CAMBRIDGE
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Fiscal Year 2011 Task Reports

final

report

prepared for

National Capital Region Transportation Planning Board (TPB)

prepared by

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Transit Assignment Application for the Version 2.3 Travel Demand Forecasting Model

■ 1.0 Introduction

The National Capital Region Transportation Planning Board (TPB) currently is working to finalize the development of the Version 2.3 travel demand forecasting model for the Washington metropolitan region. In support of this effort, TPB tasked Cambridge Systematics (CS) to assist in the transit assignment process, focusing on the following:

- Review of the Metrorail and commuter rail assignment;

- Guidance on transit assignment output and level of detail;

- Options for graphical output of the results; and

- Advice on available data sources.

In late March, TPB staff provided the travel model (Version 2.3.9), transit assignment files, and summaries that they had compiled for Metrorail. Although work continued on the Version 2.3 model development (for example, TPB staff is now working on Version 2.3.25), the effort documented herein is based on the files provided in March.

■ 2.0 Transit Assignment Process

Previous versions of the TPB travel demand forecasting model for the Washington, D.C. region did not include transit assignment. The previous model versions developed transit skims for inclusion in the trip distribution and mode choice model steps, but the final out-puts from the model for transit travel demand were only trip tables. These trip tables show transit demand in terms of zone to zone flow. Route- or link-level passenger flows were not produced. Prior to Version 2.3, the transit mode choice was not disaggregated by submodes (e.g., Metrorail, bus, commuter rail, etc.). The previous versions of the model did, however, account for two modes of access to transit: walk to transit and drive to transit. Figure 1 shows the previous (i.e., Version 2.2 model) structure for the mode choice model.

With versions of the model prior to Version 2.3, agencies performing project planning studies had to alter the transit skimming scripts in order to perform an assignment of the transit person trip tables output from the mode choice model. This would be accomplished by adding a "load" statement into the script. Since earlier versions of the model developed only total transit person trip tables, the only way to approximate the route assignment was to adjust the path building and weighting factors in these scripts. This type of process would be performed for the corridor of interest. All of the adjustments made for that specific corridor would then be applied systemwide.

**Figure 1. TPB Version 2.2 Mode Choice Model Structure[a]**
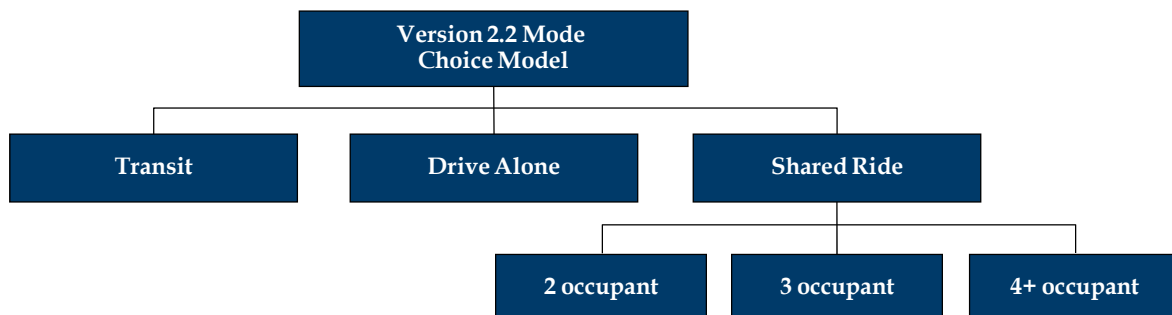
[a] In the Version 2.2 travel model, transit path-building distinguished between walk access and drive access, but, in the mode choice model itself, these were not separate modes/choices, so they are not shown as such on this figure.

Since the corridor was the focus of the planning study, areas outside of the study area were ignored. Alternative approaches to transit assignment with the older versions of the model developed postprocessing applications to adjust trip tables and disaggregate them to submodes (e.g., Metrorail, bus, commuter rail, etc.). In general, with the previous model, particularly with the lack of submodes in the mode choice model, getting a reasonable transit assignment was a challenge. Additionally, depending on the available modes in a particular study corridor, the process of validating the transit route assignment could often be a very time consuming activity while not yielding reasonable results.

The Version 2.3 model includes a nested logit mode choice model, shown in Figure 2. This model develops trip tables for four transit submodes: bus only, Metrorail, bus to Metrorail, and commuter rail. There are three modes of access: walk to transit, drive to transit, and kiss and ride. Note that although the mode choice model has 15 choices, the output trip tables from mode choice contain only 14 trip tables, not 15. This is because, for commuter rail trips, the model does not distinguish between kiss-and-ride (KNR) access and park-and-ride (PNR) access. Specifically, in transit path-building and transit assignment, the PNR-access commuter rail (CR) paths are used to develop the service levels of both PNR CR and KNR CR trips. Particularly, as compared with using the older multinomial mode choice model with a single transit alternative, the Version 2.3 nested logit mode choice model makes it a much more reasonable and straightforward application for a transit assignment to be able to produce reasonable regional and systemwide results.

The new mode choice model in the Version 2.3 model set is based on a mode choice model application developed by AECOM Consult to support the study of light-rail transit alternatives in D.C. and Arlington. It is important to note that the framework for the new mode choice model has thus been previously applied in the region and updated several times since it was originally developed. Furthermore, these applications have included successful use of transit assignment. When AECOM Consult first developed this mode choice model structure in 2004/2005, it was applied as a post process to the TPB travel model. In 2008, TPB staff reconfigured the model to run within the speed feedback loop (not simply as a post process) and recalibrated the model on the 2,191-TAZ area system. In 2010/2011, TPB staff recalibrated the mode choice model again, but this time on the 3,722-TAZ area system, using the 2008 Metrorail Survey and other surveys (Milone, 2011).

Figure 2. TPB Version 2.3 Mode Choice Model Structure
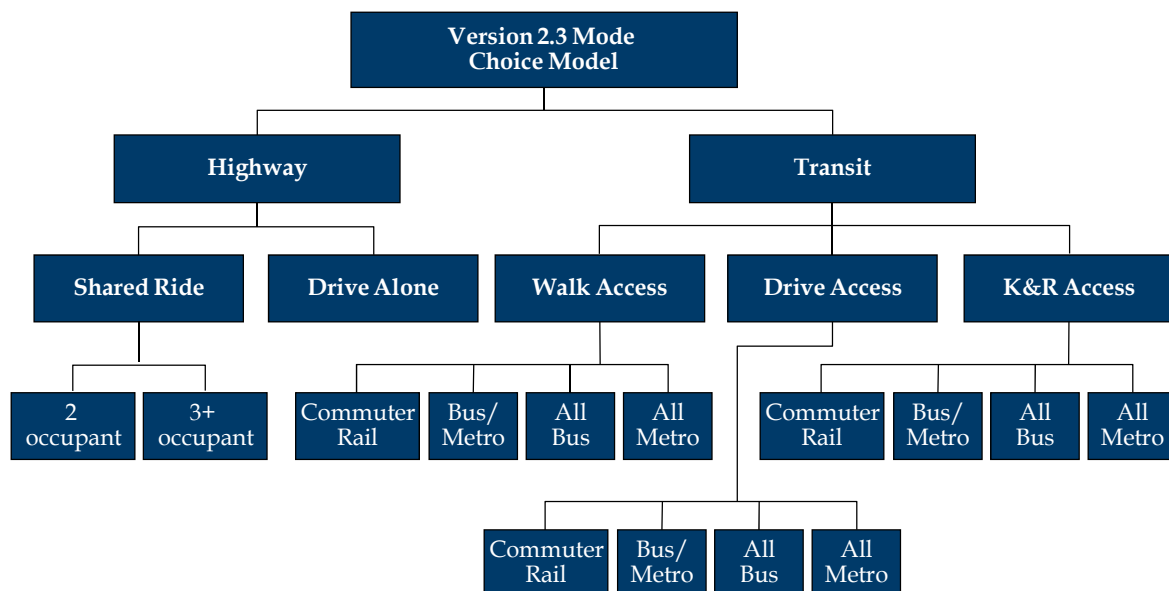
■ 3.0 Data Challenges

Collecting observed data for model estimation, calibration, or validation is always a challenge, whether it is conducting a new household survey or compiling traffic count data. Assembling good transit validation data is particularly challenging. Although it would be nice to have a range of data to use to address validation, typical transit assignment validation data assembly focuses on boardings by line (CS, 2010).

Transit validation data are typically supplied by transit operators. Most transit operators collect boarding data by station, stop, or line on a continuous basis through the use of recording fare boxes or the performance of periodic counts. Transit operators do not typically collect these data with model validation in mind. Many times these data are collected to support financial analyses or performance evaluations. The data can be focused on time-of-day, specific route, or corridor. For more robust transit systems the data can be aggregated to a specific mode and then presented either systemwide or by corridor. Boarding counts are often based only on fare collection or automated passenger counters at doors. Some agencies use GPS to more precisely capture the boarding location information (i.e., linking the fare box or automated passenger counter information to coordinates). It is not as common to have alighting counts since it is not as easy to develop the information automatically.

Most transit operators collect both entering and exiting counts for rail stations (where turnstiles or fare gates are used, this is reported on the most frequent basis). Sometimes, periodic passenger counts coupled with fare information are used to supply estimates (e.g., commuter rail ticket information combined with station-level on/off information for the same day). These methods can provide good on and off information, but do not necessarily reveal the flow of trips between specific origins and destinations.

WMATA has internal access to Metrorail farecard information that can link origins with destinations (since one must use a farecard both to enter and exit the system on a trip), but its availability to be used for planning studies and model validation may be limited due to privacy considerations. Even with linked origins and destinations, the specific path taken within the system cannot be easily discerned (i.e., Metrorail offers multiple ways to get between some station pairs). This is most common in the core area. Furthermore, the mode of access to the system is not necessarily fully revealed in the data.

Transit trips are most often developed by the travel demand forecasting model as trip productions and attractions by trip purpose.[1] Directly relating the typically available transit count data to productions and attractions is difficult (even across trip purposes). However, understanding how land use and transportation affect the work end and home end of transit trips is important in transportation planning.

Peak transit service is provided to address the demand of commuter trips. However, often boarding and alighting data (if any) do not specifically address trip purpose. Time of day factors can be applied to these data to focus on commuter trips, especially in the morning peak period when the majority of the trips are typically commuter and correspond to the home-based work trips. Validating for other trip purposes is problematic.

The bottom line is that, over time and with effort, it might be possible to produce improved validation data, but, in general and like most (if not all) metropolitan areas, the data available are challenging to work with and do not provide a completely comparable picture to use when trying to compare with the model results. The Washington metropolitan area has the added challenge of enjoying multiple transit operators, each with different standard data collection capabilities and programs.

■ 4.0 Transit Assignment Validation Guidelines

Given the data limitations, the question is what should be the focus of the transit assignment. Transit assignments are typically performed using a production/attraction matrix rather than an origin/destination matrix, focusing on assigning peak and off-peak period trips in an effort to reproduce daily transit boardings by line and, in many cases, the ridership at maximum load points along the line. Some regions developing activity-based travel models have moved from peak and off-peak transit assignments in production-attraction format to time-of-day assignments in origin-destination format.

A typical transit assignment will produce boardings and alightings on specific routes. These numbers can be compared by stop or station. Travel demand forecasting models have

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[1] For detailed discussion of trip productions and trip attractions please see Section 4.0 of Goldfarb, D. with D. Leven, R. Schiffer, J. Evans, and M. Pennington, "Evaluating and Communicating Model Results: Guidebook for Planners," Prepared for American Association of State Highway and Transportation Officials (AASHTO) Standing Committee on Planning, 2010. http://onlinepubs.trb.org/onlinepubs/nchrp/docs/NCHRP08-36(89)_FR.pdf.

coarse networks due to the geography they cover. One example of this is the way that local bus service is represented in a travel demand forecasting network. Although the actual bus-stop locations can happen anywhere along a road segment, in most transit networks, the stops are placed only at the end nodes of links, not along the length of the link. This approximation (among other reasons) makes it very hard to match boardings at each individual stop.

In the highway assignment the coarse network representation and simplicity of the macro-level highway assignment makes it unreliable to use the turning movements produced directly by traditional travel demand forecasting models. NCHRP Report 255 presents a set of techniques to deal with these types of issues on the highway side. There are no similar formal techniques for the transit side, especially since many users focus on the output of the mode choice model for understanding the transit demand.

Aggregation is one strategy for addressing the coarseness of the networks. Evaluating transit ridership in corridors and/or by mode in those corridors is useful. Knowing the transit demand in a corridor can help one plan for system needs and stop locations. However, a challenge arises when the assignment does not match the available data. When data are limited to a particular level of aggregation, it can be difficult to postulate how to resolve the mismatch. For example, if there is a disconnect between the mode choice output at the zone level and the path and there are no data on mode of access or to understand trip origins and destinations, it can be difficult to know how to adjust the model to correct for the problem.

Transit passenger load between stops or stations is another useful metric for transit assignment validation, if it can be calculated from boarding and alighting data. Observed data may only be available for links that represent key points in the system such as bridges or at crossings of regional freeway systems, such as the Capital Beltway in the Washington metropolitan area. These data can be used to focus on transit volumes at screenlines or cutlines. This is similar to the application of screenline and cutline data for vehicle flows in the highway assignment validation.

Similarly, having the transit flows into and out of a cordon area is useful. A cordon count around a CBD or activity center can provide useful data to validate to. For example the number of trips entering a CBD via different modes is important for planning for the transit needs of the CBD. So where the highway network may be at capacity, there may be a way to improve mobility into the CBD by transit. Accurately capturing the passenger flows into and out of the area becomes important, so validating to this level of detail is useful. As with any model validation, depending on the use of the model and level of planning exercise, the level of validation will vary. For a regional validation the accuracy across the region and on major corridors in the region is important. For a corridor study the flow of vehicles and transit passengers at a finer level may require additional validation.

There are no national standards for transit validation or validation in general, but there is guidance available. Transit validation guidelines focus on estimated-to-observed data for passenger miles traveled, total transit ridership by line, and screenline flows. The Florida Department of Transportation (FDOT) developed a report presenting calibration and validation standards for models they developed and maintain. Table 1 presents the FDOT standard used to evaluate transit assignment (Cambridge Systematics, 2008). Given the ease of obtaining boarding counts, these standards can serve as an easy, applicable guideline for TPB.

Table 1.   FDOT Transit Validation Standards

Validation Statistic	Acceptable	Preferable
Regional Estimated-over-Observed Transit Trips (Boardings)	+/- 9%	+/- 3%
Transit Screenline	+/- 20%	+/-10%
Transit Line Ridership Less Than 1,000 Passengers per Day	+/- 150%	+/- 100%
Transit Line Ridership 1,000 to 2,000 Passengers per Day	+/- 100%	+/- 65%
Transit Line Ridership 2,000 to 5,000 Passengers per Day	+/- 65%	+/- 35%
Transit Line Ridership 5,000 to 10,000 Passengers per Day	+/- 35%	+/- 25%
Transit Line Ridership 10,000 to 20,000 Passengers per Day	+/- 25%	+/- 20%
Transit Line Ridership More Than 20,000 Passengers per Day	+/- 20%	+/- 15%

With the FTA New Starts program, there has been more emphasis on transit modeling and transit assignment. FTA has recommended assigning on-board surveys and then evaluating the results. This can be useful in testing the validation of the transit assignment. However, in any such exercise, it is important to bear in mind that the survey data may have its own measurement errors or limitations that may then be compounded with possible errors or limitations in the transit assignment algorithm. That is, the analyst should not only understand the survey data and its shortcomings, but also needs to understand how these shortcomings might manifest themselves in terms of the results of assigning it to the transit network. Only with this perspective can observations be made regarding the quality of the assignment process and path building factors.

In general, it is best to rely on several techniques and several data sources to evaluate validation of the model. Using multiple techniques and data sources helps to reassure the user about the possible sources of error and to build confidence in the explanatory power of the model. In addition, when using the model as a decision support tool, it is important to bear in mind any limitations in the validation as similarly suggesting limitations in how the model is used and the confidence in particular outputs (i.e., the level of detail and types of uncertainties in the forecasts).

■ 5.0 Version 2.3 Rail Mode Validation Review

TPB staff requested that CS perform a transit validation review, focusing on the rail modes. CS focused the review on boarding and alighting information provided by TPB staff and on a review of screenline volumes.

5.1 Boarding and Alighting Review

When CS received the Version 2.3.9 model, TPB staff already had begun testing the transit assignment. TPB staff provided CS with the observed to estimated ratio for productions and attractions by 20 rail station groups. The observed data was derived from boarding and alighting information.

Figure 3 was prepared by aggregating rail station groups to highlight specific rail lines and rail line groupings. The overall ratio of estimated to observed for productions was 0.94 and for attractions was 0.93. At a regional level and, as the figure makes clear, by the various rail line groupings, the transit assignment is performing at an acceptable level given the guidance references.

Figure 3. Productions and Attractions by Line
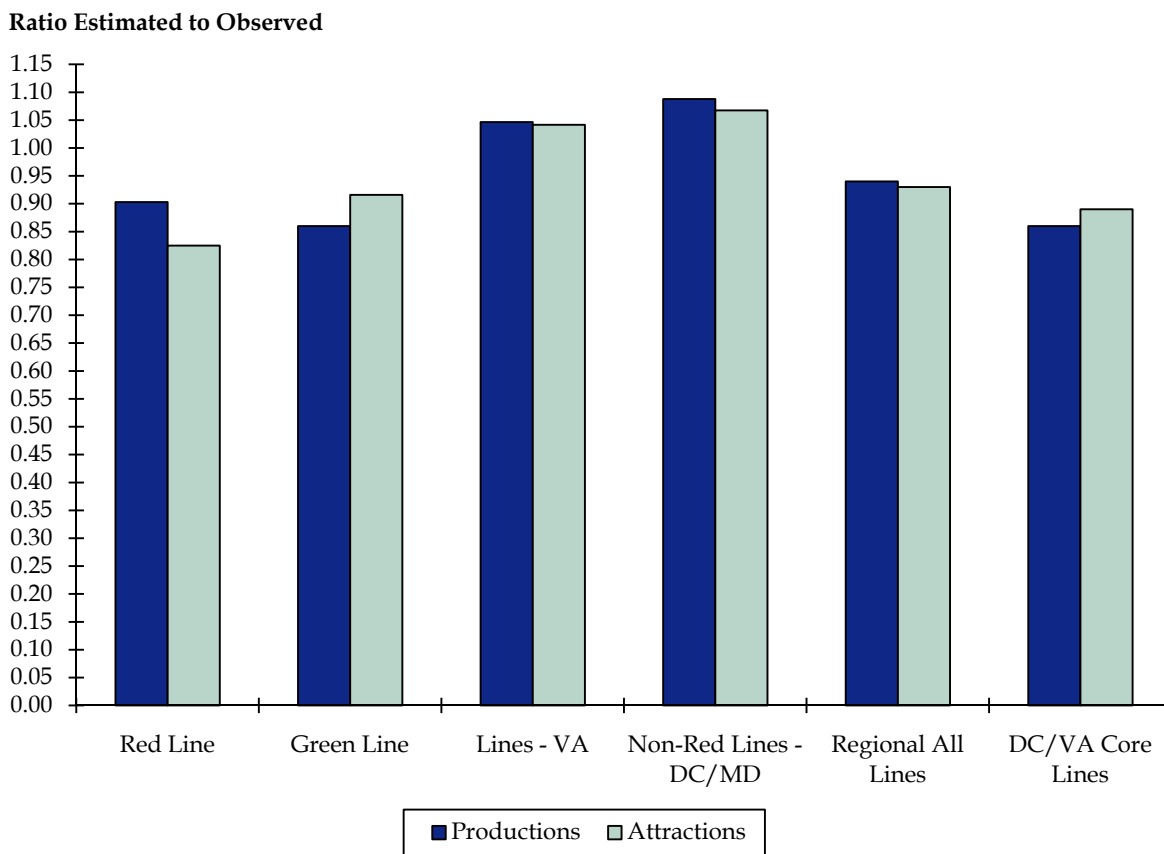
Ratio Estimated to Observed

Table 2 summarizes the match of estimated versus observed productions and attractions at the station group level. As compared with the more-aggregated results shown in Figure 3, at the specific station grouping level the transit assignment is not working as well.

Table 2.   Productions and Attractions by Station Group

Metrorail Segment	Observed 2008		Estimated 2007		Estimated/Observed	
	Prods	Attrs	Prods	Attrs	Prods	Attrs
Red Line – "A" route Maryland outside Beltway	56,808	14,571	41,241	15,537	0.73	1.07
Red Line – "A" route Maryland inside Beltway	26,662	27,751	30,822	38,529	1.16	1.39
Red Line – "A" route D.C. non-core	39,433	20,366	37,462	18,091	0.95	0.89
Red Line – D.C. core	77,420	244,253	52,335	175,797	0.68	0.72
Red Line – "B" route D.C. non-core	37,861	18,574	45,837	15,882	1.21	0.86
Red Line – "B" route Maryland	45,877	12,223	48,804	14,794	1.06	1.21
Green Line – "E" route Maryland	35,182	10,346	31,879	5,732	0.91	0.55
Green Line – "E" route D.C. non-core	28,928	15,757	21,553	11,557	0.75	0.73
Green Line – D.C. core	21,386	58,090	20,024	65,345	0.94	1.12
Green Line – "F" route D.C. non-core	27,328	25,498	31,020	21,500	1.14	0.84
Green Line – "F" route Maryland	46,024	6,575	32,142	2,359	0.70	0.36
Blue/Yellow Line – Virginia Fairfax	43,511	3,382	41,003	4,511	0.94	1.33
Blue/Yellow Line – Virginia Alexandria	19,638	15,575	18,235	16,349	0.93	1.05
Blue/Yellow Line – Virginia Core	53,475	62,198	48,879	43,270	0.91	0.70
Orange Line – Virginia Fairfax	51,403	10,798	49,461	9,261	0.96	0.86
Orange Line – Virginia Arlington non-core	45,199	25,858	47,570	40,863	1.05	1.58
Orange/Blue Line – Virginia/D.C. core	47,110	195,738	49,649	212,776	1.05	1.09

Table 2.   Productions and Attractions by Station Group (continued)

Metrorail Segment	Observed 2008		Estimated 2007		Estimated/Observed	
	Prods	Attrs	Prods	Attrs	Prods	Attrs
Orange/Blue Line – D.C. non-core	17,677	7,161	36,174	6,979	2.05	0.97
Orange Line – D.C./ Maryland	35,728	6,552	31,568	5,579	0.88	0.85
Blue Line – D.C./ Maryland	28,970	4,354	23,449	2,888	0.81	0.66
Summary	785,621	785,621	739,107	727,599	0.94	0.93
Summary D.C./Virginia Core Total	199,391	560,279	170,887	497,188	0.86	0.89

For the Red Line station groups, the model underestimates ridership for the D.C. core stations. The quality and availability of non-motorized travel modes as well as other transit modes could contribute to the mismatch. The station spacing in this area might encourage people to walk to stations that are less crowded, while the model would not necessarily reflect this phenomenon. The non-core areas are validating reasonably well for the Red Line. The model assumes a standard long and short walk and this might vary in actuality given the population in a certain areas and the quality of the pedestrian/bicycling network. This points more to the limitations of the transit assignment than to a limitation of the Version 2.3 modeling process.

The Green Line is low in Maryland on the attractions side, but there are limited attraction trip ends so the percent difference is large but the absolute number is small given the systemwide ridership. That also is represented in the Blue and Orange Lines in suburban Maryland. For that area of the region, production trip ends are dominant and are matching within acceptable guidelines for transit assignment.

In Arlington, the non-core station area is over assigning attraction trip ends on Metrorail. This might be representative of a mode choice issue, although the percent difference is substantial, when included with the Fairfax stations, the ratio of estimated to observed is reasonable. At a regional level this might be acceptable, but for a corridor study it may deserve extra attention and the possible recoding of access links to the heavy rail as well as bus modes.

5.2   Screenline Volume Review

From our experience in the region working on transit planning studies and multimodal corridor studies, we have found that screenline volumes serve as a very good measure for evaluating and demonstrating the validity of the transit assignment. The screenline volume is important because it gives a measure of the passenger load on a specific corridor by mode. Understanding if the model is moving the right passengers by mode across a screenline, and

how that load is moving across can help validate the assignment on both the highway and transit sides. Often times with competing modes, there might be more trips on one rail mode versus another or on bus or commuter bus versus rail. It is useful to determine first if the right numbers of trips are moving across a screenline by mode being SOV, HOV, or transit and then determine if the right distribution for submodes like bus or rail.

Typically in the Washington, D.C. area, focusing in on the Potomac River and the Capital Beltway are good starting pointing for validating the transit assignment. Given the availability of cordon counts there has been good data to compare observed versus estimated. In looking at these data it is important to convert the production and attraction trips in the transit assignment to origin and destination trip flows. Figure 4 shows the transit assignment results for the Potomac River screenline.

For the Potomac River screenline, the difference implied by the ratio of the estimated to observed is less than 10 percent. The model underestimates total transit ridership at this screenline, but within the generally acceptable guidance. Within the estimated transit ridership, both rail modes are slightly underrepresented (commuter rail more so), while bus is slightly overrepresented. For selected markets, based on wait and travel time, the model may view bus as more attractive than observations bear out, although the mode choice model does contain parameters to help account for unobserved attributes. Differences between modes also may be accounted for by discrepancies (versus what actually occurs) in where bus or Metrorail trips are estimated to get on or off the Metrorail system and where commuter rail trips are estimated to get on or off buses or Metrorail. The bottom line is that the transit assignment across the Potomac River is reasonable and transit planning for these markets can be done with some confidence.

Figure 4. Potomac River Screenline Transit Volumes
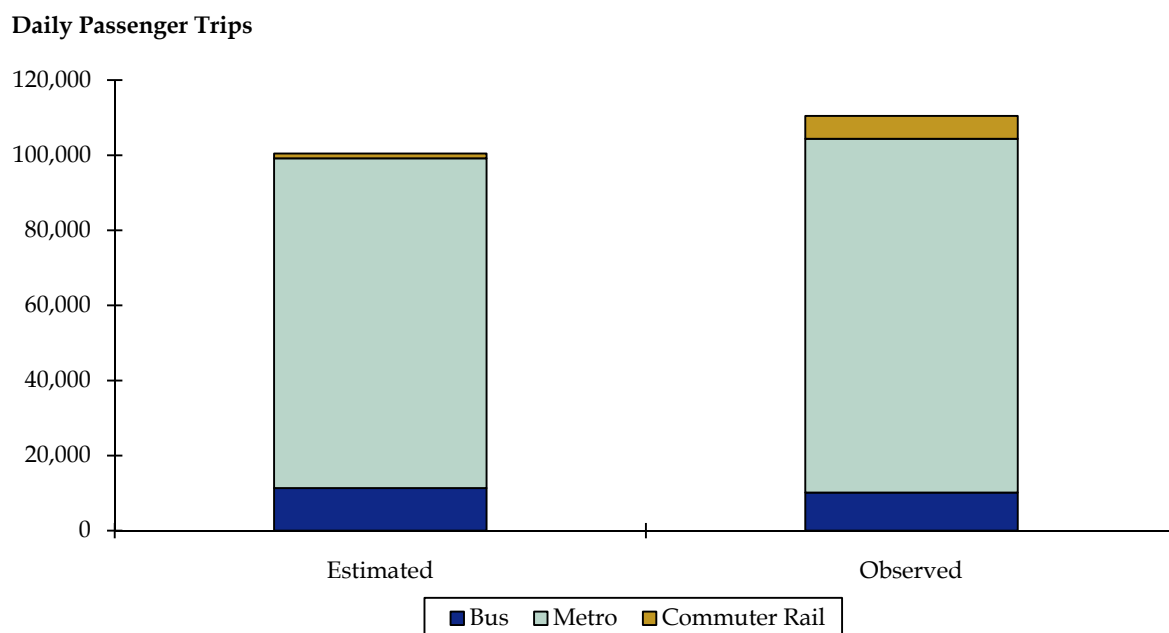
Daily Passenger Trips

Figure 5 presents transit volumes using the Capital Beltway as a screenline. We were able to process only the rail modes for this screenline. For some corridors in Northern Virginia

we had good data for bus travel at this screenline, and for those the match looked accept-able, but since we did not have complete data for Maryland and Virginia we excluded bus from the figure. The Beltway cordon count volumes were year-adjusted since they were from earlier studies. Although none of the adjustments were major, they were based on historical system growth by mode (i.e., heavy rail and commuter rail).

The figure shows that for transit volumes crossing the Capital Beltway, the model unde-restimates the volumes. Without the bus ridership it is hard to tell if bus and bus to Metrorail ridership, as with the Potomac River screenline, help compensate. We have observed this issue before in prior corridor studies in the region using the TPB model and mode choice postprocessing. We have generally attributed the issue to the model seeing bus as more attractive (in terms of time and cost) than riders apparently actually do and to challenges forecasting drive access to rail stations for both Metrorail and commuter rail.

Figure 5. Capital Beltway Screenline Transit Volumes

Daily Passenger Trips
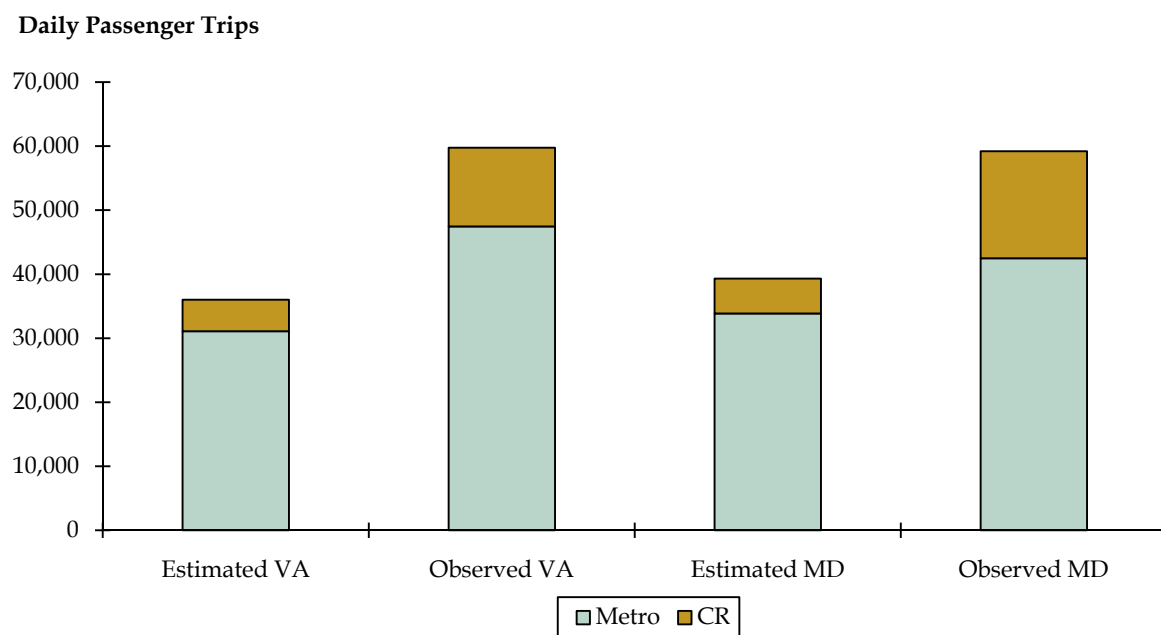
One area of focus on improving the transit assignment might be to improve the drive access coding. In the Version 2.3 travel model, the maximum length of drive access links is a function of both the "access distance code" and the transit submode. The access dis-tance code takes into account, among other things, the idea that travelers will drive longer distances to the end-of-the-line stations, such as Shady Grove Metrorail Station, (e.g., 15 miles for Metrorail Stations) than they will for middle-of-the line stations (e.g., 5 or 3 miles for Metrorail Stations). However, despite this treatment for end-of-the-line stations, CS found that drive access coding tended to favor stations further in towards the core areas. The model determines the drive access travel shed and there seems to be an under repre-sentation of the travel times from the home end to the station coded in the supplemental

link files. It tends to see farther-away stations in the path building as having easier access than might be actually available in terms of parking and travel time.[2] One potential improvement might be to explore the features available in Citilabs PT product for coding transit drive access. Within the current model structure, assigning the drive access trips to highway network might be a good way of obtaining more realistic travel times and might improve the station access and transit assignment. In the earlier versions of the model when we have applied the WMATA Postprocessor Model Choice Model, this long drive access phenomenon has impacted the commuter rail modes more than the Metrorail modes because of the outer areas having larger zone sizes which tends to further minimize the drive access-time computations (i.e., the network is more simplified in larger zones). The Version 2.3 model zone system has more and smaller zones, but may still have an issue in this area.

■ 6.0 Graphic Display of Transit Assignment

Looking at charts and tables of transit assignment can be useful, but in addition to reviewing data in tabular form, being able to view the transit assignment on the network in a geographic context can be very valuable in understanding and interpreting the assignment results. In much of the regional work that CS has performed in the Washington, D.C. area we have used a set of procedures to load the transit assignment results on to the highway network to permit plotting. This process also can be used to load other transit service characteristics such as frequency of service. We have routinely loaded the number of buses or trains in the peak period or peak hour onto the highway network for visual depiction. This provides a better understanding of service coverage and connectivity. It often has been the best way to communicate the depth of transit service for a specific region to planners and other stakeholders.

Just as the frequency of service displayed geographically is useful, so are passenger volumes. The processes we use take the output from the transit assignment and combine the passenger volumes, boardings, and alightings for each link and then post them on the network. This allows for a visual display of passenger flows on each link. In the validation set this is very useful for understanding screenline, cutline, or cordon area measures. Laid on top of the network, connectivity issues and competing services are very clear to see and understand. Figure 6 provides an example of the loaded network with the link width being a function of the transit passenger flows.

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[2] Normally, the travel time coded on to auto access links is equal to the congested, over-the-road-network time needed to reach each PNR lot from each zone (i.e., it is not simply the straight-line distance between the zone centroid and the PNR lot). However, in April 2011, TPB staff determined that there was an error in two of the model scripts (modnet.s and Highway_skims_mod.s). Because of this error, the script used to create auto access links, AutoAcc4.s, was creating auto access links with the default distance (0.5 miles), not the true over-the-road distance. This was corrected in the travel model (Ver. 2.3.16) and the mode choice model was re-calibrated (Ver. 2.3.17). However, the results presented in this report do not reflect this correction, since they are based on Ver. 2.3.9.

Figure 6. Loaded Transit Network
     Screen Capture
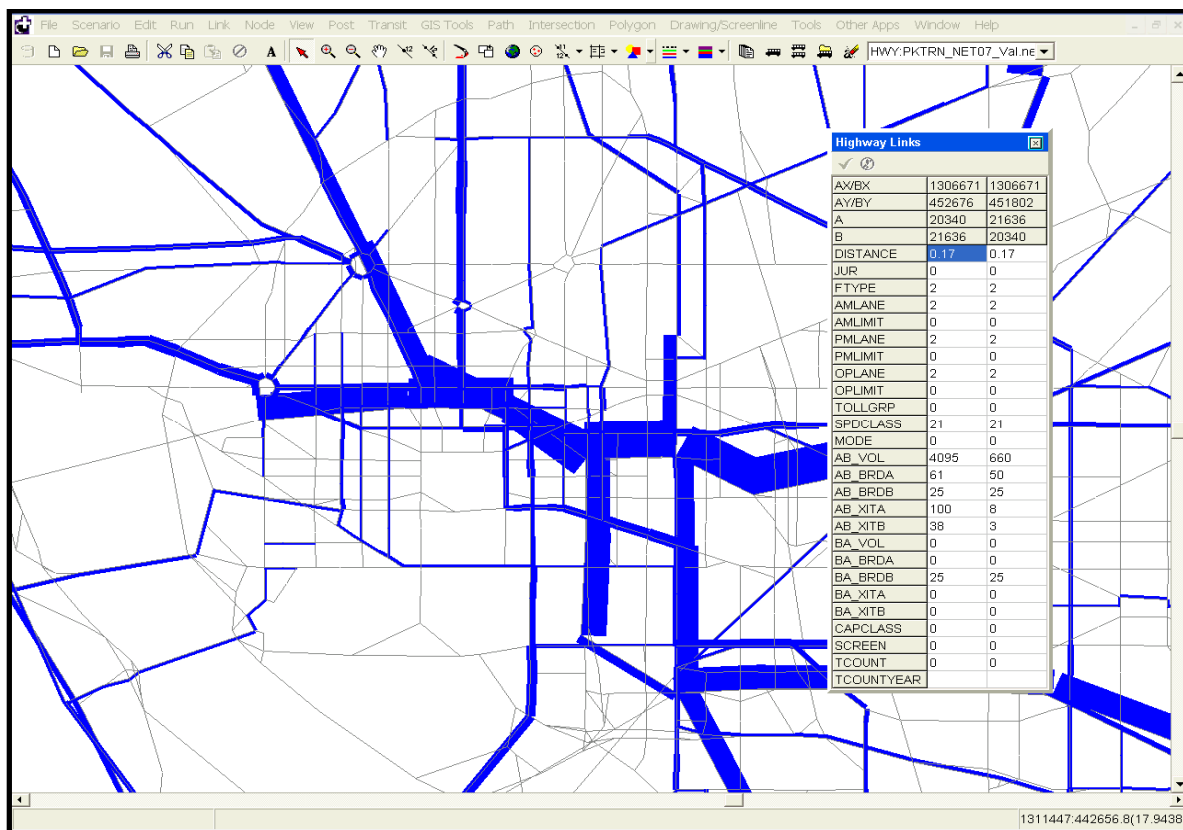
The process is very simple in that it takes the output files from the transit assignment. These are database files (e.g., i4_WKMRAMlink.dbf, etc.). A script was written to sort through the files and delete all access modes. The remaining data are then combined for each A node and B node. The volumes are summed by mode. Then, rail networks are built from the input files and added to the highway network. The data are combined with the network and the process is complete. Figure 7 summarizes the process.

Figure 7. Transit Assignment Network Loading
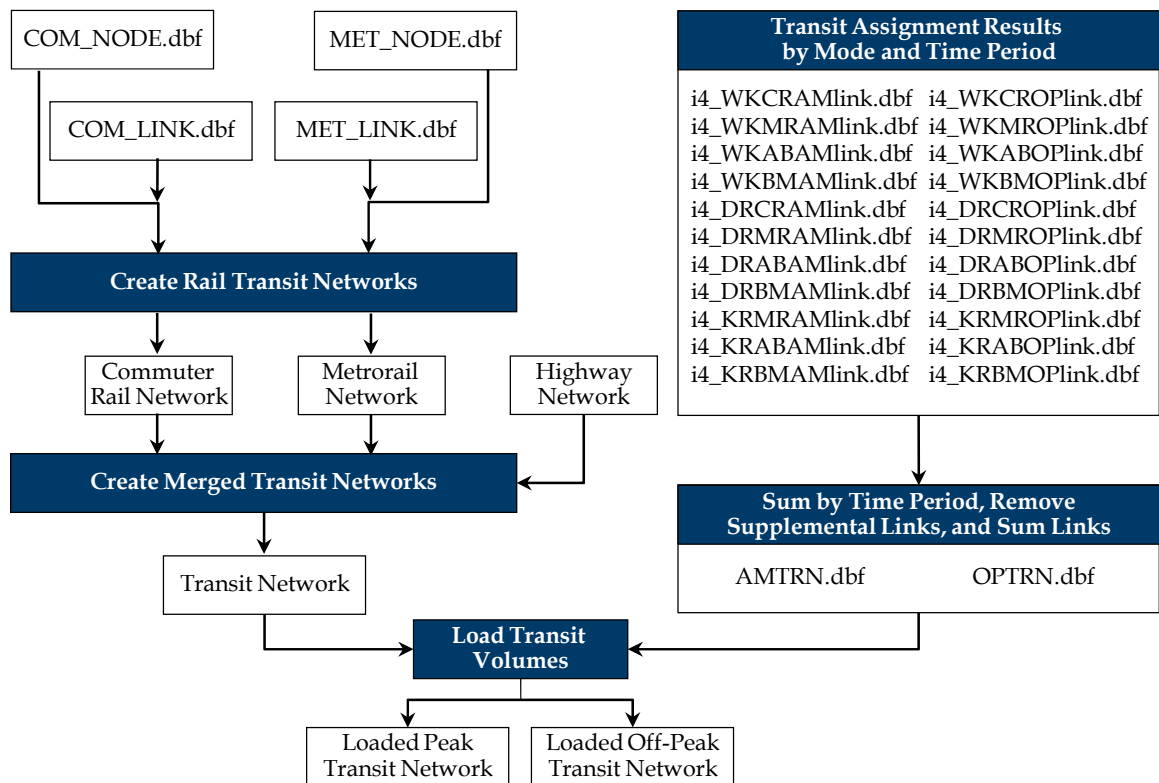
The scripts for this process are provided at the end of document as an attachment. These scripts should serve as a basis for a standardized process and may be optimized or modified to better address the needs of the TPB staff.

■ 7.0 Available Data

In directly evaluating the transit assignment and determining how well the base year validates in the past we have found the cordon count data conducted by MWCOG to be very valuable. As previously mentioned, data collected by transit operators, which is often readily available and easy to obtain, focuses more on performance measurement and financial analysis needs. The cordon counts, by contrast, capture data that is very relevant to highway and transit assignment validation. A recommendation might be to evaluate the potential and feasibility for conducting counts on three cordons in the future. The three cordons could be the central employment core, the Capital Beltway, and some combination of highway facilities to form a virtual outer beltway such as the Fairfax County Parkway in Virginia and the Intercounty Connector and U.S. Route 301 in Maryland. Having data at these screenlines/cordons would allow for a side by side comparison of SOV, HOV, and transit by mode.

Another source of data that we looked at to help evaluate the validation data for this exercise was American Community Survey data available as part of the 2010 Census Transportation Planning Products (CTPP). Although these data address only journey to work flows, commuter trips are important in transit planning since they contribute to the peak system volumes and are typically what planners focus on in terms of understanding the demand and the corresponding needs. We were able to look at these data in terms of jurisdictional flows by transit mode. CS took these data and compared them to observed data at the jurisdictional level and the model output for the version of the model that we had at the time the activity on this task started. The jurisdictions were grouped into five categories. We divided reporting to distinguish between outer jurisdictions and inner jurisdictions since transit accessibility varies greatly for the inner jurisdictions versus the outer jurisdictions. The inner Maryland category was made up of Prince George's and Montgomery Counties and the outer Maryland category is the remainder of the jurisdictions in the MWCOG modeled region in Maryland. The inner Virginia category was defined as Arlington County, City of Alexandria, Fairfax County, and Fairfax City. The outer Virginia category includes Prince William and Loudon Counties and the City of Manassas. The District of Columbia falls into its own category for this review. Remaining jurisdictions were not included in this analysis due to their relatively low transit ridership.

Figure 8 and Figure 9 show the mode share for home-based work productions and attractions. Except for home-based work productions in the District of Columbia, the observed, estimated, and CTPP mode shares are pretty consistent across jurisdiction categories.

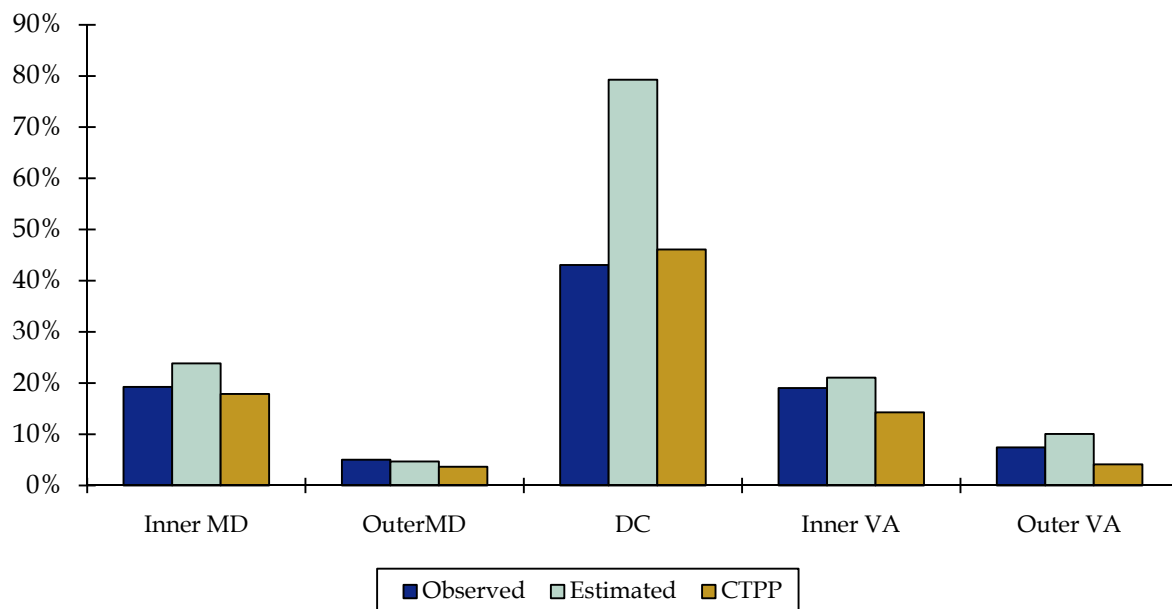**Figure 8. Home-Based Work Production-End Transit Share**

Figure 9. Home Base Work Attraction End Transit Share
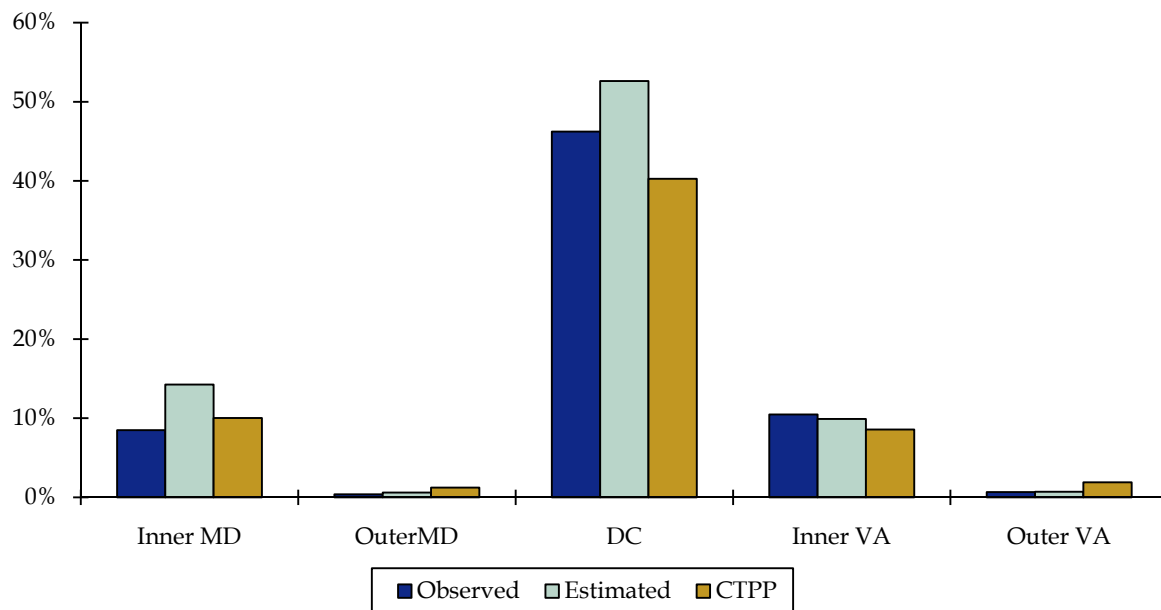
The CTPP provides information on worker residence location and work location which bear a rough correspondence to the model productions and attractions for the home-based work trip purpose. Figure 10 compares the daily home-based work productions[3] with the CTPP worker residence counts. The number of daily work trips varied more across the different data sets. In this case, the Maryland inner jurisdictions show some variation, while the other categories show a better match between the CTPP data and the model estimate.

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[3] The model productions and attractions have been halved as is required to attempt such a comparison with CTPP data.

Figure 10. Home Base Work Productions
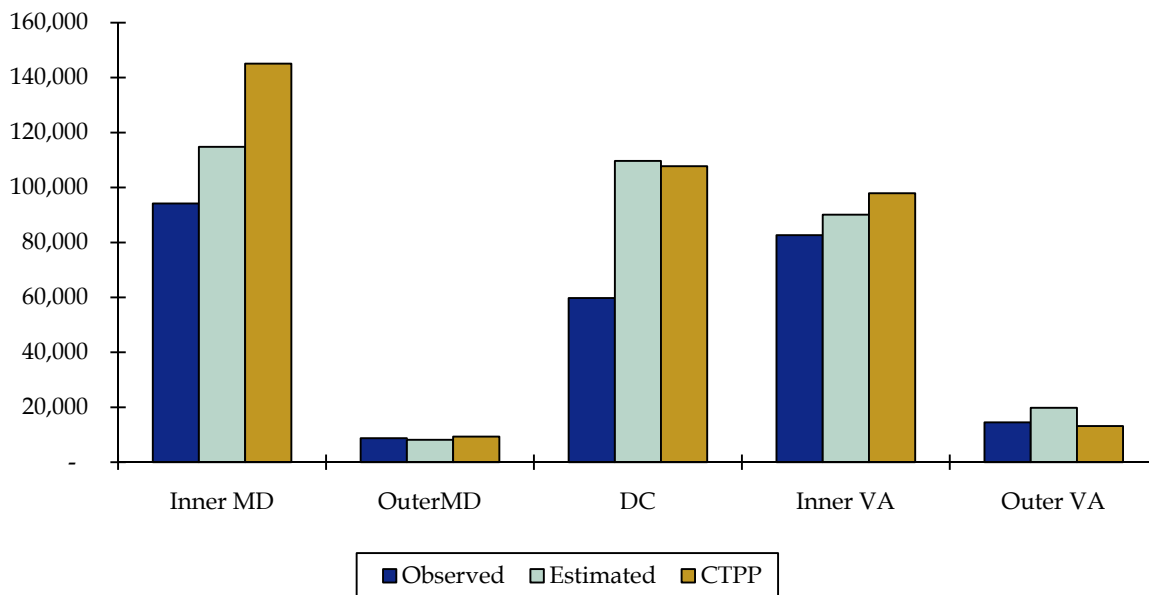
Figure 11 shows the number of daily home base work attraction trip ends. Here the data sets show more consistency than the productions. The outer jurisdiction have very low attractions as compared to the inner jurisdictions.

Figure 11. Home Base Work Attractions
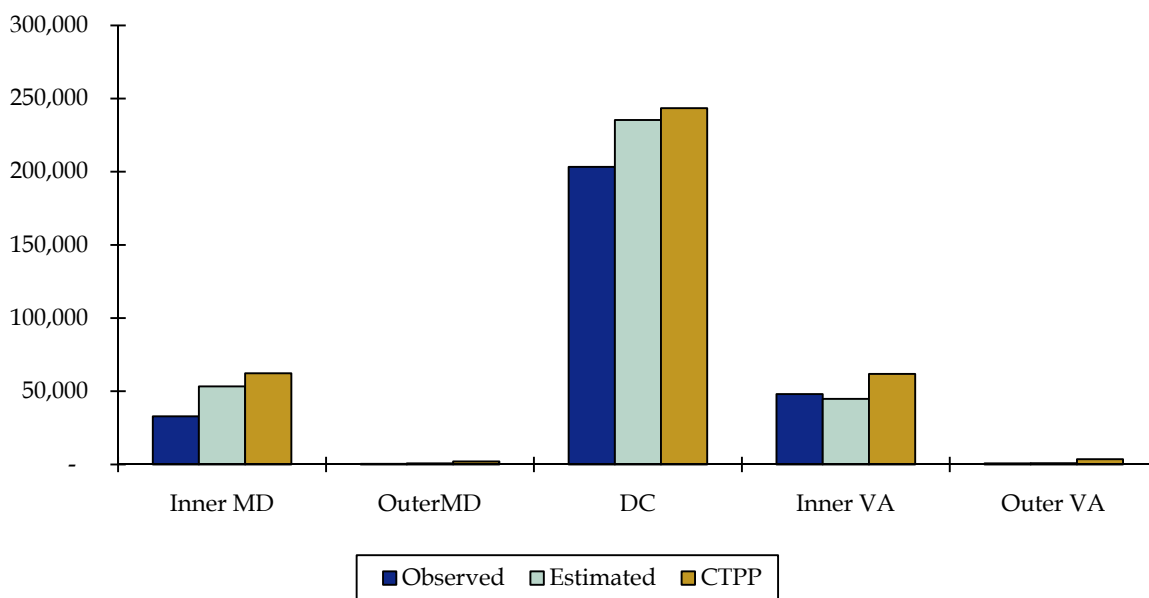
Although not able to compare observed data across modes, we did take the CTPP data and calculate the journey to work mode share for the five jurisdiction categories. The outer jurisdictions showed greater use of commuter rail and very little use of Metrorail, while the District showed the highest transit share. Figure 12 and Figure 13 show the data for worker place of residence and worker place of work, respectively.

Figure 12. Journey to Work Mode Share by Worker Place of Residence

Figure 13. Journey to Work Mode Share by Worker Place of Work

Since the CTPP includes journey-to-work flow data, we were able to compile and illustrate the journey-to-work mode share by worker place of residence for the five jurisdictional categories for workers with their place of work in the District of Columbia. This is shown in Figure 14. For trips from the outer jurisdictions, the SOV mode has the highest mode share, but for the i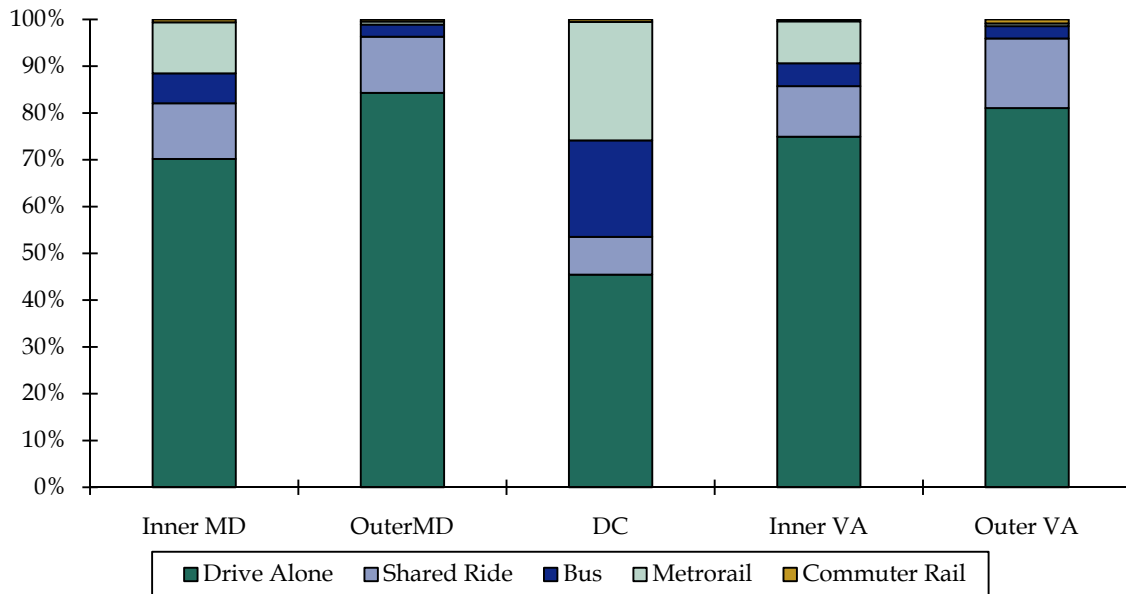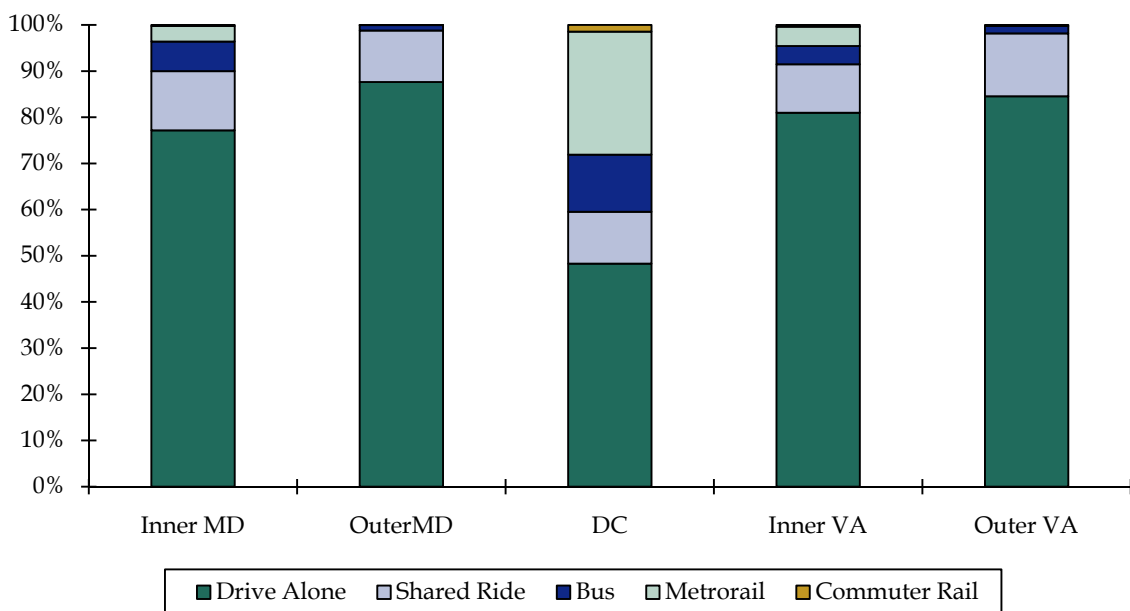nner jurisdictions Metrorail has the highest transit mode share. The share of Virginia commuters using commuter rail might be under representing VRE ridership since only Prince William and Loudon were included in the outer category for Virginia. The share of commuters from the Maryland inner jurisdictions using Metrorail to go to the District of Columbia for work is same as the share for the Virginia inner jurisdictions at around 30 percent.

Figure 14. Journey to Work Mode Share by Place of Residence for Workers with Place of Work in the District of Columbia
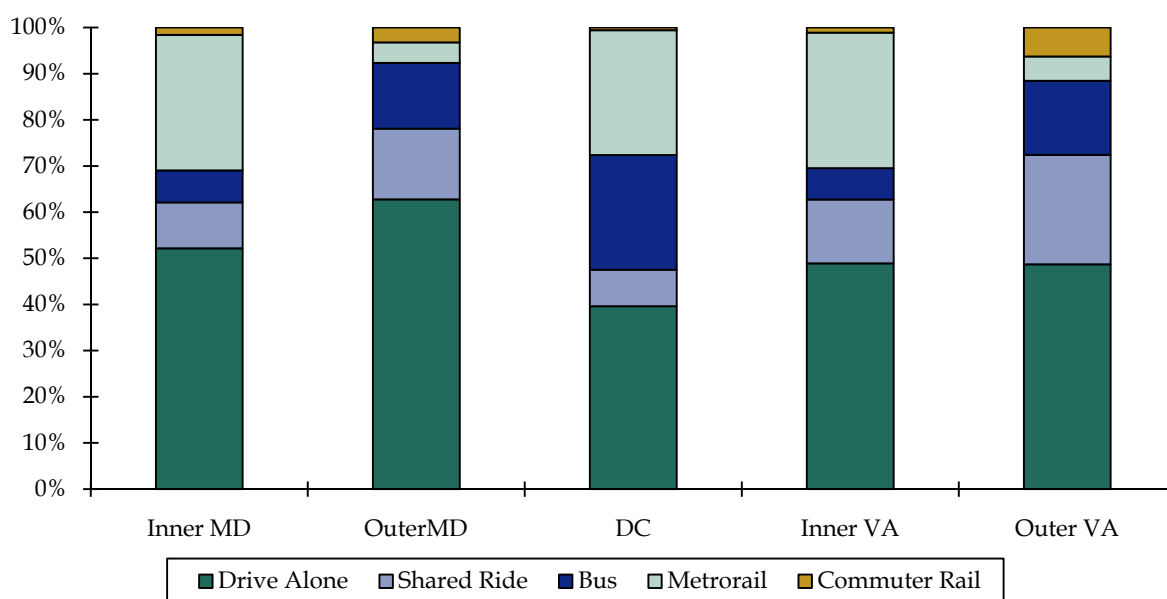
■ 8.0 Other MPOs and Transit Assignment

As part of this task CS was requested to review what some of the other MPOs are doing in terms of transit assignment. For many areas, transit is not a large part of their model. So it is not uncommon for agencies to omit transit assignment and just use the outputs from the mode choice model for transit planning activities. In a survey of over 220 MPOs published in 2006, only 55 percent of MPOs performed transit assignment. Of the largest MPOs, 94 percent performed transit assignment (VHB 2006).

For the Best Practice Model used by the New York Metropolitan Transportation Council, the current application of the transit assignment is an iterative process using origin and destination trip tables. Transit capacity is incorporated into the assignment algorithm using volume delay curves similar to highway assignment functions. The process runs for approximately 2.5 days and goes through five iterations. The transit assignment is validated only for the morning peak period. The data used to validate the model include:

- Subway station boardings;

- Screenlines for bus volumes; and

- Commuter rail ridership by line.

For the Baltimore Metropolitan Council (BMC), a transit assignment is performed as part of the model application process. BMC validates only for total daily boardings by sub-mode (e.g., bus, rail, and commuter rail) at the regional level. Table 3 presents the validation summary from the BMC model documentation (BMC 2007). The validation error is below 20 percent for the transit modes carrying the greatest number of riders, which meets the guidelines. However, to ensure that the model can serve as a useful tool in supporting decision-making for a specific corridor or subarea study, a closer match might be required in that study area (and, therefore, additional model refinement might be indicated). Ultimately, understanding the level of accuracy and the impact on the results should be the underlying rationale in accepting the validation level of error.

Table 3. BMC Transit Validation Results

Submode	2000 Observed Boardings	Version 3.3 2000 BMC Model Estimate	Percent Error
Bus	239,908	273,280	14%
Rail	74,968	64,962	-13%
Commuter Rail	17,899	12,842	-28%

Table 4 contains a summary of the Seattle metropolitan area year 2000 transit validation results. Similar to BMC, Seattle used total boardings by operator for daily transit ridership as the validation metric. Regionally, the difference between observed versus estimated transit boardings is below 10 percent. For the most significant operator in the metropolitan area, the estimated boardings were within 12 percent of the observed data (CS 2010).

Table 4. Seattle Metropolitan Area Transit Validation

Transit Operator	2000 Observed Boardings	2000 Estimated Boardings	Percent Error
King County Metro	329,913	294,226	-11%
Pierce Transit	45,265	36,661	-19%
Community Transit and Everett Transit	33,318	30,660	-8%
Kitsap Transit	11,889	14,410	21%
Washington State Ferries	21,000	23,979	14%
Total	441,385	399,936	-9%

The examples listed here demonstrate some of the challenges in validating transit assignment. Often times the issue with the validation relate to the mode choice output. Even when the mode choice is correct, the complexity of transit path building and simplicity of the path loading algorithms can present difficulties in validating the transit assignment to the same degree as the highway assignment. One goal in transit validation would be to aggregate-specific routes and stations together recognizing the limits of the access coding both for non-motorized access and motorized access. The MPO needs to be most concerned with the regional and jurisdictional transit flows. To this end, focusing on screen-lines and cordons as well as boardings may work best for regional model validation purposes. However, when using the model for major corridor or other special project studies (depending on the type of evaluation being performed), a study-area-specific validation effort should be conducted (just as is done for highway validation efforts).

■ 9.0 Next Steps

Recognizing the challenges inherent in any transit assignment, the most important element is the availability and quality of the validation data set. There is always a challenge in assembling good validation data, both in allocating the necessary agency resources and in performing the actual collection. The cordon counts in the Washington, D.C. region provide a good source of data to balance with the operator-supplied boarding data. Continuing and/or restarting some of the data collection could be beneficial to further model development.

Steps forward to improve the transit assignment could include the following activities:

- Obtain additional boarding or other validation data for Metrorail, commuter rail, and all bus services;

- Evaluate the ability to include drive access trips in the highway assignment and feed-back the travel impedance to the supplemental access link files; and

- Evaluate the potential path building advantages for different travel demand fore-casting software tools, including Citilabs PT.

■ 10.0 Script for Transit Assignment Results

```
; scrpit to build transit GIS
;create network
RUN PGM=HWYNET
  NODEI=COM_NODE.dbf

  FILEI LINKI=COM_LINK.TB,
      VAR=A,12-17,
      VAR=B,19-24,
      VAR=DIST,52-56,
      VAR=MODE, 43-45,
      VAR=SPEED,64-67
```

```
COMP DISTANCE=DIST/100
FILEO NETO=CRNET.NET, EXCLUDE=DIST
ENDRUN

RUN PGM=HWYNET
  NODEI=MET_NODE.dbf

  FILEI LINKI=MET_LINK.TB,
       VAR=A,12-17,
       VAR=B,19-24,
       VAR=DIST,52-56,
       VAR=MODE,43-45,
       VAR=SPEED,64-67

COMP DISTANCE=DIST/100
FILEO NETO=HRNET.NET, EXCLUDE=DIST
ENDRUN

RUN PGM=HWYNET

NETI[1]=ZONEHWY.NET
NETI[2]=CRNET.NET
NETI[3]=HRNET.NET

NETO=TRN07.NET,
INCLUDE=A,B,DISTANCE,SPDCLASS,CACPLASS,JUR,FTYPE,TOLLGRP,AMLANE,PMLANE,OPLANE,
       AMLIMIT,PMLIMIT,OPLIMIT,MODE,SPEED
ENDRUN

;TRN NETWORK LINE CODE POSTING

RUN PGM=MATRIX
 FILEI RECI=PK_VOL.DBF ; produced by the linvol.exe
 FILEO RECO=PKTRN.DBF,
   FIELDS=LAGA,LAGB,LAGAB_VOL,LAGAB_BRDA,

LAGAB_XITA,LAGAB_BRDB,LAGAB_XITB,LAGBA_VOL,LAGBA_BRDA,LAGBA_XITA,LAGBA_BRDB,LAGBA_XITB

 A=RI.A
 B=RI.B
 MODE=RI.MODE
 AB_VOL=RI.AB_VOL
 AB_BRDA=RI.AB_BRDA
 AB_XITA=RI.AB_XITA
 AB_BRDB=RI.AB_BRDB
 AB_XITB=RI.AB_XITB
 BA_VOL=RI.BA_VOL
 BA_BRDA=RI.BA_BRDA
 BA_XITA=RI.BA_XITA
 BA_BRDB=RI.BA_BRDB
 BA_XITB=RI.BA_XITB

IF (MODE=1-9)
  COUNT=COUNT+1
  IF (COUNT>1)
   IF(A=LAGA && B=LAGB)
     AB_VOL=AB_VOL+LAGAB_VOL
     AB_BRDA=AB_BRDA+LAGAB_BRDA
     AB_BRDB=AB_BRDB+LAGAB_BRDB
     AB_XITA=AB_XITA+LAGAB_XITA
     AB_XITB=AB_XITB+LAGAB_XITB
;
```

```
      BA_VOL=BA_VOL+LAGBA_VOL
      BA_BRDA=BA_BRDA+LAGBA_BRDA
      BA_BRDB=BA_BRDB+LAGBA_BRDB
      BA_XITA=BA_XITA+LAGBA_XITA
      BA_XITB=BA_XITB+LAGBA_XITB

  ELSE
   WRITE RECO=1
    COUNT=1
  ENDIF
 ENDIF

 LAGA=A
 LAGB=B
;
 LAGAB_VOL=AB_VOL
 LAGAB_BRDA=AB_BRDA
 LAGAB_BRDB=AB_BRDB
 LAGAB_XITA=AB_XITA
 LAGAB_XITB=AB_XITB
;
 LAGBA_VOL=BA_VOL
 LAGBA_BRDA=BA_BRDA
 LAGBA_BRDB=BA_BRDB
 LAGBA_XITA=BA_XITA
 LAGBA_XITB=BA_XITB

ENDIF
ENDRUN
;==============================================================================
RUN PGM=MATRIX
 FILEI RECI=PKTRN.DBF

 A=RI.LAGA
 B=RI.LAGB
 AB_VOL=RI.LAGAB_VOL
 AB_BRDA=RI.LAGAB_BRDA
 AB_BRDB=RI.LAGAB_BRDB
 AB_XITA=RI.LAGAB_XITA
 AB_XITB=RI.LAGAB_XITB
 BA_VOL=RI.LAGBA_VOL
 BA_BRDA=RI.LAGBA_BRDA
 BA_BRDB=RI.LAGBA_BRDB
 AB_XITA=RI.LAGBA_XITA
 AB_XITB=RI.LAGBA_XITB

IF(A<>B)
 WRITE RECO=1
ENDIF

FILEO RECO=PKTRN2.DBF,
    FIELDS=A,B,AB_VOL,AB_BRDA,AB_BRDB,AB_XITA,AB_XITB,
              BA_VOL,BA_BRDA,BA_BRDB,BA_XITA,BA_XITB

ENDRUN

;=============================================================
;Load volumes onto transit network
RUN PGM=HWYNET
ZONES=3722
NETI[1]=TRN07.NET
LINKI[2]=PKTRN2.DBF
```

```
IF (A<3722 || B<3722)
 DELETE
ENDIF

NETO=PKTRN_NET07.NET,
   INCLUDE=A,B,DISTANCE,SPDCLASS,CAPCLASS,JUR,FTYPE,TOLLGRP,AMLANE,PMLANE,OPLANE,
            AMLIMIT,PMLIMIT,OPLIMIT,MODE,AB_VOL,AB_BRDA,AB_BRDB,AB_XITA,AB_XITB,
            BA_VOL,BA_BRDA,BA_BRDB,BA_XITA,BA_XITB


ENDRUN

;Repeat process for OffPeak transit volumes
;------------------------------------------------------------------------

RUN PGM=MATRIX
 FILEI RECI=OP_VOL.DBF ; produced by the linvol.exe
 FILEO RECO=OPTRN.DBF,
    FIELDS=LAGA,LAGB,LAGAB_VOL,LAGAB_BRDA,

LAGAB_XITA,LAGAB_BRDB,LAGAB_XITB,LAGBA_VOL,LAGBA_BRDA,LAGBA_XITA,LAGBA_BRDB,LAGBA_XITB

 A=RI.A
 B=RI.B
 MODE=RI.MODE
 AB_VOL=RI.AB_VOL
 AB_BRDA=RI.AB_BRDA
 AB_XITA=RI.AB_XITA
 AB_BRDB=RI.AB_BRDB
 AB_XITB=RI.AB_XITB
 BA_VOL=RI.BA_VOL
 BA_BRDA=RI.BA_BRDA
 BA_XITA=RI.BA_XITA
 BA_BRDB=RI.BA_BRDB
 BA_XITB=RI.BA_XITB

IF (MODE=1-9)
  COUNT=COUNT+1
  IF (COUNT>1)
   IF(A=LAGA && B=LAGB)
     AB_VOL=AB_VOL+LAGAB_VOL
     AB_BRDA=AB_BRDA+LAGAB_BRDA
     AB_BRDB=AB_BRDB+LAGAB_BRDB
     AB_XITA=AB_XITA+LAGAB_XITA
     AB_XITB=AB_XITB+LAGAB_XITB
;
     BA_VOL=BA_VOL+LAGBA_VOL
     BA_BRDA=BA_BRDA+LAGBA_BRDA
     BA_BRDB=BA_BRDB+LAGBA_BRDB
     BA_XITA=BA_XITA+LAGBA_XITA
     BA_XITB=BA_XITB+LAGBA_XITB

  ELSE
   WRITE RECO=1
    COUNT=1
  ENDIF
 ENDIF

 LAGA=A
 LAGB=B
;
 LAGAB_VOL=AB_VOL
 LAGAB_BRDA=AB_BRDA
```

```
   LAGAB_BRDB=AB_BRDB
   LAGAB_XITA=AB_XITA
   LAGAB_XITB=AB_XITB
;
   LAGBA_VOL=BA_VOL
   LAGBA_BRDA=BA_BRDA
   LAGBA_BRDB=BA_BRDB
   LAGBA_XITA=BA_XITA
   LAGBA_XITB=BA_XITB

ENDIF
ENDRUN
;==============================================================================
RUN PGM=MATRIX
   FILEI RECI=OPTRN.DBF

   A=RI.LAGA
   B=RI.LAGB
   AB_VOL=RI.LAGAB_VOL
   AB_BRDA=RI.LAGAB_BRDA
   AB_BRDB=RI.LAGAB_BRDB
   AB_XITA=RI.LAGAB_XITA
   AB_XITB=RI.LAGAB_XITB
   BA_VOL=RI.LAGBA_VOL
   BA_BRDA=RI.LAGBA_BRDA
   BA_BRDB=RI.LAGBA_BRDB
   AB_XITA=RI.LAGAB_XITA
   AB_XITB=RI.LAGAB_XITB

IF(A<>B)
   WRITE RECO=1
ENDIF

FILEO RECO=OPTRN2.DBF,
      FIELDS=A,B,AB_VOL,AB_BRDA,AB_BRDB,AB_XITA,AB_XITB,
                 BA_VOL,BA_BRDA,BA_BRDB,BA_XITA,BA_XITB

ENDRUN

;=============================================================
;Load volumes onto transit network
RUN PGM=HWYNET
ZONES=3722
NETI[1]=TRN07.NET
LINKI[2]=OPTRN2.DBF

IF (A<3722 || B<3722)
   DELETE
ENDIF

NETO=OPTRN_NET07.NET,
    INCLUDE=A,B,DISTANCE,SPDCLASS,CAPCLASS,JUR,FTYPE,TOLLGRP,AMLANE,PMLANE,OPLANE,
            AMLIMIT,PMLIMIT,OPLIMIT,MODE,AB_VOL,AB_BRDA,AB_BRDB,AB_XITA,AB_XITB,
            BA_VOL,BA_BRDA,BA_BRDB,BA_XITA,BA_XITB


ENDRUN

;=====================================================================
;Combine peak and off-peak volumes
RUN PGM=HWYNET
NETI[1]=PKTRN_NET07.NET
NETI[2]=OPTRN_NET07.NET
```

```
COMP AB_VOL=(LI.1.AB_VOL)+(LI.2.AB_VOL)
COMP AB_BRDA=(LI.1.AB_BRDA)+(LI.2.AB_BRDA)
COMP AB_BRDB=(LI.1.AB_BRDB)+(LI.2.AB_BRDB)
COMP AB_XITA=(LI.1.AB_XITA)+(LI.2.AB_XITA)
COMP AB_XITB=(LI.1.AB_XITB)+(LI.2.AB_XITB)
COMP BA_VOL=(LI.1.BA_VOL)+(LI.2.BA_VOL)
COMP BA_BRDA=(LI.1.BA_BRDA)+(LI.2.BA_BRDA)
COMP BA_BRDB=(LI.1.BA_BRDB)+(LI.2.BA_BRDB)
COMP BA_XITA=(LI.1.BA_XITA)+(LI.2.BA_XITA)
COMP BA_XITB=(LI.1.BA_XITB)+(LI.2.BA_XITB)

NETO=TRANSIT_07.NET,
  INCLUDE=A,B,DISTANCE,SPDCLASS,CAPCLASS,JUR,FTYPE,TOLLGRP,AMLANE,PMLANE,OPLANE,
          AMLIMIT,PMLIMIT,OPLIMIT,MODE,AB_VOL,AB_BRDA,AB_BRDB,AB_XITA,AB_XITB,
          BA_VOL,BA_BRDA,BA_BRDB,BA_XITA,BA_XITB
```

ENDRUN

◼ 11.0 References

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VHB, Inc. (2006). Determination of the State of the Practice in Metropolitan Area Travel Forecasting: Findings of the Survey of Metropolitan Planning Organizations. Prepared for Committee B0090 of the Transportation Research Board. June 2007. .http://onlinepubs.trb.org/ onlinepubs/reports/vhb-2007-final.pdf.

Consideration of Available Commercial Travel Demand Forecasting Software Packages

■ 1.0 Introduction

The National Capital Region Transportation Planning Board (TPB) tasked Cambridge Systematics (CS) to assist with the consideration of available commercial travel demand software packages in two-specific ways:

- Assist in the development, assembly, and review of evaluation criteria for a travel demand software package, given TPB's current model development track; and

- Inventory which software packages are being used by the larger MPOs for travel demand forecasting activities, with special attention to the model software packages used in the air quality conformity process.

CS reviewed practices used for software evaluation for travel demand forecasting in other areas and developed a list of recommended criteria for use by TPB. CS also developed the backbone of a software evaluation process in which these recommended criteria can be applied objectively. These findings are presented in Section 2.0. CS also reviewed model documentation for 26 large MPOs in the United States (including TPB) to inventory the software packages used by each of these agencies, and completed a table[1] started by TPB staff to include the desired information. The results of this review are presented in Section 3.0.

■ 2.0 Software Evaluation

The evaluation of software packages for travel demand forecasting is an activity that most MPO's and state agencies undertake only on an infrequent basis due to the high-institutional costs associated with changing software platforms. In order to avoid the perception of favoritism towards any particular software package, a comprehensive list of criteria should be developed before the evaluation process begins. This ensures that all potential issues can be addressed during the evaluation in a fair and objective manner. CS began by reviewing similar software package review processes conducted by other agencies and groups around the country, including:

- Florida Department of Transportation;

- Kansas City Institute of Traffic Engineers (KCITE);

- New Mexico Department of Transportation;

- Rhode Island Department of Transportation;

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[1] MPO Survey table is provided to TPB as a Microsoft Excel file under separate cover.

- South Dakota Department of Transportation;

- Southern California Association of Governments (SCAG); and

- Vermont Department of Transportation.

2.1 Software Evaluation Criteria

In addition to reviewing the criteria used by other agencies in evaluating travel demand forecasting software packages, CS also reviewed TPB's plans for model improvements as found in the 2012 Unified Planning Work Program (UPWP). This helped CS identify specific potential needs of the Washington metropolitan region that should be considered when developing customized criteria for use by TPB in the software evaluation process. Fifteen potential evaluation criteria have been compiled based on this research:

- Advances in Modeling;

- Cost;

- Customizability;

- Data Processing;

- Network Editing and Management;

- Regional Compatibility;

- Report Generation;

- Software Interface;

- Spatial Analysis;

- Support;

- System Requirements;

- Technical Functionality;

- Transfer Issues;

- User Interface; and

- User Preference.

Each of the 15 broad evaluation criteria encompasses several more specific questions related to the functionality and use of the software. These questions may be either quantitative or qualitative in nature and relate back to the evaluation criteria to provide a clear view of all the elements that may impact the functionality in a particular area. The questions for each criterion were developed with a focus on future model development and the model application needs for travel demand forecasting in the Washington metropolitan region. The questions are designed to inspire structured discussion and brainstorming on TPBs specific desires and requirements, and are not meant to serve as an exhaustive list. A brief discussion of each of the 15 criteria along with the related questions are provided in the following tables.

Table 1. Criterion: Advances in Modeling

Criterion	Related Questions
Advances in Modeling	• Does the package support advanced modeling applications? (i.e., activity-based and/or tour-based modeling) • Does the vendor employ staff who contribute to improving the state of the art/practice through innovative methods?

This criterion attempts to account for the continual advancement of the field of travel demand forecasting, which has been evident over the last 10 years and is expected to continue in the future. The advent of tour- and activity-based models represents one of the biggest changes and improvements in the field, and MPOs across the country have begun migrating in this direction. In TPB's efforts to stay ahead of the state of the practice, the ability of TPB to also move in this direction should be considered in the selection of the next software platform.

It is difficult to know in which areas the next set of important advancements in travel demand forecasting will develop; however it is certain that the TPB model must be able to keep pace with these advancements. There is no way to know for certain which packages will make these advances first, best, and easiest. One good indicator is the amount of cutting edge research currently conducted by the staff of a given software manufacturer, which can in part be gauged by participation in professional conferences and publication in technical journals.

Table 2. Criterion: Cost

Criterion	Related Questions
Cost	• What are the total and itemized costs, including all elements such as software licenses, hardware requirements, training, support and maintenance, upgrades, add-ons, etc.? • How frequent will additional expenditures be needed? • Is pricing "modular" and based on the specific elements required by TPB? • Are there desired elements that will need to be purchased from another vendor? • Does the manufacturer offer server licenses or only licenses for individual machines?

Due to the complex nature of the software packages, there are many different elements of direct cost that must be considered, including the cost for software acquisition, and any additional repetitive costs associated with maintenance or support. In addition to considering the cost for the software elements required/desired for the current model, costs for additional elements that may be of interest in the future also should be considered (i.e., additional licenses, add-on simulation packages, advanced processing capabilities, etc.).

In an environment of limited resources, TPB will certainly be looking for a cost-effective solution. Cost also is one of the more easily quantifiable criteria. However, the importance of cost alone should not be overstated; the evaluation process should consider the costs of each potential software package without allowing it to overshadow or outweigh the other criteria. Cost effectiveness should be the ultimate goal, not simply low costs.

Table 3. Criterion: Customizability

Criterion	Related Questions
Customizability	• Can the software easily accommodate customized scripts?
	• How easy is it to implement customized methods, such as, volume delay functions and production/attraction balancing equations?
	• Is coding required or can analyses be conducted using drop down menu-style procedures?
	• If necessary, is coding easy?
	• Will the software be able to accommodate future changes to the model?

The current TPB Version 2.3 model is a highly customized model that has evolved over many years in order to model travel behavior in the Washington metropolitan region. As the region and the regional planning process continue to evolve, this need for customization is likely to retain its importance. Any software package selected by TPB should have a high degree of freedom to implement customized methods in any part of the model chain, in addition to customized reports and analyses on the model results.

In addition to the ability to customize the model, the ease of implementing customized methods also should be considered. The method used to implement customizations should be straightforward and would ideally be relatively simple and easy to learn for all model users. A platform where scripting is the only method for conducting analyses or customizing the model may limit what model users are able to accomplish.

Table 4. Criterion: Data Processing

Criterion	Related Questions
Data Processing	• What are the data handling capabilities and limitations of the software?
	• Processing speed?
	• What types and sizes of data files are used for importing and exporting?
	• Can the software read from and output to common file types?
	• Does the software package accept a wide range of both newer and older file types?

The first area addressed by this criterion is whether the software will be able to handle the processing requirements (number of zones, number of user classes, etc.) of the current TPB model. Also important is the room for growth within the software package should the processing requirements increase in the future through the addition of more zones or user classes, for example. If the current TPB model is pushing the limits of a software package's capabilities, then the ability to improve the model in the future may be limited. TPB should search for a powerful software package so that the processing capacity of the modeling software is never the limiting element of the travel demand forecasting process.

Secondly, it is important to know what types of files can be used as input and output to each alternative package. Limitations on the input file types could require reformatting of existing input files. Limitations on the output files could potentially have a cascading effect on other models and processes in the region. These types of data issues should be considered not only to determine compatibility with the current file types, but with an eye towards evaluating how accommodating the package is generally towards all types of file formats.

Table 5. Criterion: Network Editing and Management

Criterion	Related Questions
Network Editing and Management	• How fast and easy is network editing for both highway and transit networks? Is it menu driven?
	• Is it GIS-based?
	• Can it deal with master networks or multiple year or scenario networks?
	• Does it allow the use of satellite imagery/digital orthophotos as a background layer for editing highway and transit networks?

Network building and editing is an important and frequently used element in travel demand forecasting and is often a crucial element of planning studies in the Washington metropolitan region using the TPB model. As such, network coding for both highway and transit modes should be as easy and intuitive as possible.

Table 6. Criterion: Regional Compatibility

Criterion	Related Questions
Regional Compatibility	• Is the software compatible with the models used by other entities and jurisdictions in the region?

Regional and cross-jurisdictional collaboration play an important role in the success of planning in any metropolitan region. This criterion may be especially important in the metropolitan Washington region due to the high number of agencies and government bodies that hold jurisdiction over some part of the region. Each of the many jurisdictions that conduct travel demand forecasting activities or use the outputs from the TPB travel demand model need to be able to continue to interface with the model in its next software platform. Further, because of the close interaction between the two metropolitan areas, compatibility with the Baltimore regional model should be considered as well.

Table 7. Criterion: Report Generation

Criterion	Related Questions
Report Generation	• Can the software effectively map and format results?
	• Can it provide effective performance statistics?
	• Are the reports clear, useful, and easy to understand?
	• How easy is it to produce these types of reports?
	• Is it easy to develop and produce ad hoc/customized reports?

Because a single run of the TPB model produces so much data, many different reports are needed to summarize the results and provide a level of analysis. Report generation will continue to be an important part of travel demand forecasting model functionality, and the capabilities of each alternative in this area should be considered. In addition to standard reports, the selected software package should allow users to quickly and easily create an array of different customized reports to meet the needs of individual projects and studies.

Table 8. Criterion: Software Interface

Criterion	Related Questions
Software Interface	• How simple is the software to integrate with other types of models and software tools? (i.e., micro- or mesoscopic simulations, GIS tools, economic and benefit/cost models, air passenger models, freight models, database programs, spreadsheet packages.) • How easy is the interface with Summit analysis procedures for New Starts analysis?

TPB does not perform travel demand forecasting in a vacuum, and therefore the TPB model must be able to interface with other important software used by MWCOG/TPB and other agencies in the region. Travel demand forecasting software manufacturers may offer some types of software tools (specifically the simulation tools and freight models) for purchase that interface directly. Ideally, the choice of travel demand forecasting software should not limit the choices for other types of software used in the region, and the selected software package should be able to interface with tools developed by other manufacturers or that are custom-built by government agencies in the region.

Table 9. Criterion: Spatial Analysis

Criterion	Related Questions
Spatial Analysis	• Does the software package include GIS/mapping capabilities? • What other spatial analysis tools are available (i.e., transit route buffering, geocoding)? • Are the maps and results visually appealing?

The ability to visualize data from the travel demand forecasting model is an important capability for any software package, as it makes understanding both the inputs and outputs of the model easier. The important capabilities include easy interfacing with GIS programs (as discussed under the heading of Software Interface), easy visualization of results, and integration of maps into the network coding process. In addition, it may be desirable for the forecasting software package to be able to conduct many common types of spatial analyses internally.

Table 10. Criterion: Support

Criterion	Related Questions
Support	• How much does support cost?
	• How useful is the support?
	• What is the response time?
	• Does the manufacturer have a good reputation in the marketplace and with their current customers?
	• Does the company seem stable and likely to continue to manufacture and support the software?
	• How frequently are updates required?
	• How thorough and useful is the documentation/help files?
	• How easily accessible are training programs?
	• Is maintaining the model easy through software version changes?

Customer support can affect the forecasting process in many ways, and can be a primary contributor to determining if the use of a software package is pleasant or difficult. Poor support can result in substantial time and productivity losses as TPB staff try to solve problems and resolve issues with the software on their own. This is especially true when switching to a new software platform, as there will inevitably be more questions and unknowns at this point. The quality of customer support is somewhat difficult to gauge without personal experience, and no ready source of customer reviews exists in the small market of travel demand forecasting software. However, because customer satisfaction is one of the best clues to the level of support to be expected by a software vendor, interviews with current and former customers of each of the alternatives may be warranted to gain an understanding of this dimension.

Another element to consider is the frequency of software updates under each alternative. Long periods between model updates may indicate that the manufacturer is slow to respond to changes in the market, advances in the field, or reports of errors. On the other hand, a manufacturer that releases an update on a weekly basis makes it very difficult to achieve a stable platform for modeling work. A good balance between these two extremes seems to be the most desirable. Also to be considered are the types of improvements included in each update, and what types of updates to the TPB model would be necessary at these junctures. For example, model updates that typically alter the coding language rendering old scripts useless would be undesirable.

Table 11. Criterion: System Requirements

Criterion	Related Questions
System Requirements	• What are the current and future system requirements based on the dimensions of the TPB model? (Operating system, memory requirements, etc.) • What types of options are available for running complex models? (i.e., multithreading, distributed processing, cloud computing, etc.)

This criterion addresses the need for purchase of additional hardware, including processors and memory. It also addresses the ongoing issues as operating systems change from 32-bit to 64-bit platforms. Another major consideration for TPB right now should be the package's ability to handle and increase the processing speed of a complex travel demand forecasting model. With the increased complexity of the TPB model has come dramatically increased run times along with the need for advanced computing mechanisms such as multithreading, distributed processing, and cloud computing. The availability and reliability of these types of tools should be considered when evaluating alternative software packages.

Table 12. Criterion: Technical Functionality

Criterion	Related Questions
Technical Functionality	• Does the model replicate its own results when subjected to the same conditions? • How efficient are the path-building algorithms for highway and transit? • Are common matrix and link calculation functions available and easy to use? • How well does it represent non-motorized modes? • What types of preprogrammed routines and functions (i.e., gravity model, matrix balancing) are available? • What transit and traffic assignment methods are available? • What level of transit modeling capability does it have?

This criterion covers a range of important requirements that represent whether the software has the necessary technical functionality to implement the TPB model. Technical functionality should cover a range of issues related to the processes, methods, and algorithms that are built into or can be customized for use in each software package. TPB will

need to develop a complete list of functionalities for an idealized software package in order for this criterion to be evaluated in an objective manner.

Table 13. Criterion: Transfer Issues

Criterion	Related Questions
Transfer Issues	• How difficult will it be to transfer existing model sets, input data, networks, etc. into the new formats? • How difficult will it be for staff to transfer to the new system? • Will there be a steep learning curve for TPB staff and other agencies that use the model?

There is typically some amount of non-monetary cost involved in a change of software platforms that may take many forms, often time. Time is needed to install new software, to train staff, to transfer inputs and outputs, and for hands-on learning of the new software. In addition, testing of the results of the new converted model against the previous model results will be desirable and some additional validation work may be necessary. While transferring input files such as networks and land use data may in fact be a large task, software manufacturers may be willing to provide substantial assistance in this process to new customers. The major issues at the start of the transfer process are likely to be related to staff productivity as they learn the new system.

Table 14.   Criterion: User Interface

Criterion	Related Questions
User Interface	• Is the software user friendly? • What level of effort is required to operate the software? • What kind of experience is required to operate the software? • How are the different model components tied together? • Does the user interface provide a method for tracking scenarios?

The user interface criterion addresses how users interact with the travel demand forecasting model. Several of the issues in this section are very qualitative in nature, such as rating the "user-friendliness" of the software. Many people have different ideas about what makes software user friendly, but some concepts to consider would include the graphical user interface, the style of the interface design, and menus built with intuitive structures. The qualitative nature of this criterion should not downplay its importance;

the user interface will be experienced daily by all model users, and will greatly influence their experience with the model.

Table 15. Criterion: User Preference

Criterion	Related Questions
User Preference	• Do modelers at the agency prefer a specific software platform?
	• Are they more skilled at using a specific software platform?

This final evaluation criterion addresses the fact that different users prefer different software packages. These preferences may be due to familiarity, personal experience, professional relationships, or almost anything else. Despite the seemingly trivial and potentially conflicting nature of these preferences, comfort levels with a specific software package can affect the performance of staff members working with the model.

2.2   Software Evaluation Methodology

During the research for this task, CS also reviewed the methods that have been used by other agencies in applying criteria to evaluate travel demand forecasting software packages. The software evaluation methodology recommended for use by TPB would integrate the processes used by FDOT in 2002 and SCAG in 2007 (Chen 2007) to provide the most customized and appropriate methodology for TPB. The process may include the following steps:

• Definition of criteria;

• Definition of alternatives;

• Selection of evaluators;

• Data collection;

• Rating of alternatives; and

• Selection of a preferred alternative.

The first step, defining the criteria, has been discussed in Section 2.1 of this memo. The remaining steps are outlined briefly in the following sections.

Definition of Alternatives

Following the adoption of a defined set of evaluation criteria, the alternatives for analysis must be defined. The list of alternatives can be very simple or very complex, and should always include enough detail that multiple evaluators will be able to clearly identify the attributes of each alternative. The alternatives should only include the packages, applications, and add-ons that TPB is legitimately willing to consider. For example, the FDOT

study included 10 alternatives; TPB's analysis may include fewer. Each alternative should specify the package, version, and modules to be included in the evaluation.

Selection of Evaluators

It is important that all evaluators make their decisions based on identical information. Therefore, if possible, the evaluators should not be involved in the data collection step, as this process may expose them to a range of biased or inaccurate information that may influence their evaluation. In order to ensure that this is the case, a panel of evaluators should be selected at the beginning stages of the evaluation process and before data collection begins. Evaluators should represent a range of interests. Evaluators should have technical expertise in travel demand forecasting and be familiar with the transportation planning process and the uses of travel demand forecasting models and their results.

Data Collection

Data collection is one of the most important steps in the software evaluation process. It also can be a very difficult step to complete due to the prevalence of conflicting information about the available software packages. For each criterion included in the final list, a description of the capabilities, costs, and restrictions must be developed for each alternative. These descriptions must be detailed enough to provide the evaluators with the means for meaningful comparisons on each issue, but short enough to be readily understood by everyone involved in the process. Figure 1 shows an example of a portion of the data collection results of an evaluation process conducted by KCITE in 2004.

Figure 1. Sample Data Collection Report

Criteria	EMME/2	CUBE	TransCAD	VISUM
Retail Price	$9,000	$3,500 to $12,500	$2,995 to $9,995	$5,000 to $20,000
Type of Package (modular/single entity)	Single entity	Modular	Single entity	Modular
Formats for Data Import and Export	*Import:* ASCII, shape files, dBase *Export:* ASCII	*Import:* dBase, XLS, CSV, ASCII , Shape, graphics *Export:* dBase, XLS, CSV, ASCII, Shape	I*mport:* ASCII, CSV, DBF, BIN, XLS, SHP, DGN, DXF, Tranplan, EMME/2, Tmodel, graphics, etc. *Export:* ASCII, CSV, DBF, BIN, SHP, DXF, graphics, EMME/2, TP+, Tranplan, MinUTP	*Import:* Access, ODBC, DBF, ASCII, CSV, graphics, ESRI, SHP, p-GDB, Mapinfo, Tmodel, EMME/2, Tranplan, MinUTP, QRS, TransCAD *Export:* Access, DBF, ASCII, CSV, XLS, DXF, graphics, p-GDB, Mapinfo, Tmodel, EMME/2
Size Limitations	Zones = 6,000 Links = 150,000 Nodes = 60,000 Transit = 24,000	Unlimited	Unlimited	Unlimited
Trip Generation Options	a, b, c (any method can be implemented using matrix calculator	a, b, c, activity discrete-choice, records-based processing	a, b, c, ITE rates, logit, user-defined macros and user-written programs, microsimulation	a, b, c, daily schedules and time- of-day generation
Trip Distribution Options	a, b (2D and 3D trip distribution models, calibration to observed trip length distribution, matrix adjustment using observed counts, any method can be implemented by using matrix balancing procedures)	a, b; activity, discrete-choice, records-based processing	a, b, estimation and application of gravity models, destination choice, tri-proportional fratar and gravity, simultaneous gravity assignment, estimation from counts	a, b, trip chain building from activity schedules

Source: KCITE (2004).

There are many potential sources for the data collection step of a software evaluation process, including vendors, technical literature, and other users. Each of these sources should be used to their best advantage while considering any potential biases or flaws in the information they provide. Vendors, for example, are typically willing to provide a great deal of information regarding their products' capabilities, especially when there is a potential sale at stake. Vendors may be willing to perform an in-house demonstration for the evaluation team, which may provide the opportunity to ask specific questions and get more detailed answers. User guides, help files, and other documents produced by the vendor are another good source of information on a software package.

Technical literature, including papers, presentations, and other research can provide another excellent source of information about the capabilities of a particular software package. Sometimes these studies include comparisons of different packages' performance on a particular problem or in dealing with a particular issue. While these types of benchmarking studies can be useful in comparing performance, the data collection step should include only objective information about each package. Typically, these studies are more likely to include limitations and drawbacks of a software package than other sources, but it is important to know any affiliations that the author(s) may have, and any associated biases that should be considered when reporting the results.

Discussions with users of a software package can be very enlightening and often provide the type of unique insights that evaluators may find most useful and that may be unavailable from any other potential sources. Data from software users can include both benefits and drawbacks of a specific package, while giving a clearer understanding of the ease of use, understandability, user experience, and transition costs than any other source.

Rating of Alternatives

Research has revealed that two methods are primarily used for this step of the software evaluation process. Both the average scoring and weighted average scoring methods require that each evaluator rate each alternative in a number of different categories defined by the evaluation criteria. A ratings matrix outlining the criteria and the alternatives is developed and filled out by each evaluator. Generally, the value of the scores ranges from 1 (poor) to 10 (excellent). Using the average scoring method, these scores are simply summed together and then averaged across each evaluator. The packages are then ranked in order of descending points. A sample of the type of matrix used in the average scoring method is shown in Figure 2.

Figure 2. Sample Average Scoring Matrix

Functionality/ Administrative Criterion	Option 1	Option 2	Option 3	...	...	Option N
1	...					
2						
3						
...						

Dollar values for cost/price criteria
Assessment of how option performs

Source: FDOT (2002).

Using the weighted average scoring method, the relative importance of each criterion or category must be determined in advance. An example of this type of ranking as used in the Los Angeles region is shown in Table 16. In this example, the criteria are divided into three categories: "must have," "desirable," and "nice to have," each with an associated points value. This system or any other could be used, so long as the more important items are ranked with a higher point value. This score defines the relative "importance" of each category and should preferably be determined by people who are not on the evaluation panel.

Table 16. Importance of Software Evaluation Criteria

Criteria	Importance	Rank
1. Compatible with the City's Computer Environment	Must Have	5
2. Support the City's GIS System	Must Have	5
3. Support Other Business Areas in the City	Must Have	5
4. Support OCTA's Subarea Modeling Framework	Must Have	5
5. Compatible with OCTA Modeling Software	Desirable	3
6. Support Conversion of TRANPLAN Databases and Highway Networks into the New Platform	Desirable	3
7. Network Editor	Must Have	5
8. Highway and Transit Path Builders	Must Have	5
9. Matrix and Link Calculators	Must Have	5
10. Easy-to-Use Customized Scripts	Nice to have	1
11. Wrapper or Transportation Modeler	Nice to have	1
12. Capital and Maintenance Costs	Desirable	3
13. Technical Support	Must Have	5

Source: SCAG (2007).

As with the average scoring method, the evaluator rates each alternative in each of the categories. The evaluators' scores are then weighted by the importance scores as shown in Table 17. The totals are averaged across all of the evaluators and the software packages are then ranked in order of descending average weighted score. This method allows for the inclusion of more optional or "nice to have" evaluation criteria without allowing them to overshadow the truly required elements.

Table 17. Weighted Average Scoring Methodology

Criteria	Importance	Alternative 1 Rating * Importance	Alternative 2 Rating * Importance	Alternative 3 Rating * Importance
Criterion 1	5	7*5=35	9*5=45	10*5=50
Criterion 2	3	10*3=30	10*3=30	5*3=15
…	1	7*1=7	9*1=9	7*1=7
Criterion N	3	10*3=30	7*3=21	8*3=24
Sum	–	102	165	96
Rank	–	2	1	3

Note: In this example, criteria ratings are scored on a scale from 1 to 10, and importance is scored from 1 to 5.

Selection of a Preferred Alternative

Whichever rating methodology is used, it may be tempting to simply select the highest ranked package and move forward with developing a transition plan (if necessary). However, some additional analysis of the results is warranted and may provide important insights.

First, the ratings for each criterion should be reviewed to determine if there are any out-liers. Did five out of six evaluators give alternative 1 a perfect score in one category, while the remaining evaluator gave a very low score? Perhaps someone misunderstood the question? Or perhaps they simply wrote the wrong number by mistake? (A 10 can easily become a 1.) Incorrect outliers should be corrected if necessary.

Further, when two alternatives finish very close in total average score, it is a good idea to identify which category (or categories) tipped the scales. This more qualitative final review of the evaluation process can ensure that all of the most important criteria have been met by the selected alternative and that it will best suit the needs of MWCOG/TPB and other users of the model.

■ 3.0 Travel Demand Software Inventory

In today's market for travel demand forecasting software, there are four main players: Caliper, Citilabs, INRO, and PTV. This was not the case 10 years ago, when a survey of 260 MPOs revealed the use of eight different forecasting platforms. As the travel demand forecasting needs of agencies has continued to change, the capabilities of the modeling software packages have evolved and attempted to meet those needs. This has resulted in the emergence of several new companies in the field, sometimes built to combine the strengths and resources of multiple smaller companies. Periodically, agencies review their

travel demand forecasting needs and sometimes determine that a different product would serve them better. Based on the data shown in Table 18, the average length of use of a software package by MPOs in 2001 is approximately six years.

Table 18. 2001 Usage of Travel Demand Forecasting Software Packages

Software Package	Percentage of MPOs	Average Number of Years Used
TransCAD	23%	2.1
Tmodel	8%	7.5
EMME/2	9%	9.2
TRANPLAN	49%	7.1
TP+/Viper	11%	2.0
MINUTP	6%	8.5
FSUTMS	2%	18.0
TRIPS	2%	10.0

Source: Urban Transportation Monitor (2001).
Note: 260 MPOs included in survey. Some reported the use of multiple packages.

As shown, TRANPLAN was the most commonly used travel demand software package in 2001, with almost half of the market. However, TRANPLAN has been discontinued and (along with MINUTP and TRIPS) formed the basis of TP+ and other Citilabs products. In 2001 these packages (TRANPLAN, MINUTP, TRIPS, and TP+) were used by 68 percent of the MPOs surveyed. TransCAD had the second highest market share, with almost one quarter of the MPOs surveyed. Tmodel is an older tool that included only highway assignment capabilities and was typically used for Traffic Impact Studies and other small-scale analyses. It would not be used as the main travel demand forecasting tool by any large MPO today. The Florida Standard Urban Transportation Model Structure (FSUTMS) still exists as the overall structure for travel demand models in the State of Florida. In 2001, FSUTMS worked in a TRANPLAN framework; FSUTMS still exists and currently works in Cube Voyager.

A similar study was conducted in 2004 with a survey sample of 81 MPOs. As shown in Table 19, TransCAD was the most commonly used travel demand software package in 2004, with 28 percent of respondents. However, the Citilabs products (Cube, TP+, and TRANPLAN) account for an additional 28 percent of respondents.

Table 19. 2004 Usage of Travel Demand Forecasting Software Packages

Software Package	Percentage of MPOs	Average Number of Years Used
Cube	8%	4.5
EMME/2	5%	7.6
QRS II	2%	8.5
TP+	9%	2.1
TRANPLAN	11%	10.2
TransCAD	28%	3.2
VISUM	2%	2.0

Source: Urban Transportation Monitor (2004).
Note: 81 MPOs included in survey.

Obviously, the landscape has changed over the last 10 years, and to gain an understanding of those changes CS has reviewed the travel demand forecasting software packages used by a sample of TPB's peers: 26 of the largest MPOs in the country. Table 20 lists each of the MPOs included in this analysis.[2] The software package used by each MPO was ascertained through a combination of published model documentation, interviews with MPO staff, and CS' staff expert knowledge of models developed in-house.

Table 20. Travel Demand Forecasting Software used by Large MPOs

MPO	Major City	State	Software Package
Southern California Association of Governments	Los Angeles	California	TransCAD
New York Metropolitan Transportation Council	New York	New York	TransCAD
Chicago Are Transportation Study	Chicago	Illinois	EMME/2
Metropolitan Transportation Commission	San Francisco	California	Cube Voyager
North Jersey Transportation Planning Authority	Newark	New Jersey	Cube Voyager

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[2] A Microsoft Excel file including additional data collected as part of this survey is being submitted separately to TPB staff. Its structure is based on a draft version developed by Mark Moran at TPB.

Table 20. Travel Demand Forecasting Software used by Large MPOs (continued)

MPO	Major City	State	Software Package
Delaware Valley Regional Planning Commission	Philadelphia	Pennsylvania	VISUM
North Central Texas Council of Governments	Dallas	Texas	TransCAD
South East Michigan Council of Governments	Detroit	Michigan	TransCAD
Houston-Galveston Area Council	Houston	Texas	Cube Voyager
Metropolitan Washington Council of Governments/National Capital Region Transportation Planning Board	Washington	D.C.	Cube Voyager
Atlanta Regional Commission	Atlanta	Georgia	TP+
Puget Sound Regional Council	Seattle	Washington	EMME/2
Maricopa Association of Governments	Phoenix	Arizona	TransCAD
Central Transportation Planning Staff	Boston	Massachusetts	EMME/2
San Diego Association of Governments	San Diego	California	TransCAD
Southwestern Pennsylvania Commission	Pittsburgh	Pennsylvania	TP+
Metropolitan Council	Minneapolis-St. Paul	Minnesota	TP+
Baltimore Metropolitan Council/Baltimore Regional Transportation Board	Baltimore	Maryland	TP+
East-West Gateway Coordinating Council	St. Louis	Missouri	Cube Voyager
Denver Regional Council of Governments	Denver	Colorado	TransCAD
San Juan MPO	San Juan	Puerto Rico	Cube Voyager
Southeast Regional Planning Model	Miami	Florida	Cube Voyager (FSUTMS)
Northeast Ohio Areawide Coordinating Agency	Cleveland	Ohio	Cube Voyager

Table 20. Travel Demand Forecasting Software used by Large MPOs (continued)

MPO	Major City	State	Software Package
Southeastern Wisconsin Regional Planning Commission	Milwaukee	Wisconsin	Cube Voyager
Sacramento Area Council of Governments	Sacramento	California	TP+ and Cube Voyager
Ohio-Kentucky-Indiana Regional Council of Governments	Cincinnati	Ohio	Cube Voyager

Table 21 summarizes a few key statistics for the range of models that were included in this survey. Generally, the MPOs in the survey sample also use large-scale complex models with multiple assignment classes. Despite not being one of the largest MPO's by population or area in the survey, only four models in the survey (NCTCOG, SANDAG, Miami, and SCAG) include a higher number of traffic analysis zones than the TPB Version 2.3 model. In addition, the TPB model is on the higher end in complexity as judged by the number of traffic assignment classes, with a reasonable number of time periods.

Table 21. Surveyed MPOs Summary Statistics

	Internal Zones	External Zones	Total Zones	Assignment Classes	Time Periods
Minimum	938	11	956	1	1
Maximum	4,813	156	4,874	11	96*
Average	2,373	62	2,433	4	8
TPB Model	3,675	47	3,722	6	4

*Note: The SEWRPC model include 96 15-minute time periods. The second highest number of time periods among the surveyed MPOs is ten. The average number of time periods used by agencies excluding SEWRPC is four.

Table 22 summarizes these results for the software package used for conformity analysis for each of the 26 MPOs included. Cube Voyager has 11 users. TransCAD has seven users among these large MPOs. TP+, which like Cube Voyager is a Citilabs product, is used by five of the MPOS surveyed. TP+ is no longer being developed by Citilabs, and all current users are being encouraged to migrate to Cube Voyager at their next model upgrade. The Philadelphia region TIM 1.0 model is the only one in the survey that uses the VISUM platform.

Table 22. Travel Demand Forecasting Software Users

Software Package	Number of Users
Cube Voyager	11
EMME/2	3
TP+	5
TransCAD	7
VISUM	1
Total	27

Note: One MPO reported use of both TP+ and Voyager in their model.

Looking at the 10 largest MPOs by population (which includes TPB), the picture is slightly different, as shown in Table 23. Cube Voyager and TransCAD each have four users in this group of the largest MPOs, while EMME/2 and VISUM each have one user.

Table 23. Travel Demand Forecasting Software Users
        Top 10 MPOs

Software Package	Number of Users
Cube Voyager	4
EMME/2	1
TransCAD	4
VISUM	1
Total	10

Finally, this analysis looked at the geographic distribution of the various software packages used by the top 26 MPOs. The software packages are distributed around the country as shown in Figure 3.

Figure 3. Geographic Distribution of Travel Demand Forecasting Software Packages
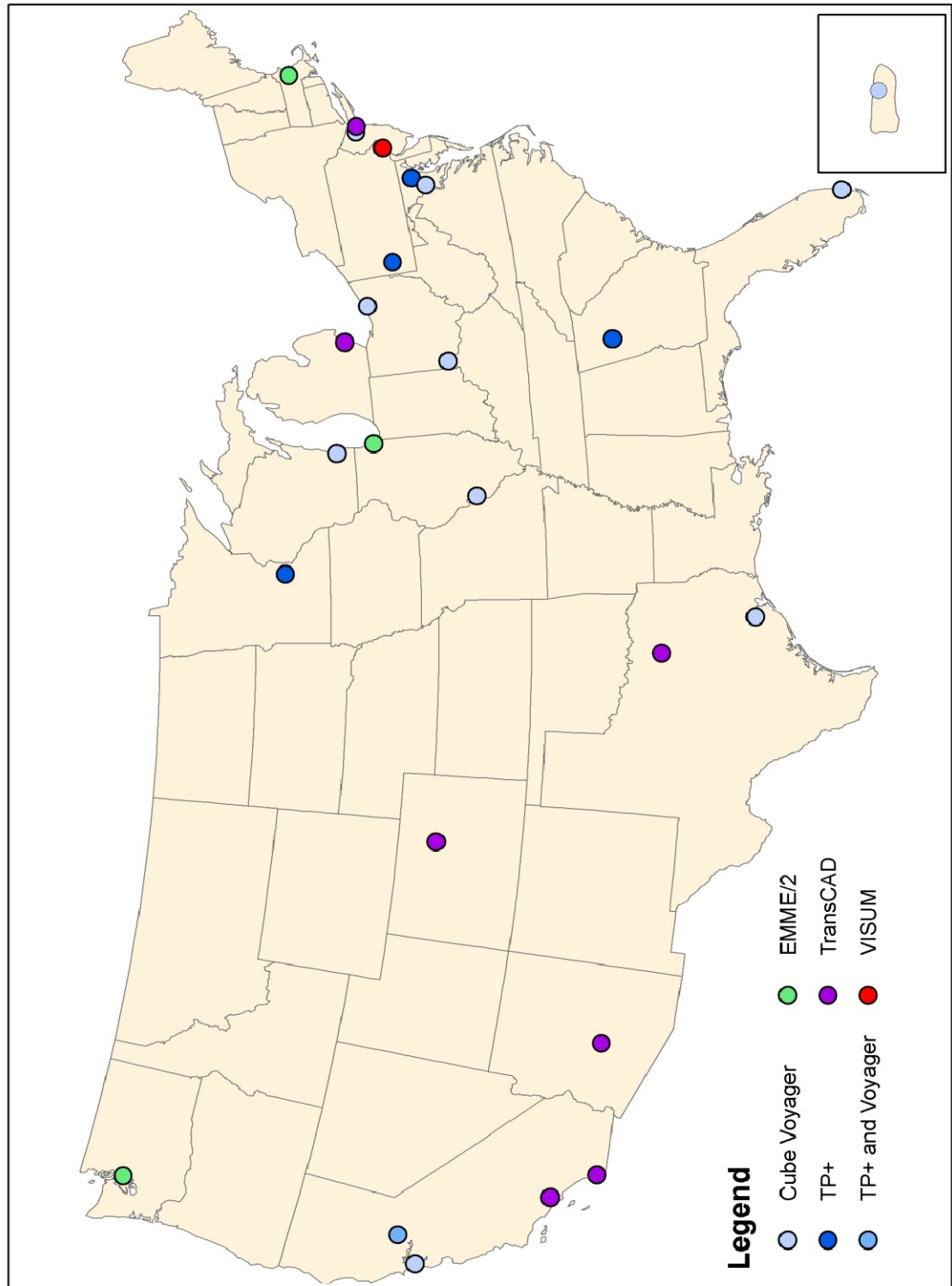
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Review of Version 2.3 Travel Demand Forecasting Model Methods, Scripts, and Potential Enhancements

■ 1.0 Introduction

The National Capital Region Transportation Planning Board (TPB) is currently working to finalize the development of the Version 2.3 travel demand forecasting model for the Washington metropolitan region. In support of these efforts, TPB has tasked Cambridge Systematics (CS) to consider several areas for making improvements or streamlining the model for efficiency, including:

- Review scripts and provide feedback on the process and the script architecture, with a focus on specific model steps of primary importance identified by TPB;

- Review the potential for use of Cube Cluster to enhance run times;

- Consider the implications of and, if desired, support the conversion of the current TP+ TRNBUILD scripts to PT application scripts; and

- Review the existing tolling methodology and potential enhancements.

CS leveraged the expert knowledge of staff around the country to review the most recent build of the Version 2.3 model, and recommended changes and improvements are outlined in Section 2.0. The work performed for the second of these subtasks included both a review of potential time savings available through the use of Cube Cluster presented in Section 3.0, but also substantial additional assistance with technical issues based on the on-the-ground needs of TPB staff as the Version 2.3 model development work continued and new issues were encountered. Section 4.0 details the potential benefits of migrating from the TRNBUILD application to PT, and also provides some information on changes needed in the model structure to accommodate this migration. Finally, the toll modeling methodology used in Version 2.3 is reviewed in Section 5.0, along with a review of toll modeling practices used by some other MPOs, and some potential areas for model enhancements. This technical memorandum documents the review and findings in the above areas. Task resources also supported some additional ad hoc assignments, including validation assistance and assistance with Cube Cluster testing, which are not documented in this report.

■ 2.0 Script Review

The first element of this task was to leverage Cambridge Systematics' expertise to provide a review of the Version 2.3 scripts and model architecture. The review was conducted on the Version 2.3 build 9 scripts, which were current as of March 29, 2011. The review

included general error checking of the scripts, ideas for potential efficiency enhancements, and a review of the overall model structure. Based on discussions with TPB, the detailed script review focused on specific areas of primary interest where computing efficiency is most important, especially the highway assignment step. In addition, the review looked at the skimming process for both highway and transit, and considered the feedback mechanism.

Generally, the results of the scripting review were very positive, with CS staff recognizing that TPB has developed effective and well-tested solutions to very complex modeling issues. CS staff believes that despite the complexity of the model and its structure, the modeling process is handled in a very solid manner. CS reviewed the scripts and the associated model documentation for any errors, all of which have been found and corrected by TPB staff for the later builds of the model.

The use of batch files is often cited as one potential limitation in the TPB model structure. Cube's Scenario and Application Manager applications could provide a graphic user interface (GUI) to manage scenarios and different steps in the model and are the preferred method for some Cube users. However, the TPB batch file system is very advanced and provides a good structure for the model. While switching to Scenario/Application Manager is an option that can be considered, at this point it is more a matter of user preference and is certainly not a requirement for the continued advancement and development of the model.

The CS review found several specific ways to provide small increases in computational efficiency and to improve the model run time. First, in the highway assignment step when calculating congested speeds, CS recommends storing the volumes as working variables instead of referring back to the network to read from the link inputs. The following changes (shown in bold/red) are recommended to the script:

```
PHASE=LINKREAD
    C = CAPACITYFOR(LI.AMLANE,LI.CAPCLASS) * 2.39808; Convert hourly
            capacities to period-specific
    SPEED = SPEEDFOR(LI.AMLANE,LI.SPDCLASS)
    T0   = (LI.DISTANCE/SPEED)*60.0
    T1   = LI.TIME_1
    LW.V_1 = LI.V_1
     :
     :

FUNCTION {          ; Congested Time (TC) specification:
    V = VOL[3]
    TC[1]= T0*VCRV(1,((V+LW.V_1)/C)) ; TC(LINKCLASS) =
    TC[2]= T0*VCRV(2,((V+LW.V_1)/C)) ; Uncongested Time(T0) *
    TC[3]= T0*VCRV(3,((V+LW.V_1)/C)) ; Volume Delay Funtion(VDF)Value
    TC[4]= T0*VCRV(4,((V+LW.V_1)/C)) ; VDF function is based on (V+LI.V_1)/C
    TC[5]= T0*VCRV(5,((V+LW.V_1)/C)) ; Note:  the LINKCLASS is defined
    TC[6]= T0*VCRV(6,((V+LW.V_1)/C)) ; during the LINKREAD phase below.
    TC[7]= T0*VCRV(7,((V+LW.V_1)/C)) ; during the LINKREAD phase below.
    }
```

This small change can produce an 18 percent time savings; testing showed one iteration of an AM HOV3+ assignment time improved from 7:40 to 6:16 with these recommended changes. Similar time savings may be possible for each iteration, for a total savings of 14 minutes for this loop of this assignment alone (assuming that only 10 iterations are needed for convergence). Similar efficiencies in all six loops, for all six assignments, could produce similar time savings for each iteration.[1]

The script review also pointed out that calculating the initial link impedance in the LINKREAD phase is unnecessary, as it has been previously calculated elsewhere in the script. Testing indicated that the same results are achieved by removing this redundant calculation, as shown below. (Bold/green text has been commented out.) This will save some computation time, but not a significant amount.

```
PHASE=LINKREAD
    C = CAPACITYFOR(LI.AMLANE,LI.CAPCLASS) * 2.39808; Convert hourly
            capacities to period-specific
    SPEED = SPEEDFOR(LI.AMLANE,LI.SPDCLASS)
    T0 = (LI.DISTANCE/SPEED)*60.0
    ; Since there is no "DISTANCE =" statement, this assumes that DISTANCE is
            avail. on input network

IF (ITERATION = 0)
    ; Define      link level tolls by vehicle type here:
    LW.SOVAMTOLL = LI.AMTOLL * AM_TFAC(1,LI.TOLLGRP); SOV TOLLS in
            2007 cents
    LW.HV2AMTOLL = LI.AMTOLL * AM_TFAC(2,LI.TOLLGRP); HOV 2 occ TOLLS
            in 2007 cents
    LW.HV3AMTOLL = LI.AMTOLL * AM_TFAC(3,LI.TOLLGRP); HOV 3+occ TOLLS
            in 2007 cents
    LW.CVAMTOLL = LI.AMTOLL * AM_TFAC(4,LI.TOLLGRP); CV TOLLS in 2007
            cents
    LW.TRKAMTOLL = LI.AMTOLL * AM_TFAC(5,LI.TOLLGRP); Truck TOLLS in
            2007 cents
    LW.APXAMTOLL = LI.AMTOLL * AM_TFAC(6,LI.TOLLGRP); AP Pax TOLLS in
            2007 cents

; Initial Iteration LINK IMPEDANCE (HIGHWAY TIME + Equiv.Toll/Time) by vehicle
type here:
    ;LW.SOVAMIMP = T0 + (LW.SOVAMTOLL/100.0)* SVAMEQM; SOV IMP
    ;LW.HV2AMIMP = T0 + (LW.HV2AMTOLL/100.0)* H2AMEQM; HOV 2 IMP
    ;LW.HV3AMIMP = T0 + (LW.HV3AMTOLL/100.0)* H3AMEQM; HOV 3+IMP
    ;LW.CVAMIMP = T0 + (LW.CVAMTOLL/100.0)* CVAMEQM; CV IMP
    ;LW.TRKAMIMP = T0 + (LW.TRKAMTOLL/100.0)* TKAMEQM; Truck IMP
    ;LW.APXAMIMP = T0 + (LW.APXAMTOLL/100.0)* APAMEQM; APAX IMP
;
;IF (LI.AMTOLL > 0)
    ; PRINT LIST = 'iteration: ',iteration(3),' A: ',A(7),' B: ',B(7),
```

---

[1] If time savings per iteration are similar, than the morning and evening peak non-HOV assignments are likely to see the most net time savings since they require the highest number of iterations to reach convergence.

```
      ;' DISTANCE: ',LI.DISTANCE(6.2),
      ;' LI.AMTOLL: ',              LI.AMTOLL(5.2),
      ;' FFSPEED: ',                  SPEED(5.2),
      ;' AM_TFAC(1,LI.TOLLGRP): ',AM_TFAC(1,LI.TOLLGRP)(5.1),
      ;' SVAMEQM: ',                SVAMEQM(5.1),
      ;' LW.SOVAMTOLL: ',           LW.SOVAMTOLL(5.2),
      ;' T0: ',                       T0(5.2),
      ;' LW.SOVAMIMP',          LW.SOVAMIMP(5.2),
      ;file = AMCHK.LKREAD
   ;ENDIF
    ;
   ENDIF
```

In addition, the link impedance calculation in the ILOOP phase may be able to be completed more efficiently in the ADJUST phase and without specifying a LINKLOOP. This has not been tested, and is likely to provide only small time savings.

Overall, the review of the Version 2.3 model scripts resulted in an affirmation of the strength of TPB's model. The current format which is executed using a series of batch files accounts for all of the complexity inherent in the model and allows for the needed flexibility to manage multiple scenarios. CS was able to identify a few areas for improvements in efficiency. These changes, while not major, may cumulatively have a positive impact on the model's performance and total run time.

■ 3.0 Distributed Processing

Distributed processing is a computing method that allows for the use of more than one computer or processor to run an application. These computers may be physically separate machines, or can be multiple processors (CPUs) within the same computer. This special case also can be referred to as parallel processing. Distributed processing systems are used in a range of computing applications to achieve a number of different benefits. In the realm of travel demand forecasting, distributed processing is primarily used to improve performance speeds of computationally complex models. The original scope for this subtask was focused on the potential use of Cube Cluster to enhance model runtimes; however due to the pace of model development by TPB staff, CS was able to provide other services related to the implementation of distributed processing in the model. This assistance is discussed in this section.

3.1 Distributed Processing in Cube

Cube Cluster is the program developed by Citilabs to implement distributed processing in their travel demand forecasting software products, including Cube Voyager which currently is used to run Version 2.3 of the TPB regional model. Cluster has the ability to distribute processes across the processors in one or many computers. Cluster can implement these distributional capabilities in two ways (Citilabs, 2007):

- Intrastep Distributed Processing (IDP): Cluster distributes a single model step across multiple cores by splitting the zones into multiple groups. For example, zones 1-1,000 on PC#1 and zones 1,001-2,000 on PC#2 in a mode choice model. IDP can be implemented on any type of zone-based computation within the Highway and Matrix Voyager modules.

- Multistep Distributed Processing (MDP): Cluster splits blocks of independent model steps across multiple cores. For example, trip generation can be run on PC#1 and network skimming can be performed on PC#2. MDP can be implemented on any process in Voyager.

To use Cube Cluster across multiple computers, the user must specify a primary computer; this is the only machine that would require a Cluster license. Additional computers only require licenses for Cube Voyager (and can be run using the less expensive Voyager node licenses) and no additional licenses are required for running Cluster on multiple cores within a single machine.

Distributed processing in Cluster is implemented by the model user in the application scripts. For each instance of distributed processing, the script must specify the number of cores to be used and how the process is to be distributed (IDP or MDP). The changes to the scripting are fairly minimal, and have not proven difficult to accommodate.[2] In addition, TPB staff has developed a switch in the model batch files that allows users to activate or deactivate the distributed processing capabilities, to accommodate users who may not have access to Cube Cluster and/or multiple processors.

Tests have been conducted by a number of parties regarding the time savings available through the use of Cube Cluster. Citilabs advertises substantial time savings on full model runs and on individual model steps. Because highway assignment is by far the most time consuming step of the TPB modeling process, Citilabs' tests regarding time savings in highway assignment may be of particular interest. These tests can give a general idea of the time savings that may be available to TPB. During the course of this task, TPB and CS also have conducted numerous tests on the effects of Cube Cluster on model run times. Several of these tests are summarized in Table 1. As indicated, very substantial time savings may be possible in individual model steps and for the model overall if Cube Cluster is used to its best potential. Further time savings may be possible if additional instances of IDP and MDP can be added to other steps in the model chain. As of June, TPB staff has added IDP to modeling steps related to fare building (MFARE2.S) and transit skimming (Transit_Skims_[AB|MR|BM|CR].s), in Version 2.3.24.

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[2] Though, as noted later in on page 7, TPB staff have noticed small changes in estimated VMT when using Cube Cluster (on the order of 1 to 3 hundredths of a percent at the regional level).

Table 1. Sample Cube Cluster Test Results

Tester	Model Step	Original Run Time	Number of Cores	Run Time with Cluster	Time Savings
TPB	Full 2007 model run (biconjugate Frank-Wolfe, 50 iterations)	45 hours	4	31 hours	31.1%
TPB	Full 2007 model run (biconjugate Frank-Wolfe, 200 iterations)	75 hours	4	33 hours	56.0%
TPB	Full 2007 model run (conjugate Frank-Wolfe, 200 iterations)	77 hours	4	37 hours	51.9%
CS	Highway assignment	70 minutes	6	14 minutes	80.0%
Citilabs	One highway assignment iteration	2 minutes	2	1 minute	50.0%
Citilabs	Full model run	10 hours	5	140 minutes	76.7%
Citilabs	Full model run	4 hours	4	67 minutes	72.1%

Note: Only the TPB tests were conducted using the TPB model.

Cube Cluster is fully scalable and can be used with any number of processers to achieve faster model run times. However, it should be noted that additional cores provide a diminishing improvement in run times. The second core provides the greatest amount (percentage) of time savings, each additional core shows somewhat less of an improvement. So while adding a second core may cut the run time in half, the third core may only reduce the run time by one-third, the fourth by one-quarter, and so on, as shown in Figure 1. Some balance must be struck between the desired processing speed and the cost of computing power.

Figure 1. Diminishing Returns of Additional Processors
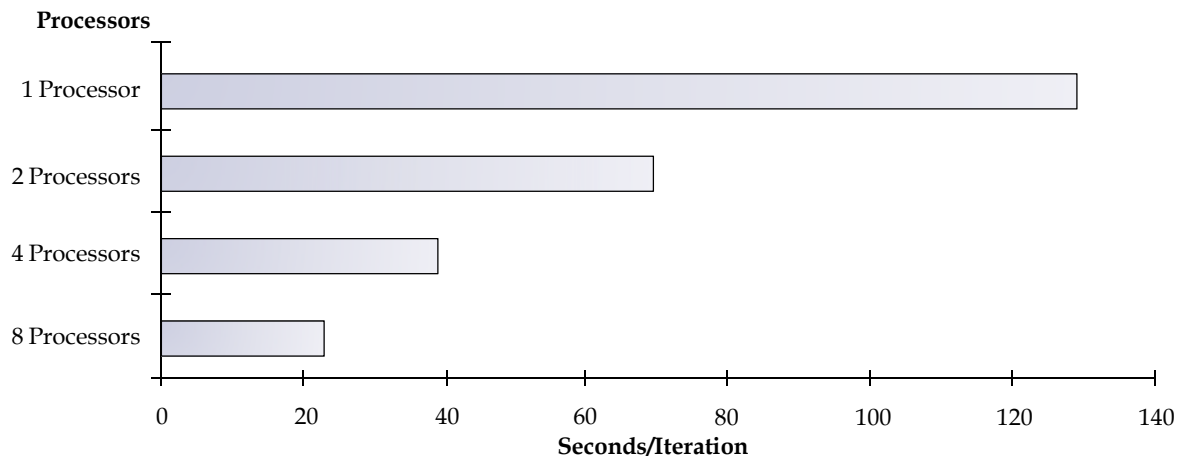
Source: Citilabs (2007).

3.2   Application of Distributed Processing

Over the course of the past several months, TPB has begun testing implementation of Cube Cluster in the Version 2.3 model. As a starting point, TPB added IDP capability to the highway assignment procedures using four processors. The results of these tests, as indicated in Table 1 have been very successful in terms of reducing the model run time. Unfortunately, TPB has found some issues with replicating the results. As found and reported by TPB staff, model runs with Cube Cluster have different results than those without distributed processing. Total vehicle miles traveled (VMT) show some small differences (on the order of 0.03 percent regionally), although individual links may have more variability.

TPB and CS continue to work on this issue in coordination with Citilabs. Several issues have been flagged as potential areas for investigation, including the level of convergence and potential rounding issues propagated through the use of multiple cores. These issues continue to be under investigation and additional findings will be presented to TPB sepa-rately as they are discovered. As of the Travel Forecasting Subcommittee meeting on May 20, 2011, TPB is recommending the consistent use of distributed processing in all model runs (same number of cores for all model scenarios) in order to achieve the benefits associated with Cube Cluster while minimizing any stability concerns or differences in model results that may be associated with its use.

◼ 4.0   Transit Application Scripts

TRNBUILD was the original transit application developed by Citilabs for use in its TP+ travel demand forecasting software. This program can still be used in Cube Voyager, although it is a fairly basic application that is designed to work best in simple transit sys-tems. TRNBUILD is a single-path transit program that calculates only the shortest transit path for each origin-destination pair. Based on the needs of larger cities like the Washington metropolitan region with more complex transit systems, Citilabs has devel-oped a more advanced transit application, called Public Transport (PT), that more accurately represents these types of areas. According to the survey of large MPOs conducted as part of Task 12, CS was able to identify three large MPOs (Houston-Galveston Area Council, San Juan, and Northeast Ohio Areawide Coordinating Agency) that have switched to PT and one model in the Miami region that uses PT for network building purposes only.

In addition to the ability to calculate and store multiple transit paths, PT includes a variety of other improvements that may be beneficial to the TPB regional model. PT is a multi-user class multi-routing transit algorithm, although it has the ability to operate as a single-path program as well. Generally, the program includes three primary steps:

- Compile data and generate networks: the results of this step are stored in a ".net" file that is substantially more complex than a standard highway network. It includes data about run time, cost, service frequency, access distance, and other transit characteristics. PT also has the ability to generate walk- and drive-access links.[3]

- Enumeration of acceptable discrete routes: enumerates all acceptable transit routes (as defined by the user) which have some probability of being used by passengers between all origin-destination pairs. Routes are enumerated separately for each user class. Enumerated routes can be saved and used in subsequent model runs.

- Evaluation of routes and analysis: The enumerated routes can be further evaluated to eliminate any illogical or unacceptable routes. Transit skims for each defined user class also are developed. Transit trips are then loaded onto the transit network by user class based on a series of submodels:

  - Walk-choice model;

  - Service-frequency or service-frequency-and-cost model; and

  - Alternative alighting model.

  The loading step may be repeated iteratively if transit crowding is included in the model. A wide range of reports can be generated as part of this step.

There are many differences in the way that PT and TRNBUILD address transit modeling. Generally, PT offers a more sophisticated framework, allowing for more flexibility in accurately analyzing the travel behavior of passengers in a complex transit system. This added flexibility does come at the cost of additional complexity in the program structure and changes to the required inputs. The combination of PT's capabilities could allow it to take the place of the traditional nested logit mode choice model currently being used in Version 2.3 of the TPB model. This is not a required application of implementing PT, and the program can perform the vast majority of its advanced functions in sequence with a mode choice model.

This section discusses the benefits and drawbacks of conversion to PT and addresses the issues that may be associated with the conversion process. For a more complete treatment of these issues and more detailed and personalized instruction, Citilabs offers an Advanced Scripting training course that TPB staff may find to be very useful.

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[3] TRNBUILD also has the ability to generate both walk-access and drive-access links, using the ZONEACCESS and PNR keywords, but the TPB, like others performing modeling in the Washington, D.C. area, has chosen to forego these built-in features, in favor of specially-built software that allows more flexibility in generating these links (e.g., the Fortran program AUTOACC4, which has now been converted to a Cube Voyager script: AUTOACC4.S).

4.1 Benefits of Using Public Transport

There are many elements included in PT that TPB may find beneficial to regional transit modeling over TRNBUILD. In the context of the TPB model, there also are a few elements that may not be considered benefits. The most important changes will be discussed in more detail in this section, including:
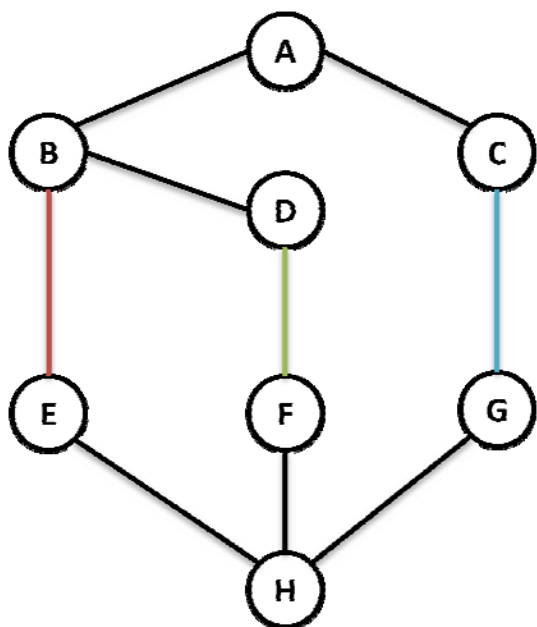
- Enumeration of multiple paths;

- Ability to save enumerated paths;

- Definition of multiple user classes;

- Advanced transit network building capabilities;

- Ability to trace transit paths on screen;

- Advanced method for calculating wait time;

- More transit skimming options;

- Advanced algorithms for transit route selection;

- Incorporation of crowd modeling;

- Better representation of complex fare systems;

- Ability to create circular and linear transit routes;

- More rigorous and flexible analysis and reporting tools;

- Acceptance by FTA; and

- Ability to function as a mode choice model.

Enumeration of Multiple Paths

One of the biggest advancements in PT is the ability to develop multiple transit paths. In TRNBUILD, the single path building limitation means that all transit passengers use the single "shortest" route, even if the second shortest route is only a few minutes longer. As we know from highway assignment theory, the probability of a traveler selecting two routes with roughly identical utilities also is roughly equal; PT allows this reality to be modeled for transit passengers as well. As shown in Figure 2 the single-path method only captures the shortest path (A-B-E-H), but the multiple path methodology may be able to capture additional transit paths (depending on the settings in path enumeration). In this example, the A-C-G-H path may be almost as heavily used as the shortest path option.

PT enumerates all paths within user-defined limits of acceptability (i.e., trip length, time above shortest path, number of transfers, etc.) and calculates the probability of using each based on a nested logit model. This functionality can be used in sequence with the TPB mode choice model to capture multiple paths of the same mode, such as multiple bus routes. PT can also be set up as a single-path program; this option most closely replicates the current practice for transit modeling in Version 2.3. A different set of paths can be enumerated for each user class, time period, or even for each access mode.

Figure 2. Comparison of Single-Path and Multi-Path Route Captures

Path	Total Cost	Single Path?	Multi-Path?
A-B-E-H	60	Yes	Yes
A-B-D-F-H	83	No	Maybe
A-C-G-H	69	No	Maybe

Saving Route Paths

Another benefit of PT's multi-path route enumeration methodology is the ability to save these paths for later use as input. The program evaluates paths only where choices in the potential paths exist, thus eliminating route overlap from the enumerated routes. PT saves the enumerated transit paths in "bundles" related to these choice points. Saved paths can be used for sensitivity testing in the transit assignment (for example, use the enumerated routes to test how the results change using a lower threshold for acceptability of a route) without the need to rerun the full transit assignment.

Multiple User Classes

Unlike in TRNBUILD, PT allows for the definition of up to 10 transit user classes.[4] This can be helpful in modeling transit passenger behavior where different groups have different values of time. Transit user classes may be defined along any characteristics such as household income, trip purpose or access mode. In the Washington metropolitan region, this capability may prove beneficial in allowing TPB to model the different sensitivities to fares for Federal employees (who generally enjoy a large transit benefit) and other workers. In concert with the results of TPB's nested logit mode choice model, user classes could also be defined along the four submodes identified by the mode choice model (commuter rail, all bus, bus to Metrorail, and Metrorail), allowing only certain modes to each class.

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[4] According to Citilabs, if more than ten user classes are desired, this can be accommodated by running PT more than once.

Advanced Transit Network Building

PT includes the creation of a comprehensive transit network file that includes both transit links and non-transit legs (i.e., walk or drive access links). This transit network includes all of the information about transit service in the region, and includes both guideway-separated and mixed-traffic transit modes. For the TPB model, this would entail incorporating the Metrorail and commuter rail facilities into the main transit network. PT can either read in access links from a separate file, or they can be generated by the program based on the transit line files and highway networks. PT also has the ability to calculate network-based distances for these non-transit links. One limitation in the PT module is that a transit path must alternate between non-transit and transit legs.

On-Screen Path Tracing

The more advanced methodology used to develop transit networks in PT includes all links used in transit paths in a single network, including roadway links with bus service, fixed-guideway transit links, transfer links, station drive access links, and station walk access links. Because all links are contained in a single file, transit paths can easily be traced on-screen, similar to the procedure already used for highway paths. An example of this capability is shown in Figure 3. This ability to visualize paths through the transit network can be very beneficial to planners and model developers.

## Figure 3. On-Screen Transit Path Tracing Example
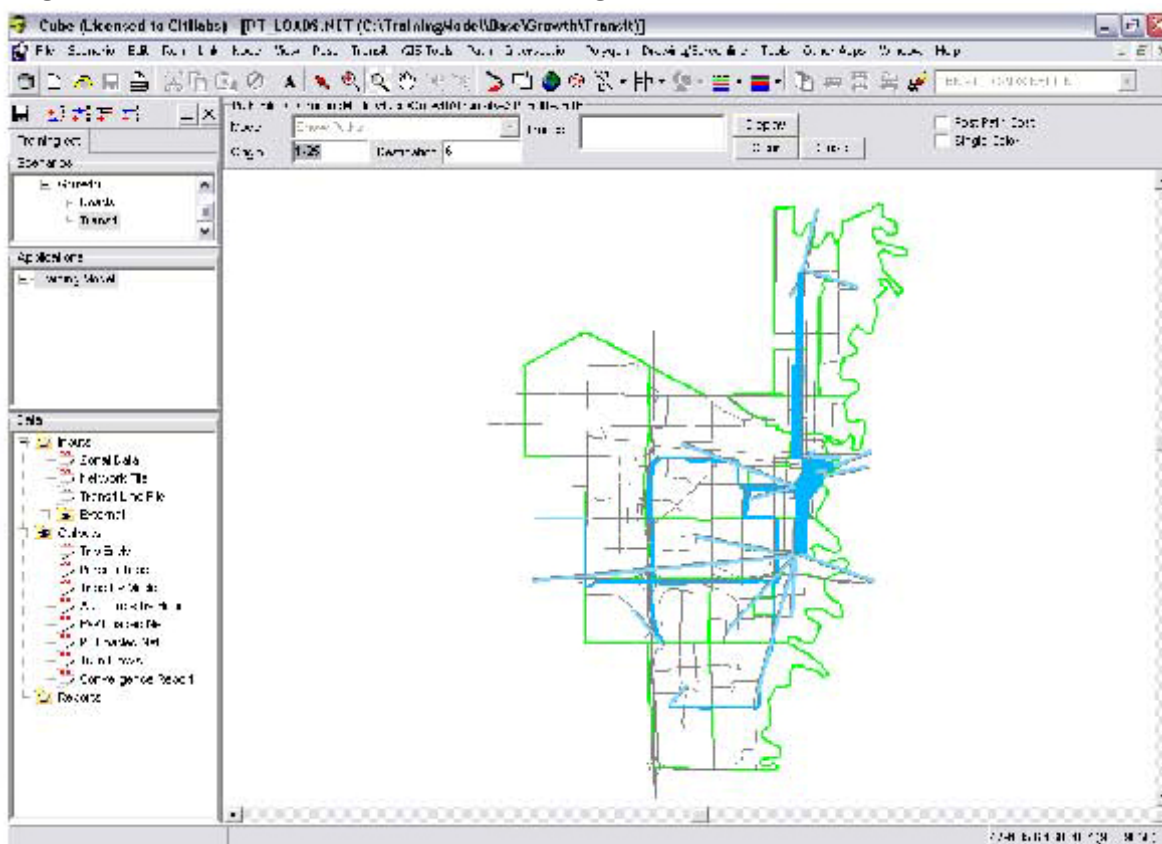
Source: Citilabs (2011).

Advanced Method for Calculating Wait Time

In TRNBUILD, transit wait time is always calculated as one half of the route headway, based on the standard assumption of random arrivals to a stop. As transit forecasting theory and data collection have advanced, it has become apparent that this is generally a valid assumption for services with high frequencies. Other transit services, particularly long-distance commuter bus and rail services with infrequent but highly scheduled services tend to cluster passenger arrivals closer to the departure time. In PT, a set of wait curves can be defined for each type of service that calculates the wait time based on the service headway. An example wait curve is shown in Figure 4, in which the minimum wait time is two minutes and the maximum wait time is 30 minutes. Each stop or station node can be assigned a curve defining both the initial wait time and the wait time for transferring passengers. Up to 255 wait curves can be defined in PT.

Figure 4. Wait Curve Example
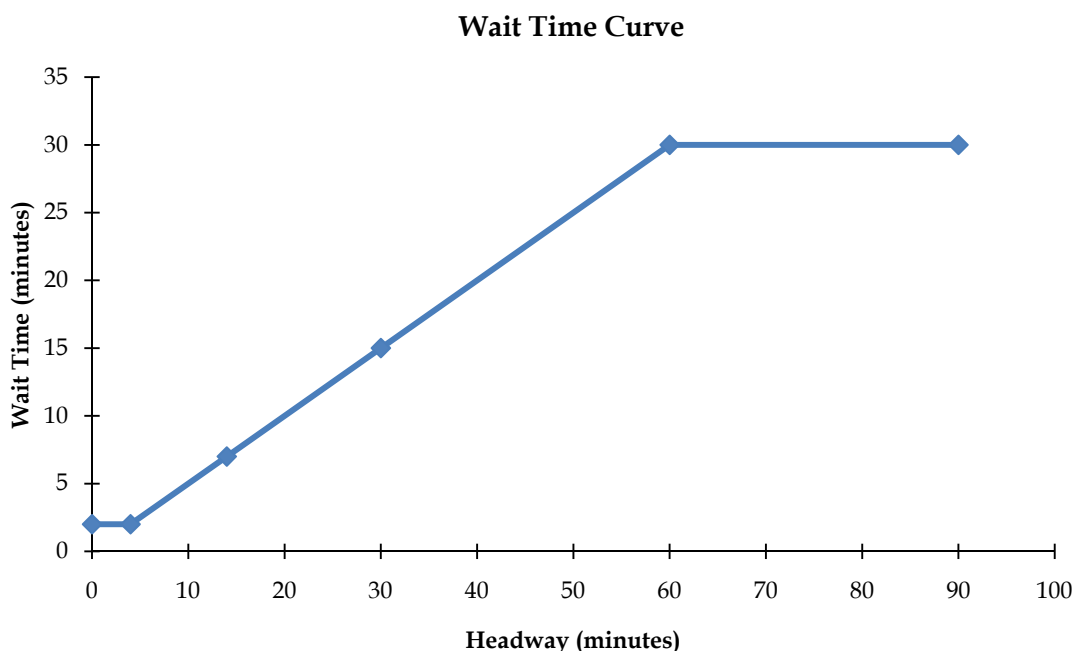
Source: Citilabs (2011).

In addition, PT can now accommodate actual transit schedule data into its route calculations. This is especially useful for determining if transfers are possible (or likely) between very infrequent services. For example, if Route B departs a certain stop at 7:00 a.m., but Route A is not scheduled to arrive at that stop until 7:05 a.m., transfers between those two routes would likely be impossible, no matter what the average service frequency might determine. This type of scheduling information can be input and used in the route enumeration and evaluation processes.

Transit Skimming Options

PT includes all of the skimming options available in TRNBUILD, in addition to some new options. When using the multi-path building options in PT, even more additional transit skims are available based on comparisons between the available transit paths. Available skims include:

- Wait times – actual and perceived:

    - Initial wait time;

    - Transfer wait time; and

    - Crowding wait time.

- In vehicle travel times – actual, perceived, and perceived with crowding effects;

- Penalties for boarding and transferring – actual and perceived;

- Fares in both monetary units and units of generalized cost;

- Best total trip time;

- Boardings – average number of boardings used between zone pairs;

- Composite cost – total perceived costs, including time and fares;

- Distance;

- Excess demand – trips between zone pairs which are unable to reach their destination via transit due to crowding; and

- Value of choice – compares average travel cost to composite travel cost and indicates the level of choice available in the transit network.

Advanced Route Selection Algorithms

As outlined, PT uses a complex system of submodels to assign passengers to specific transit lines:

- Walk-choice model: a logit model used when passengers have multiple stops that they can walk to or transfer between;

- Route selection is determined either by the service-frequency model in which passengers are more likely to use services of higher frequency, or the service-frequency-and-cost model in which passengers are more likely to board faster routes despite lower frequencies (only available in multi-path mode); and

- Alternative alighting model: a logit model to determine at which stop a passenger will choose to alight when multiple options are available.

These models determine the specific route from origin to destination that is used by each passenger. The use of these models ensures that passengers are more accurately spread among different competing routes and stops, providing a much more accurate and detailed picture of transit ridership in the region.

Crowd Modeling

The inclusion of transit capacity and the incorporation of the effects of crowding is an important enhancement in the functionality of PT. Using the optional transit capacity constraints, the level of crowding is used to determine perceived and real delays caused by traveling in crowded conditions. First, perceived link travel times can be increased to represent the discomfort of traveling in crowded vehicles. This is accomplished through the use of a series of user-defined crowd curves that can differ by mode, line, and user class. Second, the actual wait times can be increased to represent situations where demand outstrips the capacity at a specific transit stop and passengers are required to wait for the next vehicle. This element of delay also can result in "bottlenecks" when the demand during the peak period for service at a stop is greater than the total peak period capacity. In those situations, additional delays would be incurred by travelers and they may be forced to travel outside of the peak period. Crowding analysis can include one or both of these types of delay.

In an assignment which accounts for the effects of crowding, the perceived and actual increases in travel time caused by transit crowding are accounted for by iteratively repeating the route evaluation process. In each iteration (except the first), the delays caused by the previously assigned transit volumes are used as inputs and the flows are recalculated, similarly to a highway assignment. The final results are the assigned volumes on the final iteration. Because there are fewer available paths and generally fewer trips in a transit assignment than a highway assignment, fewer iterations are deemed necessary in order to achieve some level of stability; the maximum number of iterations allowed in PT is 99.

Fare System Representation

The fare system defines the cost for travel, boarding, and transfers between different lines, operators, and/or modes. PT includes substantially more flexibility in the representation of complex fare structures than its predecessor. If desired, different fare systems, structures, and costs can be assigned to each individual route, operator, and/or mode in a transit system (or any combination thereof). This flexibility and the direct incorporation of cost into the transit assignment process allows for much more accurate sensitivity testing of the effects of different fare systems on transit ridership within the travel demand forecasting model. Fare system options available in PT include:

- Flat: Flat cost per trip;

- Distance: Fare per unit of in-vehicle distance;

- HiLow: Annular fare zone structure, fare charged based on the difference between the highest and lowest fare zones crossed during a trip;

- Count: Sequential fare zone structure in which fare is charged based on the number of fare zones crossed;

- FromTo: Fare is charged as a function of the boarding and alighting fare zones (or stations);

- Accumulate: Each fare zone has an associated fare which is accumulated as the zone is traversed; and

- Free: Routes with no fares.

Although greater flexibility with respect to representing fares in the model is no doubt a good PT feature, it does warrant noting that this is only but one aspect of representing fares in the model that are observed in reality. For example, peak/off-peak fares can be modeled, but only if time-of-day factoring has already been run and it is known which period a trip falls into. Otherwise, a typical simplification is to use different fares by trip purpose with a typical time period profile for each purpose. The challenge with directly modeling fare passes for selected market segments such as Federal workers or senior-citizens was discussed in a prior task report.

Circular and Linear Routes

TRNBUILD included limitations on the structure of transit routes and could not accommodate circular routes, which are quite common in use as circulators in many parts of the Washington metropolitan region. PT has removed this limitation and both circular and linear routes can easily be accommodated.

Analysis and Reporting Tools

Many of the advanced modeling capabilities of PT allow for easier generation of reports and visualizations than with TRNBUILD. Some of the new and more interesting of these advancements include:

- Link file outputs that can easily show number of buses, passenger volumes, congested speeds and other characteristics of the loaded transit network as shown in Figure 5.

- The addition of an "operator" characteristic to transit line files allows easy reporting of ridership by operator and transfers between operators which would be useful in a region with many transit providers.

- Stop-to-stop transit reporting tracking the origin and destination of transit trips that functions similarly to the select link functionality available in highway assignment.

- Detailed boarding profiles by stop and transit line with direct connections to visualization tools as shown in Figure 6.

Figure 5. Sample Transit Volume Bandwidth Graphic
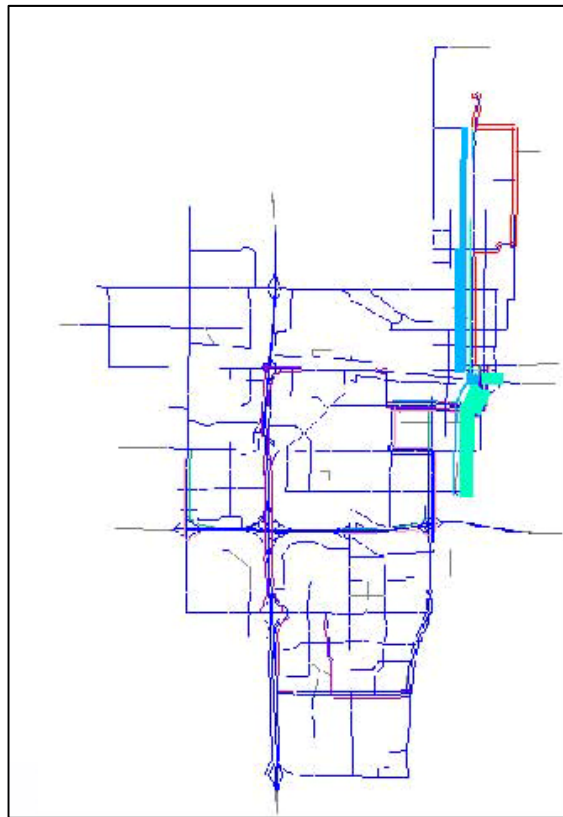
Source: Citilabs (2011).

Figure 6. Sample Transit Line Profile
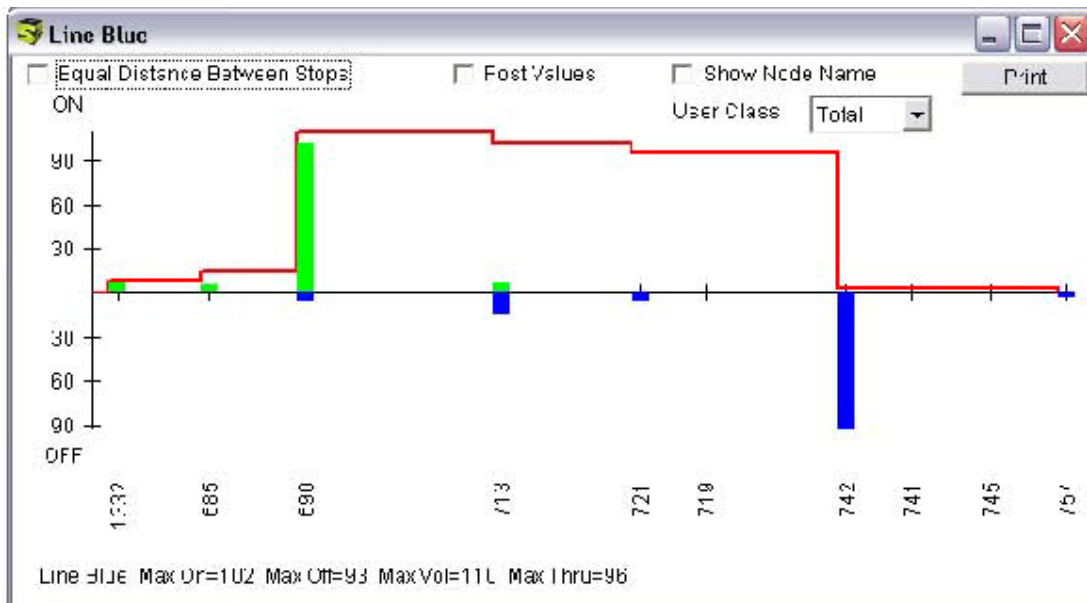
Source: Citilabs (2011).

FTA Coordination

Since the introduction of PT in the U.S., there have been concerns over FTA's acceptance of the program in New Starts applications. Citilabs has been working with FTA in order to ensure that the PT modeling procedures are in full accordance with FTA guidelines on modeling. According to Citilabs, FTA has been receptive to these modeling advances and has started to conduct presentations on multi-path transit assignment. While FTA has accepted multi-path analysis in several instances (Houston-Galveston Area Council and Florida, for example) careful reporting of user benefits is necessary, specifically when dealing with Summit. One simple way to deal with this issue is to use the multi-path option for modeling work related to system and project planning, and then switch to the best path only option for use with Summit.

Mode Choice Model Functionality

The combination of several of PT's advanced capabilities, including the use of multiple user classes and multiple transit paths have the potential to allow PT to function as a nested logit mode choice model for transit users. The program has the capability to select between different transit options proportionately and select transit access modes. This is similar to the function performed by the nested logit mode choice model included in the TPB Version 2.3 model. This is by no means a necessary function of PT, and the program can be fully implemented without replacing the current mode choice model structure. Also, it would be necessary to fully verify functionality between such an implementation as compared with the current approach. With additional testing and validation, this major change could be implemented in the future if desired by TPB.

4.2   Transferring to Public Transport

With its increased capabilities, PT also requires different input files and formats than TRNBUILD. In addition, invoking many of the advanced functions of the new program will include the incorporation of additional submodels, steps, and assumptions. In order to correctly capture the behavior of transit passengers in the region, TPB may need to conduct additional sensitivity testing, validation, and/or data collection efforts.

It is possible to migrate from TRNBUILD to PT in steps, while invoking the advanced modeling capabilities slowly as time and budgetary restrictions allow. The first potential step in such a migration would be the use of PT for network building, as currently is done in the Southeast Regional Planning Model VI (SERPM) by the Florida Department of Transportation (FDOT). For the SERPM example, after the transit network is created using the advanced capabilities of PT, a customized program converts the network back into TRNBUILD formats. The supplemental link files currently used in the TPB model can still be used (although with some minor formatting changes) to build the transit network. This ensures that access distances in the new network would remain the same as in Version 2.3, while allowing for on-screen transit path tracing, a feature greatly desired by TPB staff. Further into the migration process, new access links could be generated using PT. Similarly, transit line files would need to be updated slightly to match the formats required by PT.

A second step in this migration process would be to implement PT for transit assignment as a single-path builder by invoking the "best path only" option. This method should produce results similar to the current transit assignment procedures being implemented in Version 2.3 of the model (and those developed by the WMATA postprocessor model). Under this method, many of the inputs would still need to be updated to match the PT formats, although many of those changes are very simple and may be as easy as executing a find and replace command. Certain new files, such as the FACTORS file which includes settings for the transit assignment, would also need to be developed. Citilabs has indicated that they would be able to provide some assistance in this area. To best match the current process being used in TRNBUILD, only a single user class would be used and many of the other features could be implemented slowly as desired. There are, of course, certain limits on PTs functionality when operating as a single-path builder. For example, none of the crowding analysis is available, the service-frequency-and-cost model cannot be used in this mode, and certain skims related to multiple path analysis are unavailable.

Many of PT's other advanced transit modeling capabilities could be added to the TPB model gradually through time. The use of multiple user classes may be very beneficial to the transit modeling process, but likely cannot be implemented until additional data collection is completed. In addition, a FACTORS file must be developed for each user class. The use of wait curves and advanced fare system representations also can be added to the model in either single or multiple path assignment modes. The introduction of multiple paths to the transit assignment procedures will allow not only for the benefits associated with tracing multiple paths, but also would allow for the use of crowding analysis on transit, which may certainly be an issue in Washington region.

A step-by-step migration to PT seems to be the most reasonable path, considering the time and data requirements of a complete upgrade to all of the advanced PT features. However, unlike the SERPM example, a complete switch away from TRNBUILD appears to be the best solution. Updating to PT with a single-path builder would take advantage of the advanced network building capabilities of PT, and put TPB in a good position to advance the transit modeling practice in the region without requiring too much in the way of additional validation or data collection. Other improvements, such as wait curves and fare systems can be added fairly easily from this point. More complex changes, such as multiple user classes, multiple path evaluation, and crowding analysis may be longer-term improvements.

■ 5.0 Toll Modeling Methodology

Cambridge Systematics has been tasked with reviewing the current methodology used to model tolls in the TPB region and to suggest some areas for potential enhancements. This section reviews the potential toll facility types and toll policies that may be necessary to incorporate into the TPB model in the future. We have reviewed how these types of facilities and policies have been incorporated into models in other regions in the country as compared with how TPB has incorporated tolling. Based on these discussions, some areas for potential improvements to the tolling model are discussed.

5.1 Toll Modeling in the TPB Region

In the MWCOG/TPB Version 2.3 travel demand forecasting model, the use of a tolled facility is determined in the highway assignment step when specific routes are selected. While 'Drive with Toll' is not considered to be a distinct mode from other driving modes in the mode choice step, the effects of tolling are incorporated in the trip distribution, mode choice, and traffic assignment steps by incorporating the tolls into the generalized cost of each path as appropriate. Essentially, for any tolled facility, the toll costs are converted into the equivalent number of minutes based on the assumed value of time. This generalized cost is then added into the total path cost, lowering its utility and making it less desirable than similar non-tolled alternatives.

In the trip distribution step, value of time is determined based on trip purpose and household income group. Adding the toll cost (converted to the equivalent time cost) makes zone pairs that are connected only by tolled paths less attractive than zone pairs that are connected by a non-tolled path of similar time. This causes the trip distribution to skew slightly (depending on the amount of the toll) away from zone pairs whose shortest path connection is tolled. Similarly, in the mode choice step the value of time is still determined by trip purpose and income quartile. In this step, shortest path skims are used to compare the generalized costs of completing a trip by different modes. Whenever a shortest path between two zones includes a tolled facility, that toll in equivalent minutes is added to the cost for the driving modes (or only to the drive alone modes on HOT facilities) and can decrease the percentage of travelers using those modes.

In the traffic assignment step of the TPB Version 2.3 model, vehicles are no longer distinguished by income group, and the value of time is determined as 50 percent of the average wage rate in the region for work trips. This is a common practice in MPO models around the country. The value of time for non-work trips is calculated as 35 percent of the average wage rate. The routes selected in the assignment step are directly related to the generalized cost of each potential route. This type of approach effectively reduces travel demand on tolled paths and increases demand on competing non-tolled paths for a given origin-destination traffic analysis zone (TAZ) pair.

This method of toll modeling has been adjusted to accommodate the needs of variable-price tolling facilities, such as the HOT lanes currently planned in Virginia. By contrast, the HOT lanes are to be tolled so as to maintain service at a minimum on the Level of Service (LOS) C/D threshold during all periods. Through iterative testing, TPB has determined the approximate toll levels required to maintain this condition. This toll level is then applied to the HOT facilities during a model run in the same manner as flat tolls.

5.2 Toll Facility Operations and Policies

There are many different types of toll facilities in operation in the United States today, and additional types are planned for construction in the future. These facilities are differentiated by how they are operated. In addition, many different policies are used to implement the tolls on these facilities. A travel demand model should be able to accurately represent each of these options and to differentiate between them if necessary.

This allows for the model to be used in testing to determine the best and most effective type of toll facility for a specific corridor.

Toll Operations

Toll facilities can be operated in many different ways. Different types of toll facility operations may not only be physically different, they may require different treatments in the travel demand forecasting model as well. Currently in the Washington metropolitan region, several operating schemes for toll facilities already exist, including:

- Fixed price by vehicle type;

- Variable price by time of day; and

- Tolling on all lanes.

As tolling becomes a more prevalent way of building additional highway capacity, maintaining roadways, and managing travel demand, other types of tolling operations may be considered for the region. Other potential methods for toll facility operations include:

- Individual non-barrier separated toll lanes (i.e., a single tolled lane on a multilane facility that is not physically separated from the non-tolled lanes);

- Barrier separated toll lanes (i.e., parallel but barrier separated tolled lanes); and

- Reversible toll lanes.

Toll Policies

The policies applied to toll facilities can affect who is charged a toll, how much they are charged, and when they are charged. These policies tend to be different for each facility as they reflect the needs and priorities of a specific corridor. TPB has already witnessed the spread of different toll policies in the region, and many others are being proposed or have already been implemented in other areas of the country. These toll policies include:

- Flat/fixed toll rates;

- Differential tolls by vehicle type;

- Differential tolls by time of day;

- Dynamic congestion pricing;

- High-Occupancy/Toll (HOT) tolling; and

- Mix-and-match combinations of the above.

5.3 Toll Modeling Methodologies

One of the major questions in toll modeling is the preferred location within the travel demand forecasting model for the toll choice element. One option is to include toll choice as part of the mode choice model, generally including 'drive alone toll' and 'drive alone non-toll' as submodes within a nested logit model. The first method results in a market

segment that will never pay tolls and therefore does not see tolled facilities in their route options. The second method is to leave the decision of whether or not to pay a toll as part of the route choice decision in traffic assignment. This second method relies heavily on the idea of total generalized cost and the interchangeability of time and money to travelers. A related question is how income and value of time are incorporated into the toll choice, and how far income classifications are carried through the model chain.

The state of the practice for modeling toll facility demand generally appears to address toll choice as part of the highway assignment step. The Best Practices Model (BPM) for the New York Metropolitan Transportation Council (NYMTC) handles tolling on a range of bridges and lanes only in the highway assignment step (NYMTC, 2004). Similarly to TPB, the BPM includes income stratification only through the mode choice step and groups travelers by vehicle type for the assignment step. The Puget Sound Regional Council (PSRC) is the MPO for the Seattle region, where HOT lanes have been in place since 2008 (Lange, 2008). PSRC maintains five income categories through all steps of the model, but the toll choice also is decided as part of the traffic assignment step (Cambridge Systematics, 2007). Also of interest, the PSRC model uses different values of time in the mode choice model than in the traffic assignment model for automobile trips. In Baltimore's regional model, the four levels of household income are maintained through the mode choice step, but the toll choice is conducted as part of the highway assignment step with no separation by income (MTA, 2006). The SERPM in the Miami region also includes the toll choice as part of the assignment step (FDOT, 2008).

The Twin Cities region in Minnesota includes several HOT facilities, and its regional model includes the toll decision in the mode choice step, as the lowest nest in the nested logit structure. Likewise, the current Orange County model, OCTAM 3.2 includes toll roads as a modal option in its nested logit mode choice model (OCTA, 2009). Montreal, Quebec also has a model that distinguishes road users into toll-users and non-toll users as part of a nested logit model before the assignment step (Vovsha et al., 2006). One interesting limitation of the Montreal model is the use of median zonal income as a proxy for household income, since the latter was unavailable in the most recent household travel survey. The San Diego Association of Governments (SANDAG) implements a joint toll-HOV choice as part of the nested logit mode choice model (SANDAG, 2008). In this model all automobile trips are nested first by the number of passengers (SOV, HOV-2, and HOV-3+) and then the second nest jointly determines if the vehicle will travel on a toll and/or HOV facility.[5] SANDAG maintains a constant value of time ($0.35 per minute) for all income groups during the skimming process.

Most household travel surveys do not ask about route choice; there is no way to tell then whether a respondent should be a toll-user or not – and how strong their preference is. As a result, it is often desirable to base these models on stated preference surveys. The Quebec model was built around such work.

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[5] The Drive Alone mode includes only a toll or non-toll choice, as HOV facilities are not available to them.

An interesting middle-way approach has been implemented as part of the modeling for the Central Texas Turnpike System. In this case, it was argued that including a drive-toll alternative in the mode choice model actually distorts the model, since some of those predicted to use the facility may not do so in an assignment (Schellinger, 2009). In this study, the preferred approach is to implement a conventional mode choice model without tolls. Subsequently, an "embedded" route choice model is run before traffic assignment in which trips are grouped into those that will and will not use a tolled facility. This method requires that trip tables continue to be disaggregated by income, purpose, and time period all the way through this step. In this case, the approach resulted in a considerably closer match to observed usage on an existing facility for the base year than other potential methods. There is, however, limited applicability of this approach to new toll facilities not in existence at the time of the travel survey.

The representation of variable and congestion pricing policies can be problematic using some of the standard modeling processes. Tolls that vary by time of day can be accommodated so long as the number toll changes matches the number of time periods used in the forecasting model. In models with very fine time scales for either the toll policy or the time of day model, a high number of networks and assignments would be needed, and becomes impractical beyond a point. Congestion pricing policies that require more fine-grained changes in tolls and are generally handled in one of two ways:

- Approximate tolls for each time period are calculated off-line based on the desired congestion levels and used as input into the standard model; or

- Some of the more advanced dynamic highway assignment programs can model congestion pricing tolls, although feedback into previous model steps remains somewhat problematic.

5.4 Areas for Potential Enhancements

CS has identified some areas for potential enhancements to the TPB model based on experience in modeling tolled facilities, a review of the TPB toll modeling methodology, and a study of toll modeling in other regions. Two main areas for potential enhancements are identified and discussed in this section, and generally fall into two main categories:

- Value of time calculations; and

- Embedded post-mode choice toll route choice model.

Value of Time Calculations

The income-based equivalent-time values used in the TPB Version 2.3 model are reasonable average values, which should generally not be altered. The time equivalents are based on hourly household wage rates, which in turn were developed from the 2007 American Community Survey (Washington Primary Metropolitan Statistical Area) income data. The use of 50 percent of the prevailing wage rate for commute trips is common in many MPO models, although a recent synthesis has suggested using 100 percent of the prevailing wage

rate for work trips and 50 percent of the prevailing wage rate for non-work trips (Concas and Kolpakov, 2009).

The value of time used in the highway assignment step of the TPB model is not stratified by income and is instead an average regional value. This is perhaps the best option in the situation where income groups are not carried past the mode choice step. As toll facilities profligate across the region, there may be real benefits to carrying these income stratifications forward and maintaining the more accurate values of time in highway assignment. The route assignments made with more accurate values of time are likely to produce more accurate results.

Embedded Toll Choice Model

Another potential area for investigation would be the implementation of an embedded route choice model immediately prior to the highway assignment step like the one implemented for the Central Texas Turnpike System. Implementing this type of toll choice analysis assumes that tolling does not affect the results of a mode choice decision. This process allows for market segmentation by trip purpose, vehicle type, and potentially by income group.

An embedded toll choice model could be very computationally simple, using a binary logit model comparing total costs and travel times along tolled and untolled facilities. The model would be used in an iterative fashion, with the probability of being willing to use a toll facility recalculated based on updated travel time skims after each iteration.

Care would need to be taken to see that such a model did not have the unintended effect of pushing toll facility usage. That is, a typical mode choice based toll choice implementation determines a market segment that is not willing to use a toll facility and a market segment that is willing (but not required) to use a toll facility. A similar construct for an embedded toll choice model might be possible and desirable to avoid "forcing" travelers onto toll facilities.

Either effort would require some additional survey data regarding willingness to pay tolls based on the different market segments, although some data already does exist for specific corridors such as I-95/I-395 and the Dulles Greenway. Most likely a stated-preference survey would be needed until a wider range of toll facility types are implemented in the region and revealed-preference data can become more useful.

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