible that one or more of the 280 nesting constants per trip purpose could have a value that is too large. One hypothesis was that some of the nesting constant values were too large and this was causing a disparity in the fare elasticities between bus and bus/Metrorail. One way to quickly test this hypothesis was to re-set all of the nesting constants to zero. As was the case before, we actually needed two model runs to test our hypothesis:

- Zero out the nesting constants for the 2002 base run
- Zero out the nesting constants for 2002 transit fares reduced by 20%

The results of this test can be seen in Figure 2-10.

Figure 2-10 Fare elasticity due to a 20% drop in transit fares (year 2002): PNR-access to four transit modes: Nesting constants set equal to zero



Ref: M:\model_dev\Ver2.3_20080830\Summary\fareSensitivity2.xls, tab= fareX0.80c_noNestConst2

If we compare the column of numbers labeled “total” that can be found in both Figure 2-7 and Figure 2-10, we can see that the test was somewhat successful. The bus and bus/Metrorail fare elasticities went from -0.06 and -0.16 (ratio = 0.375) to -0.13 and -0.21 (ratio = 0.619). So, although the bus elasticity did not overtake the bus/Metrorail elasticity, the gap between the two bars did get smaller (their ratio went from 0.375 to 0.619). And this was done with just a simple change of setting all of the nesting constants to zero. If we performed a more judicious adjustment of the nesting constants, we might be able to get the bus and bus/Metrorail fare elasticities to line up with our expectations.

Given the limited success of this last test, there might be some legitimate reasons for the fact that the “transit sub-mode effect” of our fare elasticity values is the opposite of what we first presumed.

First, by definition, the “bus/Metrorail” transit sub-mode includes at least one (forced) transfer. By contrast, the other three transit sub-modes include, on average, fewer transfers, since they include trips with zero, one, or more transfers. One would expect transit users who have a forced transfer to be more sensitive to changes in fare. Second, trips that fall under the category of “bus/Metrorail” are probably longer distance than bus alone or Metrorail alone, so they might be more sensitive to cost.

Conclusions

The fare elasticity for total transit from the Version 2.3 nested-logit mode choice model is about -0.11, which is within the expected range, but on the low end of the values found by researchers for cities with heavy rail transit systems. Fare elasticities generally showed an “income effect,” with the exception being the walk-to-transit trips, which did not show this effect initially. We were able to restore this “income effect” for walk-access transit trips by setting the income constants to zero. There appeared to be a disparity between the fare elasticity for bus and bus/Metrorail trips. We showed that the values of these elasticities are affected by the values of the nesting constants, but we also pointed out that it is possible that the “reverse transit sub-mode effect” that we witnessed (namely, that bus/Metrorail had the highest elasticities, not bus-only), may in fact, be correct, since the bus/Metrorail sub-mode includes at least one (forced) transfer and the other three transit sub-modes do not. Furthermore, bus/Metrorail trips are probably longer distance than bus and/or Metrorail, so they might be more sensitive to cost.

Sensitivity to changes in the highway network

In the spring and summer of 2007, TPB staff performed several sensitivity tests on the Version 2.2 travel model for the base year (2000).¹⁸ In September of 2008 (FY-2009), TPB staff performed a similar set of sensitivity tests on the Version 2.3 travel model, working in conjunction with the Travel Forecasting Subcommittee. Prior to these sensitivity tests, the Version 2.3 travel model had just undergone several updates during the summer of 2008. The following two sensitivity tests were conducted on the Version 2.3 travel model for the base year (2005):

1. The removal of the John Phillip Sousa Bridge (Pennsylvania Avenue crossing of the Anacostia River) in the District of Columbia.
2. A reduction of capacity on the American Legion Bridge (Capital Beltway), from 5 to 3 lanes in both directions.

This type of sensitivity test is often referred to as a “dynamic validation,” since it refers to an assessment of travel pattern changes when a critical highway link is either modified or removed, for a base year condition.¹⁹ It should be noted that the sensitivity tests conducted with the Version 2.3 travel model were similar, though not identical, to those conducted with the Version 2.2 travel model. In particular, the lane reduction on the American Legion Bridge was from 4 to 3 lanes for Version 2.2 and was from 5 to 3 for the Version 2.3 model. For the base-year 2000 highway network used in the Version 2.2 travel model, the number of lanes on the American Legion Bridge was coded as 4, since there are four through lanes and one merging lane. However, when developing the 2005 highway network for the Version 2.3 model, upon further consideration, it was felt that this merging lane actually counted as a fifth lane of capacity in each direction. So, the number of lanes was revised from 4 to 5.

The two sensitivity tests performed on the Version 2.2 and Version 2.3 travel models were generally found to be reasonable and revealed similar trends, i.e., negligible change in regional VMT and transit use. The sensitivity tests conducted on the Version 2.2 travel model indicated that the Sousa bridge closure resulted in a VMT decrease of 50,000 (from a base of 143 million vehicle miles) and an increase of 7,100 transit trips (from a base of 981,000 total transit trips). The American Legion Bridge lane reduction resulted in decrease of 211,000 vehicle miles, with no significant difference in transit trips.²⁰ The results of same sensitivity tests conducted on the Version 2.3 travel model are shown in Table 2-6. The John Phillip Sousa bridge closure resulted in a VMT decrease of 100,000 (from a base of 159 million vehicle miles) and an increase of 5,000 transit trips (from a base of 1.1 million total transit trips). The American Legion Bridge lane reduction resulted in decrease of 300,000 vehicle miles, with no significant difference in transit trips.

¹⁸ Ronald Milone et al., *TPB Travel Forecasting Model, Version 2.2: Specification, Validation, and User's Guide* (Washington, D.C.: Metropolitan Washington Council of Governments, National Capital Region Transportation Planning Board (COG/TPB), March 1, 2008), 9-10.

¹⁹ Milone et al., *TPB Travel Forecasting Model, Version 2.2: Specification, Validation, and User's Guide*.

²⁰ Ibid.

Table 2-6 Comparison of Year 2000 and 2005 base vs. alternative Scenarios (in '000)

	Base 2005 (a)	JPS Bridge Closure (b)	AM Bridge Lane Reduction (c)
VMT	159,300	159,200	159,000
<i>VMT Diff. (b – a)</i>		<i>-100</i>	<i>-300</i>
Transit Trips	1,083	1,088	1,084
<i>Transit Diff. (b – a)</i>		<i>5</i>	<i>1</i>

In addition to this summary information, TPB staff also examined the directional link-level data from the base and alternative scenarios of the American Legion Bridge lane reduction. As shown in Table 2-7 for the three time periods (AM, PM, and Off-peak) in both directions (westbound and eastbound) there is a decrease in volume and an increase in V/C ratio and queuing time, which is what would be expected from a decline in capacity.

Table 2-7 Directional link level comparison: American Legion Bridge: Base and Alternative Condition

Time Period		WB		EB		WB Diff.	EB Diff.
		Base	Alt.	Base	Alt.	(Alt-Base)	(Alt-Base)
AM	Lanes	5	3	5	3	-2	-2
	Volume	24,600	17,600	22,900	16,800	-7,000	-6,100
	V/C	1.0	1.2	0.9	1.1	0.2	0.2
	Que.Time (min)	1	6	0	4	5	3
PM	Volume	30,300	23,000	30,100	22,600	-7,300	-7,500
	V/C	1.1	1.4	1.1	1.4	0.3	0.3
	Que.Time (min)	4	13	3	13	10	10
Off-Peak	Volume	77,100	55,900	77,100	55,900	-21,200	-21,200
	V/C	0.9	1.1	0.9	1.1	0.2	0.2
	Que.Time (min)	0	4	0	4	3	3

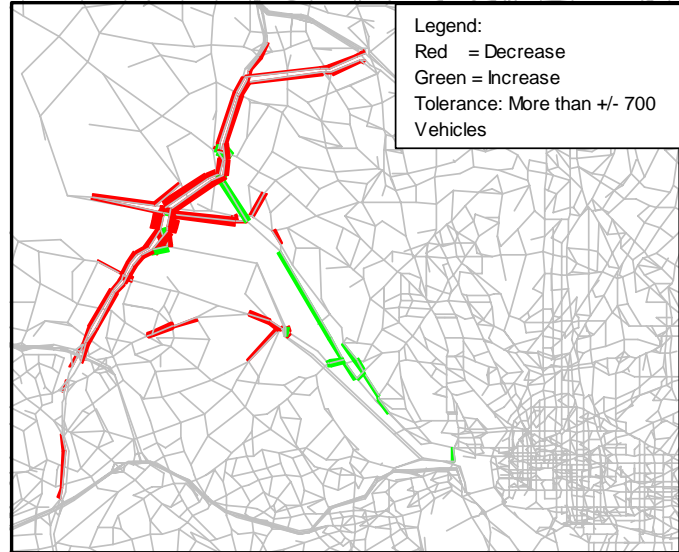
TPB staff also examined A.M. peak-period localized traffic changes for both alternatives. As shown in Figure 2-11, the bandwidth plots revealed substantial and reasonable volume changes.

Figure 2-11 Year 2005 Change in A.M Peak Period Volume

John Phillip Sousa Bridge closed



American Legion Bridge reduced by two lanes in each direction



In order to analyze the effect of the removal of the John Phillip Sousa Bridge on the other bridges in the area (see Figure 2-12), namely, South Capitol St. Bridge, 11th St. Bridge, East Capitol St. Bridge, Benning Rd. Bridge, and New York Ave. Bridge, directional link-level summary statistics by time period had been prepared (see Table 2-8). As shown in this table comparison, the VMT and volumes for all of the alternate bridges has gone up, when the John Phillip Sousa Bridge was removed, which is what one would expect. One might also expect the volumes of the two closest bridges (11th Street and East Capitol) to increase the most, since they are the closest to the closed bridge. However, the effect of the Sousa Bridge closure was higher on the East Capitol and Benning Rd Bridges. When measured by percent difference, these two bridges showed the largest percent increase in daily volumes (21.4% westbound, 25.4% eastbound for East Capitol and 18.1% westbound, 20.5% eastbound for Benning Rd).

Figure 2-12 John Phillip Sousa and surrounding bridges

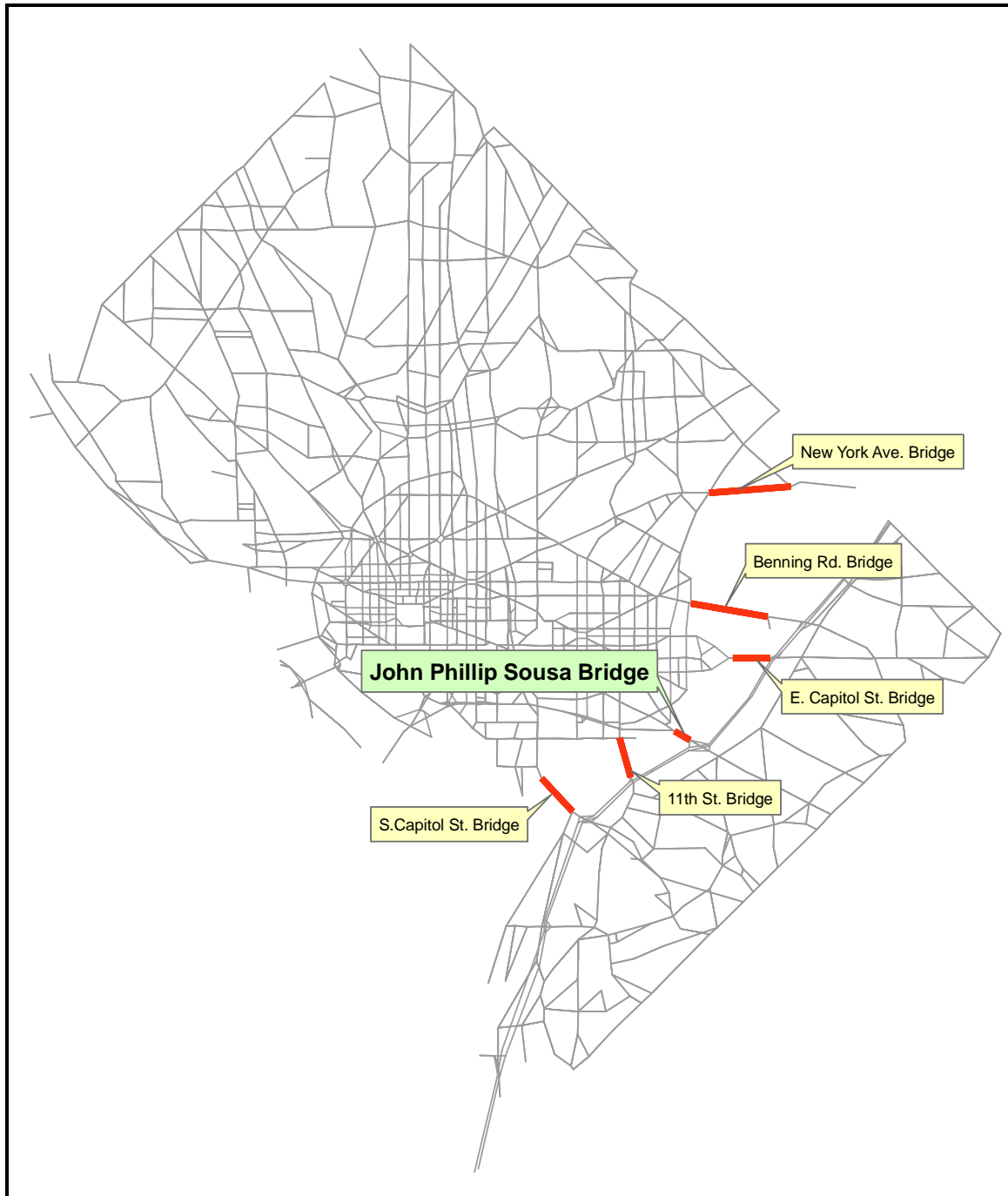


Table 2-8 Directional link level comparison of surrounding bridges in the area when the John Phillip Sousa Bridge is closed

Facility		Time Period	Westbound		Eastbound		Diff. (Alt-Base)		Pct. Diff	
			Base	Alt.	Base	Alt.	WB	EB	WB	EB
S.Cap Bridge	Volume	AM	7,800	8,400	2,500	2,700	600	200	7.69%	8.00%
		PM	4,300	4,600	7,500	8,800	300	1,300	6.98%	17.33%
		Off-Peak	13,800	14,700	13,900	14,200	900	300	6.52%	2.16%
		Total	26,000	27,700	23,800	25,700	1,700	1,900	6.54%	7.98%
	VMT	Total	15,300	16,400	14,100	15,100	1,100	1,000	7.19%	7.09%
11th St. Bridge	Volume	AM	16,200	17,500	6,200	7,300	1,300	1,100	8.02%	17.74%
		PM	11,700	13,000	20,600	22,400	1,300	1,800	11.11%	8.74%
		Off-Peak	31,400	36,700	38,900	45,800	5,300	6,900	16.88%	17.74%
		Total	59,300	67,200	65,600	75,500	7,900	9,900	13.32%	15.09%
	VMT	Total	29,000	32,900	32,100	37,000	3,900	4,900	13.45%	15.26%
E. Capitol St. Bridge	Volume	AM	7,300	8,400	900	1,100	1,100	200	15.07%	22.22%
		PM	3,900	5,100	9,500	12,500	1,200	3,000	30.77%	31.58%
		Off-Peak	12,200	14,800	8,100	9,600	2,600	1,500	21.31%	18.52%
		Total	23,400	28,400	18,500	23,200	5,000	4,700	21.37%	25.41%
	VMT	Total	10,100	12,200	8,000	10,000	2,100	2,000	20.79%	25.00%
Benning Rd. Bridge	Volume	AM	1,900	2,300	10,200	11,400	400	1,200	21.05%	11.76%
		PM	13,300	14,500	6,400	7,600	1,200	1,200	9.02%	18.75%
		Off-Peak	14,800	18,500	12,300	15,700	3,700	3,400	25.00%	27.64%
		Total	29,900	35,300	28,800	34,700	5,400	5,900	18.06%	20.49%
	VMT	Total	26,900	31,800	26,000	31,300	4,900	5,300	18.22%	20.38%
New York Ave. Bridge	Volume	AM	6,200	6,900	13,100	13,500	700	400	11.29%	3.05%
		PM	15,200	15,700	11,800	12,400	500	600	3.29%	5.08%
		Off-Peak	31,800	33,600	31,000	33,200	1,800	2,200	5.66%	7.10%
		Total	53,200	56,200	55,800	59,100	3,000	3,300	5.64%	5.91%
	VMT	Total	33,500	35,400	35,200	37,300	1,900	2,100	5.67%	5.97%

2.2.2 Incorporating employer subsidies in transit fares

Transit fares are critical inputs to the mode choice model. TPB staff has been cognizant in recent years of a growing trend in the use employer-provided transit subsidies in the Washington, D.C. region. The most widespread transit subsidy program in the Washington, D.C. area was known as “Metrochek,” however, this program has now been replaced by a program known as “SmartBenefits.” Previously, it was difficult to estimate the number of people participating in these transit subsidy programs. However, recently, with the advent of new on-board transit surveys, we have been able to get a handle on participation rates. The 2007 Metrorail passenger survey has indicated well over half of all Metrorail commuters availed themselves of the subsidy, particularly those employed by the government. In the fall of 2008, TPB staff proposed the idea of explicitly reflecting employer-based transit fare subsidies in the TPB’s existing transit fare estimation process. This section presents background on the SmartBenefits program and outlines a proposed method for modifying the Metrorail fare development process in the Version 2.3 model to reflect the SmartBenefits program. The results of reflecting the transit subsidy in the travel model, for a base year (2002), are also presented.

SmartBenefits/Metrochek Transit Benefit Program

The Transportation Equity Act for the 21st Century (TEA 21), signed into law in June of 1998, included a provision to amend the IRS tax code to allow for special employer-provided transit subsidies. Metrochek was the name of the predominant transit subsidy program for the Washington, D.C. area. Later, Metrochek was replaced by the SmartBenefits program. The subsidy is offered to employees as a direct tax-free subsidy, as a pre-tax salary deduction, or as a combination of the two. The incentive for employers to participate in the program is financially compelling. The effective reduction in taxable income enables employers to save on FICA, federal, and state income tax. Furthermore, private sector employers are allowed to write off the cost of the subsidy as a business expense.

The maximum allowable monthly benefit offered by the program has increased steadily over time since its inception. Based on information obtained from COG’s Commuter Connection program, the historical maximum benefit is shown on the table below.

Year	Maximum Monthly Benefit
2000	\$ 65.00
2002	\$ 100.00
2004	\$ 105.00
2007	\$ 110.00
2008	\$ 115.00
2009	\$ 120.00

The level of participation in the SmartBenefits program is beginning to be measured by recent on-board transit surveys. The overall proportion of subsidized commuting trips on the Metrorail system is 60% according to the 2007 Metrorail Survey. The precise subsidy for each trip is not known as the survey question inquires only about program participation. Table 2-9 lists the

percentage of Metrorail work trip attractions that are subsidized at each Metrorail station based on the 2007 survey.

Table 2-9 Percent of HBW Metrorail Trip Attractions that are Subsidized

Metrorail Station	Pct. of Subsidized HBW Attractions	Metrorail Station	Pct. of Subsidized HBW Attractions
Addison Road	16%	Landover	15%
Anacostia	43%	Largo Town Cente	9%
Archives	74%	L'Enfant Plaza	75%
Arlington Cemete	39%	McPherson Square	65%
Ballston	56%	Medical Center	79%
Benning Road	36%	Metro Center	58%
Bethesda	54%	Minnesota Avenue	9%
Braddock Road	46%	Mt Vernon Square	41%
Branch Avenue	36%	National Airport	36%
Brookland-CUA	37%	Navy Yard	64%
Capitol Heights	77%	Naylor Road	6%
Capitol South	74%	New Carrollton	54%
Cheverly	9%	New York Ave NE.	20%
Clarendon	62%	Pentagon	71%
Cleveland Park	25%	Pentagon City	56%
College Park	58%	PG Plaza	50%
Columbia Heights	14%	Potomac Avenue	8%
Congress Heights	12%	Rhode Island Ave	15%
Court House	59%	Rockville	37%
Crystal City	74%	Rosslyn	57%
Deanwood	8%	Shady Grove	32%
Dunn Loring	21%	Shaw-Howard Univ	15%
Dupont Circle	48%	Silver Spring	51%
East Falls Churc	31%	Smithsonian	84%
Eastern Market	37%	Southern Avenue	7%
Eisenhower Avenu	67%	Stadium Armory	38%
Farragut North	56%	Suitland	74%
Farragut West	57%	Summerfield	0%
Federal Center S	79%	Takoma	36%
Federal Triangle	79%	Tenleytown	41%
Foggy Bottom-GWU	57%	Twinbrook	63%
Forest Glen	36%	Union Station	66%
Fort Totten	14%	U-Street-Cardozo	23%
Franconia-Spring	35%	Van Dorn Street	19%
Friendship Heigh	47%	Van Ness-UDC	37%
Gallery Place	63%	Vienna	37%
Georgia Ave	16%	Virginia Square	69%
Glenmont	10%	Waterfront	48%
Greenbelt	28%	West Falls Churc	24%
Grosvenor	40%	West Hyattsville	0%
Huntington	23%	Wheaton	15%
Judiciary Square	70%	White Flint	72%
King Street	69%	Woodley Park-Zoo	17%

Source: 2007 Metrorail Passenger Survey

It is clear that some of the Metrorail stations with the highest percentage of participation in the SmartBenefits program are those serving government employment, including Smithsonian (85%), Federal Center SW (79%), Federal Triangle (79%), and L'Enfant Plaza (75%). The substantial level of program participation at many of the other stations indicates that the program has gained traction among employers in the private sector as well.

Method for Modeling the Transit Fare Discounts

TPB staff decided to test the effect of the SmartBenefits program in the Version 2.3 travel model by translating the monthly subsidy into a reduced or discounted average daily transit fare between station pairs.²¹ Given that over half of commuters on Metrorail avail themselves of the subsidy, it was felt that reflecting the effective fare discount would improve the real-world accuracy of the transit fare input to the mode choice model. For reference, the existing (reflecting the standard Metrorail fares) and test (reflecting the SmartBenefits program) model subdirectories are:

- Existing Subdirectory: M:\model_dev\Ver2.3_20080830
- Test Subdirectory: M:\model_dev\Ver2.3_20080830_RFD

The existing method for developing transit fares in the Version 2.3 model is accomplished with a two-step approach. First, Metrorail station-to-station fares are developed for both AM peak and off-peak periods in accordance with WMATA tariff specifications in effect for the model year. Next, *total* zone-to-zone transit fares are developed, combining the Metrorail station level fares developed previously with bus/commuter rail fare estimates developed on a super-district to super-district level. Transit fare matrices are prepared individually for each submode path, i.e., by time period (AM, off peak), by access mode (walk, drive, drop-off), and submode (commuter rail, Metrorail-only, Metrorail/ bus combination, and bus-only).

The following guidelines were proposed in designing the proposed method and application for reflecting the SmartBenefits program:

- The model year for which the transit subsidy was tested would be 2002, which was the calibration year of the NL mode choice. Although no information exists for the level of participation in the SmartBenefits program in 2002, the SmartBenefits-related information obtained from the 2007 Metrorail Survey would be assumed.
- The effect of the transit subsidy would be assessed for the Metrorail trip only, where information regarding the subsidy was more fully known from the Metrorail Survey. While the SmartBenefit subsidy is applicable to any transit mode (i.e., bus and commuter rail travel), the method used would focus on discounting the Metrorail fare only, for the time being.
- Since the SmartBenefits program is an employer-provided subsidy that encourages transit use for commuting, the subsidy would be applied to the AM period Metrorail fare only, the period associated exclusively with the HBW trip purpose. It would be assumed that the proportion of travelers using the SmartBenefit subsidy would be based on the SmartBenefit

²¹ Ronald Milone to Files, "Reflecting the SmartBenefits Program Explicitly into the V2.3 Model," Memorandum, November 14, 2008.

percentage at the attraction-end (i.e., the job-end) Metrorail station, as reported by the 2007 Metrorail Survey.

- It was assumed that each traveler would utilize the SmartBenefit rationally, i.e., the traveler would use the maximum allowable benefit to minimize his or her commuting fare on the Metrorail system.

The process for discounting transit fares to reflect the SmartBenefits program involved four steps, as outlined below:

Step 1) The regular AM peak Metrorail station-to-station fare ($MFare_{ij}$) was computed in cents based on the appropriate tariff in effect for 2002.

Step 2) The maximum allowable monthly monetary subsidy ($MxFareSub$) for 2002 was converted from a monthly dollar amount to a per trip value ($TripSub$) in cents as follows:

$$TripSub = (MxFareSub / 22 \text{ work days per month} / 2 \text{ work trips per day}) * 100 \text{ cents per } \$$$

Step 3) The subsidized per trip fare ($SubFare_{ij}$) was calculated by subtracting the maximum per trip subsidy from the regular fare between stations ($MFare_{ij}$), subject to a minimum subsidized fare of not less than zero.

$$SubFare_{ij} = \text{Maximum} (0, (MFare_{ij} - TFareSub))$$

Step 4) The final average station-to-station fare ($FinalFare_{ij}$) was computed as a weighted average of the regular fare ($MFare_{ij}$) and the discounted fare ($SubFare_{ij}$). The weighting was based on the subsidy probability at the attraction “j” station ($SubShare_j$), as shown on Table 1.

$$FinalFare_{ij} = (SubShare_j * SubFare_{ij}) + ((1.0 - SubShare_j)) * MFare_{ij}$$

The above procedure can be demonstrated by examining an example Metrorail fare from the Shady Grove to Metro Center Metrorail stations:

Step 1) The standard AM peak Metrorail station-to-station fare for 2002 (WMATA tariff #19 in effect) is **325 cents**. This fare value would normally be used in the development of total transit fares.

Step 2) The maximum allowable monthly monetary subsidy for 2002 is **\$100.0** per month, or **227 cents** per work trip (\$100 per month / 22 days per month / 2 trips per day * 100 cents per dollar).

Step 3) The discounted fare, assuming the Metrorail passenger avails himself/herself of the maximum allowable subsidy, equals the normal fare (**325 cents**) less the per-trip subsidy (**227 cents**), which equals **98 cents**.

Step 4) The final station-to-station fare is computed as a weighted average based on the attraction station subsidy probability. The probability of commuters being subsidized (i.e., paying the

discounted fare) at Metro Center is **58%** (see Table 1). Consequently, it follows that **42%** of commuters will pay the full/non-discounted Metrorail fare. Therefore, the final average fare from Shady Grove to Metro Center is computed as:

$$(0.58 * 98.0 \text{ cents}) + (0.42 * 325.0 \text{ cents}) = 193 \text{ cents}$$

Test Results of the Incorporating SmartBenefits into the Transit Fare Process

Necessary modifications were made to the Version 2.3 model transit fare process in order to execute the Metrorail discounting procedures discussed above. Specifically, the MFARE1.S script, and the input files tariff.txt and mfare1_Sta_Disc.ASC were modified.

The change in transit costs and transit trips resulting from the base case, assuming standard Metrorail fares, and the test results, reflecting the effect of the SmartBenefits fare subsidy, is shown in Table 2-10. The table shows transit information by the submode and access types. The transit costs shown reflect total (Metrorail and bus/commuter rail) fares in constant 1994 cents. The table indicates, as one would expect, that the average transit costs decrease for all Metrorail related submodes, while those non-Metrorail-related modes show no cost change (commuter rail, by definition, includes both commuter rail/Metrorail combination trips as well as “commuter rail only” trips). On average the transit fares have decreased by about 50 cents, from 197 to 148, with the Smartbenefits discount, a 25% reduction. The table shows that transit trips have increased for those sub-markets enjoying the Metrorail fare discount as one would expect (from 0 to 7.5%). Non-Metrorail related submarket trips, where fares are unchanged, are shown to lose trips, again, as one would expect. The overall impact of representing the SmartBenefits program explicitly in the model is an increase of 6,500 trips (about 1%). A 1% increase in trips is clearly less than what would be expected with a 25% decrease in cost, which might be in the 2.5% to 5.0% range.

A few caveats regarding this analysis should be pointed out. First, the results shown on Table 2-10 are not a clinical comparison of two mode choice model executions, one with standard Metrorail fares and the other with reduced Metrorail fares. It reflects two Metrorail fare assumptions as executed in the complete four-step model, with 6 speed feedback loops. Therefore, small differences in trip distribution will cause some “noise” in the person trip tables and highway skim inputs to the mode choice model. Second, it is important to note that this analysis focused on discounting Metrorail fares only. TPB staff does not yet have a sound understanding of non-Metrorail related passenger participation in the SmartBenefits program, and no such participation was assumed in this analysis.

Table 2-10 2002 Base & Test Avg. AM Peak Transit Costs and HBW Transit Trips

Submode	Access Type	Average Transit Cost (1994 cents)				Modeled Transit Trips			
		Base	Test	Diff.	% Diff.	Base	Test	Diff.	% Diff.
Commuter Rail	Walk	276	238	-38	-13.66%	1,800	1,800	0	0.00%
Bus	Walk	125	125	0	-0.02%	231,000	221,700	-9,300	-4.03%
Metrorail/Bus	Walk	235	158	-77	-32.86%	106,100	114,100	8,000	7.54%
Metrorail Only	Walk	132	58	-74	-56.07%	116,400	119,200	2,800	2.41%
Commuter Rail	PNR	299	259	-40	-13.28%	20,300	19,500	-800	-3.94%
Commuter Rail	KNR	292	252	-40	-13.61%	1,500	1,500	0	0.00%
Bus	PNR	184	184	0	-0.12%	18,100	17,300	-800	-4.42%
Bus	KNR	184	184	0	-0.12%	5,500	5,300	-200	-3.64%
Metrorail/Bus	PNR	372	309	-63	-17.05%	10,000	10,300	300	3.00%
Metrorail/Bus	KNR	273	208	-65	-23.88%	5,300	5,500	200	3.77%
Metrorail Only	PNR	314	225	-89	-28.35%	143,100	148,200	5,100	3.56%
Metrorail Only	KNR	176	98	-78	-44.43%	40,100	41,200	1,100	2.74%
Transit Total		197	148	-49	-24.94%	699,100	705,600	6,500	0.93%
						18.68%	18.85%	0.17%	0.92%

Conclusions

A method for reflecting the SmartBenefits program in the Version 2.3 model was formulated and applied for 2002. The method focused effectively discounting AM-peak Metrorail fares using information obtained in the 2007 Metrorail Survey. The effect of discounting Metrorail fares the test was an increase in HBW transit trips (6,500), about 1%. The change in demand appears to be low with respect to the average change in cost (-25%), but this response is nonetheless consistent with other fare testing work performed by recently by Mark Moran, and development on the NL model is continuing. NL model improvements will likely lead to larger impacts of the program.

Given the prevalence of the SmartBenefits program, TPB should consider including the proposed process in the Version 2.3 model. TPB should investigate the prevalence of SmartBenefits on non-Metrorail-related trips and include fare discounting on the bus fares, in addition to Metrorail fares. NL model should subsequently be re-calibrated using the modified AM transit fare inputs, which are arguably more realistic than fares assuming no subsidies whatsoever. In theory, more accurate inputs should increase the explanatory power of the NL model.

2.2.3 Avenues for reducing model run times

During FY-2009, a number of avenues have been tried for reducing run times of the regional travel model. These include reducing the number of speed feedback iterations, new traffic assignment algorithms that are becoming available in Cube Voyager, and implementing distributed processing.

Reducing the number of speed feedback iterations

In both the Version 2.2 and 2.3 COG/TPB travel models, traffic assignments are done by time of day: AM peak period (6:00 AM to 9:00 AM), PM peak period (4:00 PM to 7:00 PM), and the off-peak period (i.e., the rest of the day). For each of these time-of-day traffic assignments, we use a user-equilibrium (UE) traffic assignment with 60 iterations. This is equivalent to performing 60 all-or-nothing traffic assignments for each of our three time-of-day traffic assignments. The goal behind having a large number of UE iterations is to get a solution that is as close as possible to Wardrop's first principle, also known as a "selfish equilibrium":

Under equilibrium conditions, traffic arranges itself in congested networks such that all used routes between an O-D pair have equal and minimum costs, while all unused routes have greater or equal costs.²²

This means that, at equilibrium, no traveler can improve his travel time by changing routes. However, equilibrium within the traffic assignment step is not enough -- we also want equilibrium between the four steps of the travel model, i.e., convergence between the output speeds and volumes coming out of traffic assignment and the input speeds that are used for trip distribution and mode choice. To obtain this model-wide convergence, the Version 2.2 and 2.3 travel demand model is run seven times, in a process known as the speed feedback loop. The first running of the travel model is called the "pump prime" loop. The last six runs are called iterations 1 through 6 of the speed feedback loop.²³

One way to reduce the run time of the travel demand model would be to run fewer speed feedback iterations. In earlier COG/TPB travel models, such as Version 2 and Version 2.1, there were four speed feedback loops (called "pump prime," "base," "i1," and "i2"), not the current seven. In 2002, at the request of the TPB chairman, the TRB was asked to review the TPB travel model (Version 2 at the time, and later Version 2.1C).²⁴ In the second of its two letter reports to the TPB, the TRB indicated that the Version 2 travel model was insufficiently converged²⁵:

²² Juan de Dios Ortúzar and Luis G. Willumsen, *Modelling Transport*, 3rd ed. (Wiley, 2001), 338.

²³ Milone et al., *TPB Travel Forecasting Model, Version 2.2: Specification, Validation, and User's Guide*, 8-1; Milone et al., *TPB Travel Forecasting Model, Version 2.3: Specification, Validation, and User's Guide*, 8-1.

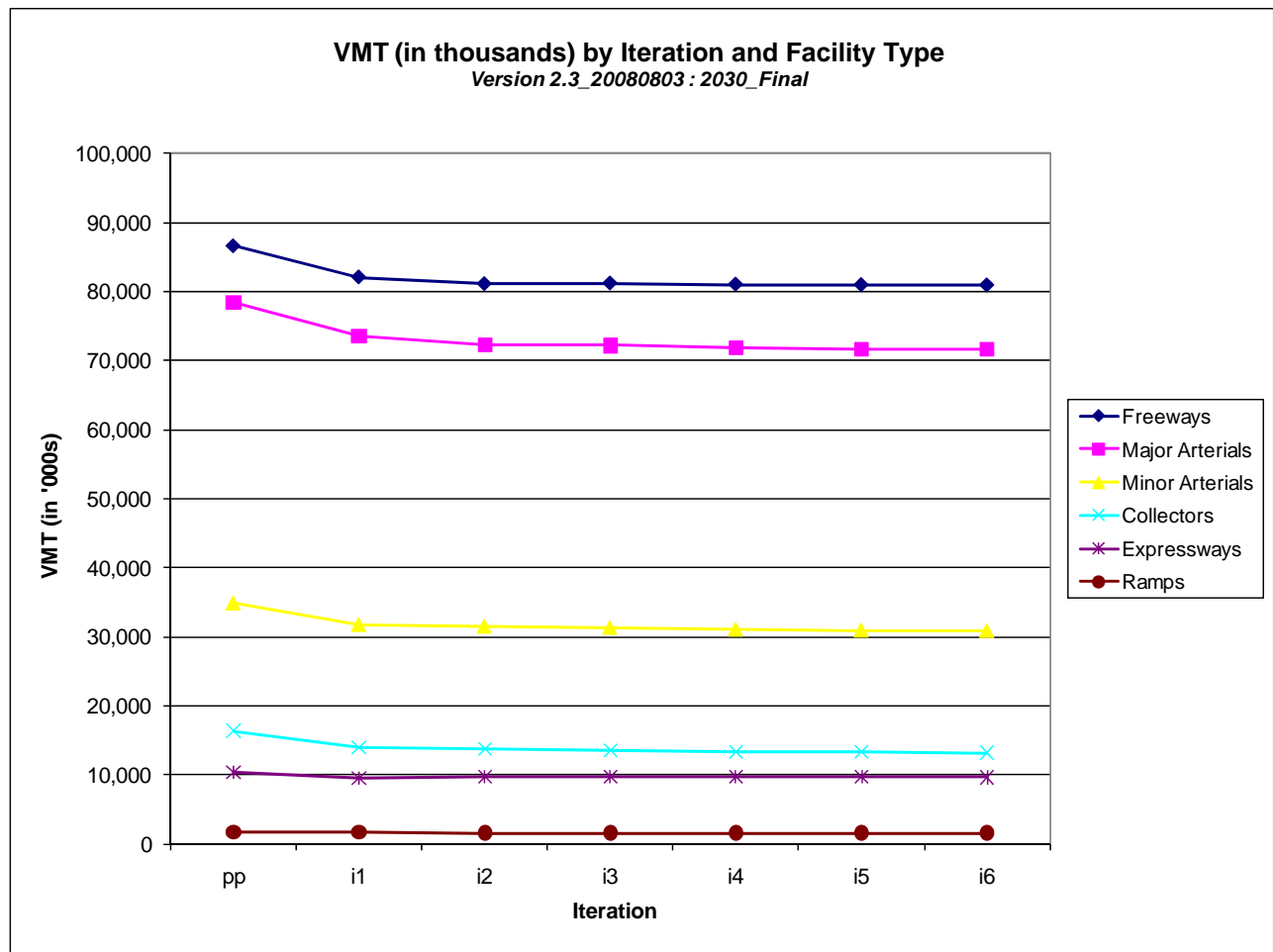
²⁴ Letter dated May 8, 2002, from Mr. Phil Mendelson, acting as Chairman of the National Capital Region Transportation Planning Board requesting that the TRB to undertake a study of the regional travel model.

²⁵ David J. Forkenbrock, *Second letter report from the Transportation Research Board's (TRB's) Committee for Review of Travel Demand Modeling by the Metropolitan Washington Council of Governments (MWCOC)* (Transportation Research Board of the National Academies, May 10, 2004), 10.

TPB’s work plan document, in contrast, describes a heuristic approach that approximates equilibrium conditions. The committee notes that the number of iterations used in TPB’s procedures appears small, and it did not find adequate documentation of how close the final assignment times are to convergence. Furthermore, the committee observes that average regional speed is not a good measure of convergence. It is possible for the regional average speed to remain nearly constant without achieving reasonable convergence in zone-to-zone travel times.

As a result of this critique, the number of speed feedback iterations was increased from four to seven. Note that, at the time, the number of iterations used in user equilibrium traffic assignment was 20, but this has now been increased to 60. Given the fact that the number of UE iterations is now 60, it was felt that we may be able to relax the number of speed feedback iterations from seven to five or so. Consequently, in December 2008, TPB staff performed several tests related to running fewer speed feedback iterations and presented the results to the TFS (January 23, 2009). The model version used was the Ver2.3_20080830. Staff summarized the results from the “2030 final” scenario by speed feedback iteration. The two summary variables were VMT by facility type and total transit trips by trip purpose. VMT by speed feedback iteration and facility type is presented in both graphical form (see Figure 2-13) and tabular form (see Table 2-11).

Figure 2-13 VMT by speed feedback iteration and facility type



Ref: I:\ateam\meetings_conf\tfs\2009\2009-01-23\fac_30_V2.2_V2.3_Jan08_Conf09.xls

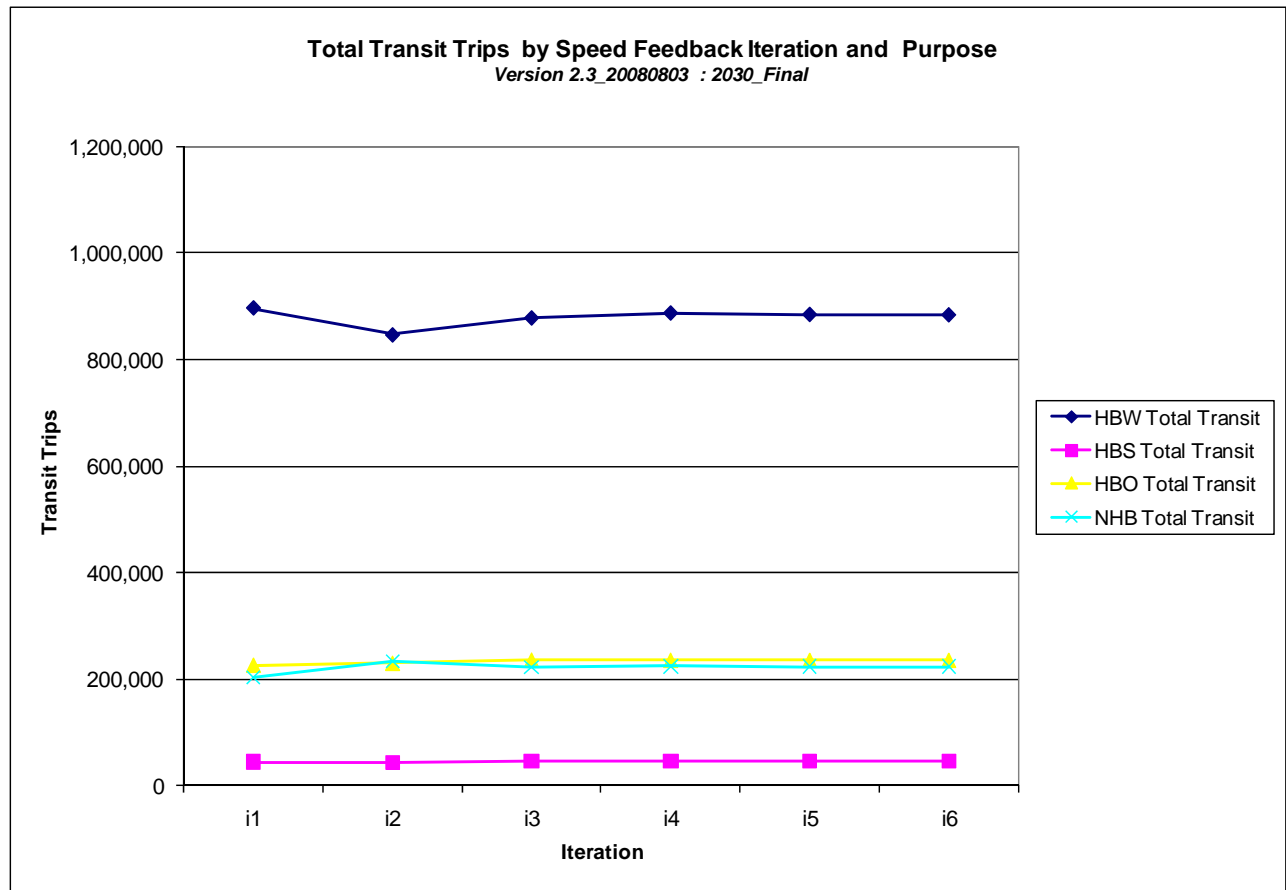
Table 2-11 VMT by speed feedback iteration and facility type

	pp	i1	i2	i3	i4	i5	i6
Freeways	86,650,764	82,070,552	81,075,304	81,180,809	81,011,163	80,928,593	80,886,227
Major Arterials	78,440,659	73,553,003	72,327,383	72,188,830	71,837,081	71,669,732	71,567,909
Minor Arterials	34,907,969	31,729,041	31,473,513	31,290,804	31,029,291	30,902,568	30,824,209
Collectors	16,398,013	13,933,199	13,766,355	13,591,360	13,384,501	13,276,053	13,208,730
Expressways	10,374,299	9,583,204	9,779,743	9,730,303	9,700,822	9,688,963	9,682,830
Ramps	1,736,410	1,678,953	1,612,925	1,611,145	1,602,219	1,597,338	1,594,199
Total VMT	228,508,113	212,547,953	210,035,222	209,593,251	208,565,076	208,063,247	207,764,105

Ref: I:\ateam\meetings_conf\tfs\2009\2009-01-23\fac_30_V2.2_V2.3_Jan08_Conf09.xls

At the regional level, it appears that the values for VMT by facility type are leveling off by the “i3” or “i4” iteration, implying that one may not need to run the fifth or sixth iteration. Total transit trips by trip purpose is presented in both graphical form (see Figure 2-14) and tabular form (see Table 2-12).

Figure 2-14 Total transit trips by speed feedback iteration and trip purpose



Ref: I:\ateam\meetings_conf\tfs\2009\2009-01-23\2030_Transit_V2.2_V2.3.xls

Table 2-12 Total transit trips by speed feedback iteration and trip purpose

	i1	i2	i3	i4	i5	i6
HBW Total Transit	896,385	847,061	878,051	887,033	884,411	883,782
HBS Total Transit	44,418	43,366	45,908	45,688	45,693	45,690
HBO Total Transit	226,582	229,963	235,917	235,552	235,489	235,418
NHB Total Transit	203,911	234,192	222,525	224,395	224,040	223,895
Total Transit	1,371,296	1,354,582	1,382,401	1,392,668	1,389,633	1,388,785

Ref: I:\ateam\meetings_conf\dfs\2009\2009-01-23\2030_Transit_V2.2_V2.3.xls

Again, at the regional level, it appears that the values for total transit by trip purpose are leveling off by the “i3” or “i4” iteration, implying that one may not need to run the fifth or sixth iteration. However, at this point, TPB staff has not reached a final decision on this question for two reasons. First, although the regional-level summaries appear to be leveling off by iteration 3 or 4, this may not be the case at the level of the sub-area, screenline, and/or link. Consequently, further investigation, at a level below the regional level, is warranted. Second, we have not used a quantifiable metric of convergence to assess whether converge has been achieved. Although there are many closure metrics used to assess convergence of traffic assignment -- e.g., gap, relative gap, average absolute volume difference (AAD), relative AAD (RAAD) – it is less well know which metric should be used to assess convergence in the speed feedback loop. One possible metric would be the root mean square error (RMSE) of the skim matrix.²⁶ We currently have a task order contract with Cambridge Systematics, Inc. to perform a scan of the best practice in the U.S. regarding travel demand modeling. One of the task order requests that TPB staff has made to CS is to prepare a technical memo regarding recommendations on feedback convergence methods. When this memo is delivered to TPB staff, around mid July 2009, we may have identified a good metric to use for assessing speed feedback convergence.

New traffic assignment algorithms in Cube Voyager

Introduction

Citilabs is planning to release several new traffic assignment algorithms in the next major update to Cube Voyager (Version 5.1, expected summer 2009):

- Conjugate and bi-conjugate Frank-Wolfe
- Gradient projection algorithm

Before discussing the TPB experience with these new traffic assignment algorithms, it is useful to present some background concerning these algorithms. In general, there are three types of algorithms for conducting traffic assignment²⁷:

- Link-based

²⁶ Howard Slavin, “Achieving planning model convergence” (Presentation at the 11th TRB National Transportation Planning Applications Conference presented at the 11th TRB National Transportation Planning Applications Conference, Daytona Beach, Florida, May 2007), 11.

²⁷ Matthew Martimo and Zhong Zhou, “New Assignment Methods in Voyager: Theory & Tests” (presented at the Futura 08, the 3rd Annual Citilabs International User Conference, Palm Springs, California, 2008).

- Path-based
- Origin-based

Table 2-13 presents a comparison of the three main types of traffic assignment algorithm, including some “observations” by the authors of the table (Matt Martimo and Zhong Zhou of Citilabs, Inc.). The most famous algorithm for solving the traffic assignment problem is the Frank-Wolfe algorithm,²⁸ which is a link-based method. Link-based algorithms have the advantage that they require the least amount of information and use the least memory compared to the other two algorithm types, but they also tend to converge slowly, especially in the later iterations.²⁹

Table 2-13 A comparison of the three main types of traffic assignment algorithm

	Link-based algorithm	Path-based algorithm	Origin-based algorithm
Decision variable	Link flow	Path flow	Origin-based approach proportion or origin-based link flow
Information	Minimum	Richest	Comparable with path-based algorithm
Memory requirement	Lowest	Highest	Medium
Convergence speed	Fast convergence at the beginning, but slower at later stages of convergence	Fast	Fast
Examples	<ul style="list-style-type: none"> • Frank-Wolfe (1956) • Improved FW, such as <ul style="list-style-type: none"> ○ Conjugate FW ○ Bi-conjugate FW 	<ul style="list-style-type: none"> • Gradient projection 	<ul style="list-style-type: none"> • Origin-based assignment (OBA) • Algorithm B (Dial) • Traffic Assignment by Paired Alternative Segments (TAPAS)
Observations ³⁰	The latest Conjugate/Bi-conjugate FW algorithms appear comparable with origin-based algorithms in speed and accuracy	Gradient Projection algorithm shows more advantages in small- to medium-size networks	Algorithm B and TAPAS show much better performance than Bar-Gera’s origin-based algorithm

Source:³¹

In the work done by Citilabs, it was found that of the various link-based algorithms, the two that showed the most promise were the Conjugate Frank-Wolfe and the Bi- Conjugate Frank-Wolfe, which, Citilabs found, appeared to be comparable with origin-based algorithms, in terms of speed and accuracy. The second new class of traffic assignment algorithms being offered by Citilabs, the Gradient Projection algorithm, is a path-based algorithm, which showed the most advantages when used on small- to medium-size networks. Given the relatively large size of the COG/TPB network, it was decided that the GP algorithm would not be advantageous for COG/TPB. Consequently, the

²⁸ Marguerite Frank and Philip Wolfe, “An algorithm for quadratic programming,” *Naval Research Logistics Quarterly* 3, no. 1-2 (1956): 95-110, doi:10.1002/nav.3800030109.

²⁹ Ortúzar and Willumsen, *Modelling Transport*, 362.

³⁰ By authors Martimo & Zhou.

³¹ Martimo and Zhou, “New Assignment Methods in Voyager: Theory & Tests.”

testing conducted by TPB staff focused on the two new link-based algorithms: Conjugate FW and Bi-Conjugate FW.

TPB staff tests with Conjugate-FW & Bi-Conjugate FW

The User Equilibrium (UE) approach to traffic assignment is considered the state-of-the practice approach for regional travel demand models. TPB travel models have used the UE approach for over ten years. TPB staff have obtained an “alpha” (i.e., pre-beta) version of Citilabs’ new software that contains the new traffic assignment algorithms (Cube Voyager 5.1.0 alpha) and have performed some tests that were presented to the Travel Forecasting Subcommittee on March 20, 2009 and are described in this section of the report. One caveat is that, in our tests, we have noticed that this alpha version of Cube Voyager does not replicate the existing results of our Version 2.3 travel model, as compared to when we use TP+/Cube Voyager version 5.0. However, the results are quite close and it is possible that these small differences will be eliminated when the software comes out of alpha release.

There are a number of convergence metrics that can be used for traffic assignment. Some of the most common are

- Gap -- also known as “absolute gap”
- Relative gap (RG)
- Average absolute volume difference (AAD)
- Relative AAD (RAAD)³²

The gap refers to the maximum difference between the current solution and the equilibrium solution, in terms of a mathematical objective function. One can think of the gap as the difference between the total vehicle hours computed with the current network volumes/times and the total vehicle hours computed using the current shortest paths. As equilibrium is approached, the gap gets smaller and smaller. In our tests, we used the “relative gap” (RG) as the metric of convergence, since this is one of the most widely-used metrics. For the tests, we used the standard highway assignment process from the Version 2.3 travel model for the year 2002. The three time-of-day traffic assignments were run (AM peak period, PM peak period, and the off peak period). The tests included both 60 UE iterations, which is used in the current Version 2.3 travel model, and 200 UE iterations. Two traffic assignment algorithms were tested: Frank-Wolfe (the base case) and conjugate Frank-Wolfe. According to Citilabs, the conjugate FW and bi-conjugate FW perform similarly, so TPB staff elected to test only one of the two (conjugate FW). Two metrics were measured: model run time and relative gap. The traffic assignment tests were conducted in isolation from the other steps in the travel model. Also note that distributed processing was not used on any of these tests. The tests were not run on the TPB travel model server, since we did not want to install the alpha software on the same computer that runs the production models. Instead, the tests were run on a relatively high end, stand-alone workstation with the following specifications (“specs”):

- OS: Microsoft Windows XP Professional

³² See Citilabs, Inc., “Citilabs Cube software, Version 5, online help,” December 12, 2008, p. 164 for formulas of the gap and relative gap.

- Processors: One Intel Quad Core Xeon CPUs (5080) @ 3.73 GHz (i.e., 4 cores total)
- Physical memory: 2 GB; L2 cache 2 MB per CPU
- Frequency of system bus: 1066 MHz

Table 2-14 shows run times (in minutes) for the three time-of-day traffic assignments with 60 user equilibrium traffic assignment iterations, using both the default Frank-Wolfe algorithm and the conjugate Frank-Wolfe. With 60 UE iterations, there is no run time advantage to using the conjugate FW algorithm. In fact, the conjugate FW took slightly longer than the baseline (151 minutes vs. 149 minutes).

Table 2-14 Run times for traffic assignment with 60 UE iterations: Frank-Wolfe vs. Conjugate FW

Period	minutes			
	Frank Wolfe	Frank Wolfe	Conjugate	
	TP+	Voyager	Voyager	
	Existing V2.3	Enhance=0	Enhance=1	
AM	50.22	49.77	50.25	
PM	48.07	48.03	48.87	
OP	50.40	51.63	52.35	
Total	148.68	149.43	151.47	~ 2.5 hours
<i>Note: Distributed Processing not used</i>				

Ref: I:\ateam\meetings_conf\tfs\2009\2009-03-20\Assignment_Results.xls

Table 2-15 shows the relative gaps for traffic assignment with 60 UE iterations: Frank-Wolfe vs. Conjugate FW. The RG for 60 UE iterations of Frank-Wolfe on the AM traffic assignment is 0.01209, or 1.21×10^{-2} . The comparable figure for conjugate FW is 0.00428, or 4.28×10^{-3} , about 35% of the baseline. The PM peak period assignment is slightly less converged: The RG of FW is 0.01541, or 1.54×10^{-2} , whereas the RG of the conjugate FW is 0.00820, or 8.20×10^{-3} , with the ratio of the two equal to 0.53. The off peak period assignment showed the tightest convergence, with a RG of FW of 0.00233 (2.33×10^{-3}) and a RG of the conjugate FW of 0.00089 (8.9×10^{-4}). There are no uniformly agreed upon standards for what degree of relative gap is sufficient – it depends on the particular application of the travel model – although some have suggest a minimum of 10^{-3} , with 10^{-4} or 10^{-5} a better goal for careful project evaluation.³³

³³ Howard Slavin to Ronald Kirby, “Comments on the VHB report entitled “Results of FY 2007 Travel Forecasting Research,”” March 3, 2008.

Table 2-15 Relative gap for traffic assignment with 60 UE iterations: Frank-Wolfe vs. Conjugate FW

		Rel Gap	Minutes	Rel Gap Reduction
AM	Frank-Wolfe	0.01209	50	
	Conjugate	0.00428	50	-64.6%
PM	Frank-Wolfe	0.01541	48	
	Conjugate	0.00820	49	-46.8%
OP	Frank-Wolfe	0.00233	50	
	Conjugate	0.00089	52	-61.8%

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Table 2-16 shows the relative gaps for traffic assignment with 200 UE iterations: Frank-Wolfe vs. Conjugate FW. The RG for 200 UE iterations of Frank-Wolfe on the AM traffic assignment is 0.00113, or 1.13×10^{-3} . The comparable figure for conjugate FW is 0.00034, or 3.4×10^{-4} , which is about 30% of the value for FW. The PM peak period assignment is slightly less converged: The RG of FW is 0.00178, or 1.78×10^{-3} , whereas the RG of the conjugate FW is 0.00051, or 5.1×10^{-4} , with the ratio of the two equal to 0.29. The off peak period assignment showed the tightest convergence, with a RG of FW of 0.00028 (2.8×10^{-4}) and a RG of the conjugate FW of 0.00010 (1×10^{-4}).

Table 2-16 Relative gap for traffic assignment with 200 UE iterations: Frank-Wolfe vs. Conjugate FW

		Rel Gap	Minutes	Rel Gap Reduction
AM	Frank-Wolfe	0.00113	166	
	Conjugate	0.00034	168	-80.9%
PM	Frank-Wolfe	0.00178	160	
	Conjugate	0.00051	163	-71.3%
OP	Frank-Wolfe	0.00028	172	
	Conjugate	0.00010	175	-64.3%

Ref: I:\ateam\meetings_conf\tfs\2009\2009-03-20\Assignment_Results.xls

Table 2-17 shows run times (in minutes) for the three time-of-day traffic assignments with 200 user equilibrium traffic assignment iterations, using both the default Frank-Wolfe algorithm and the conjugate Frank-Wolfe. As was the case with 60 UE iterations, the new conjugate FW algorithm does not result in a faster run time, but it allows one to get to a more converged solution in the same amount of time.

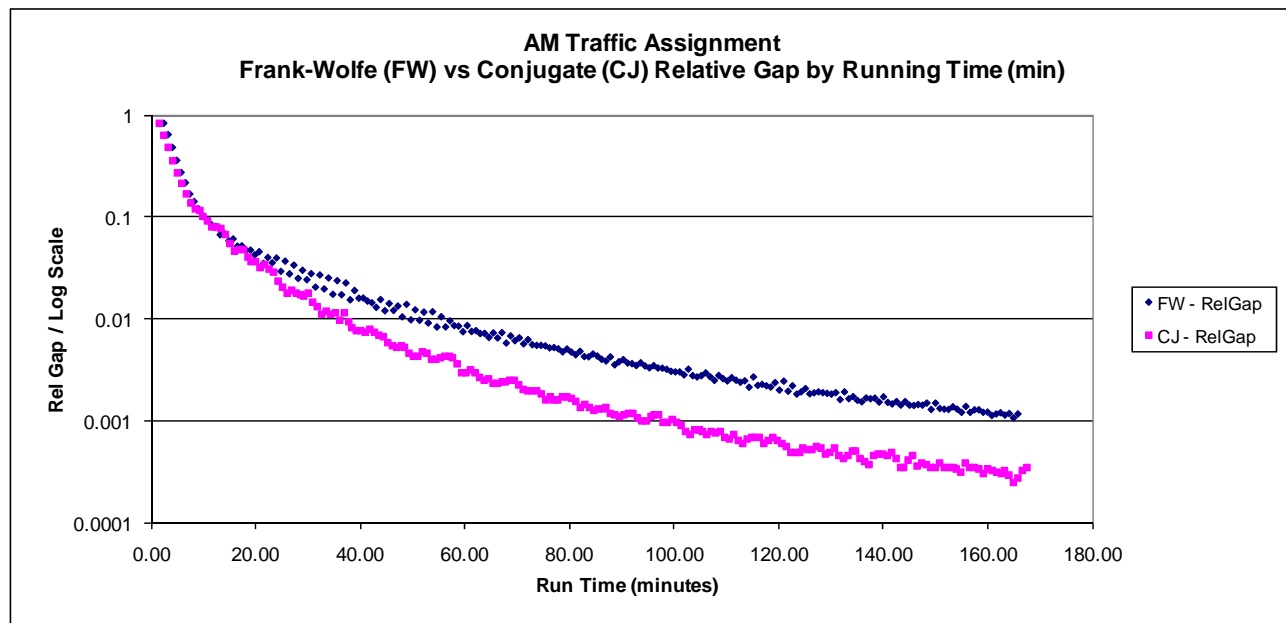
Table 2-17 Run times for traffic assignment with 200 UE iterations: Frank-Wolfe vs. Conjugate FW

Period	minutes			
	Frank Wolfe TP+ Existing V2.3	Frank Wolfe Voyager Enhance=0	Conjugate Voyager Enhance=1	
AM	167.39	165.89	167.50	~ 2.8 hours
PM	160.22	160.11	162.89	~ 2.7 hours
OP	168.00	172.11	174.50	~ 2.9 hours
Total	495.61	498.11	504.89	~ 8.3 hours

Ref: I:\ateam\meetings_conf\tfs\2009\2009-03-20\Assignment_Results.xls

Figure 2-15 is a plot of the relative gap by model run time for the AM traffic assignment. It shows the RG for both Frank-Wolfe and conjugate FW. For the first 20 minutes, both algorithms performed comparably, attaining a RG of about 0.03. At this point, the two performance of the two algorithms begins to diverge. Frank-Wolfe takes about 50 minutes to reach a RG of 0.01, whereas the conjugate FW attains the same RG in about 37 minutes, a 26% reduction in run time. To attain a relative gap of 0.001, FW takes about 170 minutes, whereas conjugate FW takes about 100 minutes, a 40% reduction in run time. So, as the relative gap gets smaller and smaller, the conjugate FW becomes more and more efficient, compared to the regular Frank-Wolfe.

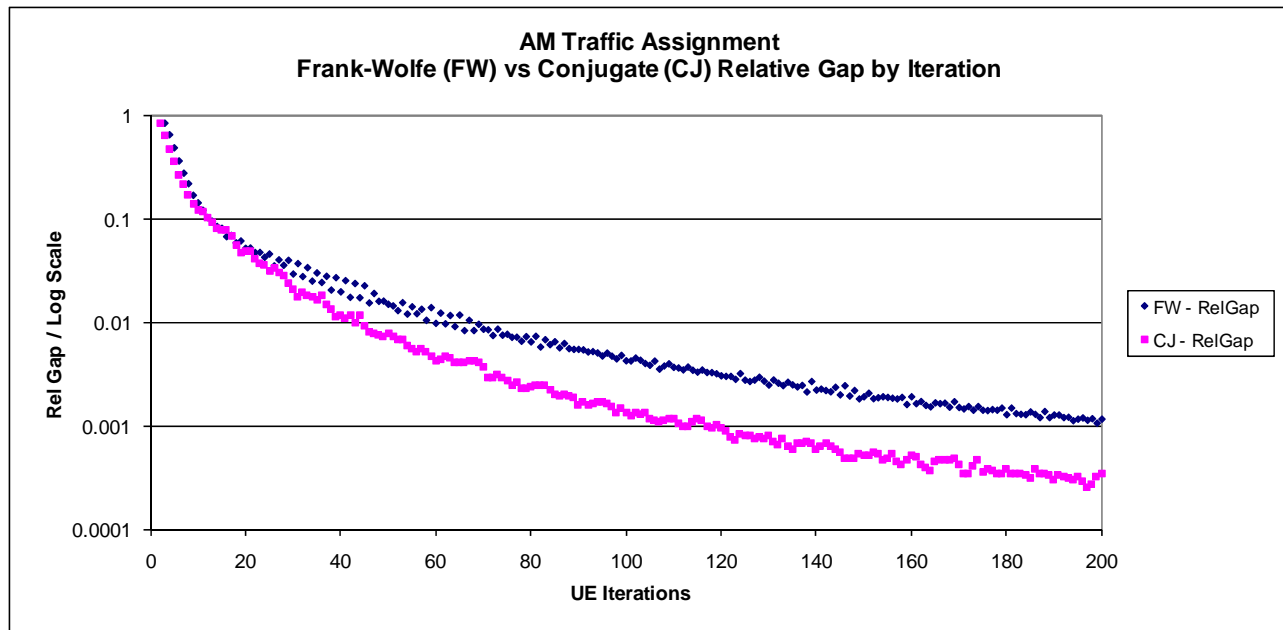
Figure 2-15 Relative gap by model run time: Frank-Wolfe vs. Conjugate Frank-Wolfe (AM traffic assignment)



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Figure 2-16 is a plot of the relative gap by UE iteration number for the AM traffic assignment. As was the case before, it shows the RG for both Frank-Wolfe and conjugate FW. The pattern of the graph is essentially identical to what was shown in Figure 2-15. In this case, in terms of iterations, not minutes, for the first 20 iterations, both algorithms performed comparably, attaining a RG of about 0.03. The performance gains should be about the same as was shown before: The Conjugate FW attains a RG of 0.01 in about 26% less time and it attains a RG of 0.001 in about 40% less time.

Figure 2-16 Relative gap by UE iteration number: Frank-Wolfe vs. Conjugate Frank-Wolfe (AM traffic assignment)



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Conclusion

The Conjugate FW algorithm does, in fact, converge faster than the traditional Frank-Wolfe algorithm and the convergence gains accelerate as the relative gap gets smaller and smaller. Once this algorithm comes out of alpha testing and is part of the production Cube Voyager software package, TPB staff will likely begin using it and will be confronted with three possible paths to take:

- Reduce the number of UE iterations in the Version 2.3 travel model from 60 to a smaller value, such that the relative gap remains about the same as it is now, but the model run time is reduced
- Keep the current 60 UE iterations in the model, while taking advantage of the higher convergence offered by the new algorithm
- Increase the number of UE iterations to a value above 60, resulting in a higher level of traffic assignment convergence.

Implementing distributed processing

Introduction

This section of the report documents the status of the testing Cube Cluster for use in the regional COG/TPB travel model.³⁴ Cube Cluster is the module in Cube Voyager that allows one to use distributed processing. “Distributed processing” or “distributed computing” refers to a computer system that uses more than one computer or processor to run an application. This includes “parallel processing,” in which a single computer uses more than one processor to execute a program. It also includes a computer system where a set of computers is connected via a local area network (LAN) with software that allows the system to divide a processing task across the set of computers. In many cases, a computer processor may contain two or more “cores” which operate in such a manner that each core can be regarded as a processor. The primary goal of using distributed processing (DP) in the application of travel demand models is to reduce the model run time, which for the COG/TPB regional travel model typically takes over 15 hours to run.

The current COG/TPB travel model is the Version 2.2 travel model.³⁵ The model under development is the Version 2.3 travel model.³⁶ At the time when the Version 2.3 travel model was split from the Version 2.2 travel model, around the spring of 2008, the main improvements in the Version 2.3 travel model were the inclusion of a 15-choice nested-logit mode choice model (replacing the 5-choice multinomial logit mode choice model) and the updating of the heavy and medium truck models. It should be noted, however, that the Version 2.2 travel model has continued to evolve after the split occurred, so there are now some features that are present in the Version 2.2 travel model that do not appear (yet) in the Version 2.3 travel model, such as the two-step assignment procedure.³⁷ Eventually, the Version 2.3 travel model should be updated such that it includes all of the relevant changes that have recently occurred to the Version 2.2 travel model. The starting point for the distributed processing work documented in this section of the report is the Version 2.3 travel model, or more particularly, the version of the Version 2.3 travel model that was converted from TP+ to Cube Voyager in January 2009 (known as Ver2.3_20080830voy). We are using Cube Voyager 5 for the tests (specifically 5.0.2 and, later, 5.0.3).

Distributed processing in Cube Voyager and the context for its use at COG/TPB

When you use Cube Cluster, you distribute a computing task across multiple processors or cores. Each processor or core is referred to as a “node”. There is generally a main process and one or more sub-processes (or sub-nodes). Although Cube Cluster can be applied to either multiple

³⁴ Mark Moran to Files, “Status of testing Cube Cluster for use in the regional travel model,” Memorandum, July 3, 2009.

³⁵ Milone et al., *TPB Travel Forecasting Model, Version 2.2: Specification, Validation, and User’s Guide*.

³⁶ Milone et al., *TPB Travel Forecasting Model, Version 2.3: Specification, Validation, and User’s Guide*.

³⁷ Metropolitan Washington Council of Governments, National Capital Region Transportation Planning Board (COG/TPB), *Air Quality Conformity Determination of the 2008 Constrained Long-Range Plan and the FY 2009-2014 Transportation Improvement Program for the Washington Metropolitan Region*; Clifford to Transportation Planning Board, “Air quality conformity assessment for the 2008 update of the Constrained Long Range Plan (CLRP) and FY 2009-2014 Transportation Improvement Program (TIP)”; Milone and Seifu to Files, “Transmittal of Version 2.2 travel model files as per the 2008 CLRP/2009-2014 TIP air quality determination”; Park to Files, “Two Step Traffic Assignment for HOT Lane Modeling in 2008 CLRP”; Milone and Moran, “TPB Models Development Status Report.”

processors within a computer (e.g., a server) or to multiple processors/computers connected via a local area network, our focus, at least initially, was to apply Cube Cluster in the first manner: to multiple processors/cores within a single computer/server. Our main travel model server (COGTMS002) has two quad-core CPUs (central processing units), so we have a total of eight cores or processors at our disposal. So, on this particular hardware configuration, one could set up a main process on one core and use the remaining seven cores for sub-processes. Or, to not monopolize the hardware, one could use up only a subset of the cores, say four or six, leaving the remaining cores for other modelers to use. The general specifications (“specs”) of the main travel model server are shown here:

- OS: Microsoft Windows Server 2003
- Processors: Two Intel Quad Core Xeon CPUs (X5365) @ 3.00 GHz (i.e., 8 cores total)
- Physical memory: 4 GB; L2 cache 8 MB per CPU
- Frequency of system bus: 1333 MHz
- Hard drive: Server is connected to a 2.27 TB direct-attach storage array
 - Number of disks: 6
 - Technology: SATA2
 - Speed: 7.2k RPM

There are two forms of distributed processing available in Cube Voyager: Intra-step distributed processing (IDP) and multi-step distributed processing (MDP). IDP breaks up zone-based processing of vectors or matrices, which are typically dimensioned up to MAXZONE (in our case, 2,191), into zone groups that can be processed concurrently on multiple computing nodes. IDP works for only certain modules in Voyager: currently the Matrix and Highway modules. A further restriction is that IDP works for most types of Matrix module operations (e.g., zone-based, but not record-based processing using RECI) and most types of Highway module operations, as long as each zone can be independently processed.

By contrast, MDP is more general, since it can be used to break up processing conducted by any module in Voyager, as well as any user-written program (e.g., Fortran). The caveat is that the distributed blocks and the mainline process must be logically independent of each other. For example, you cannot run path skimming procedures at the same time (or before) you update the speeds on the network that will be skimmed. However, you can assign peak and off-peak networks concurrently in most models, since these steps are generally independent of each other.

When using Cube Cluster, three points should be kept in mind. First, because of the zone-independent requirement on IDP and the step-independent requirement on MDP, it requires careful planning and setup by the user to implement this system. Second, Cube Cluster has limited error-handling capabilities. This should not be a problem on a production model that has already been cleaned of syntax and logic errors, but it could be an issue on a developmental model. The error-handling capabilities of Cube Cluster are governed by the way that Voyager communicates between the main process and the sub-processes: Voyager uses a file-based signaling method. Initially, the main process will check if a sub-process is available before assigning a task to it. Subsequently, Voyager will perform error checking (e.g., checking the return code of the sub-process for signs of an error), but only limited error handling. For example, if a sub-process crashes, it will cause the main process to wait forever, requiring the user to manually terminate both

the sub-process and the main process. Consequently, when using Cube Cluster with a developmental model, one needs to beware of cases where one sub-process has crashed. Third, for distributed processing to work, the main process and all the sub-processes must have access to a shared drive on a computer network so that the processes can share data. One drawback to running on a network drive is that disk intensive applications could actually run slower under Cube Cluster. According to the Cube Voyager online help.³⁸

Running on a network drive could significantly slow down a run for disk intensive applications depending on the computer network's throughput capacity so there may be little runtime benefit or take even longer when using DP on certain steps. Therefore, it is important to "tune" the DP setup to get the best performance. In general, DP works well for computationally intensive applications (e.g. doing hundreds of matrix computations for each zone in a mode choice step) but will result in less time savings for disk intensive procedures (e.g. combing 3 matrix files into one matrix file).

Thus, implementing Cube Cluster should generally be performed after model development and calibration/validation.

Analysis of run times for each modeling step

Before undertaking any distributed processing work, it makes sense to know which steps of the travel model are the most time consuming, so that one knows where to focus attention. The Version 2.3 travel model takes about 18.5 hours to run on the current travel model server, cogtms002. The model has seven speed feedback iterations, numbered 0 to 6, where the last six are referred to by their iteration number (1-6) and the first one is named "pump prime." The run time for each of these iterations can be seen in Table 2-18. The "pump prime" iteration takes less time because it omits the mode choice step, which is included in iterations 1-6.

Table 2-18 Run time for each speed feedback iteration of the Version 2.3 travel model

Model Iteration	Elapsed Time (hours)
Pump Prime Iteration	2.25
Iteration 1	2.70
Iteration 2	2.65
Iteration 3	2.67
Iteration 4	2.68
Iteration 5	2.67
Iteration 6	2.70
Transit Assignment	0.22
Total	18.53

Source: ³⁹

Rather than analyzing the component run times in all seven of the speed feedback loops, it was decided simply to analyze run times for one of the speed feedback loops -- in this case, the final, or

³⁸ Citilabs, Inc., "Citilabs Cube software, Version 5, online help," 945.

³⁹ Ronald Milone to Mark Moran, "Model Execution Time Evaluation of the Version 2.3 Travel Model," Memorandum, December 22, 2008.

“iteration 6” speed feedback loop -- which should be representative of all seven iteration of the speed feedback process. The total run time for the “i6” iteration was 2.70 hours (162 minutes). For the “i6” iteration of the travel model, it was found that two modeling steps accounted for almost two-thirds of the model run time:

- Highway assignment: 51% of model run time
- Nested-logit mode choice: 13% of model run time

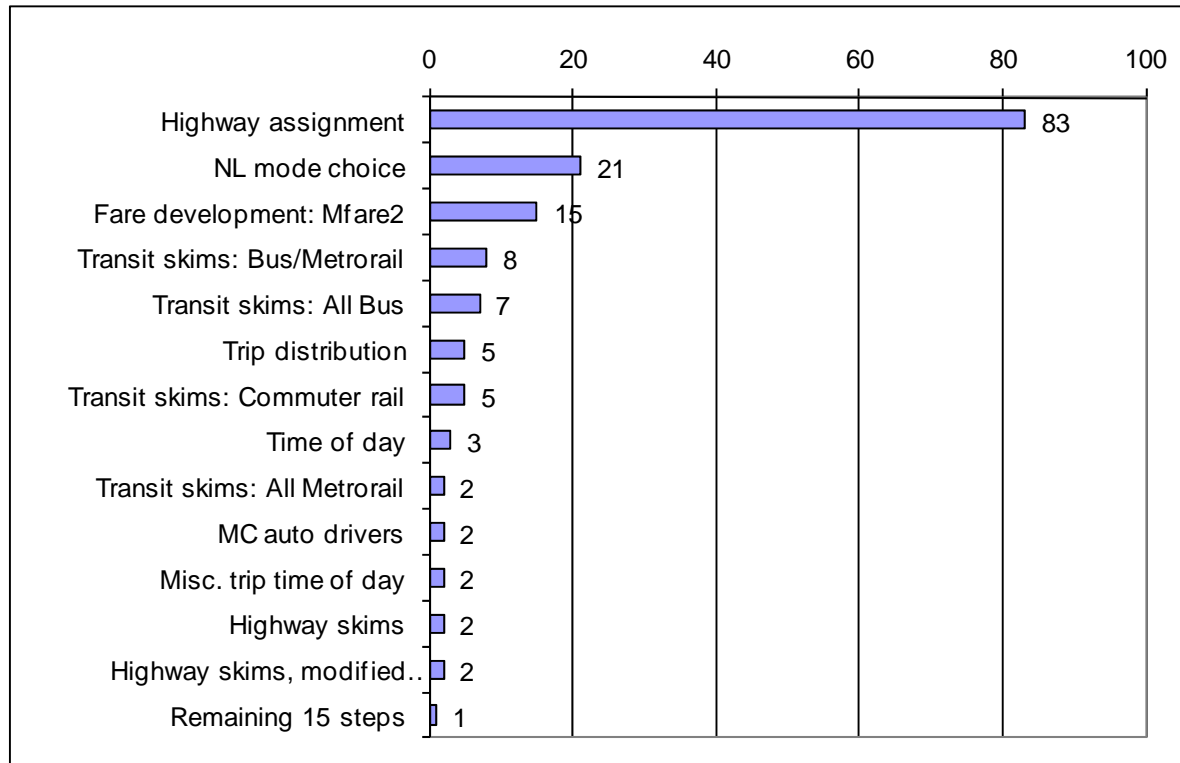
Table 2-19 presents the time use for these two steps, as well as for other steps in the model run (iteration 6 only). Similar information is presented in Figure 2-17, but in graphical, rather than tabular, format.

Table 2-19 Run times for various components in the sixth iteration of the speed feedback loop: Tabular representation

	Elapsed	Pct	
	Time	of total	Cum.
Modeling step	(min.)	time	Percent
Highway assignment	83	51%	51%
NL mode choice	21	13%	64%
Fare development: Mfare2	15	9%	73%
Transit skims: Bus/Metrorail	8	5%	78%
Transit skims: All Bus	7	4%	83%
Trip distribution	5	3%	86%
Transit skims: Commuter rail	5	3%	89%
Time of day	3	2%	91%
Transit skims: All Metrorail	2	1%	92%
MC auto drivers	2	1%	93%
Misc. trip time of day	2	1%	94%
Highway skims	2	1%	96%
Highway skims, modified network	2	1%	97%
Remaining 15 steps	1	1%	98%
Total	162	100%	

Ref: I:\ateam\meetings_conf\tfs\2009\2009-01-23\V23_2002_Execution_Time.xls

Figure 2-17 Run times (minutes) for various components in the sixth iteration of the speed feedback loop: Graphical representation



Ref: I:\ateam\meetings_conf\tfs\2009\2009-01-23\V23_2002_Execution_Time.xls

Tests tried and resultant time savings, both observed and extrapolated

Given that highway/traffic assignment accounts for about 50% of model run time, the first test we tried was using IDP on a test case of traffic assignment. Specifically, we set up a test script that applied only the AM peak period assignment.⁴⁰ The result was that a 27-minute AM peak period highway assignment was completed in 14 minutes, resulting in a 50% reduction in run time. If we extrapolate these test results to all three traffic assignment steps in the “i6” iteration of the speed feedback loop, we would expect that the 83 minutes of traffic assignment would become 42 minutes. Further extrapolating these results to the full model run, the total time savings would be expected to be about (41 minutes) x (7 traffic assignments)⁴¹ = 287 minutes, or 4.8 hours. Consequently, if the extrapolated results hold, the 18.5-hour model run would take about 13.7 hours, which is about a 25% reduction in the total model run time.

The second and final test we tried was using MDP on a test case of mode choice. Specifically, we set up a test script that ran two instances (HBW and HBS) of the nested-logit mode choice model,

⁴⁰ The typical highway assignment script has five parts: 1) Consolidate modeled and non-modeled trip tables; 2) Conduct AM assignment; 3) Conduct PM assignment; 4) Conduct the off-peak assignment; and 5) Summarize daily VMT.

⁴¹ Pump prime iteration and then iterations 1, 2, 3, 4, 5, and 6.

as applied via AEMS.EXE. In this case, the 8 minutes it normally took to run the two mode choice runs in sequence dropped to 5 minutes when the two runs were conducted in parallel with MDP. It is not exactly half of the time, due to the overhead that is involved with the distributed processing. Again, if we extrapolate this test to the four mode choice model runs that occur in the “i6” iteration of the speed feedback loop, we would expect the 21 minutes of run time would become about 6 minutes (a 15-minute time savings). Further extrapolating these results to the full travel model, which has six calls to the mode choice process, the total time savings would be about (15 minutes) x (6 calls of the mode choice process) = 90 minutes, or 1.5 hours. Consequently, if the extrapolated results hold, the 18.5-hour model run would take about 17 hours, which is about an 8% reduction in the total model run time. If the extrapolated results of the traffic assignment test and mode choice test are additive, the combine time savings would be 6.3 hours, meaning the 18.5-hour model run time would now be 12.2 hours, which is about a 34% time savings.

The next section of this report describes in more detail the two tests that were done.

Traffic assignment test of distributed processing

Work conducted

The typical traffic assignment process is applied using a TP+ (or, in this case, Cube Voyager) script called Highway_Assignment.s. This process has five main parts, which were delineated in footnote 40 mentioned above. For this initial test of DP on traffic assignment, we divided the normal script into five parts:

- Highway_Assignment_1of5.s (Trip table preparation)
- Highway_Assignment_2of5.s (AM Assignment & Volume averaging)
- Highway_Assignment_3of5.s (PM Assignment & Volume averaging)
- Highway_Assignment_4of5.s (OP Assignment & Volume averaging)
- Highway_Assignment_5of5.s (Combining the TOD networks into a final network file)

We chose to start with only one of these parts: AM Assignment & Volume averaging (Highway_Assignment_2of5.s).

As a side note, when converting from TP+ to Cube Voyager, there are two major changes one needs to make:

1. In the batch files, such as auto_drive.bat: Change calls to TP+ (start /w TPPLUS.EXE) to calls to Voyager (start /w Voyager.exe).
2. In TP+/Voyager scripts: Change some, but not all, of the “RUN PGM” statements. The rules for these changes can be found in Table 2-20.

Table 2-20 Scripting changes needed to convert a TP+ script to Cube Voyager

Statement in TP+	Equivalent statement in Cube Voyager
RUN PGM=MATRIX	No change
RUN PGM = HWYNET	No change
RUN PGM=HWYLOAD	RUN PGM=HIGHWAY
RUN PGM=TRNBUILD	No change

RUN PGM=TRIPDIST	RUN PGM=DISTRIBUTION
------------------	----------------------

As an example, a portion of the AM peak period highway assignment script can be seen in Figure 2-18 (TP+ format) and Figure 2-19 (Cube Voyager format). The only change is that “PGM = HWYLOAD” has been changed to “PGM = HIGHWAY”.

Figure 2-18 Highway_Assignment_2of5.s: Script in TP+ format (first 36 lines)

```

; =====
; V2.3
; Highway_Assignment_2of5.s
;
; =====
;AM Highway Assignment
;
path      = 'M:\model_dev\Ver2.3_20080830'      ; location of inputs
scen      = '\2002\'                          ; year or scenario
iter      = 'i6'                              ; current iteration
preiter   = 'i5'                              ; previous iteration
iterno    = 6                                ; current iteration
UEiters   = 60                                ; User Equil.iterations
PRD       = 'AM'                               ; Period
PCTADT    = 40                                ; AM Pk Ftr (%)
CAPFAC    = 1/(PCTADT/100)                    ; Cap Factor = 1/(PCTADT/100)

;;PRD     = 'PM' ;
;;PCTADT  = 37 ;
;;PRD     = 'OP';
;;PCTADT  = 12 ;

RUN PGM=HWYLOAD

NETI      = @PATH@@scen@@preiter@HWY.net      ; TP+ Network
; The input trip table has 5 Vehicle Tables:
; 1 - 1-Occ Auto Drivers
; 2 - 2-Occ Auto Drivers
; 3 - 3+Occ Auto Drivers
; 4 - Medium Trucks
; 5 - Airport Pass. Auto Driver Trips
; 6 - Heavy Trucks

```

Ref: m:\model_dev\dp_development\ver2.3_20080830\2002\deconstructed_highway_assignment\
Highway_assignment_2of5.s

Figure 2-19 Highway_Assignment_2of5.s: Script in Voyager format (first 36 lines)

```

; =====
; V2.3
; Highway_Assignment_2of5.s
;
; =====
;AM Highway Assignment
;

```



```

path      = 'M:\model_dev\Ver2.3_20080830'      ; location of inputs
scen      = '\2002\'                            ; year or scenario
iter      = 'i6'                                ; current iteration
preiter   = 'i5'                                ; previous iteration
iterno    = 6                                   ; current iteration
UEiters   = 60                                  ; User Equil.iterations
PRD       = 'AM'                                ; Period
PCTADT    = 40                                  ; AM Pk Ftr (%)
CAPFAC    = 1/(PCTADT/100)                      ; Cap Factor = 1/(PCTADT/100)

;;PRD     = 'PM' ;
;;PCTADT  = 37 ;
;;PRD     = 'OP' ;
;;PCTADT  = 12 ;

RUN PGM=HIGHWAY

NETI      = @PATH@@scen@@preiter@HWY.net        ; TP+ Network
; The input trip table has 5 Vehicle Tables:
; 1 - 1-Occ Auto Drivers
; 2 - 2-Occ Auto Drivers
; 3 - 3+Occ Auto Drivers
; 4 - Medium Trucks
; 5 - Airport Pass. Auto Driver Trips
; 6 - Heavy Trucks

```

Ref: m:\model_dev\dp_development\ver2.3_20080830\2002\deconstructed_highway_assignment\Highway_assignment_2of5.00.s

In Figure 2-20, one can see this same script, but with the code necessary for intra-step distributed processing.

Figure 2-20 Highway_Assignment_2of5.s: Script in Voyager format (first 36 lines) with statements for distributed processing

```

; =====
; V2.3
; Highway_Assignment_2of5.09.s
; Removed COMP from the exclude statement
; =====
;AM Highway Assignment
;
path      = 'e:\model_dev\Ver2.3_20080830'      ; location of inputs
scen      = '\2002\'                            ; year or scenario
iter      = 'i6'                                ; current iteration
preiter   = 'i5'                                ; previous iteration
iterno    = 6                                   ; current iteration
UEiters   = 60                                  ; User Equil.iterations
PRD       = 'AM'                                ; Period
PCTADT    = 40                                  ; AM Pk Ftr (%)
CAPFAC    = 1/(PCTADT/100)                      ; Cap Factor = 1/(PCTADT/100)

;;PRD     = 'PM' ;
;;PCTADT  = 37 ;
;;PRD     = 'OP' ;
;;PCTADT  = 12 ;

```

```
pageheight=32767 ; Preclude header breaks
DISTRIBUTE INTRASTEP=T MULTISTEP=F

RUN PGM=HIGHWAY

DistributeINTRASTEP ProcessID='mwcog', ProcessList=1-4

NETI      = @PATH@@scen@@preiter@HWY.net          ; TP+ Network
; The input trip table has 5 Vehicle Tables:
;   1 - 1-Occ Auto Drivers
;   2 - 2-Occ Auto Drivers
;   3 - 3+Occ Auto Drivers
;   4 - Medium Trucks
;   5 - Airport Pass. Auto Driver Trips
;   6 - Heavy Trucks
```

Ref: m:\model_dev\dp_development\ver2.3_20080830\2002\deconstructed_highway_assignment\
Highway_assignment_2of5.09.s

What follows is a discussion of the key changes made to the AM highway assignment script. The first change that appears is actually one that was done for streamlining the print files and has nothing to do with distributed processing:

```
pageheight=32767 ; Preclude header breaks
```

This was done to preclude header breaks in the listing file. The next change is the statement:

```
DISTRIBUTE INTRASTEP=T MULTISTEP=F
```

The DISTRIBUTE statement globally controls the DP options to turn on/off intra-step or multi-step distribute processing.⁴² In this case, intra-step has been turned on and multi-step turned off, since we will not be using MDP.

The next statement of interest is

```
DistributeINTRASTEP ProcessID='mwcog', ProcessList=1-4
```

This statement invokes intra-step distributed processing (IDP), which can be used for two Cube Voyager modules: MATRIX and HIGHWAY. The ProcessID keyword indicates the prefix of the filename that will be used to pass information between the sub-processes and the main process. The ProcessList keyword indicates a list of numbers representing the processing nodes, also called sub-nodes, that will be used. When distributed processing is used, each processor or core becomes a processing “node.” There is a main node and then one or more sub-nodes. In the case shown above, there is a main node and then four sub-nodes (numbered 1 to 4), so there are, in total, five processors or cores in use.

There is another change that was done to the code in the Voyager script to make it compliant with IDP, but it does not appear in the previous three figures because it occurs farther down in the script. The statement “IF (I=1)” has been changed to “IF (I=FirstZone)”, as can be seen in Figure 2-21.

⁴² Citilabs, Inc., “Citilabs Cube software, Version 5, online help.”

Figure 2-21 Change made to “IF (I=1)” statement for the purposes of applying distributed processing

```

238 PHASE=ILOOP
239
240 IF (I=1)
241 LINKLOOP
242 ; Initial Iteration LINK IMPEDANCE (HIGHWAY TIME + Equiv.Toll/Time) by vehicle type here:
243 LW.SOV@PRD@IMP = TIME + (LW.SOV@PRD@TOLL/100.0) * SV@PRD@EQM ;SOV IMP
244 LW.HV2@PRD@IMP = TIME + (LW.HV2@PRD@TOLL/100.0) * H2@PRD@EQM ;HOV 2 IMP
245 LW.HV3@PRD@IMP = TIME + (LW.HV3@PRD@TOLL/100.0) * H3@PRD@EQM ;HOV 3+IMP
246 LW.TRK@PRD@IMP = TIME + (LW.TRK@PRD@TOLL/100.0) * TK@PRD@EQM ;Truck IMP
247 LW.APX@PRD@IMP = TIME + (LW.APX@PRD@TOLL/100.0) * AP@PRD@EQM ;APAX IMP

```

```

238 PHASE=ILOOP
239
240 IF (I=FirstZone)
241 LINKLOOP
242 ; Initial Iteration LINK IMPEDANCE (HIGHWAY TIME + Equiv.Toll/Time) by vehicle type here:
243 LW.SOV@PRD@IMP = TIME + (LW.SOV@PRD@TOLL/100.0) * SV@PRD@EQM ;SOV IMP
244 LW.HV2@PRD@IMP = TIME + (LW.HV2@PRD@TOLL/100.0) * H2@PRD@EQM ;HOV 2 IMP
245 LW.HV3@PRD@IMP = TIME + (LW.HV3@PRD@TOLL/100.0) * H3@PRD@EQM ;HOV 3+IMP
246 LW.TRK@PRD@IMP = TIME + (LW.TRK@PRD@TOLL/100.0) * TK@PRD@EQM ;Truck IMP
247 LW.APX@PRD@IMP = TIME + (LW.APX@PRD@TOLL/100.0) * AP@PRD@EQM ;APAX IMP

```

One of the requirements in using IDP is that the order of processing groups of zones must be independent, so it does not matter which zone groups are processed first. In addition to this requirement, there are a number of commands/options that will cause IDP to turn off automatically due to data storage, calculation or input/output requirements that would overtake any benefits that IDP would provide. One example is the “IF (I=1)” statement. Other examples can be found in the online help.⁴³

Next steps for IDP of traffic assignment

The next step would be to implement IDP on highway assignment for all three time-of-day periods (AM, PM, and off peak) and then to have this occur in all seven loops of the highway assignment process (pump prime, i1, i2, i3, i4, i5, and i6). To implement IDP for all three time-of-day periods, we will need to either a) find a way to run IDP in a loop/recursive mode or b) develop three duplicate sets of Cube Voyager script (one for each time-of-day period). The drawback to the second approach is there would be three sets of very similar code and all three would need to be changed consistently when updating the script.

Mode choice test of distributed processing

Work conducted

In the existing TPB regional travel model, both Version 2.2 and 2.3, the mode choice process is called with a batch file (Mode_Choice.bat, see Figure 2-22). This is the case with most of the modeling steps (e.g., Set_Factors.bat, Set_CPI.bat, PP_Highway_Build.bat, Trip_Generation.bat).

Figure 2-22 Mode_Choice.bat: No distributed processing

```

CD %1
:: Copy iteration-specific inputs to generic names

```

⁴³ Ibid., 953.

```

if exist %_iter_%_hbw_NL.ptt copy %_iter_%_hbw_NL.ptt HBW_INCOME.PTT
if exist %_iter_%_hbs_NL.ptt copy %_iter_%_hbs_NL.ptt HBS_INCOME.PTT
if exist %_iter_%_hbo_NL.ptt copy %_iter_%_hbo_NL.ptt HBO_INCOME.PTT
if exist %_iter_%_nhb_NL.ptt copy %_iter_%_nhb_NL.ptt NHB_INCOME.PTT

if exist Hwy%_prev_%AM.SKM copy Hwy%_prev_%AM.SKM HWYAM.SKM
if exist Hwy%_prev_%OP.SKM copy Hwy%_prev_%OP.SKM HWYOP.SKM

if exist %_iter_%_TRNAM_CR.SKM copy %_iter_%_TRNAM_CR.SKM TRNAM_CR.SKM
if exist %_iter_%_TRNAM_AB.SKM copy %_iter_%_TRNAM_AB.SKM TRNAM_AB.SKM
if exist %_iter_%_TRNAM_MR.SKM copy %_iter_%_TRNAM_MR.SKM TRNAM_MR.SKM
if exist %_iter_%_TRNAM_BM.SKM copy %_iter_%_TRNAM_BM.SKM TRNAM_BM.SKM

if exist %_iter_%_TRNOP_CR.SKM copy %_iter_%_TRNOP_CR.SKM TRNOP_CR.SKM
if exist %_iter_%_TRNOP_AB.SKM copy %_iter_%_TRNOP_AB.SKM TRNOP_AB.SKM
if exist %_iter_%_TRNOP_MR.SKM copy %_iter_%_TRNOP_MR.SKM TRNOP_MR.SKM
if exist %_iter_%_TRNOP_BM.SKM copy %_iter_%_TRNOP_BM.SKM TRNOP_BM.SKM

if exist hbw_NL_MC.* del hbw_NL_MC.*
..\software\AEMS ..\controls\HBW_NL_MC.ct1
if errorlevel 1 goto error

if exist hbs_NL_MC.* del hbs_NL_MC.*
..\software\AEMS ..\controls\HBS_NL_MC.ct1
if errorlevel 1 goto error

if exist hbo_NL_MC.* del hbo_NL_MC.*
..\software\AEMS ..\controls\hbo_NL_MC.ct1
if errorlevel 1 goto error

if exist nhb_NL_MC.* del nhb_NL_MC.*
..\software\AEMS ..\controls\nhb_NL_MC.ct1
if errorlevel 1 goto error

::
:: COPY GENERIC MODE CHOICE OUTPUT FILES
:: TO ITERATION-SPECIFIC NAMES

if exist HBW_NL_MC.MTT copy HBW_NL_MC.MTT %_iter_%_HBW_NL_MC.MTT /y
if exist HBS_NL_MC.MTT copy HBS_NL_MC.MTT %_iter_%_HBS_NL_MC.MTT /y
if exist HBO_NL_MC.MTT copy HBO_NL_MC.MTT %_iter_%_HBO_NL_MC.MTT /y
if exist NHB_NL_MC.MTT copy NHB_NL_MC.MTT %_iter_%_NHB_NL_MC.MTT /y

if exist voya*.* del voya*.*
if exist %_iter_%_MC_NL_SUMMARY.rpt del %_iter_%_MC_NL_SUMMARY.rpt
start /w Voyager.exe ..\scripts\mc_NL_summary.s /start -Pvoya -S..\%1
if errorlevel 1 goto error
if exist voya*.prn copy voya*.prn %_iter_%_mc_NL_summary.rpt
if exist voya*.prn copy voya*.prn temp.rpt
..\software\extrtab temp.rpt
if exist extrtab.out copy extrtab.out %_iter_%_mc_NL_summary.tab
if exist extrtab.out del extrtab.out
if exist temp.rpt del temp.rpt
if exist *.tbl copy *.tbl %_iter_%_mc_NL_summary.txt
if exist *.tbl del *.tbl

goto end

```

```
:error  
REM Processing Error....  
PAUSE  
:end  
CD..
```

Ref: M:\model_dev\Ver2.3_20080830voy\Mode_Choice.bat

The Mode_Choice.bat batch file in the Version 2.3 travel model has essentially four parts:

1. Copy files with iteration-specific names to files with generic names.
2. Run four instances of the nested-logit mode choice model (HBW, HBS, HBO, and NHB) using the AECOM Consult Mode Choice Computation Program (AEMS.EXE), which is a compiled Fortran program.⁴⁴
3. Copy files with generic names to files with iteration-specific names.
4. Clean up temporary files and run a mode choice summary script.

For our initial test of distributed processing, we decided to focus on part 2: running several instances of AEMS.EXE. As a proof of concept, we decided to run just two of the four mode choice models (HBW and HBS). IDP works only with the Cube Voyager modules of MATRIX and HIGHWAY, so it cannot be used on Fortran programs. By contrast, MDP will work on any program in Cube Voyager as well as user-written programs, such as Fortran. The caveat is that the distributed blocks and the mainline process must be logically independent of each other. So, it appears that MDP would be approach to take for running mode choice in distributed processing. However, MDP cannot be applied within a Windows batch file. It must be applied from within a Cube Voyager script. So the first step was to convert the Mode_Choice.bat batch file (or at least the parts of interest) into a Voyager script. Figure 2-23 and Figure 2-24 show examples of the before and after case with distributed processing (MDP) for two instances of mode choice. We will next describe the differences between the two approaches.

Figure 2-23 Without distributed processing: Two instances of AEMS.EXE applied in a batch file

```
if exist hbw_NL_MC.* del hbw_NL_MC.*  
..\software\AEMS ..\controls\HBW_NL_MC.ct1  
if errorlevel 1 goto error  
  
if exist hbs_NL_MC.* del hbs_NL_MC.*  
..\software\AEMS ..\controls\HBS_NL_MC.ct1  
if errorlevel 1 goto error
```

Ref: M:\model_dev\Ver2.3_20080830voy\Mode_Choice.bat

In Figure 2-23, two instances of the nested-logit mode choice model are applied, using AEMS.EXE: one for HBW and one for HBS. Before applying each model, pre-existing print files are deleted (otherwise AEMS will not run). After each of the two runs, the return code (called an errorlevel in batch files and Windows command prompts) is tested. If it equals 1 or greater, then execution of the batch is transferred to the section of the code that has the label “error” (labels in batch files are indicated by a double colon, so control would be sent to the label “:error”, but this label does not appear in the code snippet shown in Figure 2-23 and Figure 2-24).

⁴⁴ AECOM Consult, Inc., *AECOM Consult Mode Choice Computation Programs, AEMS, Users Guide*.

Figure 2-24 With distributed processing: Two instances of AEMS.EXE applied in a Cube Voyager script

```

distribute intrastep=T multistep=T

*"C:\Program Files\Citilabs\CubeVoyager\CLUSTER.exe" testDP 1 start exit

DistributeMULTISTEP ProcessID='testDP', ProcessNum=1
*if exist hbw_NL_MC.* del hbw_NL_MC.*
**..\software\AEMS ..\controls\HBW_NL_MC.ct1 >con
EndDistributeMULTISTEP

; This second step can simply run on the main processor; the first step was already sent to
processor 1
*if exist hbs_NL_MC.* del hbs_NL_MC.*
**..\software\AEMS ..\controls\HBS_NL_MC.ct1 >con

; wait for sub-process #1 to finish before continuing
Wait4Files Files=testDP1.script.end CheckReturnCode=T printFiles=MERGE

; Close down processing nodes
*"C:\Program Files\Citilabs\CubeVoyager\CLUSTER.exe" testDP 1 close exit

```

Ref: M:\model_dev\DP_Development\Ver2.3_20080830\2002\mcWithMdp\pilot_test03_mdp07.s

In Figure 2-24, once again, two instances of the nested-logit mode choice model are applied, but this time using Cube Cluster's multi-step distributed processing (MDP) capabilities. The statement:

```
distribute intrastep=T multistep=T
```

is the global statement that turns DP on. In this case, both IDP and MDP are turned on, but only MDP is going to be used.

The statement:

```
DistributeMULTISTEP ProcessID='testDP', ProcessNum=1
```

designates the start of a multistep block. The ProcessID keyword indicates the prefix of the filename ('testDP') that will be used to pass information between the sub-processes and the main process. Since there are essentially two (independent) processes we want to run (HBW mode choice and HBS mode choice), we will run one on the main node and one on a sub-node. So, we use the DistributeMULTISTEP block to farm out the HBW mode choice run onto sub-node number one (ProcessNum=1). By contrast, the second mode choice run (HBS) is run on the main processor/node. For four instances of AEMS, we would run one on the main node (processor/core) and then farm out the other three to sub-nodes.

Continuing with Figure 2-24, as was the case before, we need to delete pre-existing print files. However, in this case, the statement is preceded by an asterisk

```
*if exist hbw_NL_MC.* del hbw_NL_MC.*
```

which sends the command to the operating system. By contrast, the statement that calls AEMS has a double asterisk in front of it.

```
**..\software\AEMS ..\controls\HBW_NL_MC.ct1 >con
```

This is similar to the single asterisk, but, in this case, the double asterisk is used to make sure the command window remains visible on the computer display. According to the online help, "The '**' approach will be appropriate if the command requires some interaction with the user, or perhaps if

it displays some progress which the user always wants to be able to view.”⁴⁵ In our case, we want to be able to see the progress of the mode choice model run as it processes each zone. Notice also the “>con” flag at the end of the statement, which is used to send the output of a command to the console (screen).

Continuing with Figure 2-24, the statement:

```
EndDistributeMULTISTEP
```

designates the end of a multistep block.

In general, we would want the execution of later modeling steps to wait until all four mode choice models have run (i.e., HBW, HBS, HBO, NHB). In this test script, where only two instances of the mode choice model are run, we still want the execution of later modeling steps to wait until the two instances of AEMS.EXE are finished. Consequently, we issue the Wait4Files statement:

```
; wait for sub-process #1 to finish before continuing  
Wait4Files Files=testDP1.script.end CheckReturnCode=T printFiles=MERGE
```

The Files keyword indicates the name of the information-transfer file (in this case, testDP1.script.end) for which the script execution should wait. If we were running all four mode choice models, three of them would likely be farmed out to sub-nodes, using “Files=testDP1.script.end, testDP2.script.end, testDP3.script.end,”. The CheckReturnCode keyword indicates that the return codes from the sub-processes should be checked. When true, the whole run will stop if a sub-process returns with a code 2 (fatal) or higher. The PrintFiles keyword controls the disposition of the print files from the sub-processes. It can be “MERGE,” “MERGESAVE,” “DELETE,” or “SAVE.” MERGE means the print files of the sub-processes will be merged back into the main print file, before the sub-process print files are deleted.

Finally, we use a statement to close down processing nodes. In our case, there was only one node to close:

```
; Close down processing nodes  
*"C:\Program Files\Citilabs\CubeVoyager\CLUSTER.exe" testDP 1 close exit
```

Next steps for MDP of mode choice

The next step would be to implement MDP on mode choice for all four trip purposes (HBW, HBS, HBO, NHB) and to implement this change on all six runs of these four models (iteration 1-6).

Next steps: Implementing DP on the regional travel model

The next steps would be to actually implement this work on the full travel model, not just two test cases (i.e., IDP for traffic assignment and MDP for mode choice). If we cannot get IDP to work across the AM-PM-OP loop in highway assignment, we would need to have redundant code. This work has pointed to two possible changes in the way the travel model is applied. The first possible change is to consider converting more of the Windows batch files into Cube Voyager scripts, just as we did with Mode_Choice.bat. The second is to consider using Cube Application Manager as a

⁴⁵ Citilabs, Inc., “Citilabs Cube software, Version 5, online help,” 83, C:\Program Files\Citilabs\CubeVoyager\RG_CubeVoyager.pdf.

possible way to run the travel model, since this should make it easier to implement distributed processing in the model.

2.3 References

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- . *CALIBMS: Nested Mode Split Model Constant Calibrator for AEMS (AECOM Consult Mode Choice Computation Programs), Users Guide*. Draft report. AECOM Consult, Inc., June 2006.
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Chapter 3 Methods Track

Methods development activities are those associated with longer term travel modeling improvements. This chapter reviews recent findings in the area of airport modeling and the current status of the TPB's advanced modeling plans.

3.1 Modeling Airport Choice and Mode of Access

Airport auto driver forecasts are currently formulated as exogenous inputs to the regional travel model. The process involves the use of a FRATAR-technique in which forecasted airport trip tables are developed using observed travel patterns that are adjusted over time in accordance with adopted household and job growth forecasts. TPB staff is interested in keeping abreast of potential ways to model airport ground travel more explicitly, and has attempted to stay abreast of emerging techniques. This chapter provides a summary of recent synthesis report on airport modeling techniques.

2.1.1 The ACRP Synthesis

The Transportation Research Board (TRB) conducted a synthesis report in 2008 entitled "Airport Ground Access Mode Choice Model" as part of the Airport Cooperative Research Program (ACRP).¹ The synthesis consisted of comprehensive review of the literature on the state of practice for choice of airport ground access (by both air passengers and airport employees). It also addressed the modeling of airport choice in regions where two or more airport options exist. The review was supplemented by survey of airport authorities, Metropolitan Planning Organizations (MPOs), consulting firms and research institutions with the purpose of documenting the characteristics of existing models and the issues relevant to their technical development and application.

The synthesis covered the following topics:

1. A description of the modeling process for airport ground access mode choice. This included a brief review of the following:
 - disaggregate, discrete logit mode choice models
 - approaches to modeling and data requirements (e.g., revealed vs. stated preference)
 - model specification, estimation, calibration, validation, mathematical form, and market segmentation.
2. A literature review including different applications, e.g. Atlanta; Boston; Chicago; Miami; San Francisco Bay Area (MTC); Portland, Oregon; San Jose, California; Toronto; the United Kingdom; Dallas, Texas (North Central Texas COG); Montreal; and Sacramento, California (SACOG).
3. A survey of airport ground access modeling at 107 different planning organizations (23 of which are MPO's).
4. A review of the state of practice of air passenger mode choice models. This is the core chapter for the synthesis.

¹ Geoffrey D. Gosling, *ACRP Synthesis 5: Airport Ground Access Mode Choice Models: A Synthesis of Airport Practice*, Airport Cooperative Research Program (Washington, D.C.: Transportation Research Board, 2008).

The following is a brief description of some important findings and conclusions of the synthesis:

A standard of best practice has slowly evolved from aggregate to discrete disaggregate choice models and from relatively simple multinomial logit models to more complex multidimensional nested-logit models. Data on airport access mode choice have been developed using revealed preference data (versus stated preference data). The nesting structures might include: grouping of private vehicles with different parking options as a second nest; grouping of ride-on-demand modes (taxi, limousine); and grouping of scheduled modes (public modes and airport bus), with transit options (rail, bus) as a second nest. Door-to-door shared vans could fit as a first nest or as a second nest with the shared ride-on-demand or with the scheduled modes. The choice of some modes, such as rental car (by non-residents), is determined by factors independent of the service levels of other modes. For this reason, it is recommended to model these modes “outside this choice process”.

Because the air passenger market is not homogeneous, common market segmentation, for most models, consists of four divisions: a) Resident business b) Resident non-business c) Non-resident business d) Non-resident Non-business. The main difference between residents and non-residents is that the latter do not have the option of parking a private vehicle at the airport, although some non-residents might rent a car for use during their visit.

The synthesis concluded that “No clear consensus has yet emerged as to what explanatory variables should be included or how the various modes and sub-modes should be nested.”² The review provided a list of modes considered in recent airport access mode choice models. It also provided a list of explanatory variables (measures of time and cost) used in the utility function. No effort has been made to develop mode choice models for airport employees – only for air passengers.

3.2 Advanced Travel Modeling

A limited number of MPOs in the United States have developed, or are planning to develop, next-generation travel modeling methods. These methods go beyond the trip-based paradigm used in conventional four-step modeling and involve tour-based or activity-based approaches. During FY-2009, TPB staff allocated funding for beginning the development of advanced modeling methods, but subsequently decided to defer this activity to FY-2010. The delay will enable TPB to consider the findings of two national studies currently underway that seek to shed light on the experience gained by the few agencies that have embarked on the development of advanced modeling methods. The studies are:

- The Advanced Practices in Travel Forecasting, sponsored by the National Cooperative Highway Research Program (Project 20-5 Synthesis Project 40-06).
- Advanced Travel Modeling Study, sponsored by a voluntary consortium of MPO’s that are administratively coordinated through the Association of Metropolitan Planning

² Ibid., 1.

Organizations (AMPO). Section 4.2 of this report describes the AMPO study approach in greater detail.

3.3 References

Gosling, Geoffrey D. *ACRP Synthesis 5: Airport Ground Access Mode Choice Models: A Synthesis of Airport Practice*. Airport Cooperative Research Program. Washington, D.C.: Transportation Research Board, 2008.

Chapter 4 Research Track

This chapter reviews some of the research conferences, information forums, and other activities that TPB staff has participated in to keep abreast of the latest travel modeling research and practice. The chapter is divided into two main sections: 1) TRB/TMIP participation and 2) AMPO Travel Modeling Work Group.

4.1 TRB/TMIP Participation

4.1.1 TMIP Webinars

The Travel Model Improvement Program (TMIP) is a federal government program designed to conduct transportation-related research and deliver technical assistance and training to transportation planning professionals. TMIP is funded jointly by the Federal Highway Administration (FHWA), Federal Transit Administration (FTA), Office of the Secretary of Transportation (OST) and the Environmental Protection Agency (EPA). TMIP periodically offers webinars (web-based seminars) on a variety of topics related to travel demand modeling. One or more TPB staff has attended the following webinars over the past fiscal year:

- Travel Modeling Workshop Session 4: Estimation of Logit Models (February 10, 2009 2:30pm - 4:30pm)
- Travel Modeling Workshop Session 5: Disaggregate and Aggregate Validation and Calibration Procedures (March 12, 2009 2:30pm - 4:30pm)
- Travel Modeling Workshop Session 6: Advanced Topics in Discrete Choice Models (April 14, 2009 2:30pm - 4:30pm)
- Travel Modeling Workshop Session 7: Highway and Transit Assignment Processes (May 7, 2009 2:30pm - 4:30pm)
- Travel Modeling Workshop Session 8: Evaluation of Model Validation Results (June 9, 2009 2:30pm - 4:30pm)
- Activity Model Development Experiences (June 18, 2009 2:30pm - 4:30pm)

4.1.2 TRB Annual Meeting (Washington, D.C.) and TRB National Transportation Planning Applications Conference (Houston, Texas)

The Transportation Research Board (TRB) 88th Annual Meeting was held in Washington, D.C. from January 11-15, 2009 (<http://trb.org/meeting/2009/default.asp>). The conference attracted more than 10,000 transportation professionals from around the world. Several TPB staff attended a number of sessions and workshops.

Similarly, the 12th TRB National Transportation Planning Applications Conference was held in Houston, Texas from May 17-21, 2009 (<http://www.trb-appcon.org>). This five day conference was sponsored by the TRB and hosted by the Houston-Galveston Area Council. The two main goals of this conference, which is held every other year, are 1) to provide an outlet for new techniques and methods and 2) to emphasize practical, innovative, and timely technical and policy approaches to transportation planning. As such, it is more practical in nature, whereas the annual meeting each January in Washington, D.C. is more theoretical. One TPB staff member attended this conference.

Over 100 presentations and workshops were conducted during the five days of the Applications Conference and detailed PowerPoint presentations, with audio, are available on the web (<http://teachamerica.com/APP09/>).

4.2 AMPO Travel Modeling Work Group

The Association of Metropolitan Planning Organizations (AMPO) is a non-profit membership organization that serves the needs and interests of MPOs nationwide. Since its inception in 1994, AMPO has established a membership-elected Board of Directors and an elaborate committee structure. For the past several years, TPB has promoted an AMPO technical committee that focuses specifically on issues relating to MPO travel models. The group, the AMPO Travel Modeling Work Group (TMWG), has been a useful forum for technicians to share information on the development and practice of travel forecasting methods.

In June of 2007, the Transportation Research Board issued a special report on the current state of the practice in travel forecasting.¹ The report addressed the current state of the practice in travel modeling with respect to conventional four-step models. The report also included recommendations for moving toward more advanced (tour-based /activity-based) modeling practice. One such recommendation stressed the need for MPOs engaged in implementing advanced modeling techniques to document their experience. Further, the report also recommended that studies should be performed to compare the performance of conventional and advanced models.

These recommendations have resonated among some AMPO members, and have ultimately led to an AMPO-directed research initiative supported through pooled funding from interested MPOs. In December 2008, an RFP was issued to conduct research on MPO experiences with advanced travel modeling practices, specifically to develop an up-to-date assessment of how well advanced travel models have performed in practice, in terms of costs, advantages, drawbacks, and transferable components. Eleven MPOs have financially contributed to the first phase of the research initiative (the TPB being one of the eleven).

The first phase will consist of four work tasks:

- 1) Identify MPO experiences with advanced travel models that would be of interest to other practitioners
- 2) Describe the status of documentation of and information available from selected MPO experiences with advanced travel models
- 3) Identify work activities required to develop additional documentation needed of MPO experiences with advanced travel models
- 4) Design a study to develop additional documentation and carry out a comprehensive assessment of advanced travel models

¹ Transportation Research Board of the National Academies, *TRB Special Report 288, Metropolitan Travel Forecasting: Current Practice and Future Direction* (Washington, D.C.: Transportation Research Board of the National Academies, 2007)

Consequently, the first two tasks would seek to identify what documentation exists on MPO experiences with advanced models, what is the quality of the documentation, and what conclusions may be drawn. The third task will be a determination of what information remains to be collected in order to permit a comprehensive assessment of the advanced models relative to conventional models. The fourth and final task will be to design a second phase of research designed to collect information identified task 3, that is to fill in the data 'gaps', so that a comprehensive assessment can be made.

The TPB has a great deal to gain from this research given that the Models Development program has allocated funding during FY-2010 to begin the development of an advanced travel modeling.

4.3 References

Transportation Research Board of the National Academies. *TRB Special Report 288, Metropolitan Travel Forecasting: Current Practice and Future Direction*. Washington, D.C.: Transportation Research Board of the National Academies, 2007.

Chapter 5 Data Collection Track: Disposition of Observed Databases

COG/TPB has completed the first phase of major data collection effort required to inform the development of a new set travel demand models. During FY-2009, a substantial amount of time was spent cleaning and reviewing survey data. This chapter presents the current disposition of the three major surveys analyzed: the 2007 Metrorail survey, The 2007/2008 Household Travel Survey and the 2008 Regional On-Board Bus Survey.

5.1 2007 Metrorail Passenger Survey

The 2007 Metrorail Passenger Survey was conducted by WB&A Market Research between April 17, 2007 and June 22, 2007,¹ under contract to the Washington Area Metropolitan Transit Authority (WMATA). The survey was conducted at all 86 Metrorail stations currently in operation. The sampling frame consisted of total daily boarding passengers stratified by four time periods:

1. AM Peak (Opening to 9:29 a.m.)
2. AM Off Peak (9:30 a.m. to 2:59 p.m.)
3. PM Peak (3:00 p.m. to 6:59 p.m.)
4. PM Off Peak (7:00 p.m. to 12:00 a.m.)

The sample size was established to attain a “± 5% margin of error at the 95% confidence level on a system wide basis and a ± 10% margin of error at the 95% confidence level at each station. Overall, the margin of error is ± 4%.² While WMATA’s primary interest in the survey is to estimate the percentage of total ridership residing in each jurisdiction for subsidy allocation purposes, other information collected included station of origin and destination, trip purpose, mode of access and egress, type of fares and information related to fare benefits. Fare gate ridership figures were collected during the survey period and were used to calculate survey expansion factors by boarding station and by time period. About 36% of total riders received a questionnaire form. For riders receiving a questionnaire, the response rate was about 28.7%. About 88% (66,321) of the surveys that were filled out had valid responses. Records with invalid responses were deleted from the survey file. A disposition of survey sample is shown in Table 5-1.

¹ WB&A Market Research, *2007 Metrorail Passenger Survey Final Report* (Washington Metropolitan Area Transit Authority, October 16, 2007).

² Ibid.

Table 5-1 2007 Metrorail Survey Disposition

1	Total Daily Boardings (Fare gate ridership) ³		717,754
2	Survey Forms Passed Out		261,009
3	Distribution Rate		36.4%
	Response Rates:		Pct of Tot Distributed Forms (2)
4	Valid Responses	66,321	25.4%
5	Invalid Responses (deleted from final file)	8,666	3.3%
6	Total Responses	74,987	28.7%
7	Overall Average Expansion Factor (1) / (4)		10.82

The original survey file (Metrorail_2007.csv) consists of 66,321 records factored to 717,754 weighted daily trips, made by both residents and non-residents of the modeled area. As shown in Table 5-2, about 95% of the records contain complete and logical information about trip purpose, origin and destination stations. The remaining 5% of the records contain missing values of destination station and/or trip purpose and/or illogical reporting of home-to-home trip purpose. During FY-2009, a new weighting variable was added to the survey file to compensate for the missing information.⁴ The weighting variable assumes a zero weight for records with missing values. Records with complete information were factored up while keeping the original survey distributions fixed by boarding station and time period. The added factor variable is consistent with the original survey factor, since both factors were computed by boarding station and by time period. Other variables with missing values were not considered for this revised factoring procedure because they were not considered as important as trip purpose and destination station. Origin station information was never missing from the survey, because, given the unique ID number on each survey, WMATA knew which surveys were distributed at which origin stations. Further information can be found in the WB&A report.

³ This is the total from the Metrorail fare gates on the days that the survey was conducted. Note that this number (717,754) is not the same as the average number of weekday boardings during the survey period.

⁴ Hamid Humeida and Clara Reschovsky to Robert Griffiths, "Processing/Documentation of the 2007 Metrorail Survey," Memorandum, April 2, 2009

Table 5-2 Survey records with missing values: (destination station, trip purpose & home-to-home)

	Un-Weighted	Pct of Total Records	Weighted	Pct of Total Records
<u>Records with No Missing Values</u>				
Home-Based (HB)	53,093		563,550	
Non-home-Based (NHB)	9,874		118,247	
Sub-Total – No Missing Values	62,967	95%	681,797	95%
<u>Records with Missing Destination Station (DSTA)</u>				
DSTA Only	576		6,364	
DSTA & Home-to-Home (HB)	40		467	
DSTA + Home-to-Missing Purpose (HB)	27		300	
DSTA + Missing Purpose-to-Home (HB)	7		96	
DSTA + Non-Home-to-Missing Purpose	26		322	
DSTA + Miss Purpose to Non-Home Purpose	14		171	
DSTA + Miss Purpose to Miss purpose	15		170	
Sub Total Missing DSTA	705	1%	7,890	1%
<u>Records with Missing Purpose</u>				
Home-to-Missing Purpose (HB)	239		2,458	
Missing Purpose-to-Home (HB)	177		2,204	
Missing Origin & Destination Purpose	39		509	
Non-Home to Missing Destination Purpose	343		4,318	
Non-Home to Missing Origin Purpose	296		3,181	
Sub-Total missing Purpose	1,094	2%	12,670	2%
<u>Records with illogical Home-to-Home Purpose</u>				
	1,555	2%	15,397	2%
<u>Total Survey Records</u>				
	66,321	100%	717,754	100%

Note: A new variable was added to the survey file to compensate for these missing values by station and time period

5.2 2007/2008 Household Travel Survey

The 2007/2008 Household Travel Survey (HTS) was conducted for MWCOC by NuStats, Inc. from February 2007 through March 2008.⁵ The sampling frame was the current listing of all deliverable city and rural route residential addresses for the TPB modeled area.⁶ The frame was stratified into high-density mixed use urban areas and low density suburban areas. The address-based frame was used because the Random Digit Dialing (RDD) has become less effective in terms of omitting many “hard-to-reach households.”⁷ A third party vendor, Marketing System Group, with access to the ADVO database generated the required random sample of addresses.

⁵ NuStats, 2007/2008 COG/TPB Household Travel Survey: Draft Report of Methods (Metropolitan Washington Council of Governments (COG), July 15, 2008)

⁶ Postal P.O. and rural area boxes were excluded to avoid double counting and because the boxes might not represent the location of the sampled household.

⁷ Such as minorities, low income households, and young mobile households, some of whom may have no land-line phone.

During the survey period, contact was made with 89,863 households, of which 15,143 were recruited to participate in the study but only 11,578 provided complete travel data. The survey attained a 21% recruitment rate and a 76% retrieval rate resulting in an overall response rate of 16%⁸. Though the overall retrieval rate is 76%, it is noted that an incentive of \$50, offered to unmatched sample, has resulted in a retrieval rate of 85% compared to 74% for matched sample (with no incentive offered).

MWCOG staff completed the processing of the survey by: a) geocoding addresses and trip ends to X-Y coordinate using NAVTEQ base file and b) conducting general editing procedures.

The models development staff participated in this effort and conducted a special analysis of respondents who reportedly made no trips during the assigned survey day. While there could be many legitimate reasons for staying at home, some reluctant respondents might try to avoid an interview by saying that they made zero trips. This kind of “soft refusal” is considered as a “hidden non-response” which needs to be identified and corrected. Analysis of the 2007 HTS revealed that about 11.1% (2,847) persons out of (25,668) reported zero trips on the assigned travel day. In terms of households, the zero trip rate is about 6% (i.e. 918 out of 14,500). These rates are within the acceptable range of other surveys as indicated in the literature review which suggested a range of 10%-15% for the standards one day, weekday-only travel diary. Further analysis indicated logical and acceptable reasons for immobility. About two thirds of the respondents indicated one of the following reasons for zero trip: doing work at home (for pay or no pay), personally sick or taking care of a sick family member, home-bound, elderly, or disabled. More than half of the respondents were retired, disabled, a homemaker, unemployed, or students.

5.3 2008 Regional Bus Survey

The 2008 Regional Bus Survey (RBS) was conducted during the summer of 2008. The sample frame consisted of total weekday ridership of nine bus systems in the Washington region⁹. On the May 22nd 2009 TFS meeting, Robert Griffiths of COG TPB staff presented initial results of the survey. The presentation included different distributions of the total factored weekday ridership (644,500) of the nine systems. A summary of major findings included the following:¹⁰

- The major users of the nine bus systems are residence of DC (38%) and Suburban Maryland (43%) and N. Virginia (18%). The remaining 1% are residence from outside the region.
- More than 90% of total ridership is carried by the three major systems: Metrobus (71%), Ride-On (15%) and Fairfax Connector (6%).
- Except for PTRC and the bus, most riders access their bus by walking.
- CUE system has the highest percentage of rail-to-bus transfers.
- Commuting to work accounts for more than half of the trips on each bus system.
- SmarTrip was a predominant method of payment.
- About 50% to 70% of the riders on each system reported making more than one transfer.

⁸ Calculated according to standards of the Council of America Survey research Organization (CASRO).

⁹ These are; Metrobus, Ride-On, Fairfax Connector, DASH, CUE, PRTC, Transit, TheBus, and ART.

¹⁰

- About 24% of bus riders received transit benefit.
- About 50% of the bus riders reported zero vehicle ownership. About 30% of the riders are choice riders with available alternative vehicle to make the trip.
- About 20% of the bus riders reported less than \$10,000 annual household income.

5.4 References

Humeida, Hamid, and Clara Reschovsky. Memorandum to Robert Griffiths.

“Processing/Documentation of the 2007 Metrorail Survey.” Memorandum, April 2, 2009.
NuStats. *2007/2008 COG/TPB Household Travel Survey: Draft Report of Methods*. Metropolitan Washington Council of Governments (COG), July 15, 2008.

WB&A Market Research. *2007 Metrorail Passenger Survey Final Report*. Washington Metropolitan Area Transit Authority, October 16, 2007.

Chapter 6 Looking Ahead

The FY-2009 Models Development program has been primarily concerned with the maintenance of the Version 2.2 model and the ongoing development of Version 2.3. This report has also described the progress made in other parts of the TPB work program which are related to the Version 2.3 model effort. These related efforts include:

- The cleaning and review of data resulting from recent survey efforts, including the 2007 Metrorail Survey, the 2007/2008 Household Travel Survey, and the 2008 Bus On-Board Survey. The Metrorail and household travel surveys will be released for model development in early FY-2010.
- The development of a more detailed (~3,700) transportation analysis zone system, which will be released at the beginning of FY-2010. The zone system will maintain the same geographic extent as the existing modeled study area, but will contain almost a doubling of internal TAZs relative to the existing zone system.
- The development of GIS application for editing and managing highway and transit networks using a multi-year database.

During FY-2010, the new wave of survey data and new TAZ system will provide a foundation upon which the Version 2.3 model will be built. The Version 2.3 model effort is envisioned to be completed in approximately one year. However several complicated, and interrelated, activities will need to be coordinated in order to meet this goal.

The new TAZ system will require a complete review of the TPB's existing highway networks with respect to the new zone boundaries. Additional highway links will be added to accommodate the higher level of detail and a new system of zone centroids and centroid connectors will need to be established. The TPB's recent development of GIS technology will facilitate the network development. Another important component to the highway network development relates to the update of traffic counts. The ground counts coded in the network will need to be updated using 2007 information. The most recent count information in COG's Transportation Data Clearinghouse will be obtained and analyzed. Whereas, in past years, ground counts were coded on directional highway links as single average annual weekday figures, traffic count data is envisioned to be compiled in a greater detail, by hour or by vehicle classification where possible.

The update in traffic counts will necessitate a review of the TPB's existing base year exogenous travel files. This includes external and through traffic assumptions will need to be reviewed and updated with respect to the 2007 traffic counts at exit/entry points along the modeled cordon.

Land activity forecasts on the new TAZ system is another necessary consideration for this development effort. The current Round 7.2/7.2a Cooperative Land Use Forecasts are available only for the existing 2,191 zone system. The next round of land use forecasts (Round 8.0) will be developed for the 3,700 zone system, but will like not be available until the end of the

calendar year, at best. It is envisioned that the existing land activity forecasts will be converted from the 2,191 zone system to the 3,700 zone system based on a process of spatial allocation.

The survey data has been extensively cleaned during FY-2009 but additional analysis will be needed before calibration files are built. The demographic profiles from the 2007/2008 HTS will need to be compared and validated against available Census data. Internal logic checks of the survey will also be undertaken. The observed vehicle trips from the survey will also need to be assigned to the highway network to assess the degree of trip under-reporting which has been historically detected in earlier household travel surveys.

During FY-2009 TPB staff investigated ways to reduce the running time of the regional travel model. The motivation for doing so has grown from a concern that the expanded number of zones could result in intolerably long running times. One such avenue was the use of distributed processing. Another option for reducing running times was to reduce speed feedback iterations. Both options will be explored during FY-2010.

The timeline for the Version 2.3 model development is shown on Figure 6-1. The figure indicates that planned phasing of activities, as envisioned at the current time. TPB staff plans to prepare networks and survey files over the summer and early fall, and continue onto calibration work until the end of the calendar year. Model validation and sensitivity work is planned to progress during the spring of calendar year 2010, along with the development of a HOT lane toll development methodology which will be similar to that used in Version 2.2.

Figure 6-1 Timeline for the development of the Version 2.3 travel model on the new TAZ system with new survey data

