FY16 Task Orders

final report

prepared for

Metropolitan Washington Council of Governments
National Capital Region Transportation Planning Board

prepared by

Cambridge Systematics, Inc.

with

Gallop Corporation

November 2016

www.camsys.com

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1.0 Task Order 16.2 – Advice and Testing

Task Order 16.2 of the fiscal year (FY) 16 work program covered 14 advice and testing subtasks, the majority of which the Cambridge Systematics (CS) team had primary responsibility for addressing. Transportation Planning Board (TPB) staff had primary responsibility for addressing the other subtasks. This report section documents the subtasks addressed by the CS team and identifies the subtasks addressed by TPB staff in the subsections that follow.

1.1 Version Control and Bug Tracking Software

This report section provides a summary of version control and issue tracking software in use by metropolitan planning organizations (MPO) to manage their travel demand models. We surveyed experiences with version control and issue tracking systems from four major MPOs:

- Atlanta Regional Commission (ARC);
- Metropolitan Transportation Commission (MTC);
- Puget Sound Regional Council (PSRC); and
- San Diego Association of Governments (SANDAG).

We summarize some major findings from the surveys and present our recommendations.

Version Control Systems

Introduction

Revision control systems, also known as version control or source control systems, allow users to automatically track the storing, logging, and merging of revisions to files over time; and compare and recall specific versions. With a version control system, file names and directory structures will be consistent for all team members, all changes will be stored and can be reverted when needed, and one can easily understand who made a change and when it happened.

The three most popular version control systems, Concurrent Versions System (CVS), subversion (SVN), and Git, are divided into two main categories: centralized and distributed (decentralized) systems. Centralized systems like SVN and CVS are based on one shared server, the repository, which provides access to all clients. It is easy to understand and simple for users to learn and start, but it depends on the server, which can be unstable and slow. Distributed systems like Git and Mercurial, are newer systems, and they do not rely on a central server. Instead, each user has his/her own database repository. These systems are fast, more detailed while tracking changes, and more reliable.

Instead of understanding the text-based or command-line-based user interfaces of version control software listed above, the graphical user interface (GUI) allows one to interact with version control software more visually, and it helps avoid the steep learning curve. GitHub for Windows, SmartGit, and TortoiseGit are popular Git GUI clients, and TortoiseSVN is a popular SVN client.

As mentioned before, distributed systems such as Git, do not rely on any central server, and users can set up their own servers or use a source code repository, such as SourceForge, Bitbucket, GitLab, and GitHub.

These code hosting sites provide a web-based archive for source code and documents. Repositories on these sites can be private or public. GitHub, one of the most popular Git repository hosting services, also provides features as a GUI and it provides bug tracking, feature requests, and task management features.

Major Findings

- Git and GitHub are the most popular version control system and hosting site being used by MPOs, including SEMCOG, MAG, SACOG, and the Metropolitan Council for the Twin Cities metropolitan region. The four MPOs that were surveyed all use and recommend GitHub. Cambridge Systematics also uses GitHub, but it has used Subversion (SVN) to manage previous software projects.
- **Client software (GUI).** All of the surveyed MPOs use GitHub for Windows, which is generally the most popular GitHub client GUI in use. Cambridge Systematics also uses GitHub for Windows, but primarily uses the built-in GUI tools (gitk and git-gui) along with the command prompt to manage projects.
- **Team size.** Most survey participants have 5 to 10 contributors.
- **Review process.** Most survey participants have a review process in place to incorporate new changes into the model and a manager needs to approve all changes.
- **Unit testing.** ARC and SANDAG have unit testing as part of the integration process. Unit testing is used to test the smallest units of a software package or application that can be tested individually and independently to determine if it has the desired proper operation and is suitable for use.
- **Challenges.** Merging conflicts was identified as the biggest challenge to using a version control system. Other challenges/issues include a steep learning curve with Git; maintaining control over the repository with multiple contributors; and managing nonsource code resources, such as input files.
- **Advantages.** The following advantages of a version control system were cited by the surveyed MPOs:
  - Maintains a historical record of model development activities;
  - Encourages proper record-keeping of model development testing;
  - Facilitates archiving legacy model systems; and
  - Enforces a code-review system onto the team.

Recommendations

Many major MPOs have adopted a version control system to support modeling work. The combination of Git and GitHub seems to be the most popular version control system and was recommended by the four MPOs that we surveyed.

For GitHub Client GUI tools, the survey results indicated that GitHub for Windows is the most commonly used GUI client. Other GUIs include specialized features but, considering the team size and work flow at the COG, GitHub for Windows is probably sufficient for the COG’s needs. GitHub for Windows is also free, so the COG can use it initially and switch to another client as they become more familiar with GitHub and have created work flows.

In summary, our recommendations are the following:

- Begin working with GitHub and GitHub for Windows.
- If further needs are identified during implementation tests, experiment with other GitHub GUI tools. If any COG staff has experience with a GitHub GUI tool, we recommend considering that tool first to minimize potential training and implementation effort. One GUI tool to consider further would be SmartGit, which was recommended by Dzung Ngo.[1]
- Establish a review process to incorporate new changes into model.
- Develop unit tests to validate changes.
- Designate a "Git Guru/Team Maintainer" who is charged with understanding GitHub, the work flow, approval process, and unit tests and will be an internal resource for the team.

Issue Tracking

An issue tracking system, also known as trouble ticket or support ticket system, is a software package that allows users to track and manage the progress from identifying an issue to resolving the issue, and understand who the "owner" of a specific issue is. It helps to better distribute issues by priority to responsible persons, monitor quality of work and time spent, and generate detailed reports of the issue resolving progress and relevant information. Issue tracking software packages available now are innumerable, and the popular ones include Bugzilla, JIRA, Lean Testing, FogBugz, etc.

Major Findings

- MPOs with comparatively large modeling groups have implemented formal processes to log issues in the mode scripts/inputs and track the resolution. For example, SANDAG has a relatively large modeling group (15 modeling staff) and they use the JIRA software package to log issues and track resolutions. Due to a relatively small number of staff involved with the model, ARC, PSRC, and MTC all keep the issue tracking process small, simple, and somewhat informal.
- **Issue tracking software.** JIRA is used and highly recommended by SANDAG. PSRC and MTC uses GitHub to informally track some scripts/issues. ARC uses generic software like Excel and Google Docs for issue tracking. Cambridge Systematics also uses the JIRA software packages to log and track issues for software development and has used this system for several years. JIRA provides two types of pricing: $10 per month for a small team (up to 10 users) and hosted in the cloud; $10 (one-time payment) for a small team, hosted on the user's server.
- **Scripts/inputs being tracked.** SANDAG uses JIRA to track issues in code, scripts, network inputs, and socioeconomic input data. PSRC and MTC use GitHub to report and track issues in the model code and scripts and to identify development tasks.
- **Issue tracking process.** SANDAG assigns a project administrator/central controller to each project; outstanding issues are assigned to a specific administrator based on their special skills. All modeling

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[1] Dzung Ngo, "Use of a version control system to support the COG/TPB modeling work," August 29, 2014.

staff and some consultants have access to JIRA and can log and report issues; the assigned administrator will resolve the issue and the project administrator can close the issue. Each software product at Cambridge Systematics has an assigned product manager who is responsible for monitoring outstanding issues. Created issues can be assigned to any individual but there are default persons set up for each type of issue.

- **Reporting features.** The built-in reporting system in JIRA is used by SANDAG to monitor outstanding issues.

Recommendations

The surveyed MPO with the largest modeling team (SANDAG) has adopted a formal issue tracking process to support modeling work. The other MPOs surveyed have smaller modeling teams and track issues informally. However, all surveyed MPOs believe that they would benefit from a formal issue tracking system. JIRA is a popular issue tracking system, and has been highly recommended. GitHub is recommended for tracking code/script issues and development tasks.

In summary, our recommendations are the following:

- Begin working with GitHub and GitHub for Windows. Develop an issue tracking process in GitHub to track scripts and development issues. The GitHub process should be complemented by a GoogleDoc or structured Excel spreadsheet form to track issues in model datasets and networks.

- Assign a central controller for each project who log issues and declares them resolved when implementation done or fix submitted.

Acknowledgements to Survey Participants

- **MTC.** David Ory dory@mtc.ca.gov;
- **ARC.** Guy Rousseau grousseau@atlantaregional.co;
- **SANDAG.** Wu Sun wu.sun@sandag.org; and
- **PSRC.** Billy Charlton BCharlton@PSRC.ORG.

1.2 Non-Resident Trips Update (TPB)

This subtask was the primary responsibility of TPB staff and is documented separately.

1.3 Screenlines/Cutlines (TPB)

This subtask was the primary responsibility of TPB staff and is documented separately.

1.4 Speed/Travel Time Validation Improvement

Background

This report section examines the volume delay functions (VDFs) as used in the current Metropolitan Washington Council of Governments (MWCOG) travel demand model and explores possible improvements of the functions to enhance the highway assignment results of the model. In a recent study conducted for the MWCOG[2], the study team compared the model estimated congested speeds of network links with the INRIX observed speed data. As indicated in Table 6-4 of that study report, the model in general underestimated link speeds during the peak periods for the freeway and expressway facilities, with underestimation of speeds by as much as 25 percent.

There have been many research studies about volume-delay functions, which provide valuable information regarding the use and performance of various volume-delay functions in practice. It is no need to conduct fundamental research or comprehensive study on this subject under this task order study. Also, given the time and budget constraints of this study, it is not feasible to conduct comprehensive tests of various volume-delay functions with the current MWCOG model.

Therefore, this task was carried out with the examination the relevant studies conducted in this subject recently, with the focuses on the basic characteristics of the volume-delay functions as represented by various mathematical formulations, and the experience of applying these functions to travel demand models. This report section summarizes the findings of the studies, as well as provides some recommendations for enhancing the volume-delay functions in the current MWCOG model and guidelines for evaluating the performance of the enhanced functions.

Basic Characteristics of Volume Delay Functions

The volume-delay function describes the relationship between traffic volume and the operating speed of a road segment. The basic relationship between volume and speed is depicted in Figure 1.1. In this figure, volume is represented by the flow rate (q). Region A represents “unsaturated conditions” (i.e., traffic demand far less than capacity). In the left portion of this region, operating speeds decrease slowly with observed traffic volumes. Under this condition, the traffic demand of a road segment is the same as the observed volumes, since the road segment can carry the demand without congestion or queuing. As traffic demand approaches capacity, operating speeds drop sharply and also becomes unstable. Region B represents “forced flow” or “saturated conditions” (i.e., flow rates are reduced below capacity). In this region, both the observed volume and speed drop simultaneously. These two regions can be seen in Figure 1.2, which displays a scattergram graph of observed volume and speed data for a typical freeway facility.

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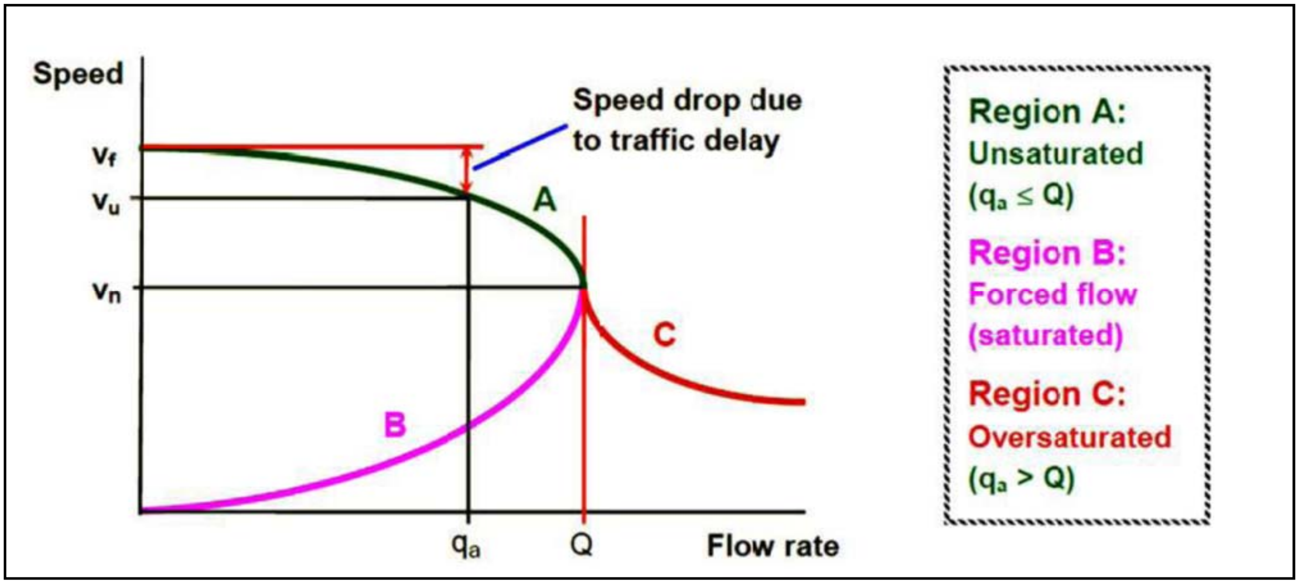
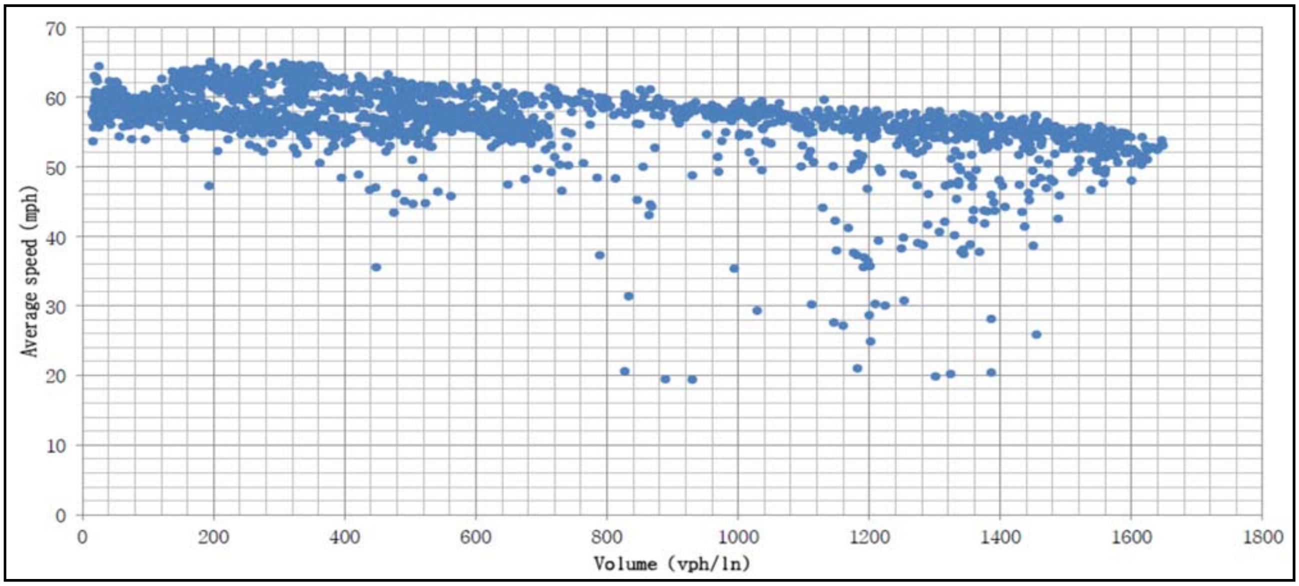
[2] AECOM (2013), *Assistance with Development and Application of the National Capital Region Transportation Planning Board Travel Demand Model*, FY 2013 Final Report, prepared for Metropolitan Washington Council of Governments, Chapters 5 and 6.

Figure 1.1 Speed-Flow Relationship Traffic Flow on Uninterrupted Flow Facilities



Source: Akçelik, *Speed-Flow Models for Uninterrupted Traffic Facilities*, Technical Report, December 2003, page 3 (as cited in Moses, Ren, Enock Mtoi, Steve Ruegg, and Heinrich McBean, *Development of Speed Models for Improving Travel Forecasting and Highway Performance Evaluation,* Final Report, Florida Department of Transportation, December 2013, page 40).

Figure 1.2 Scattergram of Observed Speed-Volume Data on a Typical Freeway Facility



Source: Moses, Ren, Enock Mtoi, “Development of Speed Models for Improving Travel Forecasting”, presented to FSUTMS – Advanced Traffic Assignment Subcommittee, March, 2012.

Lastly, Region C represents “oversaturated conditions” (i.e., the arrival/demand flow rate exceeds capacity and a queue starts to form). For travel demand models, a volume-delay function actually consists of regions “A” and “C” as depicted in Figure 1.1. However, the relationship between travel demand and speed for curve segment “C” cannot be observed directly from road traffic conditions because the observed traffic volume on an oversaturated road segment represents the “suppressed” demand, not the actual demand. Previous studies tried to estimate traffic demand under oversaturated conditions using various estimation methods (e.g., observing traffic volumes and speeds of road segments upstream of the congested road segment, and simulation techniques, etc.). Various mathematical formulations of the volume delay functions were proposed and studied, primarily to deal with the volume-speed relationship under the oversaturated condition.

A volume-delay function can be defined by following basic characteristics:

- Free-flow speed;
- Capacity;
- Speed at capacity; and
- Rate of decrease of speed.

The free-flow speed of a roadway facility is related to the functional type, the design speed and speed limit of the facility, and thus is usually well-defined. The capacity as defined in most of the current travel demand models is the “ultimate capacity”, which is the maximum traffic volume a facility can carry. It is also called as the “LOS E capacity”. However, in the original volume-delay function developed by the Bureau of Public Roads (BPR), the capacity was defined as “design capacity”, the so-called “LOS C capacity,” which is about 80 percent of the ultimate capacity for an urban freeway facility. It is thus important to ensure that the same definition of capacity is applied in both the travel demand model and the volume-delay functions.

The speed at capacity is important for a volume-delay function as it determines how far the operating speed would drop as traffic demand approaches capacity. As shown in Figure 1.2, the observed data indicate that, for a typical freeway facility, operating speeds decrease fairly slowly as traffic demand is well below the capacity. Even for volumes at a level of 70 to 80 percent of ultimate capacity, which is usually at a level of 1,800 to 2,000 vehicles per hour per lane, the operation speeds are at a level as high as about 80 percent of free-flow speed. Although it is difficult to measure the operating speed at capacity as the operating speed would be unstable at capacity, it can be roughly estimated that the speed at capacity would be in the range about 60 to 80 percent of free-flow speed, which is also the range exhibited in most of the volume-delay functions applied in many travel demand models in practice.[3]

The relationship between traffic demand and operating speed as represented by a volume-delay function is basically a reversed “S” shape curve. The slope of the curve is relatively flat at low level of traffic demand, implying the rate of change of speed is small. As the traffic demand approaches or exceeds capacity, operating speed drops rapidly. Usually the rate of decrease of speed for an uninterrupted flow facility (e.g., freeway, expressway) at capacity level is higher than the rate of a lower grade facility (i.e., the slope of the curve is steeper at capacity for a freeway facility as compared to lower grade facilities).

Various mathematical formulations of volume-delay functions were proposed and applied in travel demand models. The BPR function, developed in late 1960s, is one of the earliest. It is still the most widely used

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[3] Transportation Research Board, 2012, *Travel Demand Forecasting: Parameters and Techniques*, NCHRP Report 716, Figure 4.6.

function for travel demand models in the U.S., because of its simple mathematical form, minimum data requirement, and overall effectiveness of the models in predicting traffic volumes on a regional network.

Alternative forms of volume-delay functions were developed since the original BPR function, with the intention to enhance the function in following areas:

- Operating speeds at oversaturated conditions, which are usually over-estimated by the original BPR function;
- Traffic delay at intersections for interrupted flow facilities; and
- Computation efficiency in highway assignment process.

Figure 1.3 displays the mathematical formulations of commonly used volume-delay functions. The notations for the functions in the figure are:

u_0 = Free-flow speed;

u = Operating speed;

c = Capacity;

x = V/C ratio; and

α, β, μ, J = Parameters to be calibrated.

It should be noted that, of the four functions displayed in Figure 1.3. The BPR and the Modified Davidson functions have two independent parameters to be calibrated, while the Conical and Akcelik functions have only one each. This gives BPR and Modified Davidson functions greater flexibility to fit various traffic and local conditions in the assignment process. Also, note that in the Conical Function, the speed at capacity level (v/c =1) is set to be one-half of the free-flow speed. This relationship was specified in the original form of BPR function as developed in a study by the Bureau of Public Roads in early 1960s[4], but was later dropped in the modified forms of the BRP function. This property (i.e., $U_c = ½\, U_f$) constrains the flexibility of the curve to represent the speed as traffic volume approaches capacity level (i.e., under congested condition).

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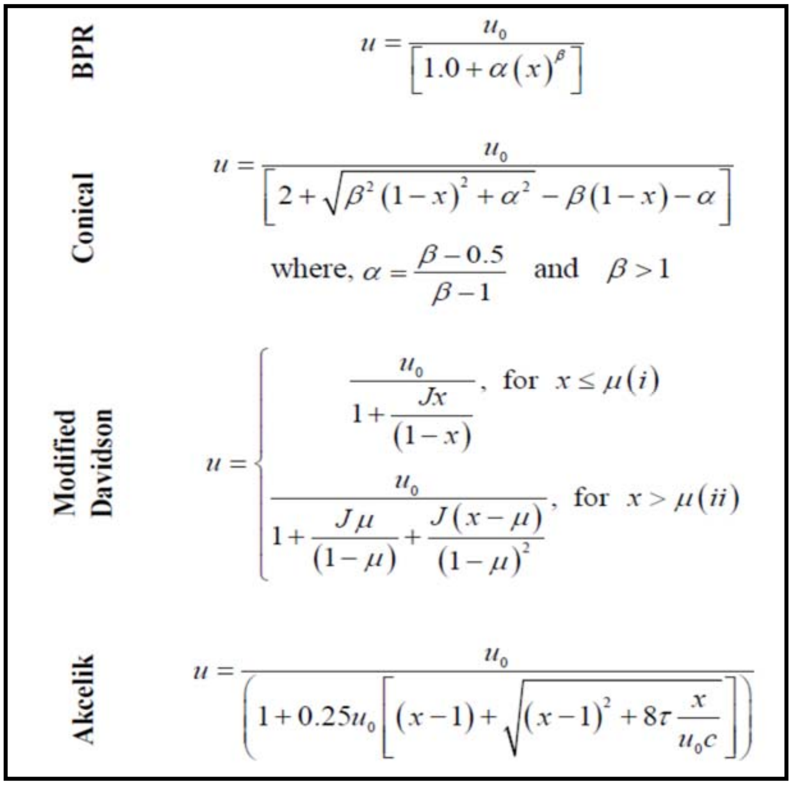
[4] Bureau of Public Roads, 1990, *Traffic Assignment Manual*, U.S. Department of Commerce, 1964 (as cited in Heinz Spiess, Technical Note – Conical Volume-Delay Functions, Transportation Science, Volume 24, pages 153-158).

Figure 1.3 Mathematical Formulations of Commonly Used Volume Delay Functions



BPR

$$u = \frac{u_0}{\left[1.0 + \alpha(x)^{\beta}\right]}$$

Conical

$$u = \frac{u_0}{\left[2 + \sqrt{\beta^2(1-x)^2 + \alpha^2} - \beta(1-x) - \alpha\right]}$$

$$\text{where, } \alpha = \frac{\beta - 0.5}{\beta - 1} \quad \text{and} \quad \beta > 1$$

Modified Davidson

$$u = \begin{cases} \dfrac{u_0}{1 + \dfrac{Jx}{(1-x)}}, & \text{for } x \le \mu \quad (i) \\[2ex] \dfrac{u_0}{1 + \dfrac{J\mu}{(1-\mu)} + \dfrac{J(x-\mu)}{(1-\mu)^2}}, & \text{for } x > \mu \quad (ii) \end{cases}$$

Akcelik

$$u = \frac{u_0}{\left(1 + 0.25u_0\left[(x-1) + \sqrt{(x-1)^2 + 8\tau\frac{x}{u_0 c}}\right]\right)}$$

Source: Enock T. Mtoi, Ren Moses, "*Calibration and Evaluation of Link Congestion Functions: Applying Intrinsic Sensitivity of Link Speed as a Practical Consideration to Heterogeneous Facility*. Types within Urban Network, Journal of Transportation Technologies, 4, 2014.

Recent Studies

There are a few studies conducted recently in the U.S. relevant to the development and application volume-delay functions for travel demand models. In early 2010s, a research team in the Florida A&M University – Florida State University (FAMU-FSU) College of Engineering conducted a study for the Florida Department of Transportation to test various forms of volume-delay functions and to evaluate their effectiveness for predicting traffic volumes in travel demand modeling.[5] In the study, one-year of field data of hourly volumes and hourly average speeds from over 260 Telemetered Traffic Monitoring Sites in the State of Florida were collected. Using the collected data, the key characteristics of volume-delay functions (i.e., free-flow speed, capacity, flow-speed relationship, etc.) were examined.

The collected traffic volume and speed data were then used to estimate the parameters for the four commonly used volume-delay functions listed in Figure 1.3. These fitted volume-delay functions are then applied to a travel demand model to examine their performance in predicting traffic volumes on a network. The study found that for an uninterrupted-flow facility, the fitted BPR function fits the data well, followed by modified Davidson and conical functions and lastly the Akcelik function, as shown in Figure 1.4. The testing

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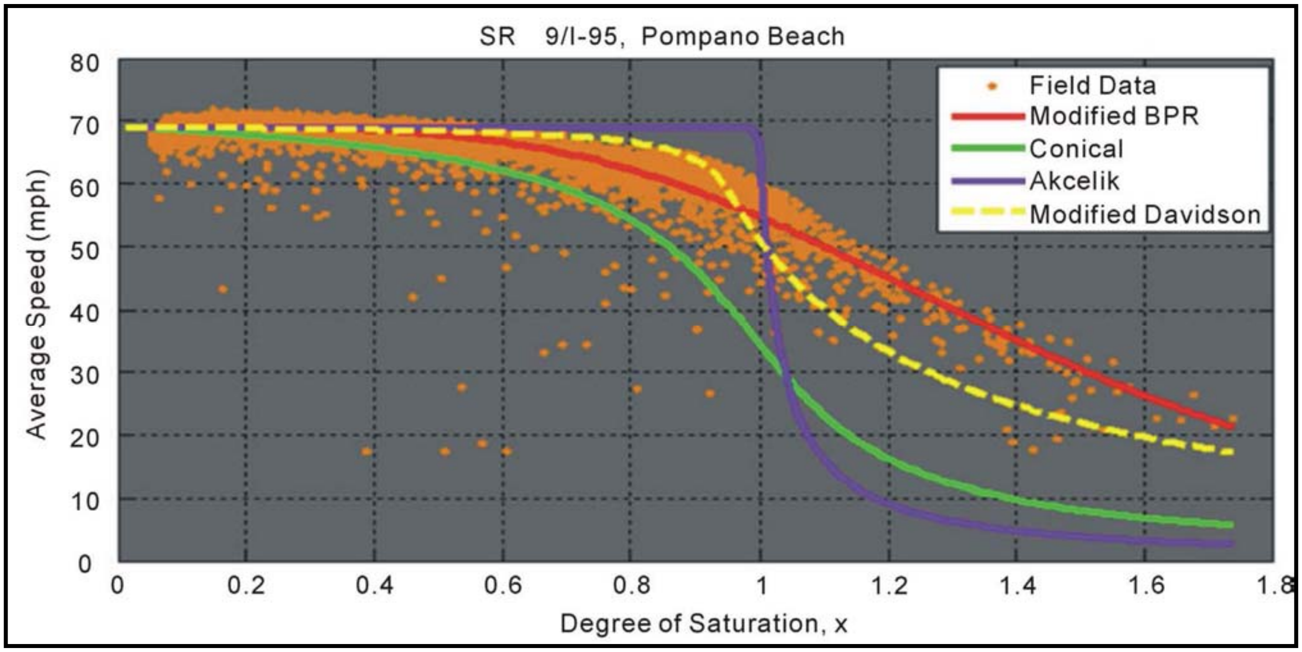
[5] Moses, Ren, Enock Mtoi, Steve Ruegg and Heinrich McBean, 2013, *Development of Speed Models for Improving Travel and Highway Performance Evaluation*, Final Report, prepared for Florida Department of Transportation.

of applying the fitted volume-delay functions to a travel demand model reveals that BPR function in general performs well, in particular for uninterrupted flow facilities, in terms of the percent RMSE for the estimated volumes versus observed counts (see, for example, pages 44-45, 65-70, and 74).

Figure 1.4 Fitted Volume-Delay Functions with Observed Data on a Freeway Segment



Source: Moses, Ren, Enock Mtoi, Steve Ruegg and Heinrich McBean, 2013, *Development of Speed Models for Improving Travel Forecasting and Highway Performance Evaluation*, Final Report, prepared for Florida Department of Transportation.

A similar study was conducted by a team in the Old Dominion University for the Virginia Department of Transportation.[6] The study examined the following three volume-delay functions: Modified BPR, Conical and Akcelik. However, instead of fitting the parameters of the functions using observed traffic count and speed data and applying the fitted functions to travel demand models, the study tested these functions directly on travel demand models, using a Generic Algorithm technique to search the parameters of the functions that minimize the estimation error of predicted traffic volumes (i.e., minimizing the RMSE of the estimated volumes versus observed traffic volumes). The results of the tests reveal that among the three volume-delay functions being tested, the BPR function performs the best in minimizing the percent RMSE. That is because, as the study explained, the BPR function has two parameters for calibration and thus provides greater flexibility in modifying travel times to estimate traffic volumes to match the link counts.

A state of practice review of volume-delay functions was conducted in a study sponsored by the National Cooperative Highway Research Program of the Transportation Research Board[7] in early 2010s. The study reveals that the BPR function was still the most commonly used function among the travel demand models in the U.S. The study report summarizes the parameters values of the BPR functions as reported in the model

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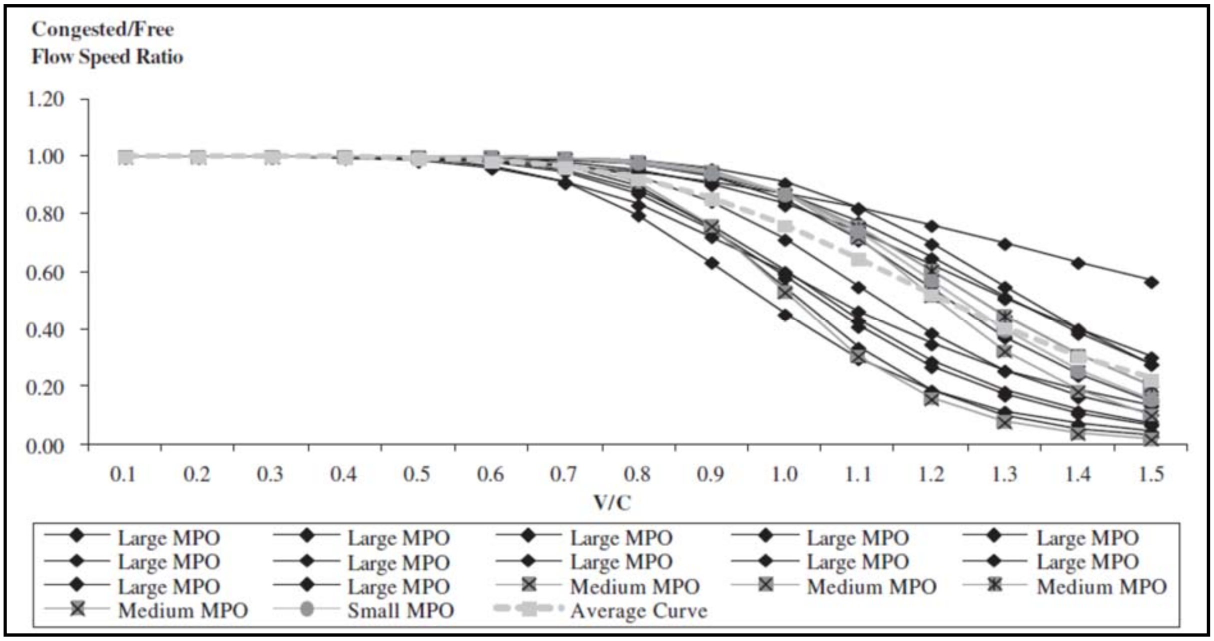
[6] Cetin, Mecit, Asad J. Khattak, Mike Robinson, Sanghoon Son, and Peter Foytik, 2012, *Evaluation of Volume-delay Functions and Their Implementation in VDOT,* prepared for Virginia Department of Transportation.

[7] Transportation Research Board, 2012, *Travel Demand Forecasting: Parameters and Techniques*, NCHRP Report 716.

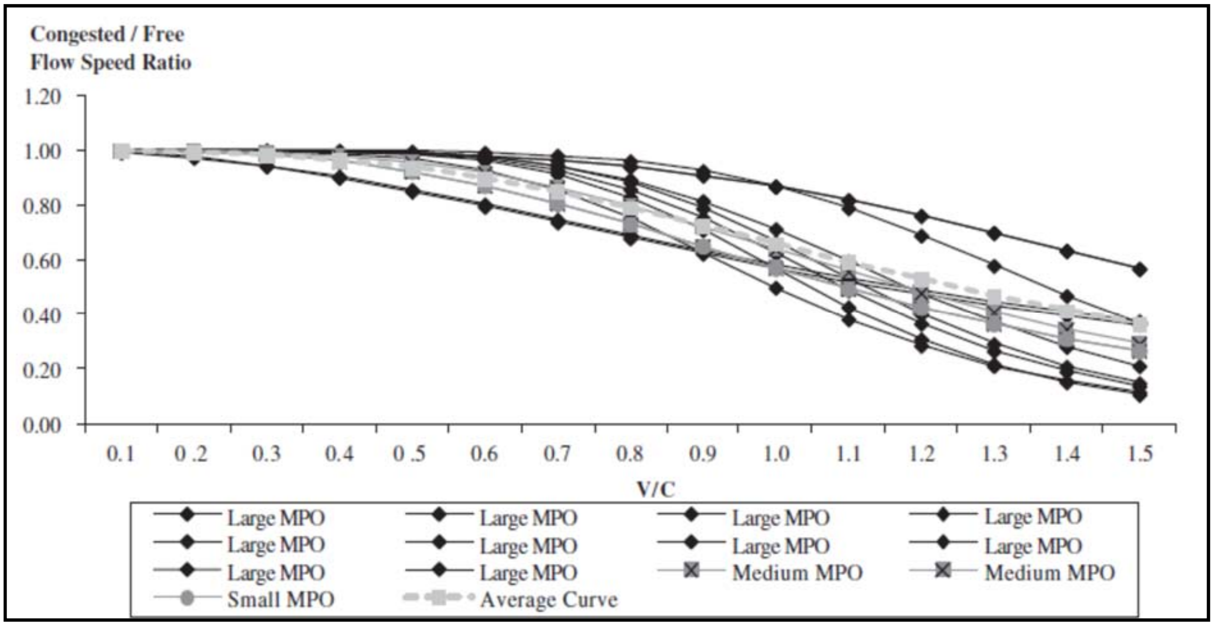
documentations of 18 MPO models. Figures 1.5 and 1.6 illustrate various volume-speed curves for freeway and arterial facilities, respectively, based on models that use the BPR functions. Although the parameters of the BPR functions vary greatly among various MPO models, the figures basically reveal that: 1) the speeds at capacity (v/c =1) are in most cases greater than one-half of the free-flow speeds; and 2) the slope of the curves at capacity level are steeper for freeway facilities than that of arterial facilities.

Figure 1.5 Volume-Speed Curves of Various BRP Functions of Existing MPO Models

a. Freeway Facilities



b. Arterial Facilities

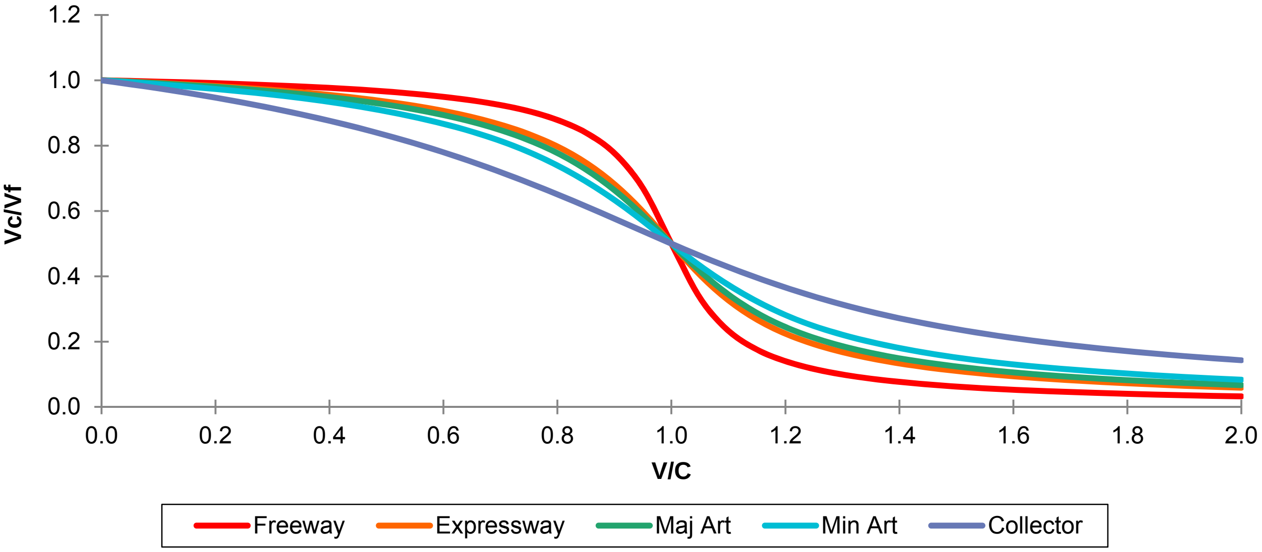


Existing MWCOG Model Volume-Delay Functions

The volume-delay functions (VDF) used in the current MWCOG model (Version 2.3.57a) are formulated as conical functions. The Version 2.2 MWCOG model was the first one to make use of conical VDFs,[8] though this model also made use of a queuing delay function that was later discontinued. Akçelik curves were also considered, but they were not used due to convergence issues.[9] The VDFs of the Version 2.3.57a model are illustrated in Figure 1.6. As mentioned previously, the conical functions constrain the speed function at capacity to be one-half of the free-flow speeds. This key characteristic of the conical function would cause the estimated speed to drop very rapidly at capacity level, in particular for the freeway facilities. This could be the main reason for the underestimation of congested speeds for freeway facilities, as reported in the AECOM study in 2013. In fact, two other recent studies in Virginia also reports the similar issue.[10,11] In both cases, the conical functions for freeway facilities were replaced with BPR functions.

The functions of various facility types, as shown in Figure 1.6, illustrate that the speed degradation at capacity is lower for low grade facilities. This is consistent with the general observations of models with BPR type volume delay functions, as reported in the NCHRP study.

Figure 1.6 Existing MWCOG Model Volume-Delay Functions



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

[9] Ronald Milone and Mark S. Moran, "Version 2.3 Travel Model on the 3,722-TAZ Area System: Traffic Assignment of Observed Trips" (presented at the November 19, 2010, meeting of the Travel Forecasting Subcommittee of the Technical Committee of the National Capital Region Transportation Planning Board, held at the Metropolitan Washington Council of Governments, Washington, D.C., November 19, 2010), 26.

[10] Whitman, Requardt and Associates, *Richmond/Tri-Cities Model Update*, Report Prepared for Virginia Department of Transportation, September 2015.

[11] Halcrow, Inc., I-95/I-395 HOT Lanes Project Independent Traffic and Revenue Forecasts Draft Final Report, prepared for Virginia Department of Transportation, January 2009.

Revisiting the BPR Function

The BPR formulation of volume-delay function is still widely used in travel demand functions in the U.S. Recent research studies also reveals the effectiveness of BPR type volume-delay functions for predicting traffic volumes on road networks, in particular for freeway facilities. It is thus worth revisiting the BPR function and exploring the possibility to replace the conical functions with BPR functions in the current MWCOG model.

A BPR function is defined by two parameters, Alpha and Beta. The parameter Alpha is a factor on the v/c ratio and it determines the speed factor at capacity (i.e., the ratio of speed and free-flow speed at capacity level). Table 1.1 below listed the speed factor at capacity for various values of Alpha.

Table 1.1 Speed Factors of Various Alpha Values

Alpha	V_c/V_f
0.10	0.909
0.25	0.800
0.50	0.667
1.00	0.500

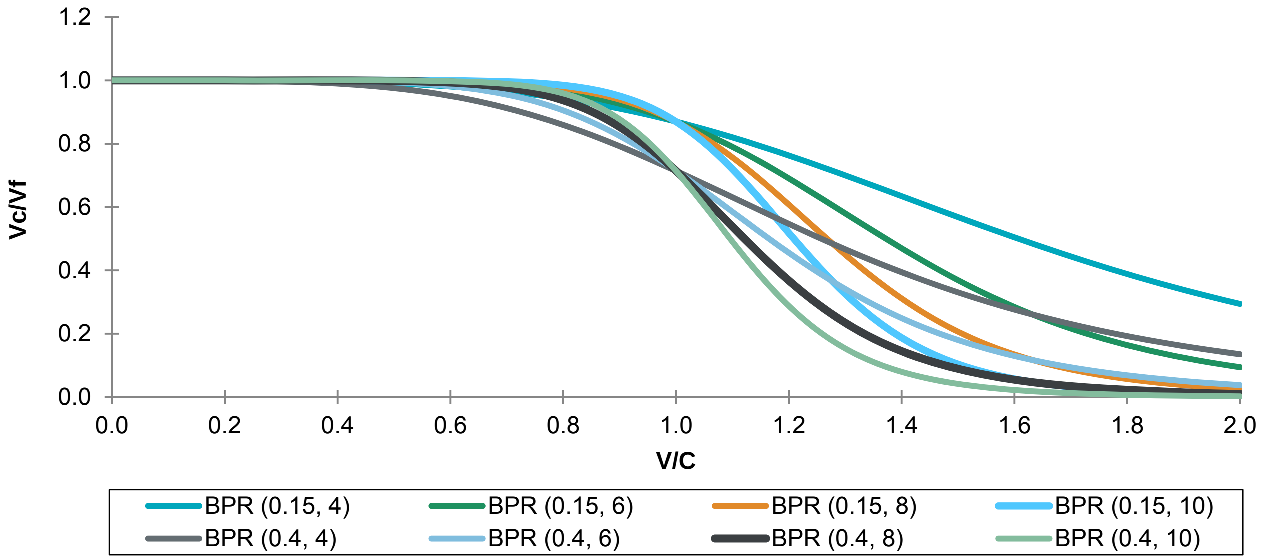
The value of Beta is the exponent on the v/c ratio and it basically determines the slope of the curve. In oversaturated conditions (i.e., v/c > 1), larger Beta values result in steeper slopes. Thus, the higher the Beta value, the greater sensitivity of speed is at oversaturated conditions. The values of Alpha and Beta used in the volume-delay functions by various models vary greatly. Table 1.2 lists the ranges of Alpha and Beta of the BPR functions used in 13 regional travel demand models with MPO population over 1 million.

Table 1.2 Range of BPR Function Parameters

	Minimum	Maximum	Average
Freeways			
Alpha	0.1	1.2	0.48
Beta	4.0	9.0	6.95
Arterials			
Alpha	0.15	1.0	0.53
Beta	2.0	6.0	4.4

In the original BPR function, the values of Alpha and Beta were set to be 0.15 and 4.0, respectively. It should be noted that in the original BPR function, the capacity was defined as the volume at LOS C (the so called the “design capacity”). In most of current models (including the MWCOG model), the capacity is defined as the “ultimate capacity” (i.e., LOS E capacity), which is about 0.8 of “design capacity” for urban facilities. Assuming the same value of Beta (4.00), the Alpha value of 0.15 with the definition of design capacity is roughly equivalent to Alpha value of 0.4 under the definition of ultimate design (i.e., Alpha = $0.15/0.8^4$). Figure 1.7 illustrates the BPR curves with various parameters. The figure demonstrates the flexibility of the BPR functions to represent a large range of volume-speed relationship under various conditions.

Figure 1.7 BPR Curves with Various Parameter Values



Conclusions and Recommendations

Based on the above discussion, it can be concluded that there is evidence that the conical form of the volume delay functions used in the existing MWCOG model may be one of the reasons why the MWCOG model underestimates congested travel speeds on freeway facilities, as compared with observed traffic speed data and as reported by other studies in the region. The functional form of the conical delay function which restricts the speed at capacity level (V/C = 1) to be one-half of the free-flow speed would cause a steep drop of speed at congested conditions.

On the other hand, the modified BPR function is still widely applied to many travel demand models. With two parameters, the modified BPR function provides greater flexibility in representing how travel speeds are affected by congestion. Also, previous studies reveal that the modified BPR function performs reasonably well, as compared with the conical function, in matching the simulated traffic volumes with observed data.

It is thus suggested to replace the conical functions with the modified BPR functions for freeway facilities. However, the change of volume-delay function of the freeway facilities will have impacts on the predicted traffic volumes on other facility types, in particular the volumes on the major arterial facilities, which in many cases are competing with the freeway facilities in the assignment process. It is thus necessary to revise the volume-delay functions for both the freeway and major arterial facilities. To avoid dramatic change of the resulted assignment results, the volume-speed curves as represented by the modified BPR functions should be comparable with those of existing conical functions.

Some considerations of setting the parameter values of Alpha and Beta are:

- The value of Alpha should be set such that the resulting ratio of congested speed to free-flow speed (Vc/Vf) should be higher than 0.5, probably within the range of 0.6 to 0.8;

- The value of Beta should be set such that the drop of the speed curve is not as steep as in the existing conical curves in oversaturated conditions; and

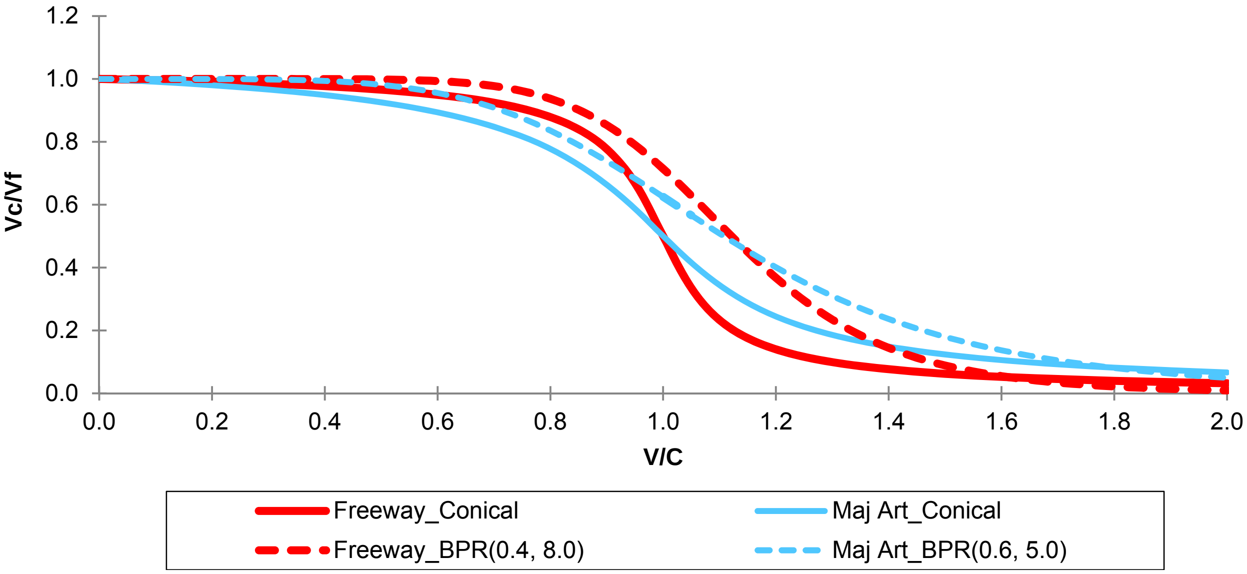
- The values are within the ranges of the values that have been used in other models.

The values of parameters Alpha and Beta can be determined through a series of tests of the assignment procedure by varying the parameter values. A suggested initial set of BPR functions for freeway and arterials is listed in Table 1.3. As shown in Figure 1.8, the volume-speed relationships as represented in the suggested BPR functions are comparable to those of the Conical function. It should be noted that the revised VDFs would likely lead to more links with v/c ratios above 1, since the revised functions result in higher speeds past a v/c ratio of 1.

Table 1.3 Suggested Initial BPR Function Parameters

	Alpha	Beta
Freeways	0.4	8.0
Major Arterials	0.6	5.0

Figure 1.8 Comparison the Existing Conical Functions and Suggested BPR Functions



The values of the parameters can be further adjusted based on the comparison of the assignment results with those of the existing model or with the observed data. The following summaries of the assignment results should be examined during the tests:

- Network-wide VMT by facility type;
- Network-wide VHT by facility type;
- Network-wide average speeds by facility type;

- Screenline traffic volume summaries by facility type; and
- Travel time/speeds of selected road segments.

1.5 Migration of Transit Path-Building Software

Introduction

This report section summarizes the work conducted in the FY16 Task Order Study to implement the Cube Public Transport (PT) scripts for transit skimming and assignment processes. This is a continuation of the work carried out in the FY 15 Task Order Study,[12] in which the study team implemented the PT process for the MWCOG model and examined the robustness of the PT process by comparing the PT-generated data with the 2012 Metrorail Passenger Survey. The study in 2015 focused on the path-building and skimming process of Metrorail trips.

The FY 16 work basically addressed the following activities:

- Complete the methodologies and validation for PT conversion from TB;
- Build transit paths and adjust path-building coefficients to match observed paths;
- Examine the compatibility of the PT process with the transit fare calculation process in the current MWCOG model; and
- Enhance the PT-based process to consider the “shadow pricing” of PnR Metrorail stations and the walk/escalator time at Metrorail stations.

Under this task order assignment, the consultant team implemented a set of consolidated PT scripts that perform transit path-building, skimming, and assignment processes for all transit submodes and access modes. The PT scripts generate a set of transit skim data files with the same format as that generated by the current Cube TRNBUILD (TB) program. In addition, the devised PT assignment process reads in the same transit trip table files with the same format as the current TB assignment process. This allows the devised PT process to be seamlessly incorporated into the current MWCOG model process. Specifically, the PT skim process generates the skim data files that can be readily used in the transit fare calculation process and modal choice process of the current MWCOG model. The PT skim process was also enhanced to take into account the “shadow pricing” and station walk/escalator times at Metrorail stations.

The PT-generated skim data were examined and validated for their robustness and compatibility with the data generated by the existing TB process. Various sets of network diagrams and thematic maps were generated to examine the validity of the path-building and skimming process. Also, the PT-generated skim data were compared with those from the existing TB process. Based on the validation results, a set of path building and skimming coefficients was determined for the PT process.

Implementation of PT Scripts

In the existing MWCOG model (Version 2.3.57), the TB skimming and assignment procedures were implemented in a number of script files, for different transit submodes and access modes separately. This

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[12] Gallop Corporation, Task Order 15.4, Modeling with Public Transport, Final Report, October 15, 2015.

involves substantial amount of effort for maintaining the script files and reduces the efficiency of executing the TB process. The implementation of the new PT scripts was streamlined and consolidated. The PT process was divided into following three "subprocesses":

1. Transit network building process;
2. Transit path-building and skimming process; and
3. Transit assignment process.

Each subprocess was implemented in a unified script file, which performs the process for all the submodes, access modes, as well as for peak and off-peak periods all together.

The transit network building process, which was implemented in the script file "PT_NetProcess.S", performs following tasks:

- Updating the transit networks by time period with revised travel time for rail links and composite cost for PnR access links;
- Generating a set of PT non-transit legs for various access modes to transit stations; and
- Assembling various transit line files for subsequent PT processes.

The input and output files of the transit network process are listed in Table 1.4. In the table, the words inside the Chevron symbols "<>" are various file name tokens that can be substituted by real words referring to various time periods, transit modes, or access modes. Each of the tokens can be substituted by a set of real words as specified in the note below the table.

The input network files of this process ("<per>_pt.net") are the revised network files that included some "hard-coded" transit specific links, such as rail transit links, the transit stations access links for various access modes, etc. The networks also include some direct walk access links from zone centroids to specific Metrorail stations in outskirt areas where zones are relatively coarse. These special links allow transit paths to be built from those zone centroids to rail stations. These revised highway network files were prepared by MWCOG staff previously. In the future update of the PT process (as well as entire MWCOG model system), it is preferable that the PT process reads in the standard highway network, instead of the revised highway network. The added transit specific links can be specified in a set of link data files and processed in this PT process. This eliminates the effort of maintaining separate network files for highway and transit modes.

This script also reads in other input files related to the transit system. The station file, rail link file, and transit line files are basically the same as those used in the existing TB process. The transit line files were revised slightly according to the PT transit network coding guideline as devised in the 2014 MWCOG Model Task Order Study.[13] The other two sets of input files are the transit system file that defines the modes, operators and other operation data of the transit system, and the factor files that specify the weighting factors of various transit and nontransit model in the skimming and assignment processes. These two files are required for each PT process.

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[13] AECOM, 2014, *Assistance with Development and Application of the National Capital Region Transportation Planning Board Travel Demand Model, FY 2014 Final Report*, Prepared for Metropolitan Washington Council of Governments, Chapter 6.

Table 1.4 Input and Output Files of Transit Network Process

File Name	File Description
Input Files	
<per>_pt.net	Transit network files
tsysd.pts	Transit system file[a]
<per>_trn.fac	Factor files[b]
rail_links.dbf	Rail link file
station.dbf	Station data files
<per>_<m#>.lin	Transit line files
Output Files	
<per>_updt_pt.net	Updated transit network
wacc_<per>_<subm>.leg wegr_<per>_<subm>.leg pnr_<per>_<subm>.leg knr_<per>_<subm>.leg xfer_<per>.leg	Non-Transit leg files
<per>_<trnm>_lines.lin	Assembled transit line files
railstations.txt	Rail station walk time and PnR access impedance file

[a] Contains the basic information about the public transit system, such as modes, operators, and relations between service frequency and wait time.

[b] Specifies the generalized cost factors and control information for the route enumeration and evaluation processes.

Note:
<per> = {am, op}
<subm> = {ab, bm, mr, cr}
<accm> = {wk, dr, kr}
<trnm> = {bus, mr, cr}
<m#> = {m1, m2, m3, m4, m5, m6, m7, m8, m9, m10}
<i#> = {i1, i2, i3, i4}

The outputs of this process include the updated network files, various non-transit leg files, assembled transit line files and a rail station file. The updated network files include additional transit specific links to the basic highway links, as well as attach additional data fields (e.g., transit mode number, transit times, etc.) to the network link data. The rail station file stores the walk access times (from PnR lots to station entrances) and station walk time (from entrances to platforms) for Metrorail rail stations. These output files are used in subsequent PT skimming and assignment processes.

A refinement of the new PT process from the current TB process is that the PT process considers the shadow costs (for constrained parking conditions) and station walk times (between station entrances and platforms) at the Metrorail stations in the skimming and assignment process. These data are specified in the following data fields of the input station data file ("STATION.DBF"):

- STAPKSHAD (in 100th minutes);
- STAOPSHAD (in 100th minutes); and
- STWALKTM (in 100th minutes).

The shadow costs and station walk times are specified in 100th minutes, with the sole purpose of maintaining the same data format of the "STATION.DBF" file of the current MWCOG model. The station file specifies all numeric values at integers. As the PT process, like other Cube Voyager processes, performs data calculations in real numbers, it would be preferable to store these station data in real numbers, instead of integer numbers in 100th units. Also, these station data can be stored in a specific GIS-based station layer that can be incorporated into a Cube-based or GIS-based network database. This can be considered in the future update of the MWCOG model.

It should be noted that the introduction of station shadow price is for the analysis of constrained parking at Metrorail PnR stations. Although the PT process provides the capability of crowding analysis of transit systems, its function is limited to the analysis of transit vehicles (i.e., on transit links), not at PnR lots (i.e., on non-transit links). Thus, the station shadow price is still a desirable option for the analysis of constrained parking at Metrorail PnR stations under the PT process.

The <u>transit skim process</u>, implemented in the script file "PT_skim.S", generates a set of 24 skim matrix files categorized by:

- Time period (peak and Off-peak);
- Transit submode (All Bus, Metrorail Only, Bus/Metrorail, Commuter Rail); and
- Access mode (Walk, PnR, KnR).

The process generates the skim files with the same format as that generated by the TB program in the current MWCOG model. The input and output files of the process are listed in Table 1.5. In addition to the skim matrix files, this process also generates the "route files" and "PT processed network files." These files can be used in the transit assignment process, or for other transit network analyses such as tracing paths and tracing the boarding/alighting stations.

The <u>transit assignment process</u> was implemented in the script file "PT_asgn.S." It performs the assignment process for each of the 12 travel segments (i.e., 4 submodes and 3 access modes), except for the KnR-to-commuter rail segment, which is grouped together with the PnR-to commuter rail segment. The assignment process uses the route files and network files that are generated in the skimming process. The transit trip tables used in the assignment process is the same as that generated in the current MWCOG model. Like the TB assignment process in the current MWCOG model, the PT assignment is conducted with trip tables in production-attraction format.

It should be noted that the transit trip tables should be "compatible" with the transit route files in the way that the i-j pairs without transit paths generated should not have transit trips in the input transit trip tables. This compatibility is usually confirmed if both the mode choice model and transit assignment process use the skimming matrix files and the route files generated from the same skimming process.

The assignment process generates a set of transit link volume files and station-to-station volume files. The input and output files of the assignment process are summarized in Table 1.6. These files are in the same formats as those generated by the current TB process.

Table 1.5 Input and Output Files of Transit Skim Process

File Name	File Description
Input Files	
tsysd.pts	Transit system file
<per>_trn.fac	Factor files
<per>_updt_pt.net	Updated transit network
acc_<per>_<subm>.leg egr_<per>_<subm>.leg pnr_<per>_<subm>.leg knr_<per>_<subm>.leg xfer_<per>.leg	Non-Transit leg files
<per>_<trnm>_lines.lin	Assembled transit line files
railstations.txt	Rail station walk time and PnR access impedance file
Output Files	
<per>_<subm>_<accm>.skm	Transit skim files
<per>_<subm>_<accm>.net	PT processed network files
<per>_<subm>_<accm>.rte	PT route files

Note 1: Shaded cells denote files generated from previous PT process

Note 2:

<per> = {am, op}
<subm> = {ab, bm, mr, cr}
<accm> = {wk, dr, kr}
<trnm> = {bus, mrl, crl}
<m#> = {m1, m2, m3, m4, m5, m6, m7, m8, m9, m10}
<i#> = {i1, i2, i3, i4}

Table 1.6 Input and Output Files of Transit Assignment Process

File Name	File Description
Input Files	
tsysd.pts	Transit system file
<per>_trn.fac	Factor files
<ix>_<per>ms.trp	Transit trip tables
<per>_<subm>_<accm>.net	PT processed network files
<per>_<subm>_<accm>.rte	PT route files
Output Files	
am*_linkvol.dbf, op*_linkvol.dbf	Link out files
am*_s2svol.dbf, op*_s2svol.dbf	Station-Station volume files

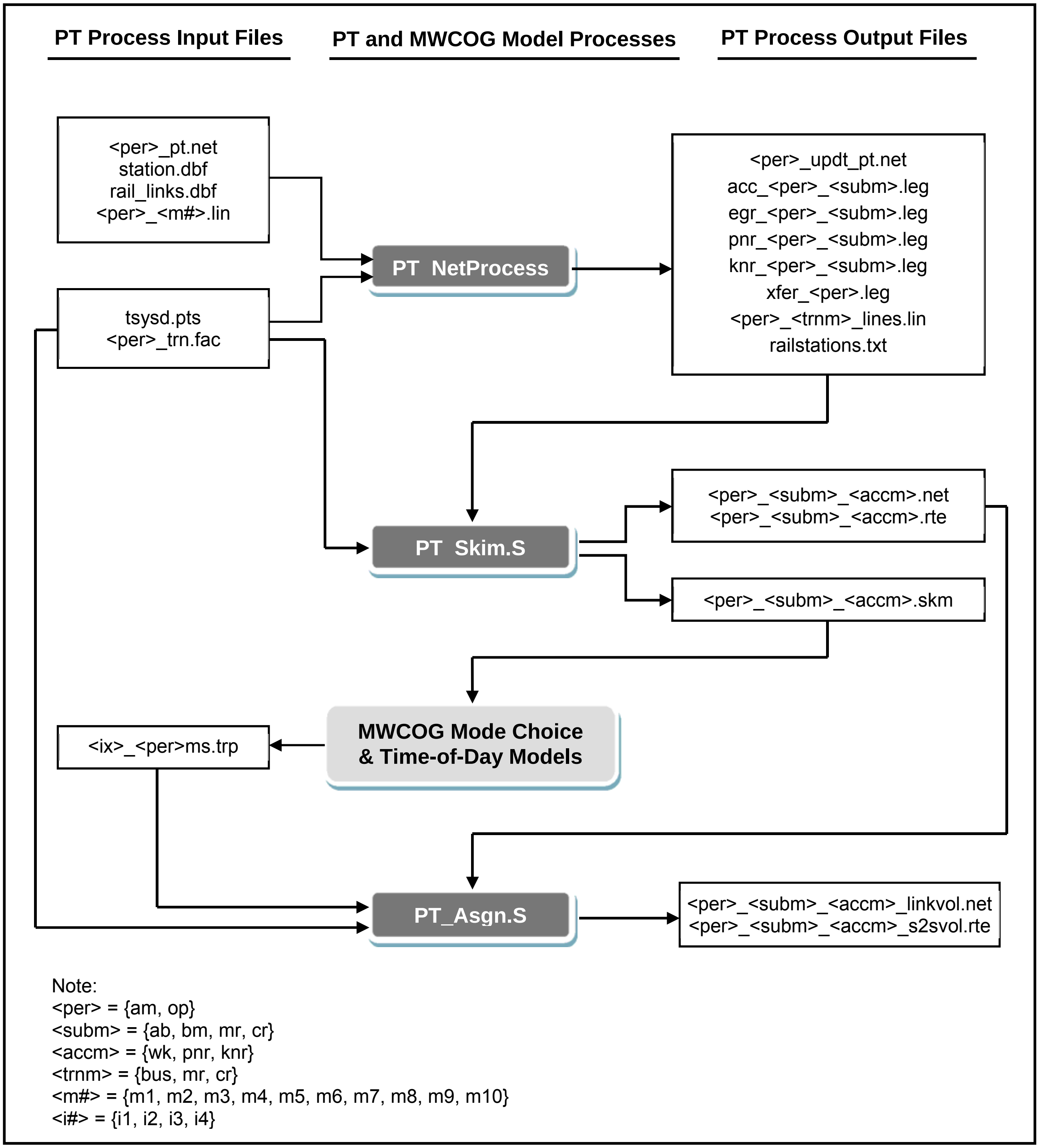
Note 1: Shaded cells denote files generated from previous PT process

Note 2:

<per> = {am, op}
<subm> = {ab, bm, mr, cr}
<accm> = {wk, dr, kr}
<trnm> = {bus, mrl, crl}
<m#> = {m1, m2, m3, m4, m5, m6, m7, m8, m9, m10}
<i#> = {i1, i2, i3, i4}

Figure 1.9 displays the flowchart of the PT processes and their interactions with the MWCOG model process.

Figure 1.9 PT Process Flowchart



Note:
<per> = {am, op}
<subm> = {ab, bm, mr, cr}
<accm> = {wk, pnr, knr}
<trnm> = {bus, mr, cr}
<m#> = {m1, m2, m3, m4, m5, m6, m7, m8, m9, m10}
<i#> = {i1, i2, i3, i4}

The conduct of PT process requires various path-building parameters and weighting factors to be specified. Table 1.7 lists the parameter values specific to the PT process. Most of the parameters are related to the creation of various non-transit legs of the transit network. The parameter "MAXCOST" specifies the maximum travel time, in minutes, of various access links between zone centroids and transit stations, either at the origin end or the destination end of a trip. It should be noted that the maximum walk access times are set to 30 minutes for bus stops and 45 minutes for rail stations. These values are higher than what are usually expected, with the consideration to allow transit paths to be generated for some large traffic zones in outskirt areas or traffic zones with irregular shape. For those traffic zones, it is likely that only portions of the zones are within the walk catchment area. However, transit paths still need to be generated for those zones.

The parameter "SLACK" specifies the amount added to the minimum cost nontransit leg to determine the maximum cost of legs to be generated. The "SLACK" parameter provides a secondary control for restricting the number of nontransit legs to be generated. The parameter "MAXCOST" provides the primary control. The parameter "MAXNTLEGS" set the maximum number of nontransit legs to be generated from a traffic zone for various transit modes and access modes.

Table 1.7 also includes two parameters related to boarding penalty ("BRDPEN") and transfer penalty ("XFERPEN"). These two parameters are equivalent to the parameter "XPEN" in the TB process. The parameter "BRDPEN" specifies the perceived boarding penalties, in minutes, for various transit modes. It should be noted that the parameter "BRDPEN", unlike other penalty parameters, does not have a weighting factor associated to it. It is thus specified directly as perceived penalty.

The perceived boarding penalties as specified for the parameter "BRDPEN", 12.5 minutes for bus modes and 6.25 minutes for rail modes, are close to what are specified for the parameter "XPEN" in the current TP process of the MWCOG model. In the current TP process, the parameter "XPEN" is set as 5 minutes and 2 minutes for bus modes and rail modes, respectively, with a weighting factor of 2.5.

The parameter "XFERPDN" specifies the penalty, in actual minutes, for transferring between transit modes. Like the parameter "XPEN" in the TB process, the parameter "XFERPEN" is associated to a weighting factor, which is set as 2.5. Note that the transfer penalty between Metrorail modes is set as "-1.49". This value is applied together with the transfer penalty between all modes and rail modes, which is set as "1.50". The net penalty of these two values combined is "0.01" minute, implying virtually no penalty for transferring between Metrorail lines. Also, the net value, in 100th minutes, allows for keeping track of the total number of Metrorail-Metrorail transfers of a transit path (i.e., by retrieving the second decimal point value of the total penalty value of an i-j path, which is stored in the matrix #11 of the skim matrix file).

Table 1.7 PT-Model Parameter Values

Parameter	PT Keyword	Mode Applied	Parameter Value
Max. Cost (actual min.) for Walk Access NT Leg	MAXCOST	Bus	30
		Metrorail	45
		Commuter Rail	45
Max. Cost (actual min.) for PNR Access NT Leg	MAXCOST	Bus	20
		Metrorail	60[a]
		Commuter Rail	60
Max. Cost (actual min.) for KNR Access NT Leg	MAXCOST	Bus	10
		Metrorail	15
		Commuter Rail	15
Max. Cost (actual min.) for Walk Transfer	MAXCOST	All modes	15
Max. number of Walk Access NT Leg	MAXNTLEGS	Bus	10
		Metrorail	5
		Commuter Rail	5
Max. number of PNR Access NT Leg	MAXNTLEGS	Bus	5
		Metrorail	5
		Commuter Rail	5
Max. number of KNR Access NT Leg	MAXNTLEGS	Bus	5
		Metrorail	5
		Commuter Rail	5
"Slack" value (actual min.) of Walk Access NT Leg	SLACK	Bus	10
		Metrorail	10
		Commuter Rail	10
"Slack" value (actual min.) of PNR Access NT Leg	SLACK	Bus	10
		Metrorail	15
		Commuter Rail	15
"Slack" value (actual min.) of KNR Access NT Leg	SLACK	Bus	5
		Metrorail	5
		Commuter Rail	5
Boarding Penalties for rail mode (perceived min., with weighting factor of 1)	BRDPEN	Bus	12.5
		Metrorail	6.25
		Commuter Rail	6.25
Xfer Penalty from bus to rail mode (actual min., with weighting factor of 2.5)	XFERPEN	Bus - Bus	3
		All - Rail	1.5
		Metrorail - Metrorail	-1.49

[a] Composite cost including walk time and PnR parking cost.

In addition to the parameters listed in Table 1.7, various factors, like the weighting factors for travel time of various transit and non-transit modes, wait time, transfer penalty, etc., are specified for the PT process. These factors are basically set with the same values as the current TB process. Basically, the values of various parameters and factors in the PT process are set with the following considerations:

1. Compatibility with the values set in the current TB process;
2. Examination of Metrorail on-board survey data conducted in the FY15 Task Order Study;[14]
3. Results from a series of tests of the PT process; and
4. Comparable with values set in other region model with implemented PT process (e.g., the Baltimore Metropolitan Council Regional Travel Demand Model).

Evaluation of PT-Generated Non-Transit Access Legs

One of the major functions of the PT program is to generate the non-transit access legs of the transit network for various access modes. These NT access legs are generated based on various parameters as specified in Table 1.7. The reasonableness of these NT access legs would have profound impacts on the reliability of resulting transit skim data, and thus needs to be examined. Figures 1.10a to 10f display various types of zone-to-station NT access legs for various transit submodes. Basically, these figures illustrate that the PT-generated NT access links are reasonable.

Also, the PT-generated NT access links are comparable with what were found from the observed data of the 2012 Metrorail Passenger Survey.[15] For example, Figures 1.11 and 1.12 display the walk access connections and PnR access connections, respectively, of observed Metrorail trips. Comparing Figure 1.10a with Figure 1.11, the pattern of observed walk access connection is very similar to that of PT generation walk access connections. For PnR access connection of Metrorail trips, the PT-generated PnR access links as shown in Figure 1.10e cover most of the observed PnR access connections as shown in Figure 1.12.

It should be noted that the main purpose of PT-generated NT legs is to provide the possible zone-to-station connections for the transit path building process, but at the same time to exclude the connections that are unlikely to be chosen by transit passengers. The chosen connections are eventually determined by the path building process. Thus, the pattern of the PT-generated access links does not necessarily exactly match the pattern of observed access connections. If the path building process is robust enough, the PT estimated chosen connections will reasonably match the observed pattern. This can be illustrated by Figure 1.13, which displays the PT-generated PnR connection links (in light gray color), and PT estimated connections of observed Metrorail trips (in blue colors). As shown in Figure 1.13, even though the PT process generates many connection links, the pattern of the PT estimated PnR connections reasonably follows the observed connection pattern, as shown in Figure 1.12.

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[14] Gallop Corporation, 2015, Modeling with Public Transport, Task Order 15.4, Final Report, prepared for Metropolitan Council of Governments/National Capital Region Transportation Planning Board, Table 3.

[15] Gallop Corporation, 2015, Modeling with Public Transport, Task Order 15.4, Final Report, prepared for Metropolitan Council of Governments/National Capital Region Transportation Planning Board, Figures 4 to 6.

Figure 1.10 PT-Generated Non-Transit Access Legs

a. Walk to Metrorail Station Access Legs

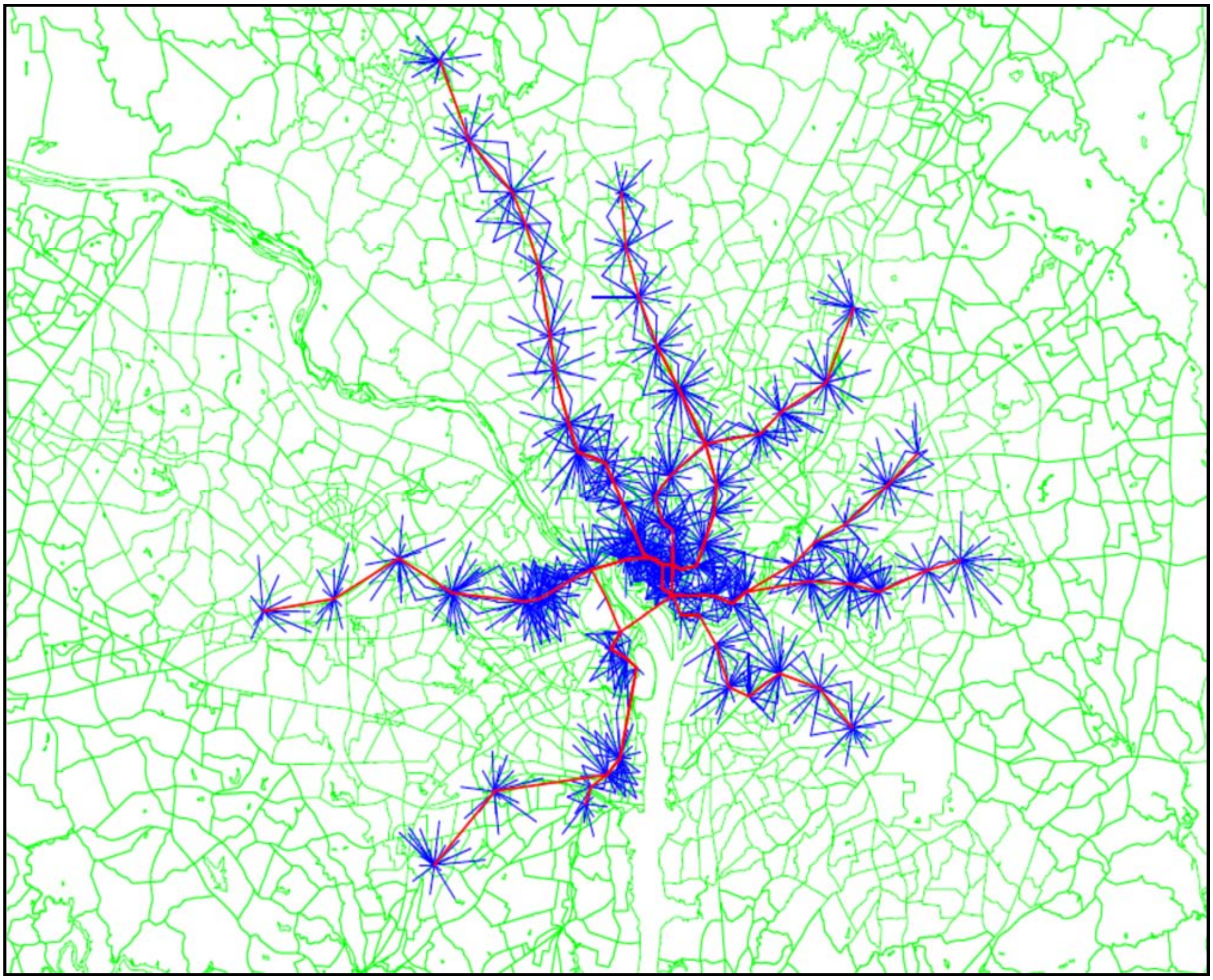


Figure 1.10 PT-Generated Non-Transit Access Legs (continued)

b. Walk-to-Commuter Rail Station Access Legs

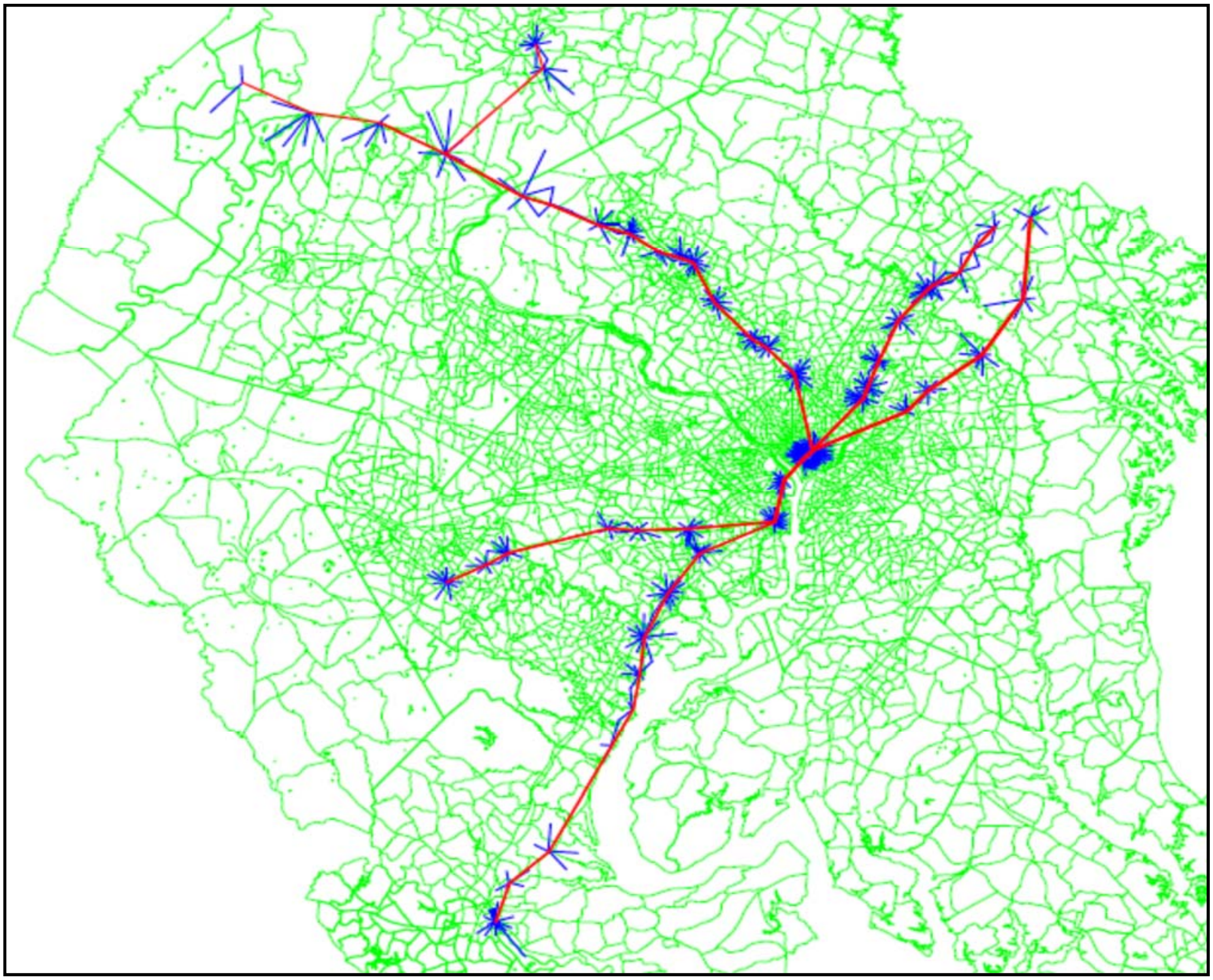


Figure 1.10 PT-Generated Non-Transit Access Legs (continued)

c. KnR-to-Metrorail Station Access Legs

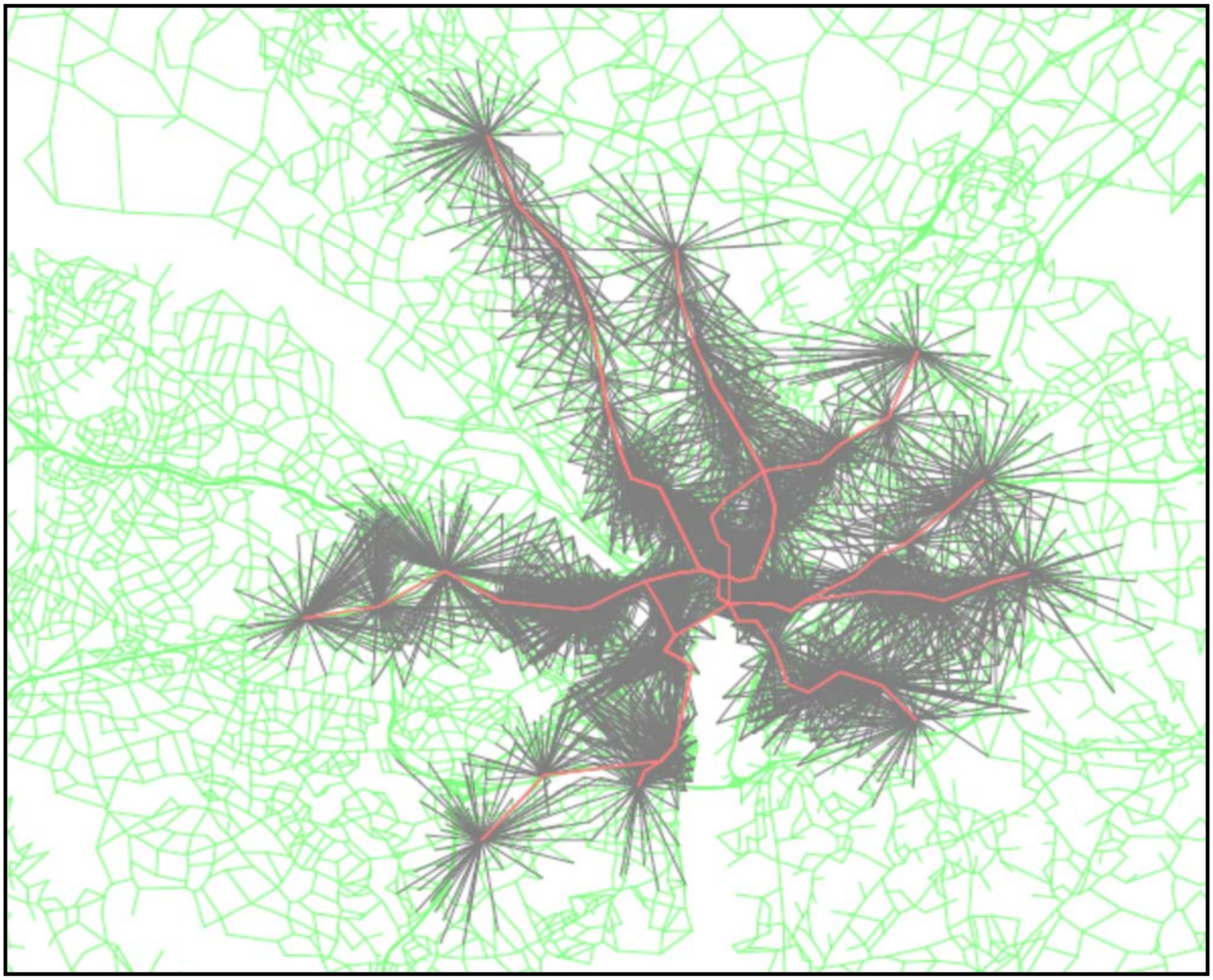


Figure 1.10 PT-Generated Non-Transit Access Legs (continued)

d. KnR-to-Commuter Rail Station Access Legs

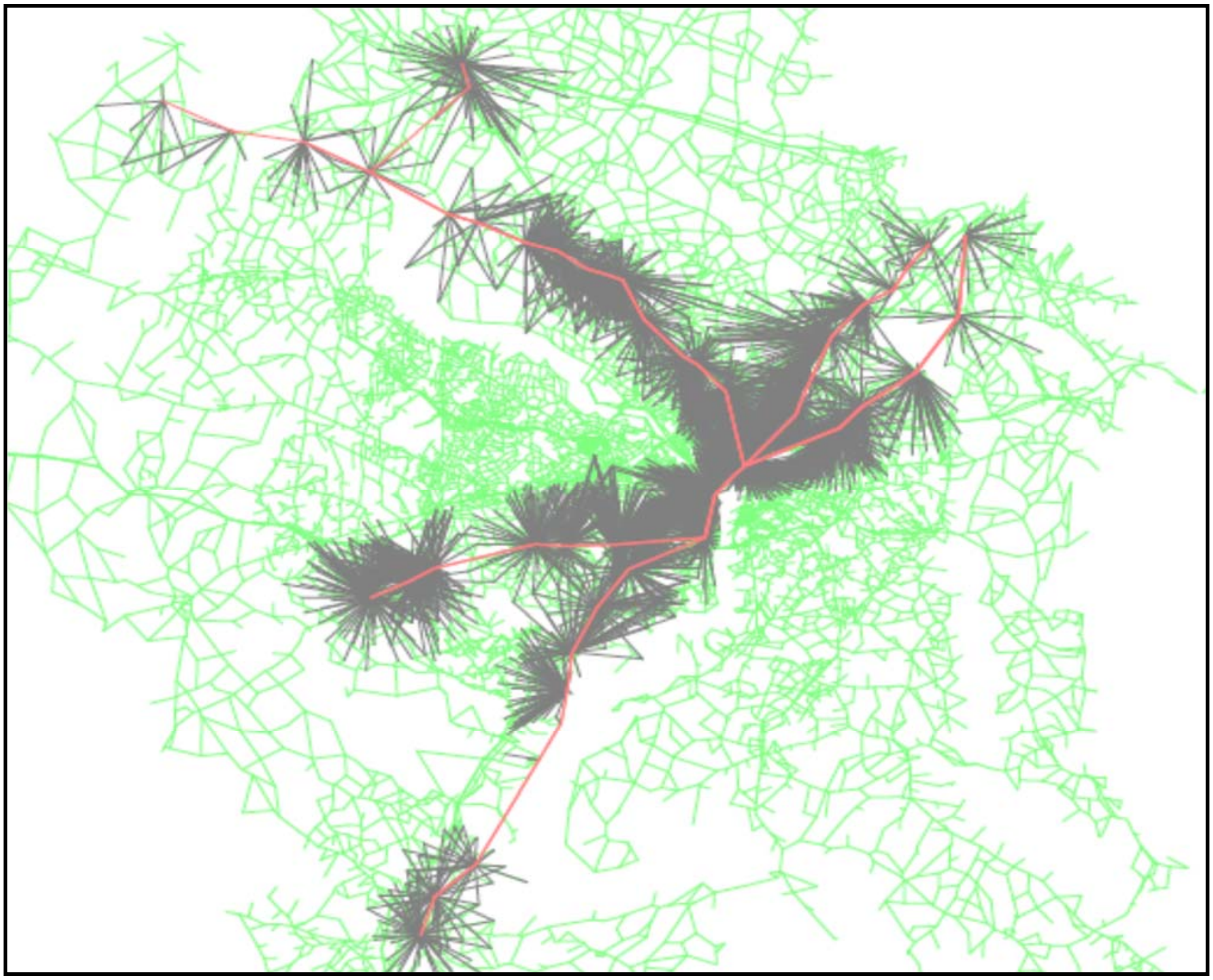


Figure 1.10 PT-Generated Non-Transit Access Legs (continued)

e. PnR-to-Metrorail Station Access Legs

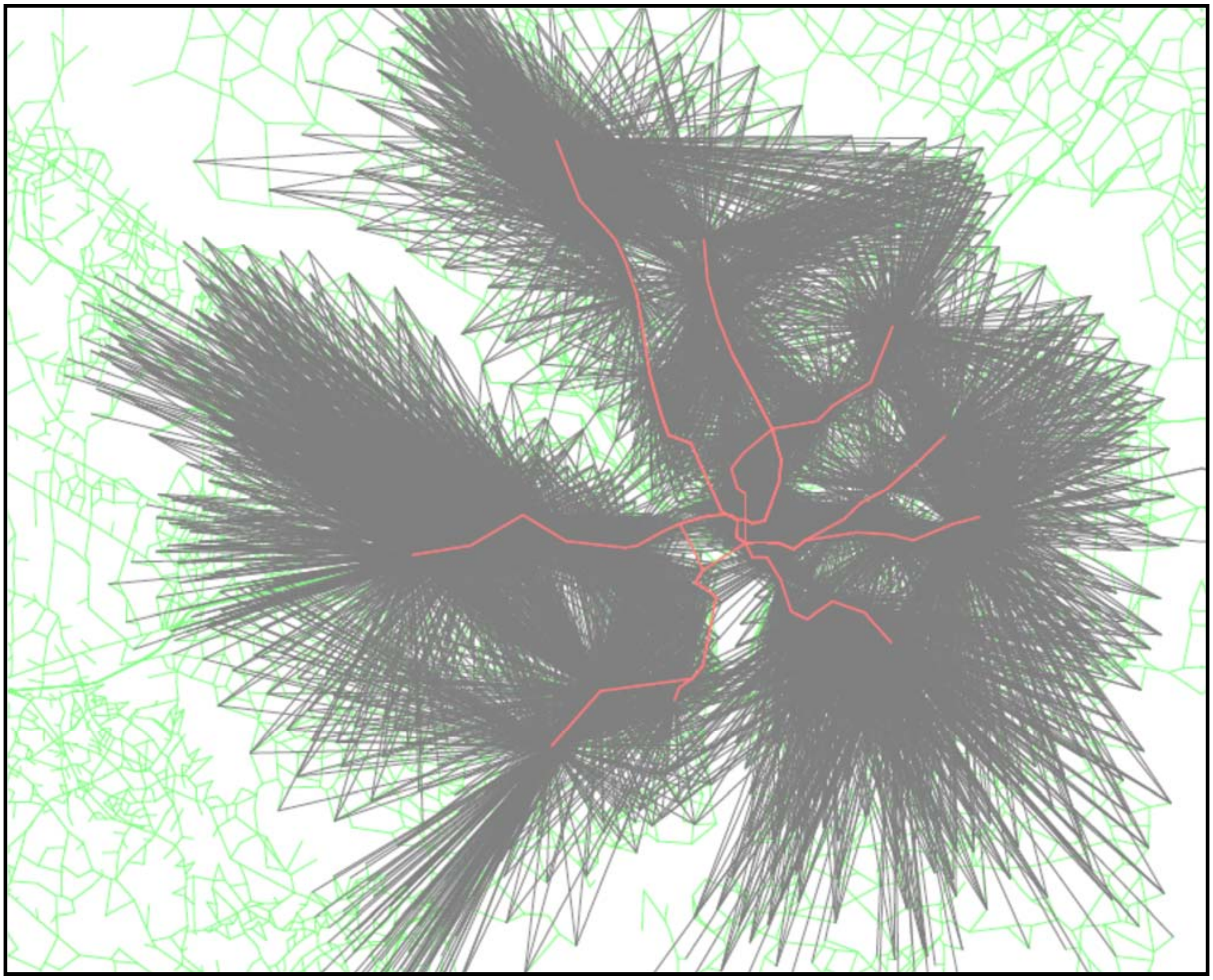


Figure 1.10 PT-Generated Non-Transit Access Legs (continued)

f. PnR-to-Commuter Rail Station Access Legs

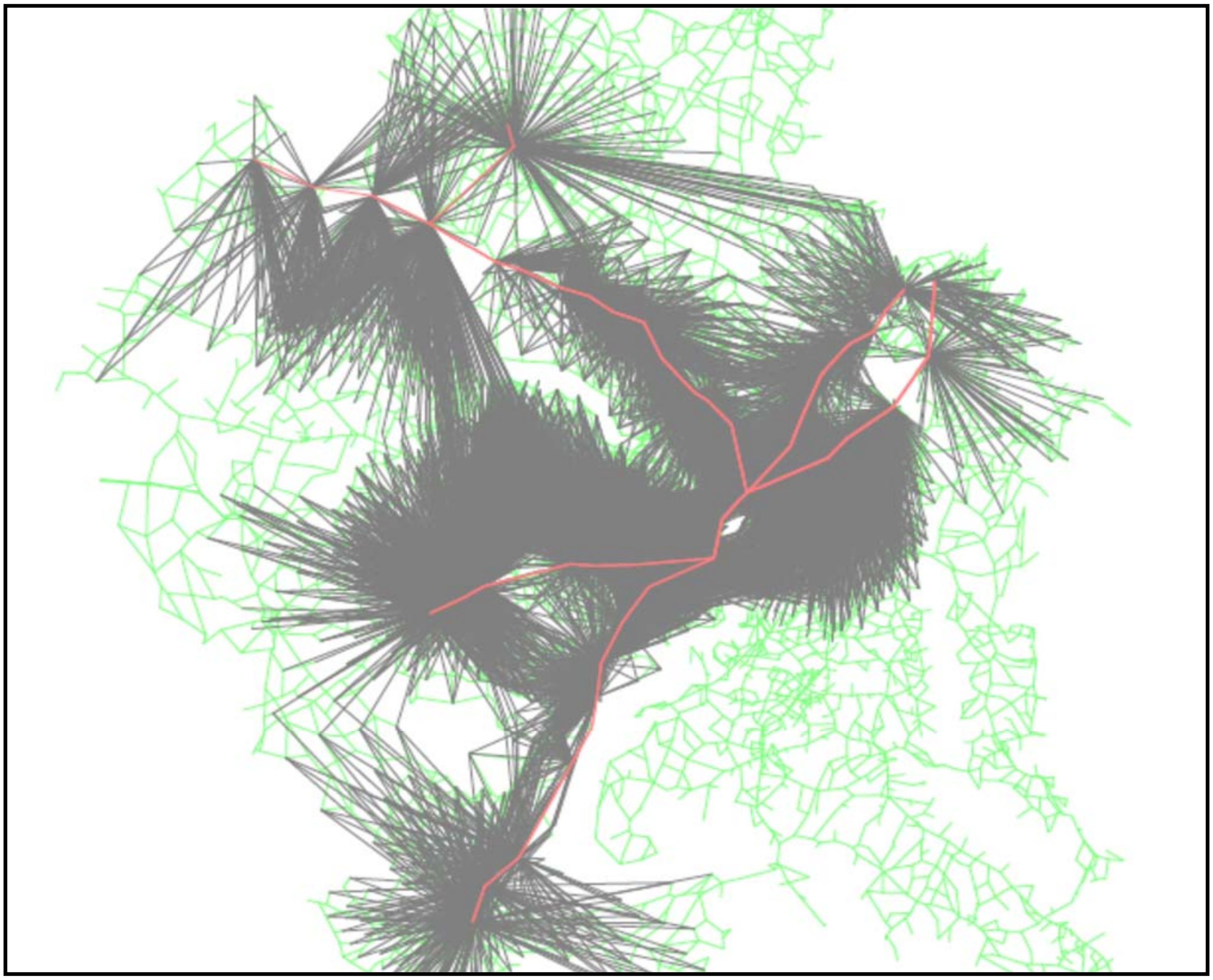
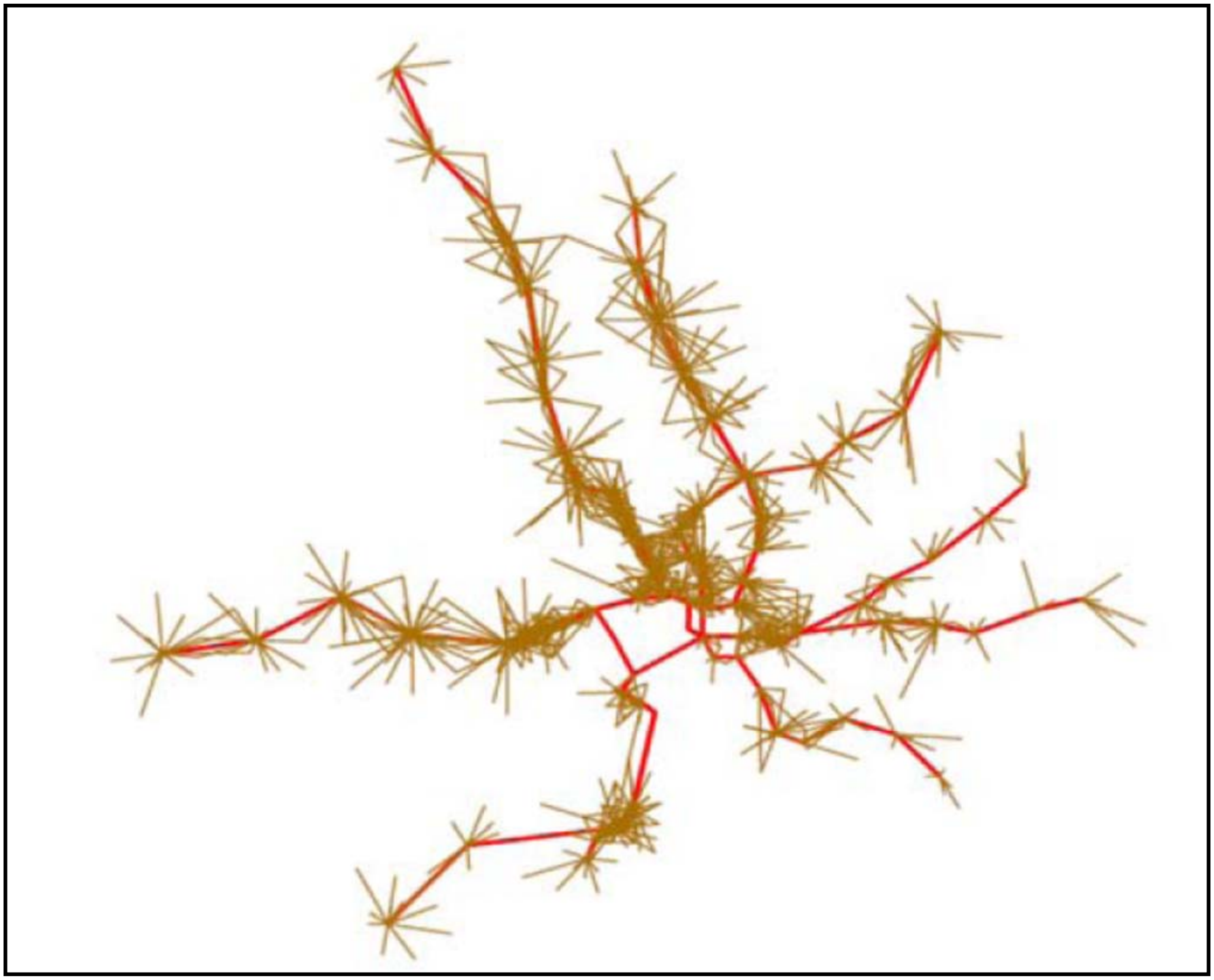
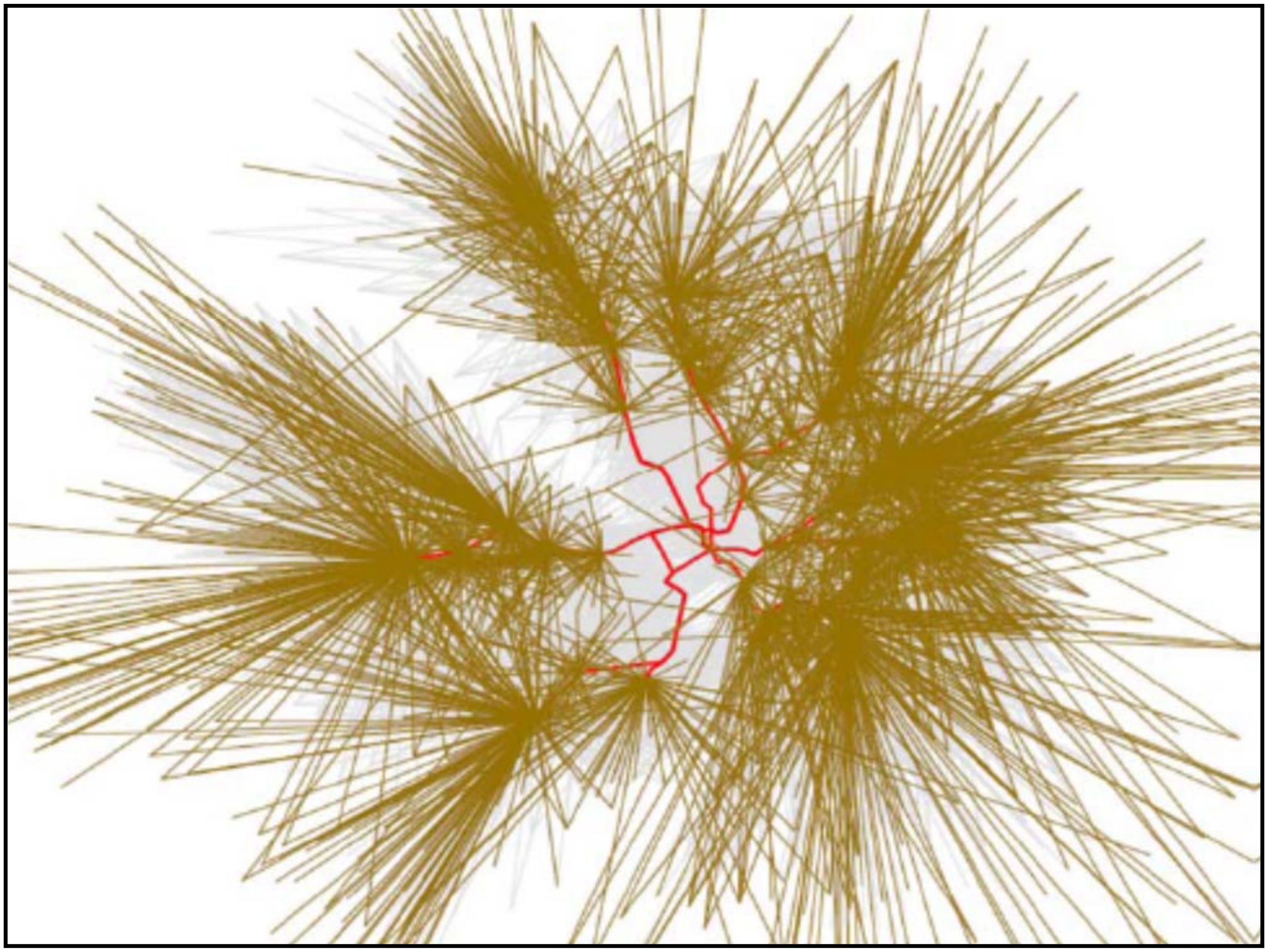


Figure 1.11 Walk Access Connections of Observed Metrorail Trips



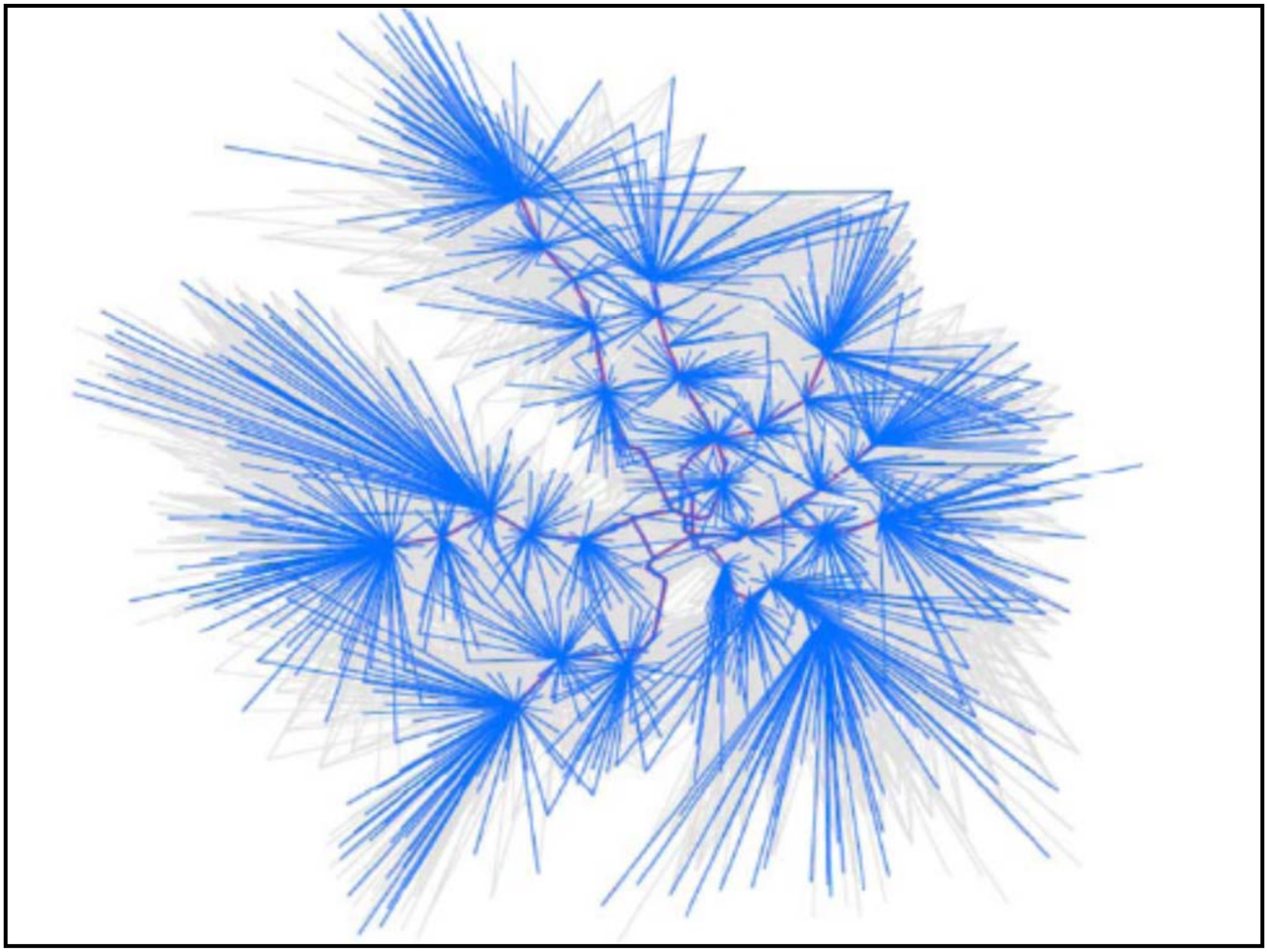
Source: Gallop Corporation, Task Order 15.4, Modeling with Public Transport, Final Report, October 2015, Figure 4a.

Figure 1.12 PnR Connections of Observed Metrorail Trips



Source: Gallop Corporation, *Task Order 15.4, Modeling with Public Transport*, Final Report, October 2015, Figure 5a.

Figure 1.13 PT Estimated PnR Connections of Observed Metrorail Trips



Source: Gallop Corporation, *Task Order 15.4, Modeling with Public Transport*, Final Report, October 2015, Figure 5b.

Evaluation PT-Generated In-Vehicle-Time Skim Data

Figures 1.14a to 1.14e display a series of thematic maps with the PT estimated in-vehicle-times from various zones to zone 23 in downtown Washington for various submode paths. These figures demonstrate that, in general, the estimated in-vehicle-times are reasonable. For walk access paths, Figures 1.14a and 1.14c illustrate that only the zones close to transit services are connected with estimated IVT values. Figure 1.14b reveals that the estimated IVT for “walk to Metrorail” paths are consistent with the scheduled Metrorail travel times. Also, the comparison of Figures 1.14a and 1.14c show that the estimated in-vehicle-times for “walk to Bus/Metrorail” paths are shorter than those for the “walk to Bus only” paths, reflecting the fact that for “walk-to Bus/Metrorail” path, transit passengers traveling to downtown can transfer to Metrorail with much shorter travel times than taking the bus all the way to downtown.

For drive access paths, Figure 1.14d reveals that basically the entire metropolitan area is connected to Metrorail service through drive-access with estimated in-vehicle-times consistent with the scheduled Metrorail travel times. On the other hand, Figure 1,14e indicates that only zones in outskirt areas are connected to Commuter rail. This is because transit passengers from travel zones closer to center city can take the Metrorail, instead of the commuter rail, to downtown.

Figure 1.14 In-Vehicle Travel Time from Various Origin Zones to Zone 23

a. Walk to All-Bus Mode

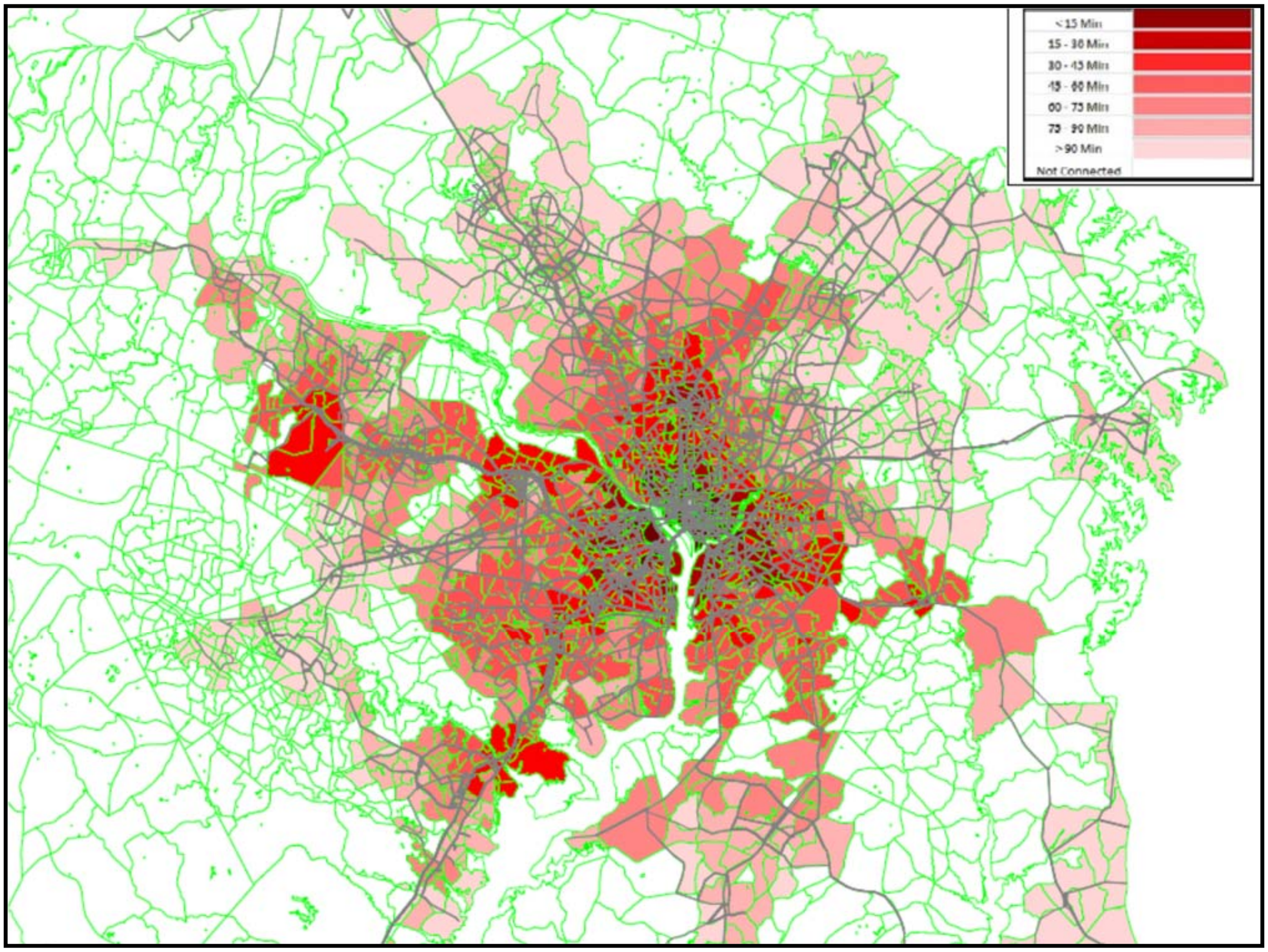


Figure 1.14 In-Vehicle Travel Time from Various Origin Zones to Zone 23 (continued)

b. Walk to Metrorail Mode

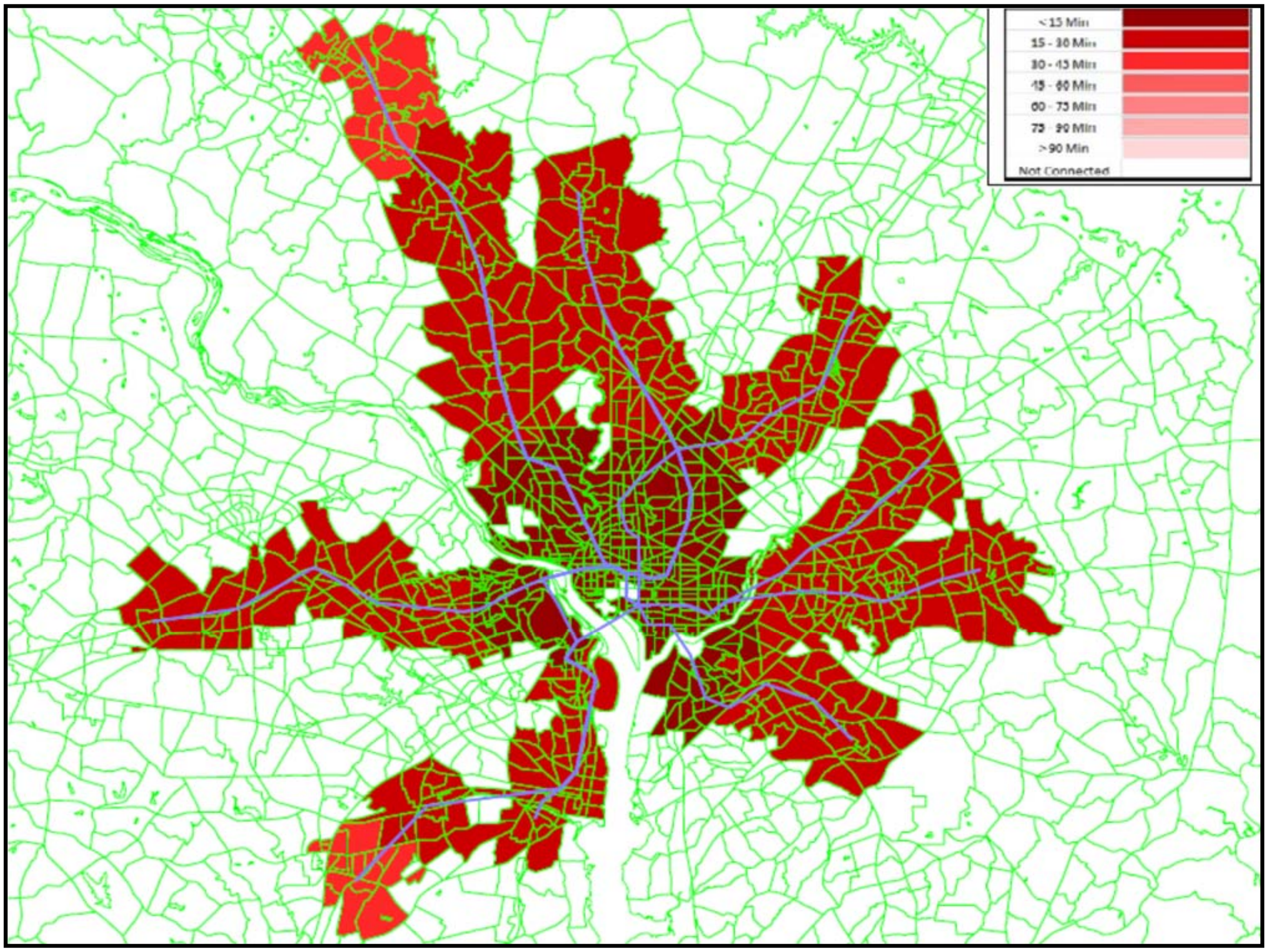


Figure 1.14 In-Vehicle Travel Time from Various Origin Zones to Zone 23 (continued)

c. Walk-to-Bus/Metrorail Mode

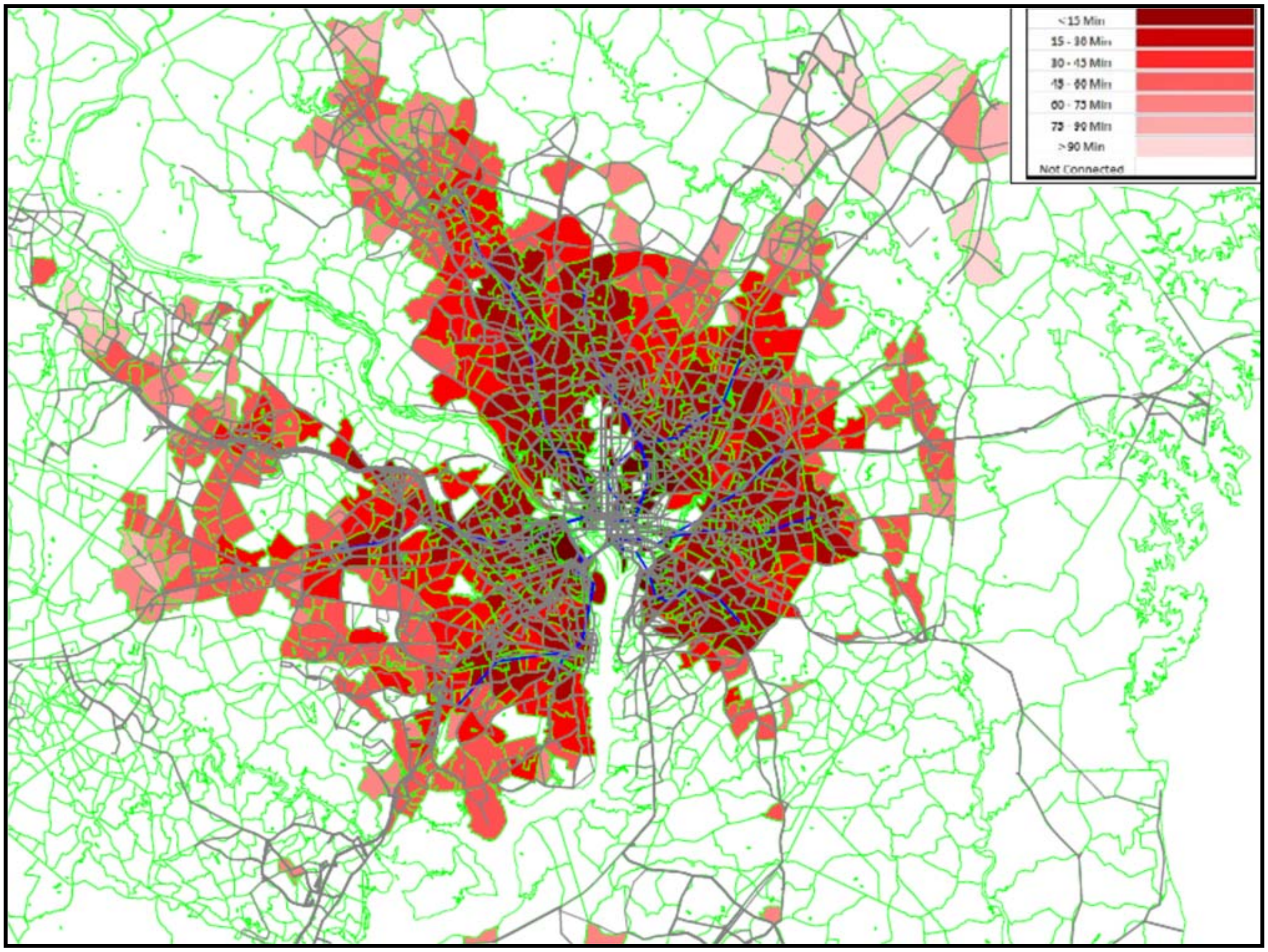


Figure 1.14 In-Vehicle Travel Time from Various Origin Zones to Zone 23 (continued)

d. PnR to Bus/Metrorail Mode

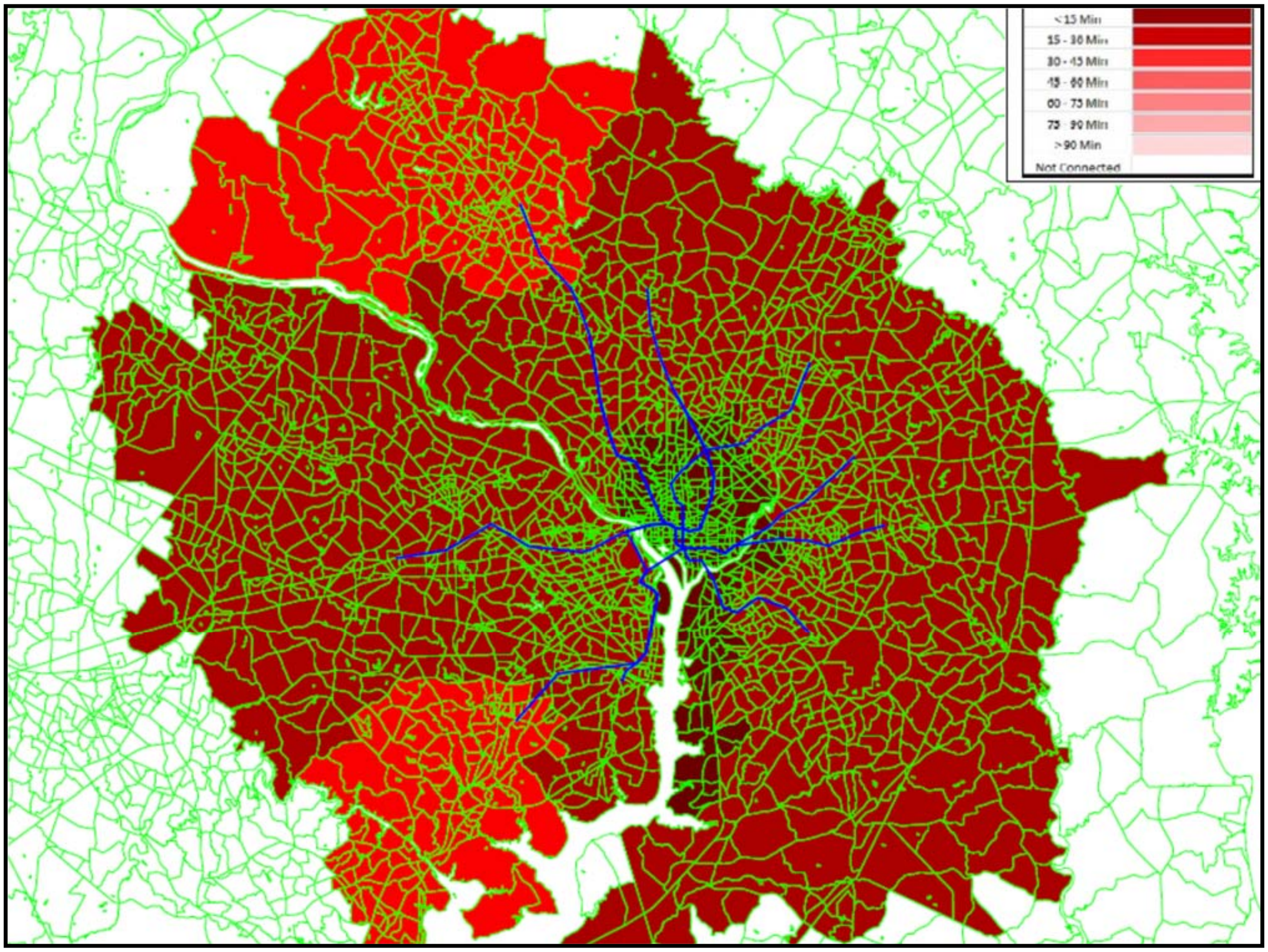
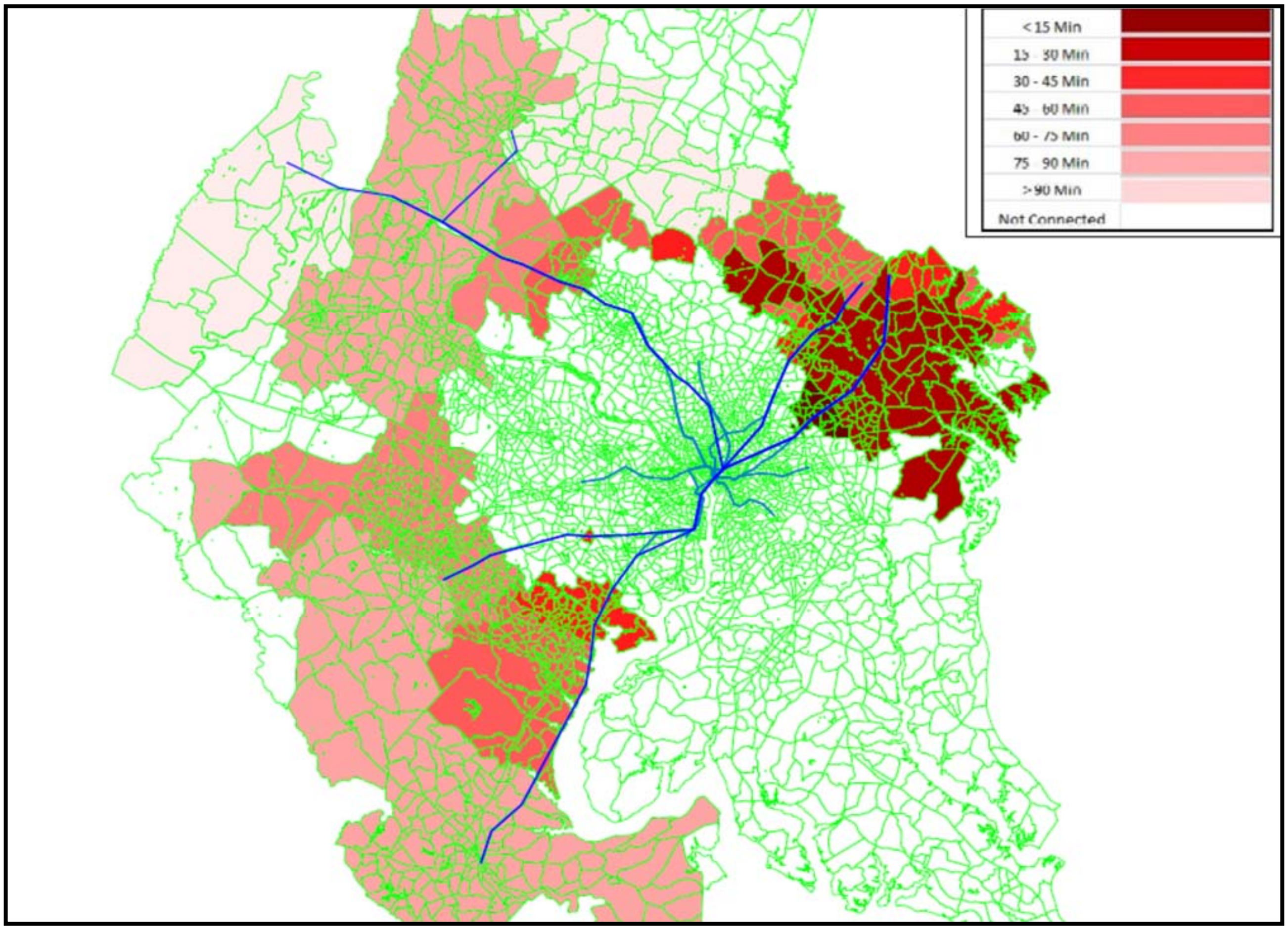


Figure 1.14 In-Vehicle Travel Time from Various Origin Zones to Zone 23 (continued)

e. PnR to Commuter Rail Mode



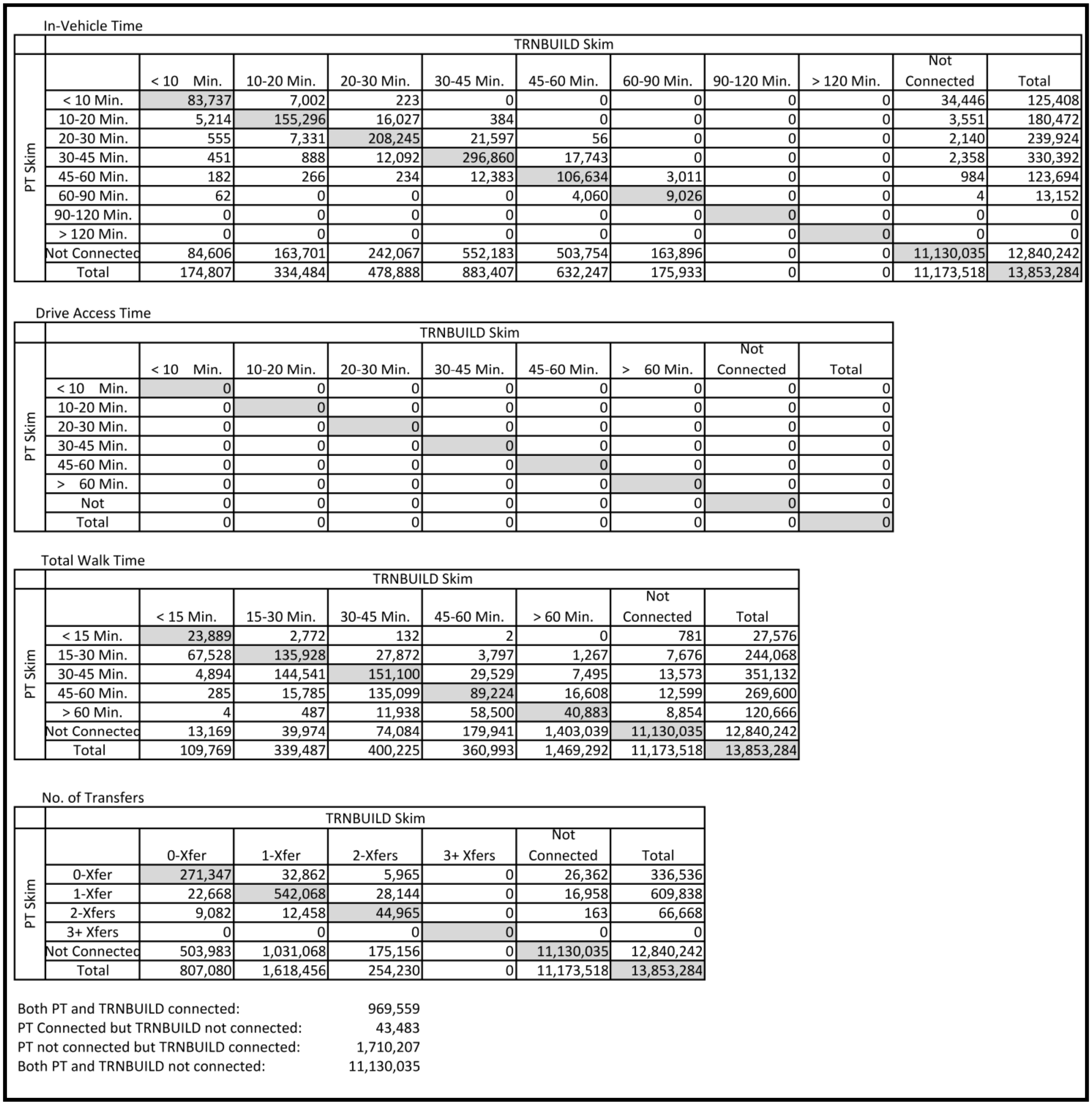
Comparison of PT and TB Skim Data

The skim data generated by the PT process were compared with those generated by the existing TB process. The 2015 transit skim files of the “2014 CLRP Conformity” scenario generated from the MWCOG Regional Model Version 2.3.57 were used in the analysis. The comparison for various submode/access-mode paths is summarized in Tables 1.8a to 1.8f. In each of the two-dimensional tables, the value in each cell is the number of i-j pairs with values of a skim variable that falls in the respective ranges of the skim data generated by the PT and TB processes. If the two sets of skim data are identical, all the values should appear in the diagonal cells only.

However, the two sets of skim data were derived from different processes. Also, the transit networks used to derive the skim data are not the same. It is thus expected that a certain degree of difference would exist between the two sets of data. Still, the tables reveal that most of i-j pairs are matched into the diagonal cells or cells next to them, indicating the high degree of compatibility between these sets of data. In general, the skim data for Metrorail and commuter rail modes are more compatible than the bus skim data, since for rail modes, the path choices are limited and the serviced characteristics (e.g., frequencies, travel time, etc.) are more accurately represented in the coded networks.

Table 1.8 Comparison of PT and TRNBUILD Transit Skim Data

a. Walk to Metrorail Mode



In-Vehicle Time

		TRNBUILD Skim									
		< 10 Min.	10-20 Min.	20-30 Min.	30-45 Min.	45-60 Min.	60-90 Min.	90-120 Min.	> 120 Min.	Not Connected	Total
PT Skim	< 10 Min.	83,737	7,002	223	0	0	0	0	0	34,446	125,408
	10-20 Min.	5,214	155,296	16,027	384	0	0	0	0	3,551	180,472
	20-30 Min.	555	7,331	208,245	21,597	56	0	0	0	2,140	239,924
	30-45 Min.	451	888	12,092	296,860	17,743	0	0	0	2,358	330,392
	45-60 Min.	182	266	234	12,383	106,634	3,011	0	0	984	123,694
	60-90 Min.	62	0	0	0	4,060	9,026	0	0	4	13,152
	90-120 Min.	0	0	0	0	0	0	0	0	0	0
	> 120 Min.	0	0	0	0	0	0	0	0	0	0
	Not Connected	84,606	163,701	242,067	552,183	503,754	163,896	0	0	11,130,035	12,840,242
	Total	174,807	334,484	478,888	883,407	632,247	175,933	0	0	11,173,518	13,853,284

Drive Access Time

		TRNBUILD Skim							
		< 10 Min.	10-20 Min.	20-30 Min.	30-45 Min.	45-60 Min.	> 60 Min.	Not Connected	Total
PT Skim	< 10 Min.	0	0	0	0	0	0	0	0
	10-20 Min.	0	0	0	0	0	0	0	0
	20-30 Min.	0	0	0	0	0	0	0	0
	30-45 Min.	0	0	0	0	0	0	0	0
	45-60 Min.	0	0	0	0	0	0	0	0
	> 60 Min.	0	0	0	0	0	0	0	0
	Not	0	0	0	0	0	0	0	0
	Total	0	0	0	0	0	0	0	0

Total Walk Time

		TRNBUILD Skim						
		< 15 Min.	15-30 Min.	30-45 Min.	45-60 Min.	> 60 Min.	Not Connected	Total
PT Skim	< 15 Min.	23,889	2,772	132	2	0	781	27,576
	15-30 Min.	67,528	135,928	27,872	3,797	1,267	7,676	244,068
	30-45 Min.	4,894	144,541	151,100	29,529	7,495	13,573	351,132
	45-60 Min.	285	15,785	135,099	89,224	16,608	12,599	269,600
	> 60 Min.	4	487	11,938	58,500	40,883	8,854	120,666
	Not Connected	13,169	39,974	74,084	179,941	1,403,039	11,130,035	12,840,242
	Total	109,769	339,487	400,225	360,993	1,469,292	11,173,518	13,853,284

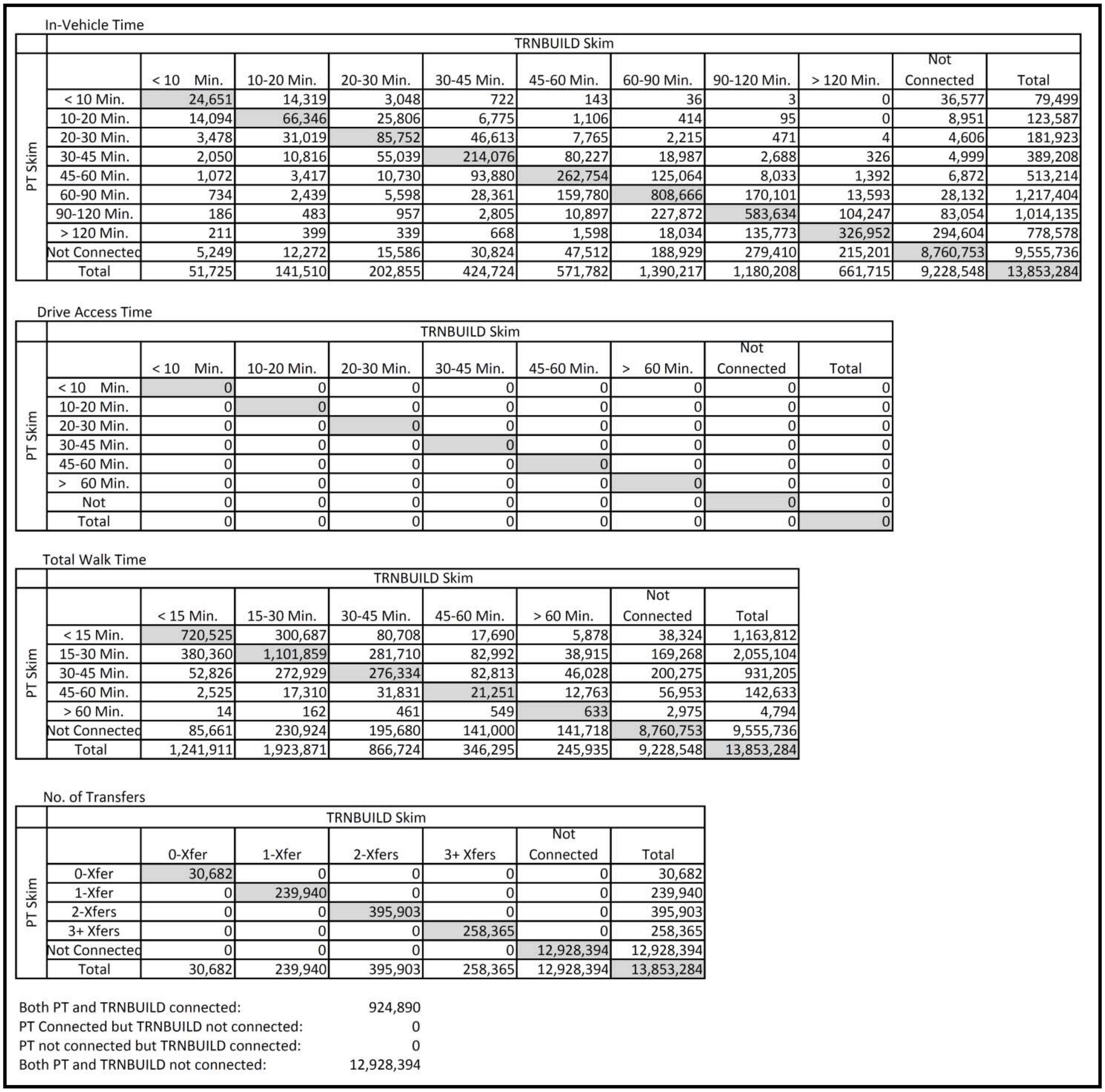
No. of Transfers

		TRNBUILD Skim					
		0-Xfer	1-Xfer	2-Xfers	3+ Xfers	Not Connected	Total
PT Skim	0-Xfer	271,347	32,862	5,965	0	26,362	336,536
	1-Xfer	22,668	542,068	28,144	0	16,958	609,838
	2-Xfers	9,082	12,458	44,965	0	163	66,668
	3+ Xfers	0	0	0	0	0	0
	Not Connected	503,983	1,031,068	175,156	0	11,130,035	12,840,242
	Total	807,080	1,618,456	254,230	0	11,173,518	13,853,284

Both PT and TRNBUILD connected:	969,559
PT Connected but TRNBUILD not connected:	43,483
PT not connected but TRNBUILD connected:	1,710,207
Both PT and TRNBUILD not connected:	11,130,035

Table 1.8 Comparison of PT and TRNBUILD Transit Skim Data (continued)

b. Walk to All Bus Mode



In-Vehicle Time

		TRNBUILD Skim									
		< 10 Min.	10-20 Min.	20-30 Min.	30-45 Min.	45-60 Min.	60-90 Min.	90-120 Min.	> 120 Min.	Not Connected	Total
PT Skim	< 10 Min.	24,651	14,319	3,048	722	143	36	3	0	36,577	79,499
	10-20 Min.	14,094	66,346	25,806	6,775	1,106	414	95	0	8,951	123,587
	20-30 Min.	3,478	31,019	85,752	46,613	7,765	2,215	471	4	4,606	181,923
	30-45 Min.	2,050	10,816	55,039	214,076	80,227	18,987	2,688	326	4,999	389,208
	45-60 Min.	1,072	3,417	10,730	93,880	262,754	125,064	8,033	1,392	6,872	513,214
	60-90 Min.	734	2,439	5,598	28,361	159,780	808,666	170,101	13,593	28,132	1,217,404
	90-120 Min.	186	483	957	2,805	10,897	227,872	583,634	104,247	83,054	1,014,135
	> 120 Min.	211	399	339	668	1,598	18,034	135,773	326,952	294,604	778,578
	Not Connected	5,249	12,272	15,586	30,824	47,512	188,929	279,410	215,201	8,760,753	9,555,736
	Total	51,725	141,510	202,855	424,724	571,782	1,390,217	1,180,208	661,715	9,228,548	13,853,284

Drive Access Time

		TRNBUILD Skim							
		< 10 Min.	10-20 Min.	20-30 Min.	30-45 Min.	45-60 Min.	> 60 Min.	Not Connected	Total
PT Skim	< 10 Min.	0	0	0	0	0	0	0	0
	10-20 Min.	0	0	0	0	0	0	0	0
	20-30 Min.	0	0	0	0	0	0	0	0
	30-45 Min.	0	0	0	0	0	0	0	0
	45-60 Min.	0	0	0	0	0	0	0	0
	> 60 Min.	0	0	0	0	0	0	0	0
	Not	0	0	0	0	0	0	0	0
	Total	0	0	0	0	0	0	0	0

Total Walk Time

		TRNBUILD Skim						
		< 15 Min.	15-30 Min.	30-45 Min.	45-60 Min.	> 60 Min.	Not Connected	Total
PT Skim	< 15 Min.	720,525	300,687	80,708	17,690	5,878	38,324	1,163,812
	15-30 Min.	380,360	1,101,859	281,710	82,992	38,915	169,268	2,055,104
	30-45 Min.	52,826	272,929	276,334	82,813	46,028	200,275	931,205
	45-60 Min.	2,525	17,310	31,831	21,251	12,763	56,953	142,633
	> 60 Min.	14	162	461	549	633	2,975	4,794
	Not Connected	85,661	230,924	195,680	141,000	141,718	8,760,753	9,555,736
	Total	1,241,911	1,923,871	866,724	346,295	245,935	9,228,548	13,853,284

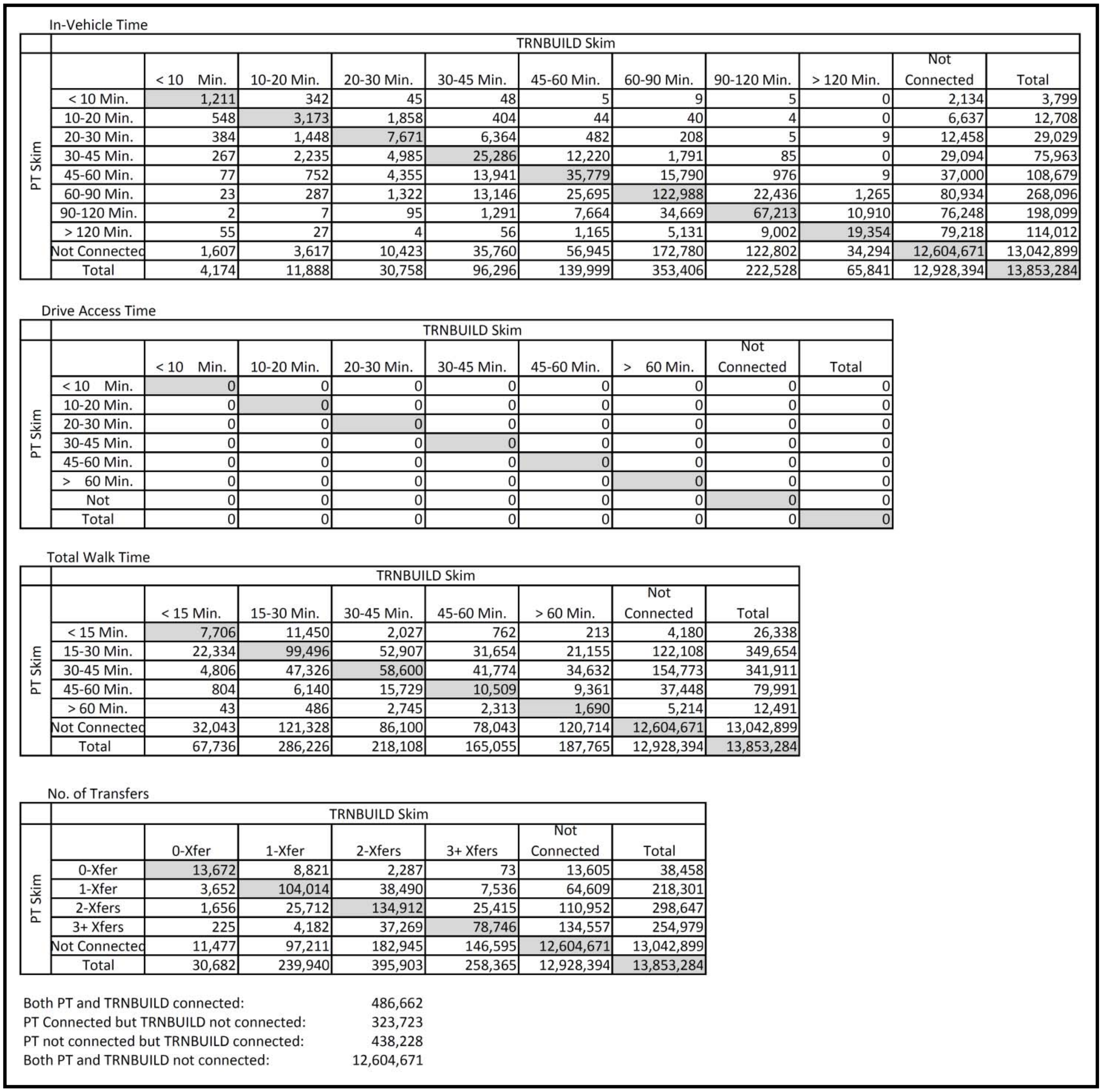
No. of Transfers

		TRNBUILD Skim					
		0-Xfer	1-Xfer	2-Xfers	3+ Xfers	Not Connected	Total
PT Skim	0-Xfer	30,682	0	0	0	0	30,682
	1-Xfer	0	239,940	0	0	0	239,940
	2-Xfers	0	0	395,903	0	0	395,903
	3+ Xfers	0	0	0	258,365	0	258,365
	Not Connected	0	0	0	0	12,928,394	12,928,394
	Total	30,682	239,940	395,903	258,365	12,928,394	13,853,284

Both PT and TRNBUILD connected:	924,890
PT Connected but TRNBUILD not connected:	0
PT not connected but TRNBUILD connected:	0
Both PT and TRNBUILD not connected:	12,928,394

Table 1.8 Comparison of PT and TRNBUILD Transit Skim Data (continued)

c. Walk to Commuter Rail Mode



In-Vehicle Time

		TRNBUILD Skim									
		< 10 Min.	10-20 Min.	20-30 Min.	30-45 Min.	45-60 Min.	60-90 Min.	90-120 Min.	> 120 Min.	Not Connected	Total
PT Skim	< 10 Min.	1,211	342	45	48	5	9	5	0	2,134	3,799
	10-20 Min.	548	3,173	1,858	404	44	40	4	0	6,637	12,708
	20-30 Min.	384	1,448	7,671	6,364	482	208	5	9	12,458	29,029
	30-45 Min.	267	2,235	4,985	25,286	12,220	1,791	85	0	29,094	75,963
	45-60 Min.	77	752	4,355	13,941	35,779	15,790	976	9	37,000	108,679
	60-90 Min.	23	287	1,322	13,146	25,695	122,988	22,436	1,265	80,934	268,096
	90-120 Min.	2	7	95	1,291	7,664	34,669	67,213	10,910	76,248	198,099
	> 120 Min.	55	27	4	56	1,165	5,131	9,002	19,354	79,218	114,012
	Not Connected	1,607	3,617	10,423	35,760	56,945	172,780	122,802	34,294	12,604,671	13,042,899
	Total	4,174	11,888	30,758	96,296	139,999	353,406	222,528	65,841	12,928,394	13,853,284

Drive Access Time

		TRNBUILD Skim							
		< 10 Min.	10-20 Min.	20-30 Min.	30-45 Min.	45-60 Min.	> 60 Min.	Not Connected	Total
PT Skim	< 10 Min.	0	0	0	0	0	0	0	0
	10-20 Min.	0	0	0	0	0	0	0	0
	20-30 Min.	0	0	0	0	0	0	0	0
	30-45 Min.	0	0	0	0	0	0	0	0
	45-60 Min.	0	0	0	0	0	0	0	0
	> 60 Min.	0	0	0	0	0	0	0	0
	Not	0	0	0	0	0	0	0	0
	Total	0	0	0	0	0	0	0	0

Total Walk Time

		TRNBUILD Skim						
		< 15 Min.	15-30 Min.	30-45 Min.	45-60 Min.	> 60 Min.	Not Connected	Total
PT Skim	< 15 Min.	7,706	11,450	2,027	762	213	4,180	26,338
	15-30 Min.	22,334	99,496	52,907	31,654	21,155	122,108	349,654
	30-45 Min.	4,806	47,326	58,600	41,774	34,632	154,773	341,911
	45-60 Min.	804	6,140	15,729	10,509	9,361	37,448	79,991
	> 60 Min.	43	486	2,745	2,313	1,690	5,214	12,491
	Not Connected	32,043	121,328	86,100	78,043	120,714	12,604,671	13,042,899
	Total	67,736	286,226	218,108	165,055	187,765	12,928,394	13,853,284

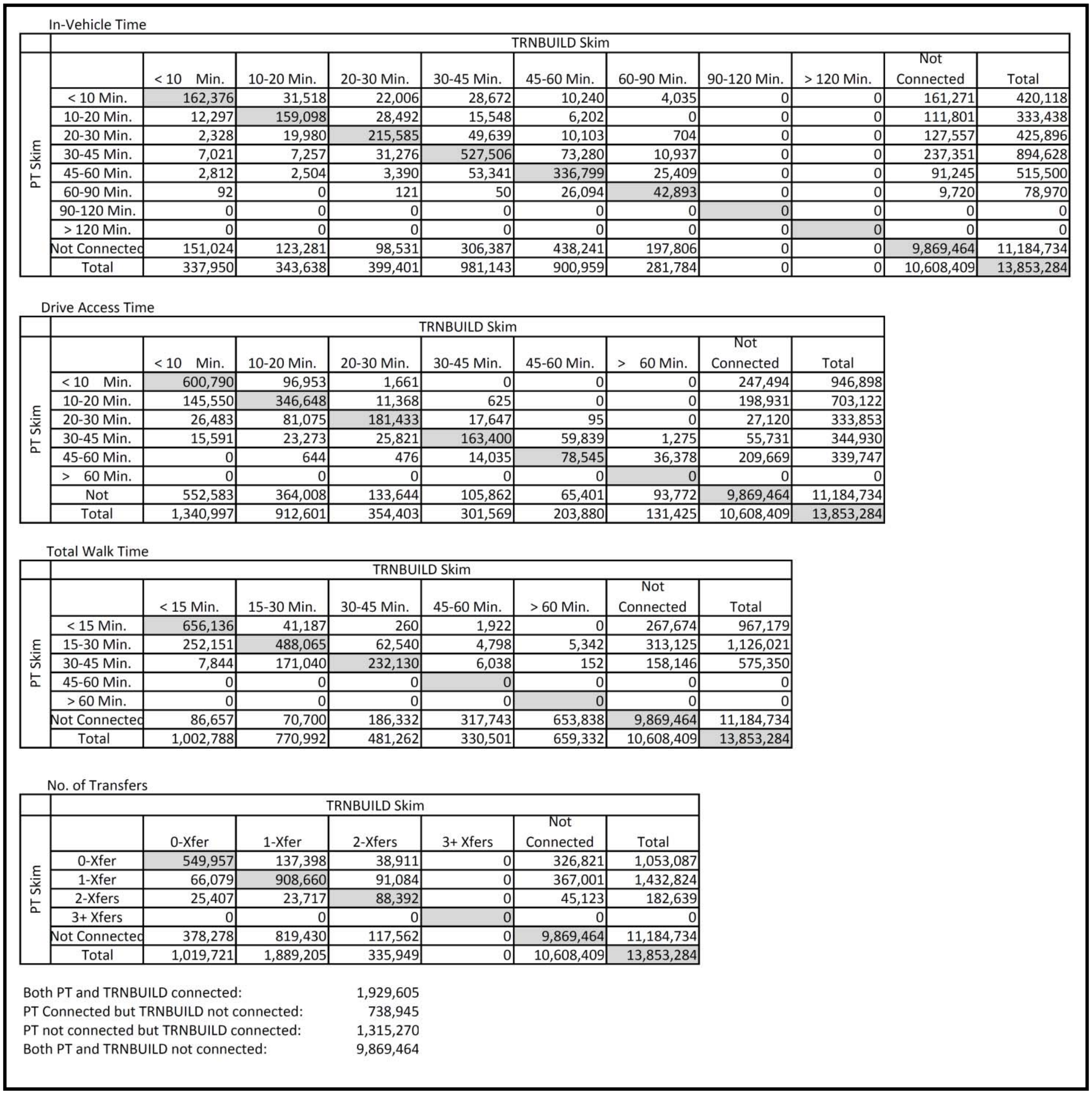
No. of Transfers

		TRNBUILD Skim					
		0-Xfer	1-Xfer	2-Xfers	3+ Xfers	Not Connected	Total
PT Skim	0-Xfer	13,672	8,821	2,287	73	13,605	38,458
	1-Xfer	3,652	104,014	38,490	7,536	64,609	218,301
	2-Xfers	1,656	25,712	134,912	25,415	110,952	298,647
	3+ Xfers	225	4,182	37,269	78,746	134,557	254,979
	Not Connected	11,477	97,211	182,945	146,595	12,604,671	13,042,899
	Total	30,682	239,940	395,903	258,365	12,928,394	13,853,284

Both PT and TRNBUILD connected:	486,662
PT Connected but TRNBUILD not connected:	323,723
PT not connected but TRNBUILD connected:	438,228
Both PT and TRNBUILD not connected:	12,604,671

Table 1.8 Comparison of PT and TRNBUILD Transit Skim Data (continued)

d. PnR to Metrorail Mode



In-Vehicle Time

		TRNBUILD Skim									
		< 10 Min.	10-20 Min.	20-30 Min.	30-45 Min.	45-60 Min.	60-90 Min.	90-120 Min.	> 120 Min.	Not Connected	Total
PT Skim	< 10 Min.	162,376	31,518	22,006	28,672	10,240	4,035	0	0	161,271	420,118
	10-20 Min.	12,297	159,098	28,492	15,548	6,202	0	0	0	111,801	333,438
	20-30 Min.	2,328	19,980	215,585	49,639	10,103	704	0	0	127,557	425,896
	30-45 Min.	7,021	7,257	31,276	527,506	73,280	10,937	0	0	237,351	894,628
	45-60 Min.	2,812	2,504	3,390	53,341	336,799	25,409	0	0	91,245	515,500
	60-90 Min.	92	0	121	50	26,094	42,893	0	0	9,720	78,970
	90-120 Min.	0	0	0	0	0	0	0	0	0	0
	> 120 Min.	0	0	0	0	0	0	0	0	0	0
	Not Connected	151,024	123,281	98,531	306,387	438,241	197,806	0	0	9,869,464	11,184,734
	Total	337,950	343,638	399,401	981,143	900,959	281,784	0	0	10,608,409	13,853,284

Drive Access Time

		TRNBUILD Skim							
		< 10 Min.	10-20 Min.	20-30 Min.	30-45 Min.	45-60 Min.	> 60 Min.	Not Connected	Total
PT Skim	< 10 Min.	600,790	96,953	1,661	0	0	0	247,494	946,898
	10-20 Min.	145,550	346,648	11,368	625	0	0	198,931	703,122
	20-30 Min.	26,483	81,075	181,433	17,647	95	0	27,120	333,853
	30-45 Min.	15,591	23,273	25,821	163,400	59,839	1,275	55,731	344,930
	45-60 Min.	0	644	476	14,035	78,545	36,378	209,669	339,747
	> 60 Min.	0	0	0	0	0	0	0	0
	Not	552,583	364,008	133,644	105,862	65,401	93,772	9,869,464	11,184,734
	Total	1,340,997	912,601	354,403	301,569	203,880	131,425	10,608,409	13,853,284

Total Walk Time

		TRNBUILD Skim						
		< 15 Min.	15-30 Min.	30-45 Min.	45-60 Min.	> 60 Min.	Not Connected	Total
PT Skim	< 15 Min.	656,136	41,187	260	1,922	0	267,674	967,179
	15-30 Min.	252,151	488,065	62,540	4,798	5,342	313,125	1,126,021
	30-45 Min.	7,844	171,040	232,130	6,038	152	158,146	575,350
	45-60 Min.	0	0	0	0	0	0	0
	> 60 Min.	0	0	0	0	0	0	0
	Not Connected	86,657	70,700	186,332	317,743	653,838	9,869,464	11,184,734
	Total	1,002,788	770,992	481,262	330,501	659,332	10,608,409	13,853,284

No. of Transfers

		TRNBUILD Skim					
		0-Xfer	1-Xfer	2-Xfers	3+ Xfers	Not Connected	Total
PT Skim	0-Xfer	549,957	137,398	38,911	0	326,821	1,053,087
	1-Xfer	66,079	908,660	91,084	0	367,001	1,432,824
	2-Xfers	25,407	23,717	88,392	0	45,123	182,639
	3+ Xfers	0	0	0	0	0	0
	Not Connected	378,278	819,430	117,562	0	9,869,464	11,184,734
	Total	1,019,721	1,889,205	335,949	0	10,608,409	13,853,284

Both PT and TRNBUILD connected:	1,929,605
PT Connected but TRNBUILD not connected:	738,945
PT not connected but TRNBUILD connected:	1,315,270
Both PT and TRNBUILD not connected:	9,869,464

Table 1.8 Comparison of PT and TRNBUILD Transit Skim Data (continued)

e. PnR to All Bus Mode

In-Vehicle Time

		TRNBUILD Skim									
		< 10 Min.	10-20 Min.	20-30 Min.	30-45 Min.	45-60 Min.	60-90 Min.	90-120 Min.	> 120 Min.	Not Connected	Total
PT Skim	< 10 Min.	29,331	11,524	6,115	5,126	1,842	755	192	6	24,909	79,800
	10-20 Min.	9,340	31,431	17,581	10,930	5,464	3,784	476	31	60,225	139,262
	20-30 Min.	4,378	13,397	32,305	27,055	10,329	9,215	1,619	263	75,739	174,300
	30-45 Min.	3,451	8,423	24,312	92,187	53,441	30,584	5,480	1,126	155,582	374,586
	45-60 Min.	2,082	4,422	8,669	46,981	141,150	99,577	15,956	3,359	202,195	524,391
	60-90 Min.	603	1,812	3,504	19,812	93,680	494,796	165,605	27,470	453,113	1,260,395
	90-120 Min.	79	92	313	1,514	7,734	129,123	407,531	122,618	364,543	1,033,547
	> 120 Min.	296	54	116	156	484	9,677	86,290	293,470	409,360	799,903
	Not Connected	10,717	8,022	9,325	15,696	22,013	85,424	146,670	176,467	8,992,766	9,467,100
	Total	60,277	79,177	102,240	219,457	336,137	862,935	829,819	624,810	10,738,432	13,853,284

Drive Access Time

		TRNBUILD Skim							
		< 10 Min.	10-20 Min.	20-30 Min.	30-45 Min.	45-60 Min.	> 60 Min.	Not Connected	Total
PT Skim	< 10 Min.	2,183,785	441,274	15,459	0	0	0	1,745,666	4,386,184
	10-20 Min.	0	0	0	0	0	0	0	0
	20-30 Min.	0	0	0	0	0	0	0	0
	30-45 Min.	0	0	0	0	0	0	0	0
	45-60 Min.	0	0	0	0	0	0	0	0
	> 60 Min.	0	0	0	0	0	0	0	0
	Not	324,064	136,057	11,297	2,916	0	0	8,992,766	9,467,100
	Total	2,507,849	577,331	26,756	2,916	0	0	10,738,432	13,853,284

Total Walk Time

		TRNBUILD Skim						
		< 15 Min.	15-30 Min.	30-45 Min.	45-60 Min.	> 60 Min.	Not Connected	Total
PT Skim	< 15 Min.	1,662,685	270,362	44,771	7,383	3,618	1,179,010	3,167,829
	15-30 Min.	242,622	304,101	55,539	14,297	8,627	515,916	1,141,102
	30-45 Min.	3,865	10,757	8,205	1,916	1,539	50,496	76,778
	45-60 Min.	25	52	63	48	43	244	475
	> 60 Min.	0	0	0	0	0	0	0
	Not Connected	259,360	113,611	53,754	25,353	22,256	8,992,766	9,467,100
	Total	2,168,557	698,883	162,332	48,997	36,083	10,738,432	13,853,284

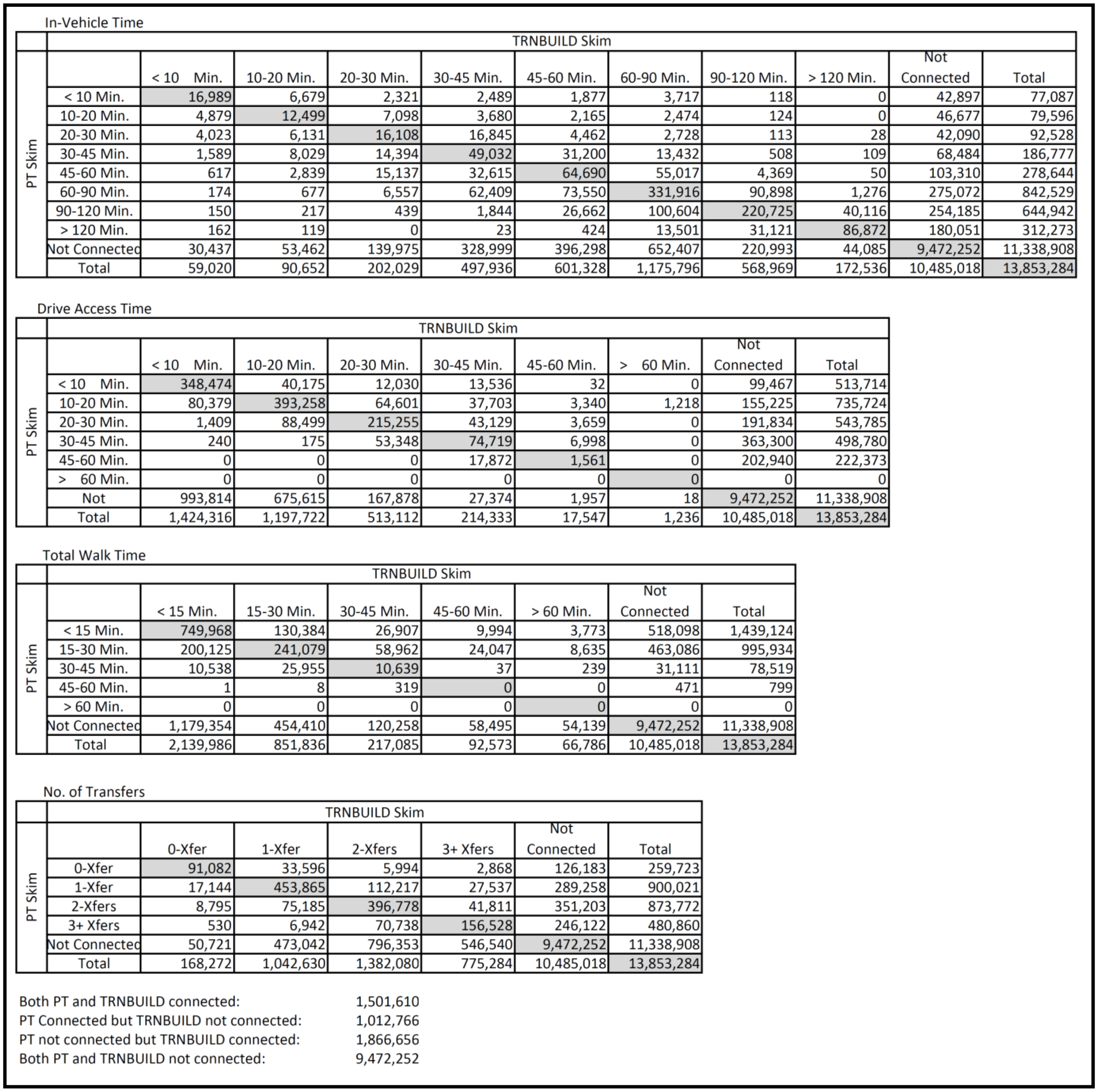
No. of Transfers

		TRNBUILD Skim					
		0-Xfer	1-Xfer	2-Xfers	3+ Xfers	Not Connected	Total
PT Skim	0-Xfer	169,313	87,708	20,670	1,932	140,707	420,330
	1-Xfer	55,431	522,149	190,335	32,639	401,389	1,201,943
	2-Xfers	11,330	131,593	640,584	199,581	609,382	1,592,470
	3+ Xfers	1,205	19,111	130,448	426,489	594,188	1,171,441
	Not Connected	28,709	63,173	106,868	275,584	8,992,766	9,467,100
	Total	265,988	823,734	1,088,905	936,225	10,738,432	13,853,284

Both PT and TRNBUILD connected:	2,640,518
PT Connected but TRNBUILD not connected:	1,745,666
PT not connected but TRNBUILD connected:	474,334
Both PT and TRNBUILD not connected:	8,992,766

Table 1.8 Comparison of PT and TRNBUILD Transit Skim Data (continued)

f. PnR to Commuter Rail Mode



In-Vehicle Time

PT Skim	TRNBUILD Skim < 10 Min.	10-20 Min.	20-30 Min.	30-45 Min.	45-60 Min.	60-90 Min.	90-120 Min.	> 120 Min.	Not Connected	Total
< 10 Min.	16,989	6,679	2,321	2,489	1,877	3,717	118	0	42,897	77,087
10-20 Min.	4,879	12,499	7,098	3,680	2,165	2,474	124	0	46,677	79,596
20-30 Min.	4,023	6,131	16,108	16,845	4,462	2,728	113	28	42,090	92,528
30-45 Min.	1,589	8,029	14,394	49,032	31,200	13,432	508	109	68,484	186,777
45-60 Min.	617	2,839	15,137	32,615	64,690	55,017	4,369	50	103,310	278,644
60-90 Min.	174	677	6,557	62,409	73,550	331,916	90,898	1,276	275,072	842,529
90-120 Min.	150	217	439	1,844	26,662	100,604	220,725	40,116	254,185	644,942
> 120 Min.	162	119	0	23	424	13,501	31,121	86,872	180,051	312,273
Not Connected	30,437	53,462	139,975	328,999	396,298	652,407	220,993	44,085	9,472,252	11,338,908
Total	59,020	90,652	202,029	497,936	601,328	1,175,796	568,969	172,536	10,485,018	13,853,284

Drive Access Time

PT Skim	TRNBUILD Skim < 10 Min.	10-20 Min.	20-30 Min.	30-45 Min.	45-60 Min.	> 60 Min.	Not Connected	Total
< 10 Min.	348,474	40,175	12,030	13,536	32	0	99,467	513,714
10-20 Min.	80,379	393,258	64,601	37,703	3,340	1,218	155,225	735,724
20-30 Min.	1,409	88,499	215,255	43,129	3,659	0	191,834	543,785
30-45 Min.	240	175	53,348	74,719	6,998	0	363,300	498,780
45-60 Min.	0	0	0	17,872	1,561	0	202,940	222,373
> 60 Min.	0	0	0	0	0	0	0	0
Not	993,814	675,615	167,878	27,374	1,957	18	9,472,252	11,338,908
Total	1,424,316	1,197,722	513,112	214,333	17,547	1,236	10,485,018	13,853,284

Total Walk Time

PT Skim	TRNBUILD Skim < 15 Min.	15-30 Min.	30-45 Min.	45-60 Min.	> 60 Min.	Not Connected	Total
< 15 Min.	749,968	130,384	26,907	9,994	3,773	518,098	1,439,124
15-30 Min.	200,125	241,079	58,962	24,047	8,635	463,086	995,934
30-45 Min.	10,538	25,955	10,639	37	239	31,111	78,519
45-60 Min.	1	8	319	0	0	471	799
> 60 Min.	0	0	0	0	0	0	0
Not Connected	1,179,354	454,410	120,258	58,495	54,139	9,472,252	11,338,908
Total	2,139,986	851,836	217,085	92,573	66,786	10,485,018	13,853,284

No. of Transfers

PT Skim	TRNBUILD Skim 0-Xfer	1-Xfer	2-Xfers	3+ Xfers	Not Connected	Total
0-Xfer	91,082	33,596	5,994	2,868	126,183	259,723
1-Xfer	17,144	453,865	112,217	27,537	289,258	900,021
2-Xfers	8,795	75,185	396,778	41,811	351,203	873,772
3+ Xfers	530	6,942	70,738	156,528	246,122	480,860
Not Connected	50,721	473,042	796,353	546,540	9,472,252	11,338,908
Total	168,272	1,042,630	1,382,080	775,284	10,485,018	13,853,284

Both PT and TRNBUILD connected:	1,501,610
PT Connected but TRNBUILD not connected:	1,012,766
PT not connected but TRNBUILD connected:	1,866,656
Both PT and TRNBUILD not connected:	9,472,252

The walk-access skim data as summarized in Tables 1.8a to 1.8c reveal that more i-j pairs are connected by the TB process than by the PT process. This is because the TB process allows paths with a long walk access distance or a long in-vehicle travel time to be generated. As indicated in Table 1.8a, for “walk to Metrorail only” paths, most of i-j pairs that are connected in the TB process but not in the PT process are those with total walk time greater than 60 minutes. These i-j pairs, with long access distance to Metrorail, should actually be better served by “walk-to-bus/Metrorail” path. Thus, even though the TB process generates these paths, most of these paths will not be assigned any trips, and thus do not have major impacts on the model results. For the comparison of the “walk-to-all-bus” paths, as shown in Table 1.8b, most of paths that are generated by the TB process, but not by the PT process, are those with total in-vehicle-times greater than 60 minutes. These i-j pairs are either better served by other transit submodes or not in the major transit markets (e.g., not in the same transit service corridor). Therefore, very few passengers would take the “bus to all-bus” paths to travel between these i-j pairs.

For the drive-access paths, Table 1.7 reveals than the PT process generates more “drive to all bus” paths than the TB process. It is because the TB process restricts the paths to be built only for the paths of i-j pairs with drive access times less than 10 minutes. The PT process allows drive-access time up to 20 minutes. The maximum drive-access time of 20 minutes is set in the PT process with the assumption that some commuter bus passengers are willing to drive longer distances to access commuter bus stations. This assumption could be examined if survey data are available for further analysis.

Conclusions

In this subtask, a set of Cube PT scripts were developed to perform the transit path building, skimming, and transit assignment processes. The PT scripts are consolidated in the way that each script performs the PT process for all the submode and access-mode segments and for the two analysis periods. This significantly reduces the amount of effort for maintaining or updating the scripts files, as well as improves the efficiency of performing the PT processes. These script files were tested with the 2015 transit network data. Also, the PT process generates the same set of skim data files with the same format as that generated by the current TB process.

The transit network data and skim data generated by the PT process were examined for their reasonableness in several ways. First, the nontransit access legs and transfer legs generated by the PT process were visually checked if they were generated properly. Second, a series of thematic maps were generated to display the PT estimated in-vehicle-times from various traffic zones to a traffic zone in downtown for various types of submode/access mode paths. Finally, the PT-generated skim data were compared with those generated by the TB process implemented in the current MWCOG model. The examination reveals that the network and skim data generated from the PT process are reasonable, and also compatible with the data generated by the existing TB process.

With the implementation and test of the PT scripts, MWCOG can move forward to incorporate the PT process into the existing MWCOG Model System. However, further study needs to be conducted to examine how the new PT process would affect the model results, in particular, the results of the mode choice process and transit assignment process. Also, some comprehensive validation of the PT process should be conducted with observed transit passenger on-board data of all transit modes.

1.6 Perform Transit Network Coding Enhancements (TPB)

This subtask was the primary responsibility of TPB staff and is documented separately.

1.7 Include Transit Drive Access Trips into Highway Assignment

This subtask involved providing Cube scripts to TPB staff.

1.8 Add External-to-Internal Transit Trips (TPB)

This subtask was the primary responsibility of TPB staff and is documented separately.

1.9 Revise Bus Speed Linkage to Highway Speeds

Overview

CS was tasked with making recommendations on improving the methodology of representing bus speeds in the MWCOG/TPB travel demand model. CS addressed this mission by: 1) reviewing the state of the practice in regional travel demand models in the country's largest MPOs; 2) performing a corridor speed analysis using data provided by MWCOG/TPB; and 3) developing recommendations. These are all reported on within this report section.

Since the Fiscal Year 2010 Task Report (Cambridge Systematics 2010) included a review of practice in this topic area, we began the latest effort by checking on changes in the regions looked at last time. This check confirmed there are still three main approaches being used: 1) bus speed curves, 2) regression models, and 3) highway time/speed with bus delay.

Each region exhibits unique characteristics that require agencies to adapt to their environments. So, no one-size-fits-all strategy exists with regard to modeling of transit speeds. The specific method used depends on how various elements of transit time are explicitly or implicitly represented, including:

- Auto travel speed/time on roadway network;
- Acceleration/deceleration of transit vehicles;
- Dwell time at stops/stations; and
- Recovery time at the end of each trip.

There are some variations on how the relationships between highway travel time and mixed-flow transit travel time are represented in the MPO models reviewed. For transit service operating on exclusive right-of-way, such as fixed guideway or dedicated bus lanes, it is state-of-the-practice to directly code the typical transit travel time or speed. For transit operating in mixed traffic, the MPO models reviewed contain a linkage between the highway travel time and the travel time of transit in the shared right-of-way.

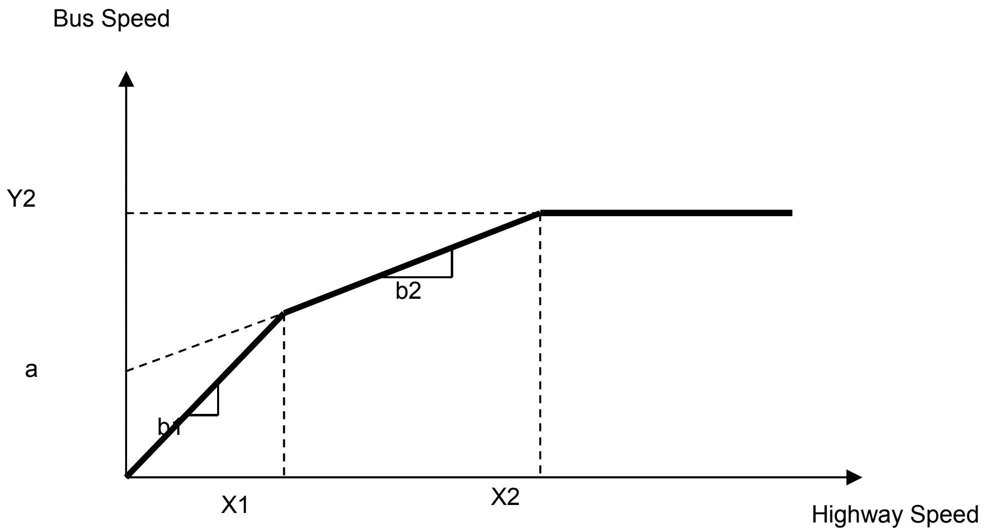
For this latest review, CS focused on adding examples from models updated since the last CS transit speed review was performed, representing incremental improvements to already existing transit speed modeling practices. The following subsections discuss the Triangle Regional Model (Raleigh, North Carolina), the Atlanta Regional Council Model, the Houston-Galveston Area Council Model, and the Baltimore Metropolitan Council Model.

Triangle Regional Model

The Triangle Regional Model (TRM Version 5 and Version 6) algorithmically calculates the bus speed from the highway speed using local parameters (Triangle Regional Model Service Bureau 2012). In the TRM network, each link is assigned a facility type and a bus speed category according to the facility look up table. There are nine bus speed categories, one for each combination of area type (urban, suburban and rural) and facility type (freeway, arterial and local). Each bus speed category has two bus speed equations (18 bus speed equations in total), one for peak period (PK) and one for off-peak (OP). The equation information is stored in the file of "BusSpeed_Equations.bin" of the model. On transit only links, specific speed values are coded, instead of the calculated speed based on the equations.

A typical bus speed equation used in TRM is visualized in Figure 1.15. It consists of three line segments: at low highway speed, it is a line crossing the origin; at medium highway speed, it is a line with a certain intercept; and at high highway speed, it is horizontal and the bus speed is independent of the highway speed. For the peak periods, the highway speed refers to congested highway speed; and for off-peak, the highway speed refers to free-flow highway speed. A bus speed equation is defined by 6 parameters: $X1$, $X2$, $b1$, $b2$, $Y2$ and a (a can be negative), as shown in Figure 1.15, where $b1$ and $b2$ are slopes and a is an intercept. These parameters were obtained by conducting linear regressions to observed highway and bus speeds from the year-2000 data.

Figure 1.15 Visualization of Bus Speed Equations



Atlanta Regional Council Model

Documentation for the Atlanta Regional Council (ARC) model states that the MPO has developed an empirical model to relate bus speed to congested highway speed (Atlanta Regional Commission 2011). The previous model included a lookup table with a constant bus speed for each area type and facility type. These speeds were independent of highway speed. Their stated objective for updating this aspect of the model "was to add highway congested speed into the lookup table and change each cell of the table into a dynamic function." The constant speed was replaced with a curve for each area type and facility type combination relating bus speed to congested highway speed. They found this approach closely approximated observed operational speed. The resulting functions are linear, following the equation below:

$$\text{Bus speed} = a\ (\text{congested highway speed}) + b$$

Where both *a* and *b* are parameters closely related to bus cruise speed, frequency of stops, and dwell times at stations. This information was drawn from the MARTA and CCT bus schedules. The model took the factors as inputs allowing it to dynamically calculate bus speed based on the congested highway speed. The speeds therefore vary and "the model feedback loop is modified to reflect bus path building within every iteration." The values generated, including distance, time and speed, are output by bus route. The factors were calibrated by comparing the output to the matching bus line's schedule until the average error level was below five percent.

Houston-Galveston Area Council Regional Travel Model

The Houston-Galveston Area Council (H-GAC) model uses a set of functions to calculate travel time on each link in the network (Houston-Galveston Area Council 2012). These use automobile travel time and type and location of transit service. The three types of functions are: 1) assumed constant speed, 2) proportion of auto speed, or 3) congested travel time estimation. The function used is based on the context and time period. Type 3 is not used in off peak, but all three are used in the peak period.

Type 1 is a universally set constant transit speed. Type 2 multiplies the auto time by a factor for transit time. The Type 3 function uses a free-flow transit time and a factor calculated using the v/c ratio and a location-based constant. The general form of this function is:

$$t_c = t_{ff} \cdot \left(1 + \alpha \cdot \left({}^{v}/_{c}\right)\right)$$

Where t_{ff} is free-flow transit travel time, and α is a transit line specific factor. For equations applied to nonstop bus operations outside the CBD, $\alpha = 0.15$, but in all other cases $\alpha = 0.10$. The congested travel time is kept between a minimum (auto time) and a maximum (the time associated with 10 percent of the LOS E speed). This maximum time can put the bus speed at 3-5 mph for certain type of roads.

Baltimore Metropolitan Council Model

Baltimore Metropolitan Council (BMC) developed a formula process rather than route-specific data to simplify model development and to allow for use of dwell times to be calculated for new and rerouted bus lines (de Rouville 2009). They set out to see if "dwell times at stops would correlate to the density of the zone as measured by the area type variable used in the modeling process". It was assumed that high density areas tend to have heavier volumes of boarding and alighting passengers, while sparse areas had only light activities.

BMC used published Maryland Department of Transportation/Maryland Transit Administration (MDOT/MTA) transit schedules from year 2008 to compare with peak and off-peak travel times estimated by the model. In addition to a general overview, several urban and suburban bus routes were selected for a more detailed comparison in peak and off-peak times. Sections were selected and travel times were compared to highway travel time using the time-period specific estimated speed inputs.

Highway links were matched with a variable marking the area type of its location. This area type reflected a composite of residential and employment density, from the lowest to highest. Link-level precision was not possible due to too little data. Their solution was to take longer sections, applying an average area type and calculating an average delay per stop. This exercise showed little relationship between area type and delay per stop.

As a result of this process, BMC estimated a single average dwell time per stop for each time period for all area types. The dwell times are shown in Table 1.9.

Table 1.9 Average Dwell Time per Stop

	Peak	Off-Peak
Local Bus	0.673	0.652
QuickBus[a]	1.417	1.420

[a] MTA bus service with limited stops.

Due to the limited difference between peak and off-peak, model inputs were simplified to a dwell time per stop of 0.65 minutes for local buses and 1.4 minutes for limited stop services for all time periods.

Latest Considerations

For representation of bus travel times on roadway links shared with autos, current practice focuses on use of some functional relationship to the model-produced auto travel times on those links. Unfortunately, these approaches are somewhat dependent on a travel model's ability to reasonably predict auto travel times, which can be a challenge, particularly on arterial streets with lots of signalized intersections (where some streets have better signal coordination than others), or where local buses are making frequent stops to load/unload passengers.

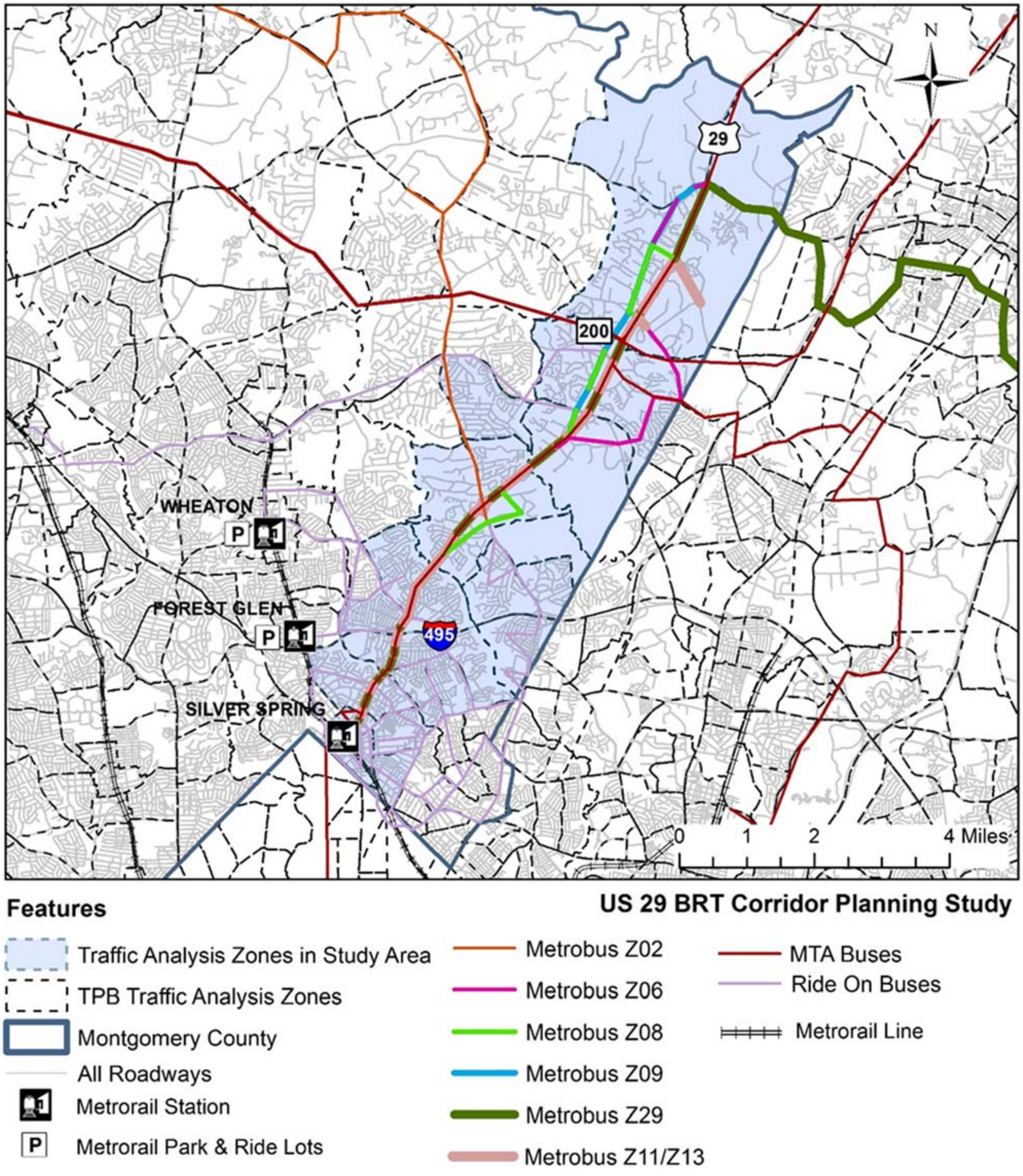
An alternative state-of-the-art approach is to use the actual scheduled bus travel times between stops via General Transit Feed Specification (GTFS) files to represent existing transit service over any specified time-of-day period, and a model-produced prediction of the changes in auto travel times to predict the future changes in transit travel times. Transit times include the moving-in-traffic times plus the extra time associated with making passenger stops, so the "change over time" relationship might not be directly proportional, and an increase in the model-predicted auto travel times may be necessary to compensate for that percent increase.

Growing access to "Big Data" sources (actual auto travel times and GTFS-based scheduled transit times) creates a potential to identify the relationship of changes in actual auto and actual transit travel times over time, as well as the differences between the actual versus scheduled transit travel times. This may result in additional approaches to linking bus speeds and highway speeds being available in the future.

Corridor Transit Speed Analysis in D.C. Region

As part of the model enhancement exercise, CS looked at existing bus and highway service information from available INRIX data and WMATA timepoint data for a specified time period for a selected corridor. The study team decided to test the U.S. 29 BRT project corridor in Montgomery County, Maryland, as shown in Figure 1.16. The portion of the U.S. 29 BRT corridor that the team looked at lies between the Burtonsville Park-and-Ride lot and the Silver Spring Transit Center, with a total length of approximately 14 miles. Metrobus, Montgomery Ride-On, and MTA commuter buses operate along and near U.S. 29. Figure 1.16 displays the boundaries of the studied U.S. 29 corridor.

Figure 1.16 U.S. 29 BRT Corridor Planning Study Area



Prior to this CS analysis of bus travel times on the U.S. 29 corridor, MWCOG/TPB put a substantial effort into examining existing bus and highway service information from the regional travel demand model (for the year 2015) at the transit line level of analysis and presented a memorandum to CS summarizing their observations (dated April 21, 2016). In the memo, MWCOG/TPB staff presented comparisons of transit and highway times and speeds for each bus line in the regional transit network. The transit information used reflects published schedule information extracted mostly from recent GTFS sources. The highway information is taken directly from the morning peak and midday restrained speeds developed through the standard highway assignment process.

The MWCOG/TPB staff analysis indicated that scheduled bus run times are generally longer than travel times derived from estimated/restrained highway speeds, except for longer bus routes (highway minutes greater than 100), which appeared to exhibit scheduled bus times that are less than the restrained highway times. MWCOG/TPB staff examined these specific observations and discovered that these faster buses are express/commuter bus services that use special facilities, such as the Inter-County Connector (ICC) in Maryland or the I-95 HOT lanes in Virginia. However, it is not known whether these seemingly faster buses result from inaccurate schedules, inaccurate restrained highway speeds from the assignment, or a combination of both.

For the CS effort, the average workday data from WMATA and INRIX were provided from the second one-half of 2015. Data comparisons of transit and highway times and speeds were performed to establish the relationship between the two sources of observed data. Figures 1.17 and 1.18 reflect peak times and speeds, and Figures 1.19 and 1.20 reflect off-peak times and speeds. The transit information was derived from published scheduled and observed information extracted from timepoint data for the routes running on the U.S. 29 corridor.

The scheduled times were then compared with actual bus and highway run times. Peak observed and scheduled transit times and speeds (Figures 1.17 and 1.18) indicated that times derived from schedules were generally shorter than actual run times, and, therefore, scheduled speeds were higher than actual bus running speeds. Overall, the correlations between scheduled and observed bus speeds were low; however, suggesting that scheduled bus speeds do not replicate observed running speeds precisely.

The same analysis for the off-peak period (Figures 1.19 and 1.20) yielded better results for speeds, although a few outliers still existed. Data variation for speeds was lower than that found in the peak period.

Figure 1.17 2015 Peak Transit Line Running Times: Schedule versus Actual

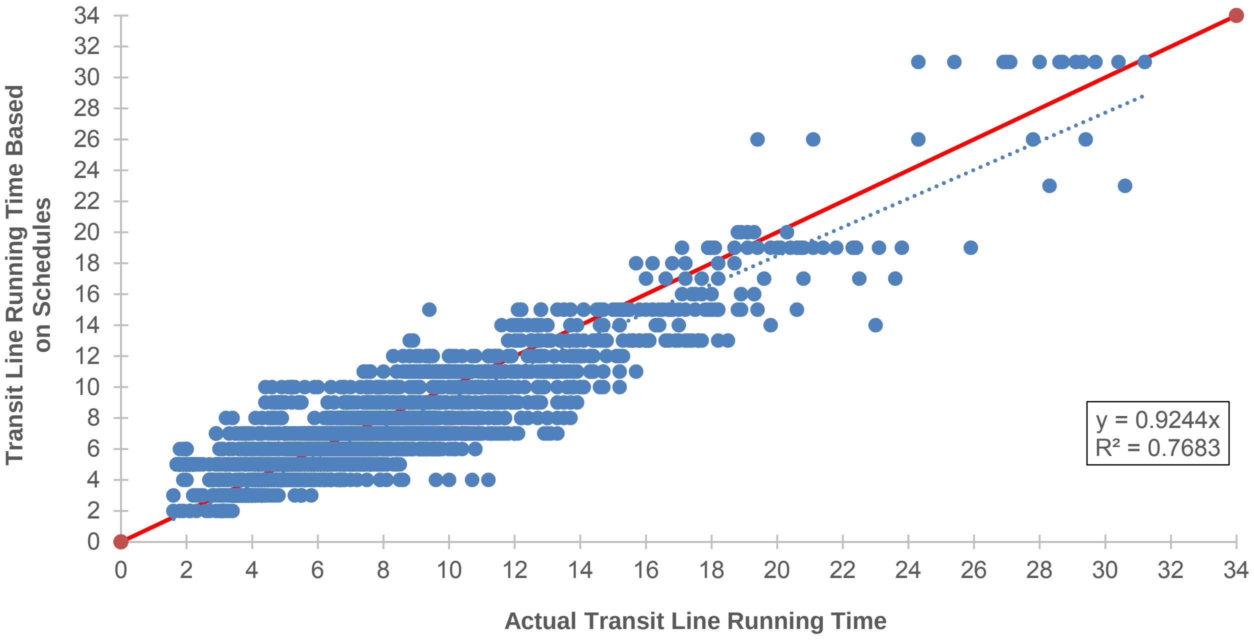


Figure 1.18 2015 Peak Transit Line Running Speed: Schedule versus Actual

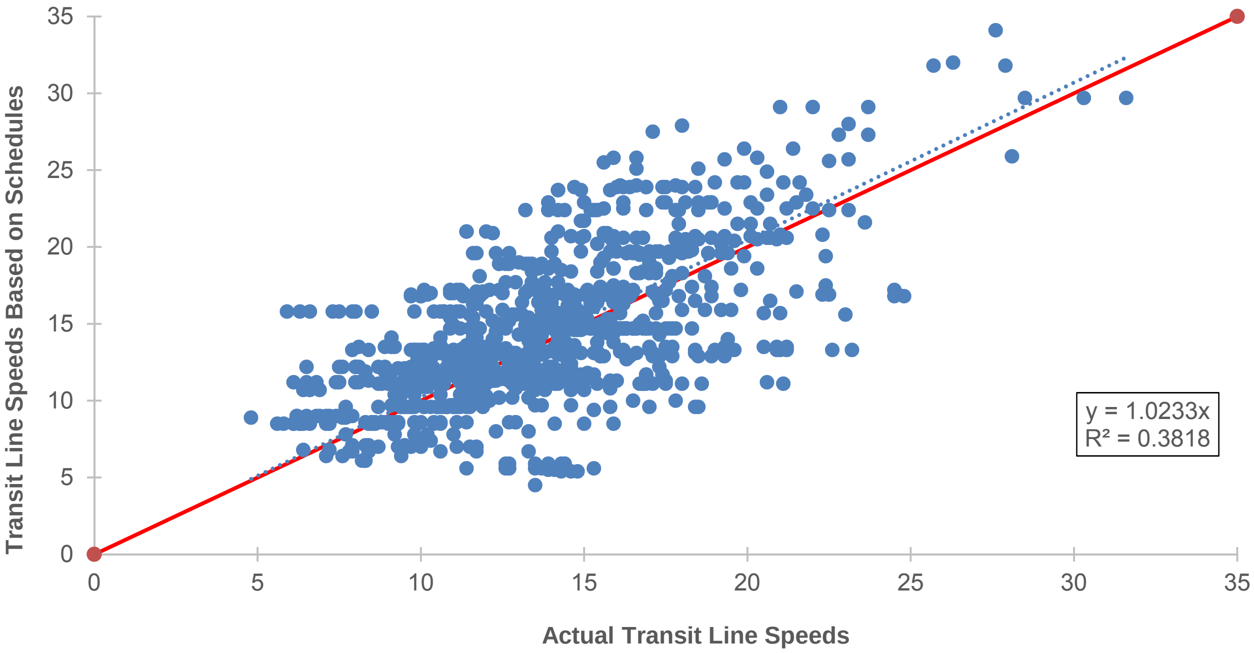


Figure 1.19 2015 Off-Peak Transit Line Running Times: Schedule versus Actual

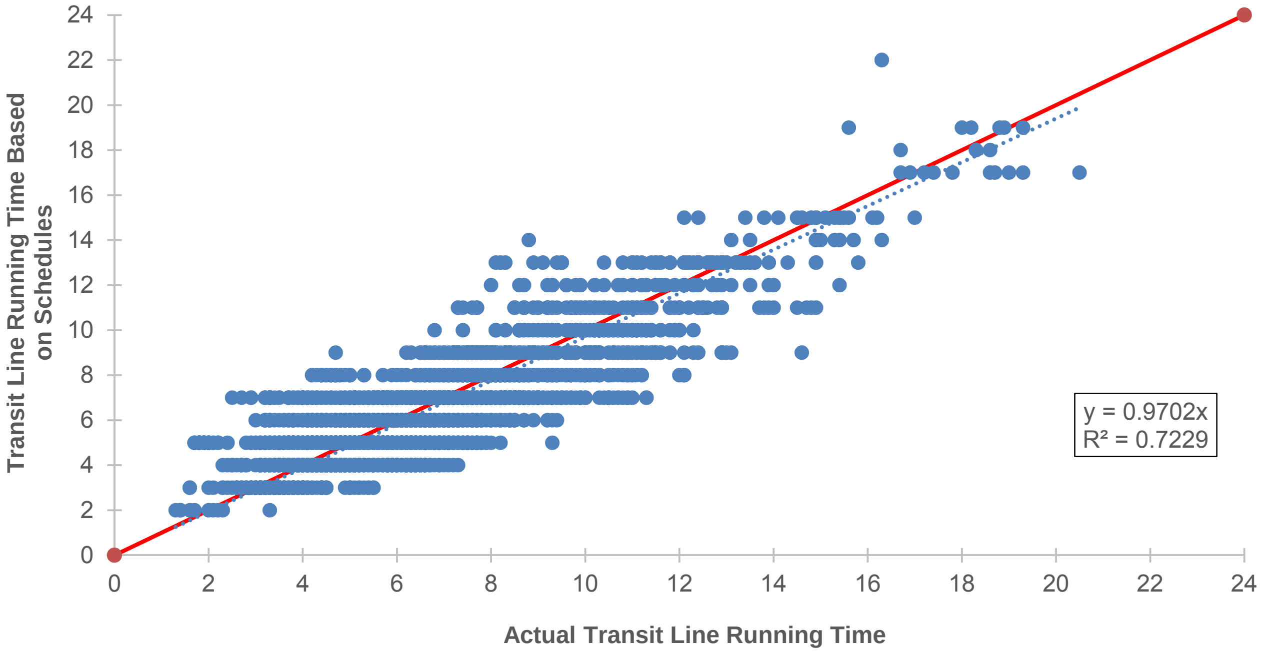
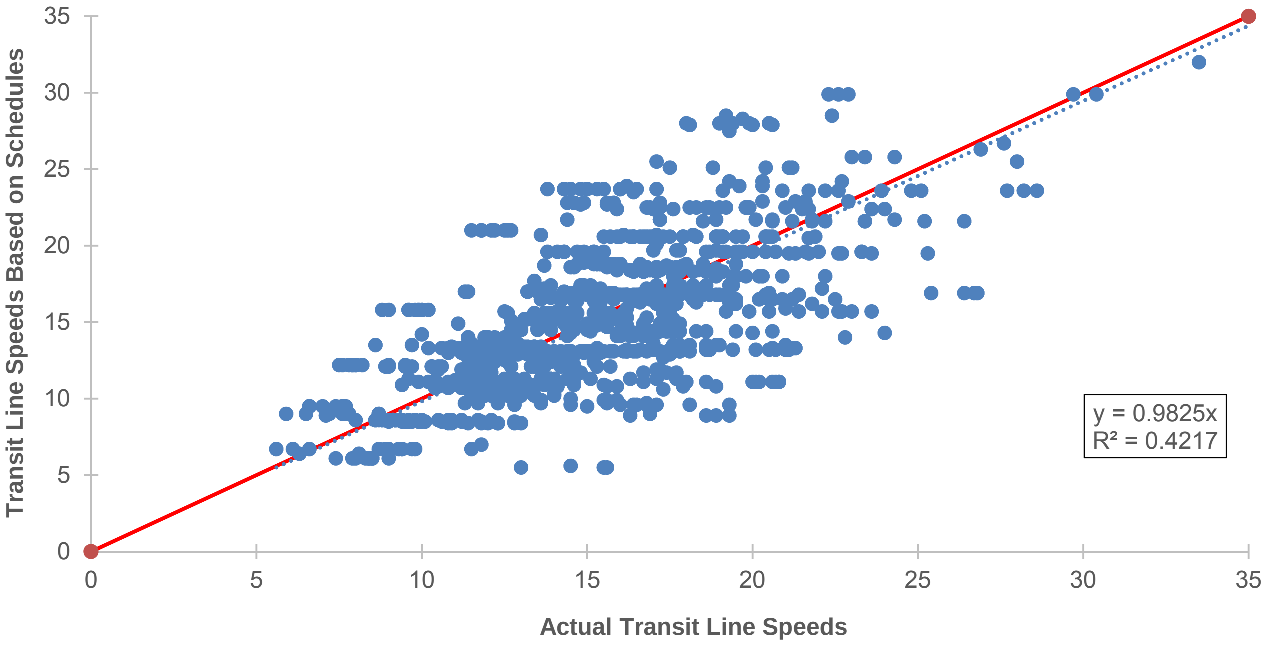


Figure 1.20 2015 Off-Peak Transit Line Speeds: Schedule versus Actual



The team looked at the relationship between observed bus speeds from WMATA data and average observed speeds from INRIX data. Data were assessed at the segment level to allow direct comparison. The U.S. 29 corridor was divided into segments of major intersections or attraction centers. The INRIX data were summarized into segments by average weekday speed for a segment. The WMATA data were also summarized into segments and the average dwell time and running time and speed data was derived by segment. Figures 1.21 and 1.22 show fairly weak relationships between observed transit speed and INRIX road traffic speeds, but the number of observations was quite small.

Figure 1.21 Peak Observed Transit Speed versus INRIX Speed

Mile per Hour

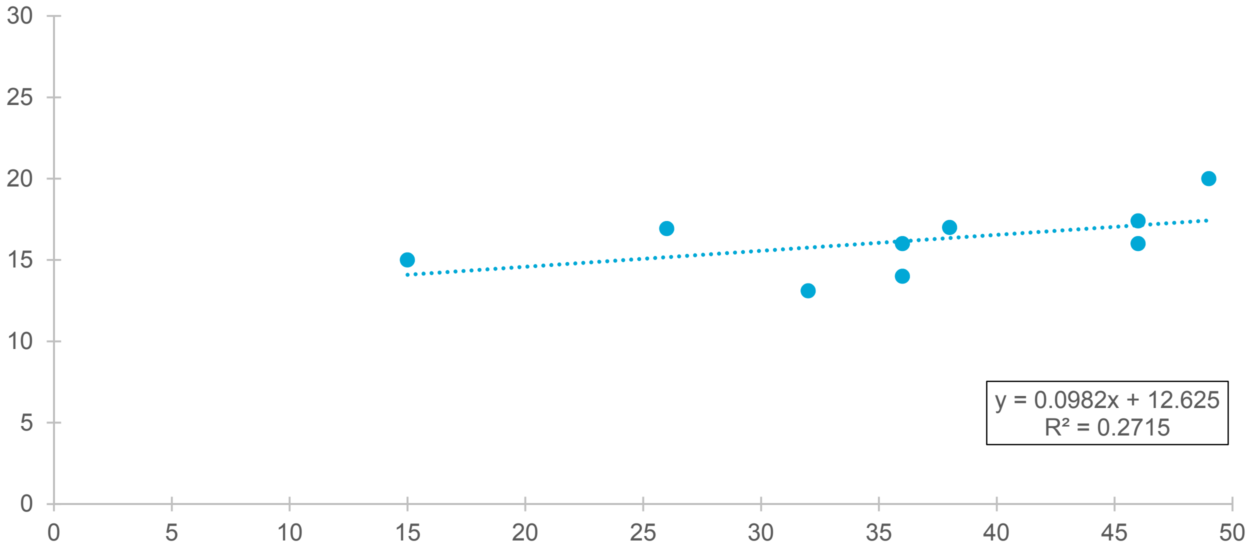
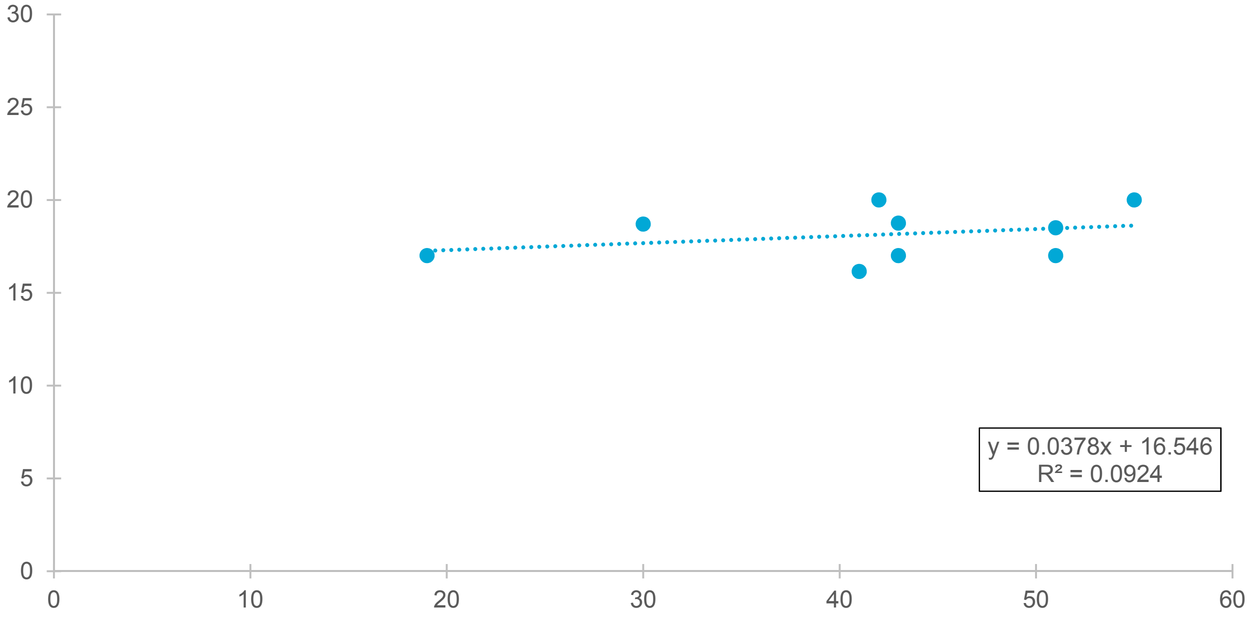


Figure 1.22 Off-Peak Observed Transit Speed versus INRIX Speed

Mile per Hour



The main observations we derive from this analysis are:

- Given the complexity of fitting various data sources into one format, it is a challenging task to build a model using observed highway and transit speeds. In addition, it is challenging to update the model on the basis of scheduled times and traffic assignment-based speeds, as evidenced from the peak and off-peak transit/highway time comparisons.

- Given the variations in the figures from the analysis we did perform, it seems that no single regression model can easily reflect actual bus times for all bus routes in the system.

- When updating the model, it is important to make sure that transit network coding is adjusted to accommodate the modeling approach. In the case where a bus speed model differentiates between freeways and arterials, transit line files would need to be prepared such that freeway segment running times are distinguished from arterial segment running times. Thus, the modeling approach influences network coding.

- A bus speed model will require thresholds governing the degree to which congestion degrades bus speeds.

Findings and Recommendations

No state-of-the-practice consensus exists among transportation practitioners regarding the best methods for calculating transit speeds in regional models. A review of the state of the practice for transit speed estimation in several MPOs revealed no major advancements with regard to transit modeling over the past six years. Linking transit travel time/speed to highway travel time/speed in one way or another is the general practice in regional models of large MPOs, but the method used varies.

Given current practices and challenges, and considering the desirability to make improvements in the short term, it is recommended that the MWCOG/TPB consider the following refinements:

- Improve representation of the base-year bus run time/speed through analysis of scheduled run time/speed versus observed run time/speed;

- For future years, calculate bus run time/speeds based on the base year bus run time/speed and the changes in modeled roadway speeds between base and future years;

- In implementing changes in modeled roadway speeds, use degradation factors segmented by area types/facility types (rather than a global factor), with certain thresholds governing the degree to which congestion degrades bus speeds. These factors would be confirmed using local-data case reviews such as the ones described under “Corridor Transit Speed Analysis in D.C. Region”, above, coupled with professional judgment.

References

1. Atlanta Regional Commission (ARC), 2011, The Travel Forecasting Model Set for the Atlanta Region: 2010 Documentation.

2. Cambridge Systematics, Inc., 2008, FSUTMS Cube Framework Phase II Model Calibration and Validation Standards Final Report, prepared for Florida Department of Transportation Systems Planning Office, October 2, 2008.

3. Cambridge Systematics, Inc., with Gallop Corporation, 2010, Fiscal Year 2010 Task Reports, prepared for National Capital Region Transportation Planning Board (TPB), Houston-Galveston Area Council, Regional Travel Models, 2009 Model Validation and Documentation.

4. de Rouville, M., 2009, Memorandum to Transportation Technical Staff, Transit Time Investigation, Baltimore Metropolitan Council.

5. Seifu, M., and R. Milone (COG/TPB), 2016, Memorandum to Feng Liu (Cambridge Systematics), subject “Bus Speed Modeling Thoughts (per Task 9 of Task Order 16.2),” April 21, 2016.

6. Triangle Regional Model Service Bureau, 2012, Triangle Regional Model (TRM) Version 5 Model Documentation Report.

1.10 Migration of Mode Choice Application Software (TPB)

This subtask was the primary responsibility of TPB staff and is documented separately.

1.11 Walk Access Script Enhancement (TPB)

This subtask was the primary responsibility of TPB staff and is documented separately.

1.12 Develop Parcel-Level Development Database

This report section summarizes activities that CS performed under Task Order 16.2, Advice and Testing, Task #12, Develop Parcel-Level Database. Specifically, the task activities included a review of existing data sources and their potential use in the upcoming model updates in trip-based and activity-based models (ABM).

Most jurisdictions maintain a parcel database containing three types of information: 1) physical characteristics, ownership, and assessed values; 2) sales data; and 3) parcel geographic data (Abt, 2013). Physical characteristics such as land use, land area, building structure area and geographic information such as coordinates are particularly important when parcel information is used in the ABM. The use of up-to-date parcel data in an ABM can improve the responsiveness of the model to nonmotorized travel times and other important variables, with more accurately measuring walk access to transit, travel distance and times for nonmotorized and short trips, and destination attractiveness in heterogeneous zones (Liu et al., 2012; Castiglione et al., 2015).

In the following subsections, a review of existing data sources about parcel level data in the modeling domain is summarized. Then, the process of preparing parcel level database for the Baltimore ABM (InSITE), which is under development by the Baltimore Metropolitan Council (BMC), is described and may be helpful to a better understanding of the potential uses, issues and limitations of similar databases. Finally, several findings are summarized, and recommendations are made for a parcel/point database to help with the upcoming trip-based and ABMs.

Review of Existing Data Sources

The TPB member jurisdictions include those in the District of Columbia, Northern Virginia, and suburban Maryland. The COG/TPB model domain also includes one jurisdiction in West Virginia, as well as jurisdictions adjacent to the TPB member jurisdictions. The inventory of parcel/point databases vary by states and jurisdictions. Maryland and D.C. maintain statewide parcel datasets with an array of physical characteristics, use type, and geographic information accessible from online for free; Virginia and West Virginia do not appear to have statewide standardized parcel database, and each individual jurisdiction needs to be contacted to request the data.

Local Data Sources

The State of Maryland maintains a comprehensive real property database MdProperty View (Maryland Department of Planning, 2013) combining tax assessment data with other GIS data sets and covering all jurisdictions in the State. This GIS database provides a consistent database with variables that are useful for the model development and application. Among those which are especially useful:

- Geographic representation of real property as point or polygon (X, Y);
- Parcel size (land area) and building size (number of buildings, stories, units, foundation structure size); and
- Land use activity of each parcel (land use classification).

Other useful GIS layers as part of the MdProperty View include:

- Land Use/Land Cover;
- Priority Funding Area (PFA) designations;
- Floodplain data; protected lands boundaries; watershed data; National Register of Historic Places (NRHP) Maryland coverage;
- Generalized zoning designations;
- Sewer service area boundaries, and public water service area boundaries for selected jurisdictions;
- Topographical quad maps; and
- State Highway Administration (SHA) 1:24,000 centerline roads.

These data can be used to define existing development patterns and measure the potential for future development.

Table 1.10 shows, for Maryland counties in the COG/TPB modeled area, the number of parcels by jurisdictions in the MdProperty View database. As of May 2016, the 2012/2013 edition database contains 1,268,123 parcels in the Maryland jurisdictions of the COG/TPB modeling domain. Data by jurisdictions can be downloaded from the web site of Maryland Department of Planning directly (http://www.mdp.state.md.us/OurProducts/downloadFiles.shtml).

Table 1.10 MdProperty View Database: Number of Parcels by Jurisdictions

Jurisdiction	Number of Parcels (2012/2013)
Montgomery	336,764
Prince George's	294,127
Anne Arundel	211,091
Howard	106,404
Frederick	95,671
Carroll	66,501
Charles	65,507
St. Mary's	49,259
Calvert	42,799
Total	**1,268,123**

The District of Columbia makes its parcel data in D.C. available through the web site of D.C. GIS OpenData (D.C. Government, 2016), http://opendata.dc.gov/). This growing web site is part of the effort to make the District's data accessible and usable to the public. The parcel dataset is in the ESRI shapefile format, and both polygon and point data are available. Attributes such as parcel size, land use code, and number of building in each parcel are included in the dataset.

In Virginia, there is not an official standardized statewide database similar to that of Maryland. Based on our review of on-line databases and inquiries to individual jurisdictions, we found that parcel/point databases vary by jurisdictions in terms of availability and contents in the database. Parcel/point databases appear to be available online or upon request for free for the following jurisdictions:

- Arlington, Cities of Alexandria and Falls Church, and Fairfax County; and
- Fauquier, Spotsylvania, Stafford, King George, and Clarke County.

Parcel/point databases are available with a fee for the following jurisdictions:

- Cities of Fairfax, Fredericksburg, Manassas Park, and Manassas; and
- Loudoun County and Prince William County.

Table 1.11 summarizes the availability of parcel GIS databases in all jurisdictions in the COG/TPB modeling domain. Where available, we have provided the prices charged by jurisdictions for the data. Nine out of fifteen jurisdictions have polygons of parcels, which could be used to measure parcel size (the rest of the jurisdictions use points to represent the land parcels). Among those jurisdictions, only four have the field of land use classification associated with the parcel shape file. The classification categories are quite different among them. The City of Falls Church only has two categories regarding the attribute of land use, namely, residential and nonresidential. Stafford County has land use codes but not classification description. Data from some jurisdictions are without a land use code field.

Table 1.11 Data Inventory Table for Parcel Database

State	Jurisdiction	Data Availability	Cost	Data Format	URL	Contact Person	Email or Phone Number	Major Fields Available in Dataset
DC	District of Columbia	Accessible directly	Free	Points	http://opendata.dc.gov/#datasets?keyword=property			X,Y,USECODE,ADDRESS,MIXEDUSE,COOPUNIT
MD	Anne Arundel County	Accessible directly	Free	Points	http://planning.maryland.gov/OurProducts/downloadFiles.shtml			Data Points ACCTID, X, Y, CIUSE, RESITYP, SQFTSTRC,ACRES
	Calvert County							
	Carroll County							
	Charles County							
	Frederick County							
	Howard County							
	King George County							
	Montgomery County							
	Prince George's							
VA	Alexandria	Accessible directly	Free	Polygons	http://data.alexgis.opendata.arcgis.com/	NA	703-746-4357	PID,X,Y,LANDDESC, LAND Area
	Arlington	Accessible directly	Free	Polygons	http://gisdata.arlgis.opendata.arcgis.com/	Tim Ernest	ternest@arlingtonva.us	TaxID,X,Y, LAND Area
	City of Fairfax	Need to request parcel data	$55			Maurice Rioux	Maurice.Rioux@fairfaxva.gov	NA
	City of Falls Church	Accessible upon request	Free	Polygons		Matthew Viverito	MViverito@fallschurchva.gov	X,Y, LAND Area, Res (only 2 types: Residential and Nonresidential)
	City of Fredericksburg	Need to request parcel data	$100			Kim B. Williams	kbwilliams@fredericksburgva.gov	NA
	City of Manassas	Need to request parcel data	$250			Margaret Montgomery	mmontgomery@ci.manassas.va.us	NA

State	Jurisdiction	Data Availability	Cost	Data Format	URL	Contact Person	Email or Phone Number	Major Fields Available in Dataset
	City of Manassas Park	Need to request parcel data	NA	NA	NA	Ryan Gandy	703-930-5709	NA
	Clarke County	Accessible directly	Free	Polygons	ftp://ftp.clarkecounty.gov/gis	Robert Fuller	gis@clarkecounty.gov	Land acres, X, Y, ZONE (probably zoning information, and a data dictionary is needed)
	Fairfax County	Accessible directly	Free	Polygons	http://data.fairfaxcountygis.opendata.arcgis.com/	NA	703-324-2712 (Monday through Friday 9:00 AM to 3:00 PM)	Land area, X, Y, DU and LUGRP
	Fauquier County	Accessible directly	Free	Polygons	ftp://vm-ftp.fauquiercounty.gov/	NA	GIS.GISOffice@fauquiercounty.gov	Land area, X, Y, Land use/Zoning
	Loudoun County	Need to request parcel data.	$22			Marty King	Martha.King@loudoun.gov	NA
	Prince William County	Need to request parcel data	$10			Matt LaShell	pwcmaps@pwcgov.org	NA
	Spotsylvania County	Accessible directly	Free	Polygons	http://www.spotsylvania.va.us/content/20925/20971/23800.aspx	Tina Kolodziej	TKolodziej@spotsylvania.va.us	Land area, X, Y, Comp_Plan
	Stafford County	Accessible directly	Free	Polygons	http://gis.stafford.va.us/Public/PARCELS/	Dave Capaz	gis@co.stafford.va.us	Land area, X, Y, DUTYPE, and APA & LUGRP
WV	Jefferson County	Need to request parcel data	$8[a]	Polygons		Tori Myers	tmyers@Jeffersoncountywv.org	Data Polygon

[a] $8 per map sheet with no data, except parcel identification numbers and $9 per map sheet with data. Currently, there are 411 map sheets. So, the total with data would be $3,699.

Private Data Vendor

DynamoSpatial[16] is a private data vendor and GIS consulting firm located in Pittsburgh, Pennsylvania, providing parcel data and spatial solutions to clients (Dynamo Spatial LLC, 2016). The parcel database it maintains covers 2,715 counties across US in ESRI shapefile point format. A price for 14 counties/cities in Virginia was quoted at approximately $4,000.

Review of Parcel/Point Database Development for BMC InSITE

In the data development process for InSITE, the Baltimore region Activity-Based Model (ABM), MdProperty View data and D.C. parcel/point databases were used as the base, on which data processing was conducted to develop attributes needed for InSITE. Steps taken to process the original databases include:

- Coordinates in the parcel point databases were verified and corrected with centroids of parcel polygons where available, including those missing parcels in the parcel point databases.
- Key data items in the databases were checked for any missing values and corrected where possible.
- Additional variables were added to the parcel/point databases, including TAZ numbers, BMC jurisdiction, nearest transit stop, intersections within ½ mile, and Parcel ID.
- Weights for assigning households, group quarters, and school enrollment/universities to parcels within TAZs were developed, based on property use codes and quantity for each parcel (e.g., units within an apartment building).
- Weights for assigning employment by categories to parcels within TAZs were developed, based on square footage of each parcel and its property use and land use codes, with conversion factors varying by employment categories.
- Where key variables such as square footage were missing, a default value was assigned to the parcels missing these values.
- A reconciliation was made between the TAZ level land use data used in the model and TAZ totals aggregated from parcels within TAZs.
- Buffer-level density variables were plotted and visually inspected for reasonableness.
- Finally, a representative parcel was selected for each TAZ to show the average employment and household density of each TAZ.

At the time that parcel/point data were assembled for processing, MdProperty View data had a mix of parcel point and polygon data and has since integrated parcel polygon data for most jurisdictions for the 2013 edition. MdProperty View Data has been regularly maintained and periodically updated with new parcels, based on sales records. Similarly, D.C. GIS OpenData also periodically update and maintain its Owner Point and Polygon parcel databases with new information as it becomes available. However, sensitive sites and government facilities still do not have much detail in the database.

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[16] Email communications with Shawn Rancatore at DynamoSpatial (shawn@dynamospatial.com).

Findings and Recommendations

This subsection documents a review of existing data sources about parcel level data in the COG/TPB modeling domain:

- The State of Maryland maintains and periodically updates a comprehensive and consistent real property database MdProperty View, which includes variables that are useful for model development and application;
- The District of Columbia also maintains and periodically updates a parcel point/polygon database with property use codes via the D.C. GIS OpenData portal;
- The Commonwealth of Virginia does not have an official standardized statewide database similar to that of Maryland, and the local jurisdictions maintain their own databases which are available online, upon request, or with a fee; and
- The existing databases are typically georeferenced for parcels either in point or polygon format, but the attributes vary widely across jurisdictions (e.g., building structure square footage data are missing for parcels in D.C. and Virginia).

Parcel point/polygon databases are useful to improve measurements of variables at the micro- and disaggregate level, which are essential for enhancing the trip-based model and developing an ABM. To fulfil the objectives of enhancing trip-based model in the immediate short term and developing an ABM in the long term, development of a consistent parcel point/polygon database is recommended, including the following considerations:

- MdProperty View and D.C. GIS OpenData serves as the base data for jurisdictions in Maryland and D.C., which can be enhanced with efforts to improve their quality for some records, as done in the parcel/point database development for the BMC ABM.
- Parcel point/polygon data from local jurisdictions in Virginia should be compiled, processed, and standardized in a consistent georeferenced system, with collaboration from local jurisdictions. Where local data are unavailable or inadequate in its content and quality, a private vendor database can be acquired for current use.
- The new database should include key attributes such as coordinates, property use/land use code, and a size variable such as square footage, at a minimum.
- A consistent land use and property use code system needs to be established for parcel/point data from local jurisdictions in Virginia.
- Key attributes need to be checked for missing values and reasonableness, as done in the parcel/point database development for the BMC ABM.

References

1. Abt Associates Inc., *The Feasibility of Developing a National Parcel Database: County Data Records Project Final Report*, U.S. Department of Housing and Urban Development, January 2013, http://www.huduser.gov/portal/Publications/pdf/feasibility_nat_db.pdf.

2. Liu, F., J. Evans, and T. Rossi, 2012, Recent Practices in Regional Modeling of Non-Motorized Travel, Transportation Research Record: Journal of the Transportation Research Board, No. 2303, Page 1-8, Transportation Research Board, Washington, D.C.

3. Castiglione, Joe, Mark Bradley, and John Gliebe, *Activity-Based Travel Demand Models: A Primer,* SHRP 2 Capacity Project C46, Washington, D.C.: Transportation Research Board of the National Academies, 2015.

4. Maryland Department of Planning, 2013, MdProperty View, accessed June 23, 2016, from http://planning.maryland.gov/OurProducts/downloadFiles.shtml.

5. D.C. Government, 2016, D.C. GIS Opendata, accessed June 23, 2016, from http://opendata.dc.gov/datasets?q=building permits&sort_by=relevance.

6. Dynamo Spatial LLC, 2016, Dynamo Spatial Property Boundaries and Ownership Data, accessed June 23, 2016, from http://www.dynamospatial.com/nationwide/parcel-data.

1.13 Develop Census and Household Travel Survey Database

This report section summarizes activities that CS performed under Task Order 16.2: Advice and Testing, Task #13 Develop Census and Household Travel Survey Database. Specifically, the task activities included a review of existing Census and survey data and their potential use, such as for model estimation and calibration, in the upcoming model updates in trip-based and activity-based models. This report section contains two distinct parts. The first part identifies the data enhancements needed for the short-term trip-based model improvements. The second part contains a description and specification of the survey data to be used in estimating an activity-based model for the region.

Survey Data Enhancement for Trip-Based Model Improvements

Existing Practice

COG/TPB staff has conducted model estimation and calibration in the past. The current version of the regional (trip-based) travel demand forecasting model is known as Version 2.3.57a, but the mode choice model was calibrated in 2011 (this was an earlier version of the 2.3 model). The calibration included the following two steps:

1. **Statistical estimation.** Statistical estimation was used for some coefficients (e.g., in-vehicle time and cost for income group 1), but the values of other coefficients were set by fiat, typically based on rules of thumb (e.g., out-of-vehicle time coefficients are some multiple of in-vehicle time coefficients).[17]

2. **Calibration.** Calibration typically involves adjusting one or more constants, such as alternative-specific constants, to ensure that the model will fit observed data. In the case of the COG/TPB mode choice model, staff made adjustments to the nesting constants, which are based on a series of geographic market segments.[18] More specifically, staff used a series of "calibration targets," defined as the number

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[17] Ronald Milone, et al., Calibration Report for the TPB Travel Forecasting Model, Version 2.3, on the 3,722-Zone Area System, Final Report (Washington, D.C.: National Capital Region Transportation Planning Board, January 20, 2012), 6–14, http://www.mwcog.org/transportation/activities/models/documentation.asp.

[18] Ibid, 6–18.

of person trips, for an average weekday, for each trip purpose (5), travel mode (15), and geographic market segment (20). Calibration targets were divided into two groups: transit person trips and auto person trips. Transit person trip calibration targets came from on-board transit surveys, but the auto person trip calibration targets came from the 2007/2008 Household Travel Survey. As staff noted, "although it would be more consistent to get both transit person trip targets and auto person trip targets from one source, such as the HTS, the reality is that by using on-board transit surveys for the transit person trip targets, we were able to take advantage of more data (compare ca. 5,000 unweighted transit person trips in the HTS versus ca. 50,000 unweighted transit person trips in the on-board transit surveys."[19] The following transit on-board surveys were used to develop transit person trip targets:

a. 2008 Metrorail Passenger Survey;

b. 2008 Regional Bus Survey (supplemented by the Fairfax Connector Bus Survey);

c. 2007-2008 On-Board Survey of Maryland Transit Administration (MTA) Riders, which would include survey information from riders of the Maryland Area Regional Commuter (MARC) train service; and

d. 2005 Virginia Railway Express (VRE) Passenger Survey.

Household Travel Survey

Household survey data will be instrumental to estimating the mode choice models. Household surveys were conducted in both Baltimore and Washington regions in 2007/2008, using the same survey designs and generating a combined total of nearly 15,000 completed samples (households). The survey data are organized in a relational database containing three tables/files: the household file, person file, and trip file. The household file contains household-level information for each person surveyed, including household size, number of workers, household income, and number of vehicles, which will be important variables to the mode choice models. The person file likely will not be needed for estimation of the model choice models. The trip file contains all of the critical trip information, including origin location, destination location, trip purpose, trip mode, and time of day.

In addition to the 2007/2008 Household Travel Survey (HTS), the 2011/12 TPB Geographically-Focused Household Travel Survey (GFHTS) surveys may be useful, particularly to the non-motorized model enhancements.

The two surveys will need to be enhanced with additional attributes such as the Census block numbers associated with household and workplace locations and trip ends, in order to facilitate development of more refined variables related to urban form and built environment, as outlined in the Section 3.0 of this report, Task Order 16.4 – Non-Motorized Model Enhancements.

Skimmed highway and transit attributes will be attached to the data for model estimation. Since skimmed attributes are coded at the TAZ-to-TAZ level and survey data is coded at the Census block level, a crosswalk between TAZ and Census block will be used in attaching the skim attributes. To enhance the accuracy of measurements for short-distance trips, the orthogonal distance (ΔX plus ΔY) can be used to replace the TAZ-TAZ skim distance when the skim distance is less than a certain threshold (e.g., 3.75 miles for the Baltimore model). For the model estimation data set, the orthogonal distances can be determined from the

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[19] Ibid.

coordinates of the trip ends. Alternatively, if privacy rules do not allow for the use of the trip end coordinates, one could also use the coordinates of the Census block centroids associated with those trip ends.

Transit On-Board Survey

The transit on-board survey was conducted on many transit vehicles including local, regional, and commuter bus providers, Metrorail subway, MTA light rail, and MARC commuter rail[20]. Derived from roughly 13,000 usable questionnaires[21], the survey data contain information on the respondent's current transit trip. This includes trip starting and ending stations, home location, trip start time, time spent waiting for the transit vehicle, access and egress modes, as well as several socioeconomic characteristics of the respondent like gender, age, and vehicle availability.

The transit on-board survey can be used in two ways. First, it can be added to the household survey dataset to create a more robust dataset for model estimation. Since all records in the on-board survey dataset use the transit mode, careful attention needs to be paid to the weights assigned to on-board survey records to ensure that the overall share of transit suggested by the survey weights is reflective of the region's transit share. The larger, more robust combined dataset should allow us to obtain more precise estimates of the different coefficient estimates we plan on testing in the mode choice model (e.g., different in-vehicle time weights by transit technology, and nontraditional transit variables).

The second way the data can be used is to test the path-building weights used to generate transit paths. It is currently planned to use Cube Public Transport (PT) for transit path-building. Cube-PT can be used to generate either a single best path between each origin and destination or multiple paths between each O&D. When the single path option is selected, Cube-PT finds the single best path (based upon the path building parameter set) and reports the travel attributes of that single path in the skim variables. When the multiple path option is selected, Cube-PT finds all paths that would be reasonably chosen by a traveler for the OD pair. Cube-PT will ultimately generate "averaged" paths, meaning the transit skim attributes will represent averages of the attributes across all used paths, but it can also be used to generate best paths and potentially second-best paths. These paths generated by Cube-PT can then be compared against the on-board survey data. While the on-board survey data does not contain all path-related information,[22] it contains information about the type of transit the survey was conducted on, which can be compared to the skimmed paths. In other words, the comparisons will not be perfect, but the on-board survey data can be used to tweak the path-building parameters.

Similar to the HTS, the transit on-board survey database can be enhanced with more refined geocoding such as Census block numbers. To enhance the accuracy of measurements for transit walk access and egress, the orthogonal distances for transit walk access and egress can be used to replace the TAZ-TAZ skim distance, using the coordinates of the trip ends and the nearest transit stop/station.

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[20] Cambridge Systematics, Inc., Model Design Plan for BMC Activity-Based Model, prepared for the Baltimore Metropolitan Council. 2014.

[21] Baltimore Metropolitan Council, 2007 On-Board Transit Survey – BMC Analysis, Task Report 10-1, 2010. Accessed via http://www.baltometro.org/reports/On-Board-Transit-Survey-2007.pdf.

[22] For example, the 2007 Metrorail Passenger Survey did not include the production-end mode of access to the first transit vehicle in a path, only the production-end mode of access to Metrorail. This is one of the reasons COG/TPB staff decided to use the 2008 Metrorail Passenger Survey instead of the 2007 survey.

Activity-Based Model Estimation Data

Household Survey Data

The household and person variables for model estimation for an activity-based model are shown in Table 1.12,[23] which includes both original survey response variables and some of the variables that can be derived from the survey responses.

Table 1.12 Person and Household Data

Description	Details	Type
Person and Household Demographic Variables		
Household ID number	Survey ID field	Integer
Person ID number	Survey ID field	Integer
Household size	Count of people in household	Integer
Household vehicles	Count of vehicles in household	Integer
Total household income level	Categorical household income	Categorical
Gender	male, female	Categorical
Age	In years	Integer
Employment status	employed full-time, employed part-time, not employed	Categorical
Student status	enrolled full-time, enrolled part-time, not enrolled	Categorical
Type of school enrolled in	preschool, K-12, post-HS, not enrolled	Categorical
Relationship to respondent	Head, spouse, partner, other HH member, visitor	Categorical
Person and Household Derived Variables		
Person type	Derived (e.g., full-time worker, part-time worker, retired other adult, university student, driving age high school student, child age 5-15, child age 0-4)	Categorical
# of employed HH members	Derived by adding across HH members	Integer
# of student HH members	Derived by adding across HH members	Integer
# of HH members by person type	Derived by adding across HH members	Integer
Person and Household Location Variables		
Household residence ID number	Survey ID field	Integer
Household Census block	Geocode (Dependent variable for population synthesizer)	Integer
Regular work location id	Survey ID field	Integer
Regular work Census block	Geocode (Dependent variable for regular work location model)	Integer

The trip file is processed to create an additional file/table of tours. The tours consist of a series of at least two trips that start and end at the same location – home or work. One stop in the tour is designated as the location of the primary activity. This is the tour's destination and its purpose is determined by the primary

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[23] Cambridge Systematics, Inc., Model Design Plan for BMC Activity-Based Model, prepared for the Baltimore Metropolitan Council, 2014.

activity. All trips before the primary activity are in the first one-half of the tour. Trips that follow it are in the second one-half. Table 1.13 shows the estimation variables necessary from the trip and tour databases.

Table 1.13 Trip and Tour Data

Description	Details	Type
Trip-Level Variables		
Trip tour half	1 or 2, Created ID field	Integer
Trip ID within tour half	Created ID field	Integer
Trip ID	Survey ID field	Integer
Trip origin activity purpose	Same codes as primary destination activity purpose	Categorical
Trip destination activity purpose	Same codes as primary destination activity purpose	Categorical
Trip origin location ID	Survey ID field	Integer
Trip origin zone	Zone Number (Tour destination, or destination of previous trip)	Integer
Trip destination location ID	Survey ID field	Integer
Trip destination zone	Zone Number (Tour origin, or dependent variable for stop location)	Integer
Trip mode	Same codes as tours (Dependent variable for trip mode model)	Categorical
Trip origin departure time	Dependent variable for trip departure time model	Continuous
Trip destination arrival time		Continuous
Day Pattern-Level Variables		
# home-based tour records		Integer
# home-based tours by tour type	Dependent variables for day activity pattern models	Integer
# work-based subtour records		Integer
# intermediate stops by stop purpose	Dependent variable for day activity pattern models	Integer
Tour-Level Variables		
Tour ID number (in priority order)	Created ID field	Integer
Subtour parent tour ID	Created ID field (work-based subtour only)	Integer
Subtour ID within parent tour	Created ID field (work-based subtour only)	Integer
# of subtours within tour	Dependent variable for subtour frequency/purpose model	Integer
Primary destination activity purpose	(Work, school, shopping, meal, social/recreation, etc.)	Categorical
Tour origin outbound departure time		Integer
Primary destination arrival time	Dependent variable for tour times of day model	Integer
Primary destination departure time	Dependent variable for tour times of day model	Integer
Tour Origin Return Arrival Time		
Primary destination location id	Survey ID field	
Primary destination zone	Zone Number (Dependent variable for tour destination model)	Integer
Tour primary mode	(Dependent variable for tour mode model)	Categorical
# trips in outbound tour half	Dependent variable for tour stop frequency/purpose model	
# trips in return tour half	Dependent variable for tour stop frequency/purpose model	

The tables above contain six main categories of data:

1. **Basic person and household variables.** These are the truly exogenous variables. In model application, these will be taken from the U.S. Census Public Use Microdata Sample (PUMS) records in the synthetic sample, and so certain variables from the household survey may need to be recoded in a way that is consistent with PUMS coding.

2. **Key-derived person and household variables.** These variables are developed using the definitions of the basic variables. One such important variable is person type, which has been found to be very useful in other activity-based models. While the specific person type categories for this model will emerge from an analysis of the household survey data, typical classifications include full-time worker, part-time worker, driving-age child, child below driving age (and occasionally infant as a separate category), nonworking adult, and senior. Note that additional variables can be derived from these and used in specific models (e.g., a dummy variable for female adults with one or more children aged 0 to 4).

3. **Person and household location variables.** This is the start of the endogenous variables in the model system. In application, the household location (at the zone level) will be predicted by the population synthesizer, and the regular work zone will be predicted by the choice models.

4. **Trip-level variables.** These variables include trip origin and destination location and purpose, trip departure and arrival time, and trip mode. They come directly from the survey, with the exception of the tour half ID. In model application, the order is reversed with tours preceding trips – trip characteristics will either already be known from the tour-level predictions (e.g., the locations for half-tours with no intermediate stops), or will be predicted by the trip-level models.

5. **Day pattern-level variables.** These are created by the code that processes trips into tours. They are person-day counts of the numbers of home-based tours and intermediate stops for each of the seven proposed activity purpose types, plus the count of the number of work-based subtours made. In application, these will be predicted by the day activity pattern model(s).

6. **Tour-level variables.** These are also generated by the tour formation code and contain all the variables needed to model a tour: purpose, timing, destination, mode, the number of intermediate stops on each half-tour, and the correspondence between work tours and subtours. In application, these will all be predicted by the various tour-level models.

Other Data for Model Estimation

In addition to the information from the household travel survey, other data items needed for model estimation include:

- Land use data such as aggregate household and employment and other data at the zonal level for the model year;

- Parcel/parcel point-based data as outlined in Section 1.12, “Develop Parcel-Level Development Database”;

- Highway network and skims such as auto travel distance, time, and toll; and

- Transit network and skims such as transit travel time, distance and cost, as well as transfers and first and last transit stops/stations.

1.14 Prepare Non-Motorized GIS Database

This report section summarizes activities that CS performed under Task Order 16.2, Advice and Testing, Task #14, Prepare Non-Motorized GIS Database. Specifically, the task activities include a review of existing data sources and their potential use in the upcoming model updates of both the trip-based and activity-based models. For more information about non-motorized model enhancements, the reader is referred to Section 3.0 of this report, "Task Order 16.4 – Non-Motorized Model Enhancements."

GIS data sources reviewed in this task include data from local jurisdictions and data accessible by the general public, as related to the following transportation infrastructure:

- Sidewalk;
- Trails;
- All bicycle-available roads and streets (unmarked with lanes, routes, etc.);
- Bike facilities at the link level (such as bike lanes, bike routes, and bike paths); and
- Bike sharing stations.

It should be noted that non-motorized modes make extensive use of local streets, so local streets should be part of any GIS database of non-motorized facilities.

Review of Existing Data Sources

Local Data Sources

Data sources from local jurisdictions within the MWCOG/TPB modeling domain were investigated through their web sites and, if necessary, local jurisdictions were contacted. A brief summary of initial results is summarized below.

- **Sidewalk data.** Sidewalk data are accessible on-line or upon email request for 15 of 24 jurisdictions. Two jurisdictions indicate that they do not have the sidewalk data available (City of Fredericksburg and Prince William County). Several other jurisdictions do not appear to have sidewalk data available.

- **Bike share locations.** Capital Bike Share locations are available for jurisdictions with the service in a point shape file (i.e., D.C., Montgomery County, Arlington County, and the City of Alexandria).

- **Bike Facilities.** Currently, GIS shapefile data for bike facilities are readily available for four jurisdictions (D.C., Arlington, Alexandria (.kmz format), and the City of Falls Church). Additional GIS data may also be available (e.g., Fairfax) via a request to jurisdiction sources. Jurisdictions have not adopted a standard bike facility classification scheme. A standard classification scheme for bike treatments would be needed in a modeling database (e.g., on-street facilities versus off-street trail/track).

- **Trail.** Data from 12 out of 24 jurisdictions are available. Some jurisdictions need additional follow-up such as Prince William County Department of Parks and Recreation, Alexandria, City of Fairfax, Fauquier (available in mid-summer this year), King George, Clarke, Charles, Carroll, St. Mary's, and Frederick. There appears to be a cost associated with obtaining data from Jefferson County ($84) and the City of Fairfax ($50).

Table 1.14 summarizes the findings regarding non-motorized GIS database availability in the MWCOG/TPB modeling region.

Table 1.14 Non-Motorized GIS Data Inventory

Jurisdictions	Bike Facilities	Bike Share Stations	Sidewalk	Trails	Costs
District of Columbia	Yes	Yes	Yes	Yes	Free
Fairfax	Yes	Not Applicable (N/A)	Yes	Yes	Free
Prince William County	Availability Not Verified	N/A	Availability Not Verified	Availability Not Verified	Unknown
Loudoun County	Availability Not Verified	N/A	Yes	Yes	Free
Alexandria	Yes	Yes	Yes	Yes	Free
City of Falls Church	Yes	N/A	Yes	Yes	Free
Arlington	Yes	Yes	Yes	Yes	Free
City of Fairfax	Availability Not Verified	N/A	Availability Not Verified	Yes	$50 per layer
City of Fredericksburg	Availability Not Verified	N/A	Availability Not Verified	Yes	Free
Fauquier County	Availability Not Verified	N/A	Availability Not Verified	Available mid-summer	Free
Spotsylvania	Availability Not Verified	N/A	Yes	Yes	Free
Stafford County	Availability Not Verified	N/A	Yes	Yes	Free
King George County	Availability Not Verified	N/A	Availability Not Verified	Availability Not Verified	Unknown
Clarke County	Availability Not Verified	N/A	Yes	Availability Not Verified	Free
Montgomery County	Availability Not Verified	Yes	Yes	Yes	Free
Prince George's County	Availability Not Verified	N/A	Availability Not Verified	Yes	Free
Howard County	Yes	N/A	Yes	Yes	Free
Anne Arundel County	Availability Not Verified	N/A	Yes	Yes	Free
Carroll County	Availability Not Verified	N/A	Availability Not Verified	Availability Not Verified	Free
Calvert County	Availability Not Verified	N/A	Availability Not Verified	Yes	Free

Jurisdictions	Bike Facilities	Bike Share Stations	Sidewalk	Trails	Costs
Charles County	Availability Not Verified	N/A	Availability Not Verified	Availability Not Verified	Free
St Mary's County	Availability Not Verified	N/A	Availability Not Verified	Availability Not Verified	Free
Frederick County	Availability Not Verified	N/A	Yes	Yes	Free
Jefferson County	Availability Not Verified	N/A	Availability Not Verified	Yes	$84 per layer

Public Data Sources

MWCOG has a subscription to HERE (formerly NAVTEQ) map data, which includes information about links for which auto access is restricted, which basically corresponds to bike/pedestrian facilities. However, the HERE maps carry some license restrictions. By contrast, there are public data sources, such as the OpenStreetMap (OSM), which do not carry any restrictions. The OSM project began in 2004 in England, supported by the nonprofit OpenStreetMap Foundation. Major contributors to OSM include GIS professionals, planners, engineers, and mapping enthusiasts – volunteers (Goodchild, 2007). The database is widely used in web sites, mobile apps, and hardware devices.

Researchers have conducted several independent reviews of the quality of OSM. One study of London, England data showed that OSM information could be deemed accurate (Haklay, 2010). In the United States, researchers from USGS conducted a test over the OSM software and found it well adapted to ArcGIS 10.0 platform and “generally easy to set up and use” (Wolf et al., 2011). In recognition of the quality in terms of pedestrian environmental factors, the National Center for Transit Research in the University of South Florida also supported a series of studies relevant to walk access to transit (Hillsman and Barbeau, 2009; Zielstra and Hochmair, 2011).

In a study on jobs within 30 minutes of walk access across metropolitan areas in the United States conducted by the University of Minnesota, a walking network was built for each metro area based on OSM database. Sidewalk links were identified using the conditions below:

- Highway=’footway’;
- Highway=’pedestrian’; and
- Highway=’residential’.

Comparison

As a proof of concept, we sought to review the accuracy of OSM non-motorized facility data for this region by making comparisons in the jurisdictions for which we had data.

For OSM bicycle facility data, we worked first to rely on the bicycle wiki of OSM. We extracted a layer of cycle tracks (i.e., facilities separate from the roadway), using the condition below:

- **Highway='cycleway'**.

However, in this database, no attributes could be found to identify on-road bicycle treatments. Therefore, we sought to construct a new dataset with key features identifying respective bike facilities. This new data set was comprised of four .pbf[24] files for three states and D.C. sourced from geofabrik.de. These files could be opened in QGIS, an open-source GIS software, and converted to .csv files for further analysis. We adjusted the coverage to the following jurisdictions:

Jurisdictions below are included in the database:

- **D.C.**;
- **Maryland.** Montgomery, Prince George's, Howard, Anne Arundel, part of Calvert, and part of Frederick;
- **Virginia.** Arlington, Alexandria, Loudoun, Fairfax, King George; and
- **West Virginia.** Jefferson County.

Fields associated with the classification of bike facilities include:

- **Bike lane.** The field [other_tags] contains
  - "cycleway"=>"lane"; or
  - "cycleway:right"=>"lane"; or
  - "cycleway:left"=>"opposite_lane".
- **Bike routes (shared lane).** The field [other_tags] contains
  - "cycleway"=>"shared_lane".

We also developed a line layer of sidewalks from the OSM database by making several assumptions: 1) Sidewalks are associated with all residential streets; 2) Sidewalks are on both sides of these streets; 3) Plazas or pedestrian malls were counted the same as residential street sidewalks.

We then compiled mileage metrics and visual comparisons to permit an evaluation of accuracy. We performed several comparisons. Table 1.15 shows an example comparison for D.C. and Montgomery County. The length of sidewalk in these jurisdictions derived from OSM data is 14 percent to 32 percent less than that present in the GIS database (which is derived from local government data), suggesting that our initial selection criteria for developing the sidewalk layer were perhaps too restrictive. There may be differences in definitions of facilities.

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[24] A PBF file is a binary file containing OSM data.

Table 1.15 Comparison between OSM and Local Data – Sidewalks

Jurisdiction Name	Residential (Miles)	Pedestrian (Miles)	Footway (Miles)	Total (Miles)	Local Data (Miles)	Difference (Percentage)
DC	746	8	271	1,025	1,503	-31.79%
Montgomery County	2,586	1	498	3,086	3,606	-14.42%

Figures 1.23 to 1.25 show a comparison of overlap in designated bike lanes, bike routes, and cycle tracks/bike trails, respectively, found using our selection methodology between the OSM database and the local dataset for D.C. As highlighted in Figure 1.23, for bike lanes, only one segment without bike lanes according to DDOT was flagged as having bike lanes in the OSM (false positive). Several facilities that DDOT identify as having bicycle lanes, though, were not flagged as such in the OSM. As highlighted in Figure 1.25, for cycle tracks/bike trails, the OSM data show more such facilities than the DDOT data, but this is attributable in part due to the different classifications (and some of the cycle tracks shown in the OSM database are actually bike lanes in DDOT data).

Figure 1.23 Comparison of Bike Lanes between DDOT and OSM Database

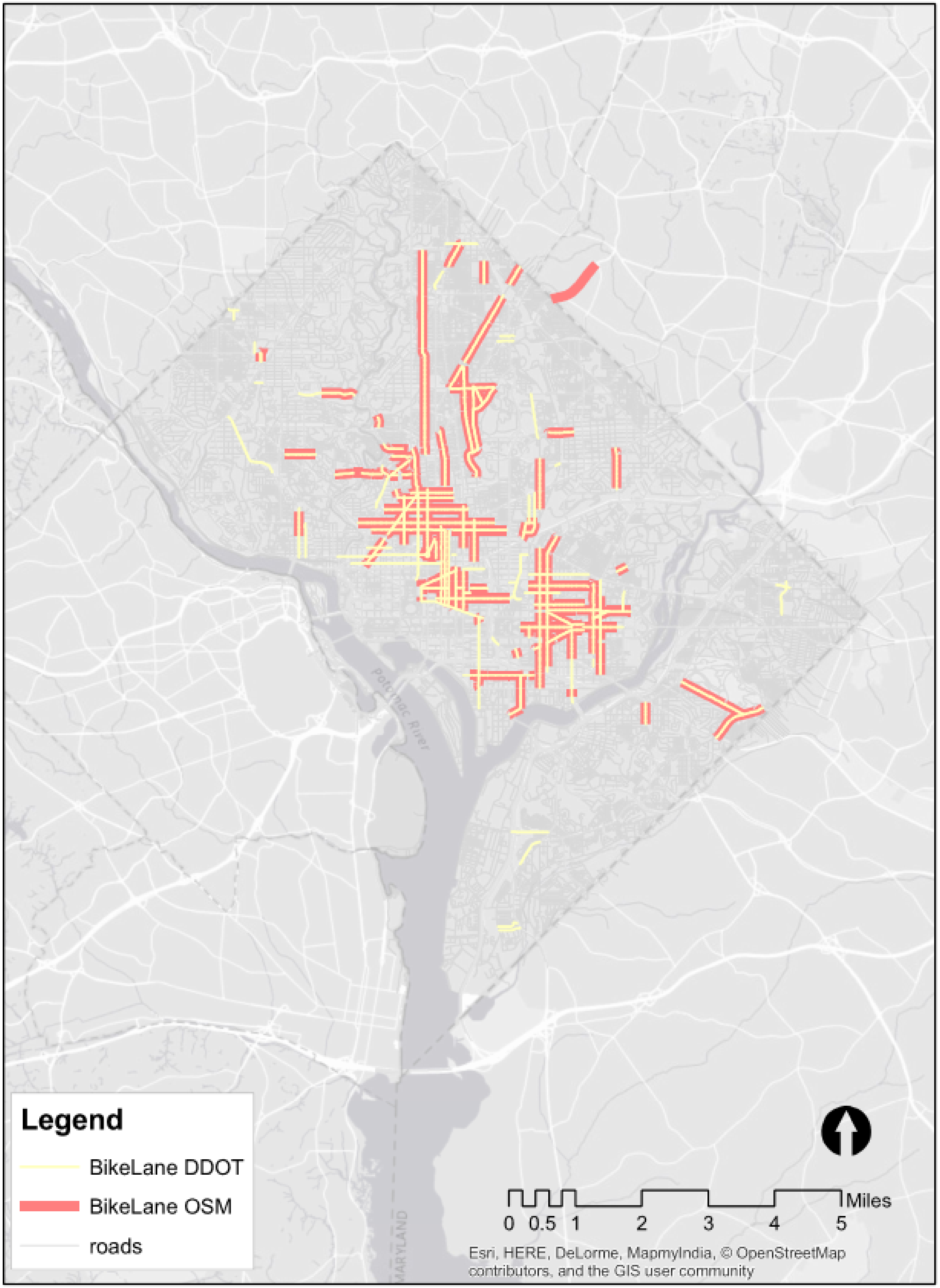


Figure 1.24 Comparison of Shared Bike Lanes between DDOT and OSM Database

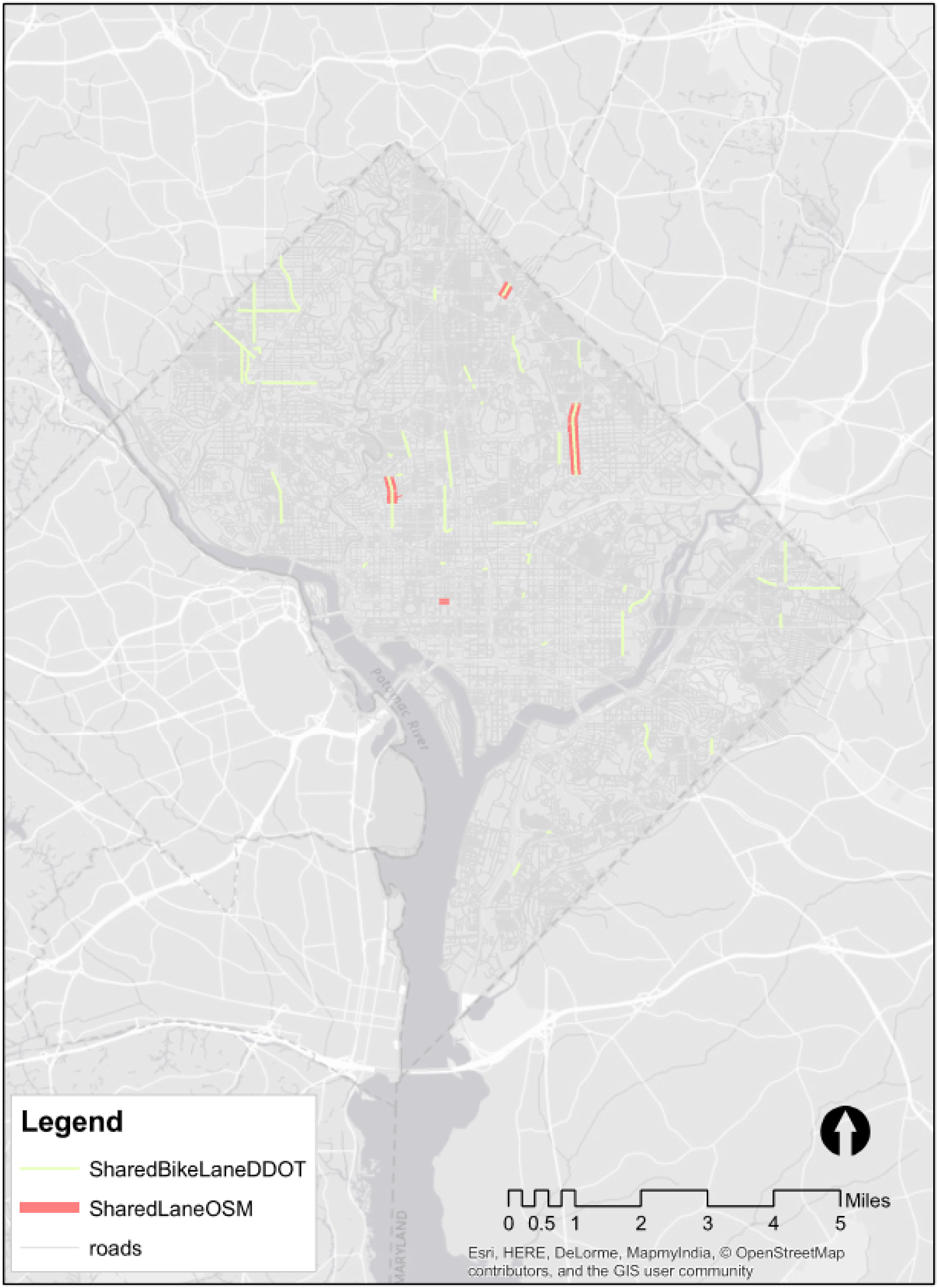
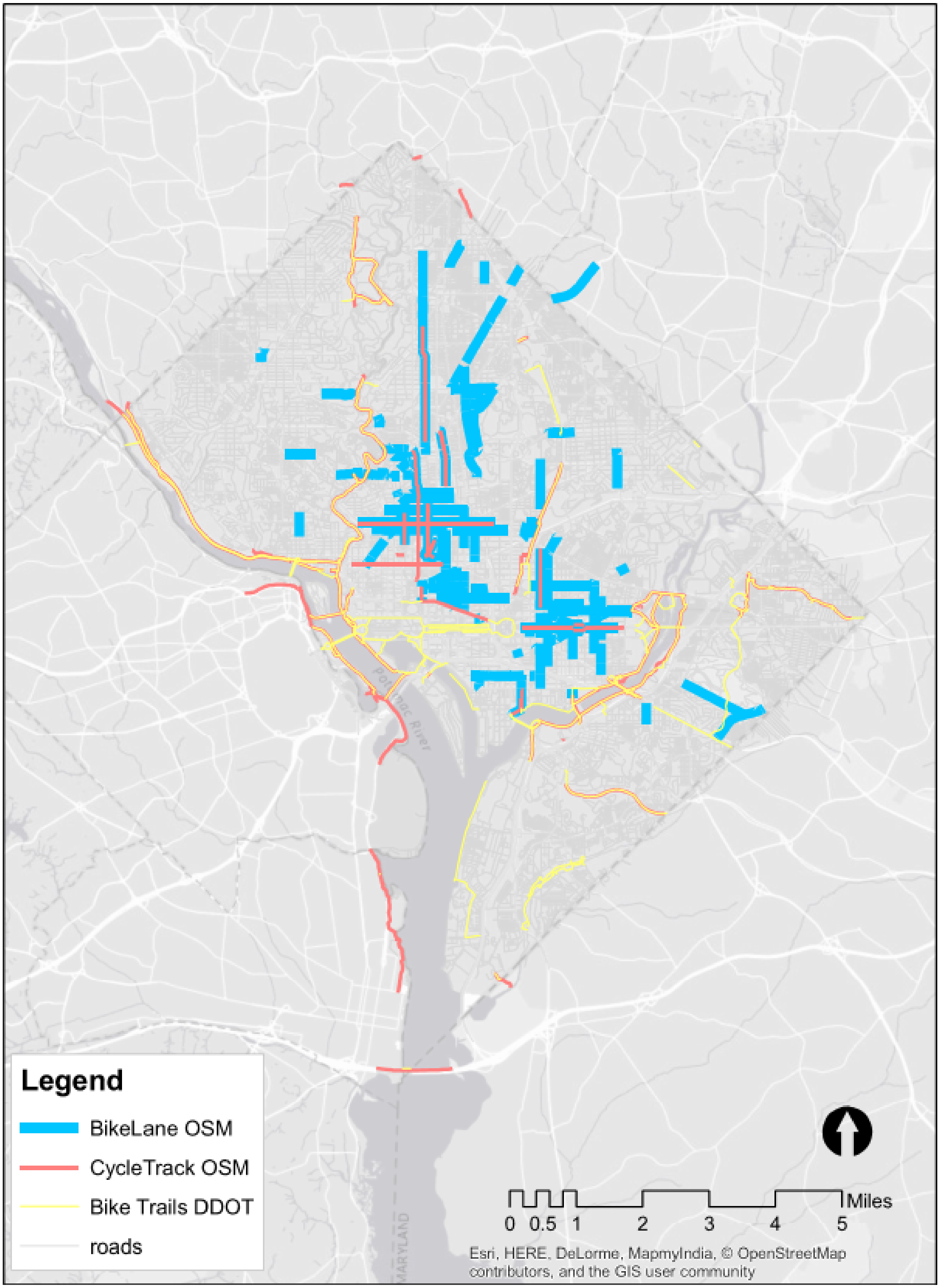


Figure 1.25 Comparison of Cycle Tracks between DDOT and OSM Database



Esri, HERE, DeLorme, MapmyIndia, © OpenStreetMap contributors, and the GIS user community

Findings and Recommendations

It is recommended that local nonmotorized databases be used when available. However, some local jurisdictions do not have such databases or they do not have near-term plans to develop such databases. Moreover, each jurisdiction we identified with bike data has its own way of classifying the bike treatments.

As shown in the review and comparisons above, OSM provides an option for producing regionwide mapping of nonmotorized regional facilities within the MWCOG modeling region. Features of interest such as sidewalks can be selected quickly; however, the accuracy of locations of features cannot be assured. For bicycle facilities, there is room for improving the accuracy of the OSM. However, the OSM data could serve as a placeholder for jurisdictions without local jurisdictions before local data are collected and available to use (though it likely cannot substitute fully for local nonmotorized databases, given the possible accuracy issues we observed in our test comparison). As noted earlier, MWCOG staff also has access to subscription-based HERE (formerly NAVTEQ) map layers, which include some bike trails.

When assembling and using a different dataset for each local jurisdiction, it is necessary to introduce standardization in classifying the bike treatments in each. As Table 1.16 shows, when compared to the classification schemes for D.C., Arlington, Alexandria, and Falls Church all differ. Other alternatives include the scheme used by Los Angeles, or AASHTO's (2012) guidance on the designation and development of bike facilities.

Table 1.16 Bicycle Facility Type Classifications

AASHTO	Los Angeles	D.C.	Arlington	Alexandria	Falls Church
• Shared Use Paths • Bicycle Lanes • Signed Shared Roadways • Shared Lanes • Bicycle boulevards	• Bike Trail • (Class I) • Cycle Track (Class 1.33) • Bike Lane • (Class II) • Bike Route • (Class III)	• Bike Trail • Climbing lane • Contraflow Bike Lane • Cycle Track • Existing Bike Lane • Shared Lane	• Marked Route • Off-Street Trail • Sharrow • Suggested Routes (actually are streets without any bike treatments, but bike-friendly)	• On-Street • Off-Street	• Bicycle Route

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2.0 Task Order 16.3 – Managed Lanes

2.1 Overview

CS was tasked with reviewing how managed lanes (ML) are being evaluated and incorporated into the travel demand models throughout the country and developing a recommendation for managed lanes evaluation in the context of the MWCOG regional model structure. This effort was completed under Task Order No. 3 of Fiscal Year 2016 (Task Order 16.3) of MWCOG Contract #14-056, "Assistance with the development and application of the MWCOG/NCRTPB travel demand model."

For the purposes of this project, managed lanes were defined as follows:

> "Managed lanes are defined as highway facilities or a set of lanes where operational strategies are proactively implemented and managed in response to changing conditions...Examples of operating managed lane projects include high-occupancy vehicle (HOV) lanes, value priced lanes, high-occupancy toll (HOT) lanes, or exclusive or special use lanes." *(1)*

CS reviewed the state of the practice of managed lane modeling in the regional travel demand models for a select number of MPOs that operate toll facilities. Due to the relatively limited presence of managed lanes in several regions, there are a limited number of MPOs that have developed specific procedures for the estimation of demand for managed lanes. Procedures employed in modeling and estimating demand for such projects range from sketch planning, to post-processing methodologies, to the implementation of procedures adapted for use with state-of-the-practice four-step travel models and state-of-the-art activity-based models (ABM). In Section 2.2, these methods were synthesized into five categories and the strengths and weaknesses of each method are discussed. CS also presents a synthesis of its literature review of available published documents that describe managed-lane modeling procedures in use and describes the toll modeling procedures in the following metropolitan areas: Southern California (including Los Angeles); Southeast Florida (including Miami); Atlanta, Georgia; Seattle, Washington; and Houston, Texas.

Section 2.3 presents the current MWCOG practice of toll modeling according to the latest travel model user's guide *(4)*. The literature review revealed that there is no one-size-fits-all strategy that exists with regard to managed lanes modeling. Each region exhibits unique characteristics that require agencies to adapt various experiences to their environments.

Section 2.4 presents an alternative method of addressing managed lane modeling within the current MWCOG model framework. This is followed by Section 2.5, which provides recommendations.

2.2 State of the Practice in Toll Road/Managed Lanes Modeling

NCHRP Reports on Managed Lanes

NCHRP Synthesis 364

NCHRP Synthesis 364 *(2)*, published in 2006, concluded that no state-of-the-practice consensus exists among transportation practitioners regarding the best methods for achieving managed lanes representation in a regional model. A review of the state of the practice for managed lanes projects in several U.S. cities identified the following five approaches to modeling procedures:

- **Modeling managed lanes as part of an activity-based model.** Activity-based modeling is considered the state of the art in travel demand modeling and facilitates the inclusion of pricing into the decision hierarchy. NCHRP Synthesis 364 notes that revealed and stated-preference survey data could be used in combination to develop the managed lanes modeling procedures, as was done in Portland, Oregon. The stated-preference data would be used to provide information on choices that do not yet exist (e.g., new time-varying tolls). (Note that at the time when NCHRP Report 364 was written, only Portland had used an activity-based model to analyze managed lane demand, but, since, other metropolitan areas have begun using this approach.)

- **Modeling managed lanes at the mode choice stage of a four step model.** In this approach, tolled and nontolled roads are considered distinct auto mode choice alternatives. (However, as noted later in Section 2.4 of this report, the trips using the "toll" alternatives may not actually be assigned to toll facilities.) As in nearly all regional models, separate mode choice models are applied for work and nonwork trip purposes. Out-of-pocket costs in this approach are modeled explicitly, as travelers' utilities are dependent on the toll amount. The modeling of toll demand as part of mode choice requires that the generalized cost impedances (i.e., impedances that account for monetary values – such as tolls – as well as travel times) are fed back from trip assignment to trip distribution and mode choice. The process iterates until a stable equilibrium is achieved.

- **Modeling managed lanes within the trip assignment stage of a model.** This approach allocates auto trips to tolled and nontolled facilities within the route choice (highway assignment) step of the model (or in the absence of a demand model). It assumes that trip distribution and modal shares are not affected by the choice of a tolled or nontolled route.

  There are two general methods for modeling traffic diversion in highway assignment. The first method incorporates the effects of toll cost directly into the impedance of the highway path. The monetary toll is converted to a time equivalent through the use of values of time, and the equivalent times are incorporated into the model's volume-delay functions. An equilibrium assignment technique is adopted to allocate trips among different paths. The values of time used to convert toll costs to time equivalents can be derived for different trip purposes, income levels, and other market segments. This is the method used in the MWCOG model.

  The second method uses "diversion curves" to determine as a binary choice the proportions of trips using tolled and nontolled facilities. The diversion curve may use the form of a logit function, which calculates the probability of using a tolled facility (which translates in application to the facility's share of traffic) as a function of the difference in generalized cost between the tolled and nontolled route (for each origin-destination path that could use the tolled facility). A benefit of using diversion curves is that they can be applied to an existing model without having to recalibrate it.

- **Modeling managed lanes as a post-processing step** that can be performed either within the framework of an existing four-step model or outside the model, using its outputs. In such applications, the assigned volumes on general purpose lanes are diverted to managed lanes based on considerations such as the excess capacity on the managed lanes.

- **Using a sketch planning method.** Examples of these include FHWA's Spreadsheet Model for Induced Travel Estimation (SMITE), which estimates induced traffic due to increased travel speeds (including traffic diverted from other facilities, destinations, or modes) using demand elasticities with respect to travel time. In SMITE, price and demand are equilibrated. A modified version is the Spreadsheet Model for Induced Travel Estimation-Managed Lane. In this version, a pivot-point logit model estimates changes in travel demand based on differences in travel times and tolls and also considers improvements in transit service.

NCHRP Report 722

While NCHRP Synthesis 364 provides a macro level categorization of toll road modeling methods, the more recent NCHRP Report 722 *(3)* provides substantially more in-depth analysis of models applied for highway pricing studies, for both four-step trip-based models and activity-based models.

NCHRP Report 722 outlines the model features that are specifically relevant for pricing projects. These include:

1. **Network microsimulation** and associated route choice sensitivity to tolls. Changes in route choice represent first-order responses to pricing, and associated tradeoffs between travel time savings and tolls are the cornerstone of toll facility traffic forecasts.

2. **Mode choice and time of day choice**, which represent a first-order response to pricing.

3. **Second-order considerations – destination choice and choosing not to make the trip**. These impacts are generally considered to have a lower elasticity to pricing, although long-term impacts could be significant.

   NCHRP Report 722 also recommends incorporating pricing as part of network assignment and skimming and as part of a generalized cost function. Segmentation by mode and occupancy and purpose is also recommended. The reasons for segmentation are as follows:

   a. Different vehicle classes and purposes have different values of time;

   b. Toll rates may be different by vehicle class or occupancy class; and

   c. General prohibitions and eligibility rules can be applied by vehicle type or facility type.

4. In order to satisfy the aforementioned criteria, a **multiclass assignment** is recommended. This approach is recommended to **reduce not just assignment bias, but also mode choice and time-of-day choice bias**, since skims feeding into these processes are also impacted.

5. **All-or-nothing assignments**, which are frequently adopted in toll and revenue studies. It has been recognized that this methodology is not an adequate tool in itself, since the traveler choice route is not a simple linear combination of time and cost.

This following bullets summarize the conclusions of NCHRP Report 722, based on documentation from approximately 30 different managed-lane model applications:

- The demand modeling approaches for managed lanes varied greatly. Since the model used for a highway pricing project was usually a modification of the existing regional model, most of the limitations and deficiencies of the existing regional model were not overcome.

- In most cases, only route choice (assignment) and binary toll versus nontoll route type choice models were used in the alternative analysis. This implies that other choice dimensions such as mode, time of day, destination, and even whether to travel are not significantly affected by the implementation of the pricing scenario. The authors felt that this was not appropriate for forecasting managed lane demand in metropolitan areas.

- It is unknown whether doubly constrained gravity models (such as those used in the COG/TPB model) are appropriately sensitive to changes in level-of-service (LOS) variables, including the introduction of or changes in tolls. In some trip distribution models, mode choice logsums are used in the impedance variables, allowing some consideration of price. The authors believed that more testing of the use of mode choice logsums in gravity models (as opposed to logit destination choice models) was needed to show its effectiveness. It was also noted that some models had inconsistent impedance functions between trip distribution and mode choice. This inconsistency may be due to the desire for simplicity in trip distribution models, or it may be that in some cases the inconsistencies were inadvertently introduced. The effects of such inconsistencies have not been tested to our knowledge.

- The authors concluded that some mode choice utility functions were misspecified. Specifically, toll utilities that are a function of the toll alternative travel time and travel time savings relative to the free alternative could produce counterintuitive results when LOS attributes on either the toll or free routes changed. Another potentially problematic issue is the use of thresholds (i.e., “cliffs”), such as making the toll alternative available only if it meets a predefined minimum time savings goal. The nesting coefficients on such models can result in unreasonably high sensitivities to LOS differences when the toll diversion is examined at the root level of the model (where they are comparable with the elasticity of route type binary choice models).

- No consensus on how road pricing costs should be shared among vehicle occupants (if at all) was noted. Most of the models examined assumed either that the full toll cost is either borne by all occupants or that it is equally shared among the occupants.

- Some of the models examined made explicit assumptions regarding the willingness-to-pay differences between cash-payment users and Electronic Toll Collection (ETC) users while others simply used the average toll cost per transaction.

- Four-step trip-based models rarely explicitly account for peak spreading (which may occur due to either peak congestion or peak pricing) although a few of the models examined were revised to include a new peak spreading component. ABMs include explicit time-of-day choice functions that can consider peak spreading directly. Some models are not explicitly sensitive to cost differences by time of day because the data to estimate such parameters was insufficient

- Few of the activity-based models examined are sensitive to pricing effects in all model components. Specifically, daily activity pattern and long term choice models were not usually sensitive to pricing.

- Almost all models, including advanced ABMs, have a significant discrepancy between the user segmentation for the values of time in the demand modeling components compared to highway assignment. In the demand modeling stage, segmentation usually includes trip or tour purposes, income groups, vehicle occupancy levels, and time-of-day periods. By contrast, highway assignment is characterized by more limited segmentation. Traffic assignments are implemented by time periods and for multiple vehicle classes that typically include vehicle type and occupancy. However, trip purposes and income groups are combined before assignment, creating aggregation biases with respect to value of time.

- Cost functions for network skimming can differ from those used for assignment. Specifically, sometimes the best paths for skimming are built without considering monetary cost, while highway assignment is based on both time and cost.

- In mode choice models where toll and nontoll auto alternatives are used, there was often a significant number of “toll” alternative users being assigned only to free routes during highway assignment.

- In some models where travel time/cost feedback from highway assignment to the demand components is used, the number of feedback loops is fixed for all model runs. This may result in insufficient convergence for scenarios where congestion effects are much greater than in the validation scenario.

- The number of time periods used in highway assignment is usually limited to four, generally two peak periods of two to four hours, a mid-day period, and a night period. This level of aggregation may be insufficient for applications where conditions or prices change significantly within periods.

- With few exceptions, highway assignment validation is limited to average weekday conditions and does not consider validation for different periods of the day.

Other Regional Models

Documentation of several regional models was reviewed with respect to how managed lanes are handled. Managed lane modeling methodologies adopted by these MPOs are presented below.

SANDAG Model – California

Model Overview

The San Diego Association of Governments (SANDAG) model is an activity-based model based on the CT-RAMP (Coordinated Travel Regional Activity-Based Modeling Platform) implementation framework *(5)*. The SANDAG model has been tailored specifically to consider current and future projects and policies and also takes into account the special markets that exist in the San Diego region. The model system addresses requirements of the metropolitan planning process, relevant Federal requirements, and provides support to SANDAG member agencies and other stakeholders.

Mode Choice in the Context of Pricing

One of the SANDAG model components where the toll facilities are addressed is in the tour mode choice model. This model determines how the “main tour mode” (used to get from the origin to the primary destination and back) is determined. As in all tour-based models, there are two different levels where the mode choice decision is modeled: the tour level and the trip level (conditional upon the tour level choice).

The choice set for the tour mode choice model includes separate toll and nontoll choices among the auto submodes. Toll modes for three auto occupancy levels are among the 26 modes in the choice set. The toll modes allow paying a choice or “value” toll along the highway route. Tolls on bridges are counted as a travel costs, but the mode is considered “free.”

Network Characteristics/Highway Assignment in the Context of Pricing

The average expected travel time savings provided by toll facilities to work is calculated using a simplified destination choice logsum. The expected travel time savings of households in a zone *z* is given by:

$$\frac{\sum_d (AutoTime_{zd} - TollTime_{zd}) \cdot Employment_d \cdot \exp(-0.01\ AutoTime_{zd})}{\sum_d Employment_d \cdot \exp(-0.01\ AutoTime_{zd})}$$

The times are calculated in minutes and include both the AM peak travel time to the destination and the PM peak time returning from the destination. The percentage difference between the AM nontoll travel time to downtown zone and the AM nontoll travel time to downtown when the general purpose lanes parallel to all toll lanes requiring transponders were made unavailable in the path finder. This variable is calculated as:

$$\frac{Non\ Toll\ Time\ Avoiding\ Facility - Non\ Toll\ Time}{Non\ Toll\ Time}.$$

Other Features Related to Pricing

Another module where the SANDAG model addresses toll facilities is the toll transponder ownership model. This model predicts whether a household owns a toll transponder unit. It was estimated based on aggregate transponder ownership data using a quasi-binomial logit model. It predicts the probability of owning a transponder unit for each household based on aggregate characteristics of the zone.

SERPM 7 – Florida

Model Overview

The Southeast Florida Regional Planning Model (SERPM 7) is an activity-based model of travel in the Southeast Florida region, including Miami. SERPM 7 is designed to be used to analyze conventional highway projects, transit projects, and various policy studies such as highway pricing and managed lane analysis *(6)*. At its core is the internal resident travel model, which is based on the CT-RAMP framework. The SERPM 7 model transfers the resident and visitor travel components from the SANDAG model.

Mode Choice in the Context of Pricing

The tour mode choice model determines the “main tour mode” used to get from the origin to the primary destination. As in most ABMs, there are tour and trip level mode choice models.

The tour-level mode choice model reflects the most important decisions that a traveler makes in terms of using a private car versus using public transit, nonmotorized, or any other mode. Trip level decisions correspond to details of the exact mode used for each trip. There are 26 modal alternatives, including auto by occupancy and path choice (free, HOV, toll) as well as transit and nonmotorized modes. The auto choices provide an opportunity for toll road and HOV lane choice as a path choice within the nesting structure. Implementation of these “pre-route” choices requires separate free, pay, and HOV skims to be provided as inputs to the model.

Network Characteristic/Highway Assignment in the Context of Pricing

The Southeast Florida region includes multiple toll facilities and HOV lanes. The cost of using the toll facilities is coded on the network links at the point where the cost is incurred (i.e., location of toll plazas and collection points). The cost of using managed lanes is computed as a function of the volume-to-capacity ratio on the managed lane facility, based on a function developed by Florida Turnpike Enterprise *(6)*.

The allowable occupancy levels on all managed lane facilities (HOV and HOT), as well as the toll discounts, where applicable, are handled entirely via facility-type coding and attribute fields in the input network. Similarly, the input network includes an attribute to account for reversible lanes, which are expected to operate on I-595 in the near future.

Free-flow speeds are calculated based on methodologies reflected in the NCHRP Report 3-55(2) *(7)*. Free-flow speed is assumed to be a linear function of the posted speed limit, using relationships published in the NCHRP report, which in most cases result in average uninterrupted free-flow speeds that are higher than the posted speed limit. The resulting speed is further modified to account for traffic control devices using relationships documented in NCHRP Report 387 *(8)*, which attempt to quantify the effects of G/C, cycle length, and the degree of signal coordination.

In the highway assignment step, the trip lists output from the model are converted to trip matrices, segmented by mode and time period, combined with commercial, internal-external, and air passenger trips, and assigned to the five period-specific highway networks. Each time period’s assignment is a multiclass static user equilibrium assignment with the following user classes: Drive Alone (free), Drive Alone (pay), Shared Ride 2 (free), Shared Ride 2 (pay), Shared Ride 3+ (free), Shared Ride 3+ (pay), Small Trucks, and Large Trucks. Traffic assignment step is done using the Frank-Wolfe algorithm. The convergence criterion is a relative gap of 0.0001.

Other Features Related to Pricing

Another module where the SERPM 7 model addresses toll facilities is the toll transponder ownership model. This model predicts whether a household owns a toll transponder (SUNPASS) unit. The model is based on SUNPASS sales data – the number of active SUNPASS accounts by TAZ. While the data comprise individual sales records, no information is known about the SUNPASS account holders besides their addresses. Therefore the model was estimated as a regression model that predicts the probability of owning a transponder unit for each zone based on aggregate characteristics of households in that zone and distance to the nearest major toll facility. Once the probability of owning a transponder unit is known, whether each household owns a transponder is determined using Monte Carlo simulation.

ARC Model – Georgia

Model Overview

Similar to the SANDAG and SERPM 7 models, the Atlanta Regional Commission (ARC) *(9)* also utilizes the CT-RAMP framework. The auto choices provide an opportunity for toll road and HOV lane choice as a path choice within the nesting structure. Implementation of these “pre-route” choices requires eight separate free, pay, and HOV skims to be provided as inputs to the model.

Mode Choice in the Context of Pricing

The ARC tour mode choice model has 13 modal alternatives, including auto by occupancy level and toll/nontoll choice, as well as transit and nonmotorized modes. The costs of using managed lane facilities are calculated during highway assignment based on a unit toll (expressed in cents per mile) that is a function of the volume-to-capacity ratio. The volume/capacity ratio and corresponding segment toll are recalculated at each user equilibrium iteration.

Network Characteristic/Highway Assignment in the Context of Pricing

The trip list outputs from the model are converted to trip matrices, segmented by mode and time period. These trip tables are combined with matrices of commercial, internal-external, and air passenger vehicle trips and assigned to five time-period-specific highway networks. Each trip assignment is a multiclass static user equilibrium assignment with the following user classes: Drive Alone (free), Drive Alone (pay), Shared Ride 2 (free non-HOV), Shared Ride 2 (free HOV), Shared Ride 2 (pay), Shared Ride 3+ (free non-HOV), Shared Ride 3+ (free HOV), Shared Ride 3+ (pay), Small Trucks, and Large Trucks. The solution to the traffic assignment problem is found using the Frank-Wolfe algorithm. The convergence criterion is a relative gap of 0.0001 achieved on three consecutive equilibrium iterations. A generalized cost function that includes travel time and toll cost is used to find the least-cost paths at each user equilibrium iteration.

SCAG Model – California

Model Overview

The Southern California Association of Governments (SCAG) trip-based model was developed and adopted for the 2012 Regional Transportation Plan/Sustainable Communities Strategy (RTP/SCS) analysis. The model was updated, calibrated, and validated to base year of 2008 *(10).* New modeling capabilities introduced as part of this update address the need for evaluating a wide variety of projects and transportation policies, including the addition of highway pricing strategies, expansion of existing transit services, introduction of new types of transportation services (such as bus rapid transit and high speed rail), and land use policies.

Mode Choice in the Context of Pricing

The SCAG mode choice model is a nested logit model. Among the auto choices, the model distinguishes four levels of occupancy (1, 2, 3, and 4 persons per vehicle) and includes a pre-route toll/no toll binary choice as part of the mode choice model. The model includes a HOV/non-HOV path subnest for the shared-ride choices.

Network Characteristic/Highway Assignment in the Context of Pricing

The SCAG region, which includes the Los Angeles and Riverside metropolitan areas, includes over 300 centerline miles of HOV lanes restricted to 2 plus person carpools, one 10-mile facility restricted to 3 plus person carpools, and several toll facilities including two HOT lane facilities nearing full implementation. A generalized cost function is used to build the highway travel time and cost matrices (skims). Up to eight different sets of skims are built for the mode choice model, one for each highway mode and time period combination. For each of these combinations, best path skims are built for the toll, nontoll and HOV paths, as appropriate.

$$GC_{ij} = Travel\ Time_{ij} + \left(AOC \times Distance_{ij} + Toll_{ij}\right)/VOT$$

In the highway assignment, vehicle trips for all trip purposes are loaded onto each of five time period highway networks. Prior to assignment, the mode choice output is converted from peak/off-peak production-attraction format to time-of-day OD format. The procedure used to accomplish this conversion is based on trips-in-motion diurnal factors. A binomial diversion model is applied prior to highway assignment to split carpool trips between vehicles that use the HOV lanes and vehicles that remain on the general purpose flow lanes. The probability of choosing the HOV facility is given by the function below:

$$P(HOV) = \frac{b}{b + e^{at}}$$

Where *t* represents the travel time savings from using the HOV facility, *t* = HOV time – general purpose time + access penalty, and *a* and *b* are calibrating factors. The HOV access penalty measures the inconvenience of entering and exiting the lanes, given that many of them are buffer or barrier-separated with limited opportunities for access and egress. The access penalty is 5.0 minutes across all time periods. The calibrating factor *a*, determines the steepness of the logistic curve, while *b* determines the likelihood of using the HOV lanes at zero travel time savings. To encourage carpool trips to stay on the HOV lanes, a factor of 1.1 is used on the mainline travel times. All the parameters of the HOV diversion function can be specified by time period; however, the same parameters are currently used for all time periods and implementation of HOV diversion model applicable prior to highway assignment to split carpool trips between vehicles that use HOV lanes and vehicles that remain on the general purpose flow lanes.

Houston Travel Demand Model – Texas

Model Overview

The Houston-Galveston Area Council (H-GAC) recently developed an activity-based model. This model of the entire Houston region includes components related to long-term choices (vehicle availability, workplace location, and school location); tour generation (daily activity pattern, school escorting, joint household travel, and nonmandatory travel); tour level choices (destination, time of day, and mode); and stop/trip level choices (destination, time of day, and mode). The model is documented in a series of 15 technical memos; the most relevant to the managed lanes review is the Tour Mode Choice Model memo *(11)*. There is also a model validation report *(12)*.

Mode Choice in the Context of Pricing

As with other activity-based models, mode choice is modeled in two steps, at the tour and trip levels. Since the trip level choice is highly dependent on the tour level choice; the tour level choice *(11)* is more relevant to managed lanes choices since the tour level is where the decision of whether to leave the home by auto or not is made. If auto is used, the choice of whether to have multiple occupants in the car is influenced more by household composition and activity pattern characteristics (for example, whether people are being dropped off or picked up along a tour).

The mode choice model structure is “shallow,” meaning that the number of modal alternatives is small, and the choices of specific “submodes” such as transit type and whether to use managed lanes is handled at the trip assignment step. Hence there are no toll/nontoll alternatives, and the only three auto submodes are drive alone, two person carpool, and three person carpool.

Network Characteristics/Highway Assignment in the Context of Pricing

There are managed lanes in the Houston region's highway network that are used extensively. The Katy Freeway Managed Lanes, operated by the Harris County Toll Road Authority (HCTRA), are free for HOVs during peak periods and offer SOV drivers the option of paying a toll to use the managed lanes. Other HOT lanes are operated by the Metropolitan Transportation Authority of Harris County. There are also toll roads, both conventional and barrier-free, operated by the HCTRA.

Toll rates vary by facility and time of day. While the toll rates are generally fixed, some of them change on an hourly basis during peak periods. However, highway assignment in the H-GAC model is done for four separate time periods, including single a.m. peak and p.m. peak periods, and so a single toll rate is used for each facility for each time period. Tolls are coded on the appropriate links.

The model validation specifically looked at the assignments on toll facilities *(12)*. The model is able to reasonably reproduce managed lane volumes, according to the validation report.

PSRC Model – Washington

Model Overview

In 2007, the Washington State Department of Transportation (WSDOT) used the Puget Sound Regional Council (PSRC) trip-based model *(13)* for their Congestion Relief Analysis (CRA) study in the Seattle-Tacoma area. (Note that in 2015 PSRC introduced a new activity-based model.) The PSRC trip-based model addressed tolls in mode choice, and network assignment. Network coding conventions provided access to HOV/HOT lanes only at specific crossover points (slip ramps) or via direct access ramps from interchanges; therefore managed lanes were treated as physically separated facilities. In addition, a spreadsheet-based toll matrix was developed to optimize tolls based on time of day, link volume, and type of vehicle. The three-hour peak periods were split into six periods of 30 minutes each to determine the range of possible peak period tolls if dynamic tolling were implemented.

Mode Choice in the Context of Pricing

PSRC's mode choice model uses the multinomial logit formulation. In a logit mode choice setting, the choice among travel modes is determined by the following factors:

- Characteristics of the trip maker (e.g., income, gender, age, household size, auto availability).
- Characteristics of the modes of travel available to the trip maker (e.g., travel time, cost of travel).
- Characteristics of the trip itself (e.g., work versus non-work trips). The probability of a trip maker choosing a mode of travel is a function of the "utility" of that mode versus the aggregate utility of all available modes.

The PSRC model system includes values of time explicitly in the mode choice model, with time and cost coefficients that provide estimates of travelers' values of time. The mode choice models allocate person trips among the available auto, transit and non-motorized modes and five trip purposes: home-based work;

home-based college; home-based school; home-based non-work (shop and other); and non-home-based (work and other). Home-based work trips are kept separate by income group throughout the modeling process, to facilitate evaluating the impacts of tolls and other pricing policies on commuters with different values of time, while non work trip purposes use an average value of time. The auto mode alternatives do not distinguish between toll and nontoll.

Network Characteristic/Highway Assignment in the Context of Pricing

The trip assignment model is applied separately for each of the five time periods (a.m. peak, midday, p.m. peak, evening and night), which supports three primary objectives: producing impedance measures, producing volumes by mode, and producing data for the time of day model.

The highway assignment model relies on estimates of values of time in the calculation of generalized costs that are separate from the mode choice estimates. These estimates serve as the basis of the skimming and path-building. For the final highway assignment model, the recommended values of time used for route choice, are more than double the mode choice model values, based on observed values of time reported on SR 91 and I-15 in Southern California. In addition, these values of time are higher for peak-period assignments than for off-peak-period.

Other Features Related to Pricing

The time of day model has two key features that make the model sensitive to congestion pricing:

- First, the three time periods where congestion occurs (a.m. peak, midday, p.m. peak) were further divided into 30-minute subperiods in order to model peak-spreading behavior; and

- Second, in addition to auto travel time variations between periods, the model is sensitive to auto travel cost differences between periods, for instance from time-of-day-specific congestion pricing.

Travel cost differences by time of day are added separately into the models, but as part of the generalized cost impedance used in trip distribution. This comes from the assignment procedure as a separate price/toll skim by time of day.

2.3 Current TPB Model Toll/Managed Lane Treatment

Summary of Current Methodology

TPB staff has developed a procedure for using the regional travel demand model to forecast demand on managed lanes. This procedure involves running the travel model twice *(4).* The “base run” captures the travel time for unimpeded flow of HOV traffic in the High Occupancy Toll (HOT) lanes. The purpose of this step is to generate the HOV travel time skims used in the mode choice model that reflect the mandated Virginia HOV policy that the introduction of HOT lane facilities should not significantly deteriorate travel times for HOV. The “final run” of the travel model uses the HOV skims obtained from the “base run” to reflect unimpeded HOV skims, which would otherwise be obtained by simply skimming the networks with HOT lanes in operation. Skims for all other modes are taken from the “final run.” Under this framework, the “base run” serves solely as a means for measuring times for HOV traffic on HOT facilities. This procedure is referred to as the “HOV3+ skim substitution option,” the “HOV3+ skim replacement (HSR),” or the “multirun procedure” for modeling HOT lanes.

In summary, TPB travel forecasts involving HOT lane scenarios are developed using two separate model executions: 1) the “base” run from which HOV 3+ skims are developed, and 2) the “final” run which uses specially developed HOT lane toll rates and the HOV 3+ skims from the base run.

Potential Issues or Limitations with Current Methodology

There is no explicit toll choice mechanism in the model stream; the choice of using toll or nontoll facilities is determined in the assignment process based on the generalized impedance that consists of travel times and toll charges. This somewhat limits the ability to calibrate or validate the process, except by adjusting the toll rates or the values of time.

In the toll setting procedure, the toll rates for HOT lanes are adjusted using rules based on the ranges of the volume/capacity (V/C) ratio. These “discrete” rules may result in adjusted toll rates oscillating between two toll levels associated with two neighboring V/C ranges during the toll setting process, potentially increasing the time for convergence. In addition, the model employs a large number of toll groups, which requires substantial computation effort during the modeling process. The toll rate of each toll group is adjusted individually during the toll setting process. The entire toll setting process involves many iterations of assignment runs until the desired traffic conditions on HOT/HOV facilities are met. During each iteration a significant amount of processing of network data is required. Calculating average V/C ratios and adjusted toll rates by toll group and attaching the toll rate data to the network link data are examples of this processing.

MWCOG conducted a validation test of the current MWCOG toll model by applying the model for 2015 conditions and comparing the model simulated and observed toll rates and traffic volumes on the HOT facilities on I-495 and I-395 in Northern Virginia. The comparison revealed that the model is not able to match observed conditions very well. In general, the simulated toll rates are lower than the actual rates, and the simulated traffic volumes are higher than the actual volumes on those HOT facilities, according to [1] simulated versus observed weekday data provided by Transurban.

Prior Recommendations on Model Improvements

In 2014, AECOM proposed and tested a process that made specific improvements to the regional travel demand model to enhance the way managed lanes were addressed in the model *(14)*. TPB staff evaluated these procedures and compared them to the existing process (described in “Summary of Current Methodology,” above) and documented the evaluation in a memorandum *(17)*. This subsection presents a summary of their findings.

AECOM’s proposed process incorporated a new HOV choice model (executed post mode choice) and a revised process for modeling HOT lanes into the highway assignment process, including the capability to automatically estimate suitable tolls on the HOT lanes (“toll setting”). After receiving the proposed enhanced model, TPB staff spent several months testing the process. Staff found a few areas where the revised model was not working as expected. Staff documented the findings and shared them with AECOM (*15)*. In response, AECOM recommended two fixes, one of which (“Fix 1”) corrected an error in the highway assignment script. The second fix (“Fix 2”) addressed the issue that for some values of the link V/C ratio, the function that determines how much to raise a toll in response to a congested link could actually be negative *(16)*. TPB’s summary (*17*) suggested that Fix 1 could be considered a “required fix” and Fix 2 an “optional fix.”

Table 2.1 summarizes the issues discussed in the response memorandum *(16)* and whether these issues were resolved by applying the fixes. Fixes 1 and 2 fix most of the issues, but as noted, Fix 2 causes a longer running time.

Table 2.1 Summary of Issues Identified by TPB Staff and Whether They Were Resolved by the Two Fixes Provided by AECOM

Issue	Resolved?	Note
1. Negative values coming from AECOM's continuous toll increase function (Finding 5)	Yes, by Fix 2	Running time is long. Recommend using a lookup table instead.
2. Using well "seasoned" seed tolls did not save running time (Finding 9)	Yes, by Fix 1	Now, well-seasoned toll values were shown to reduce runtime.
3. Two toll groups with V/C above 1 have very different tolls (Finding 10)	Yes, by Fix 1	
4. AECOM process seems to result in both higher average toll rates and higher average V/C values (Finding 11)	Yes, by Fix 1	Although toll rates and average V/Cs are still higher in the AECOM process, they are generally close to those developed using the MWCOG process. This may be because the HOV Choice Model attracts more trips to the HOT lanes.
5. When comparing the two processes, the existing MWCOG process seems to result in more realistic/believable toll rates (Finding 11)	Partially, by Fix 1	The maximum value of $10 per mile no longer exist. Both processes underestimate tolls compared to observed data. The existing process slightly performs better.
6. It appears that AECOM may have consolidated some toll groups that should have been left unconsolidated (Finding 16)	No	Recommendations about toll group consolidation made by TPB staff (see *(17)* pp. 22-23).

Source: TPB memorandum , Reference *(17)*.

The key comparisons between the existing MWCOG HOT lane modeling process and AECOM's proposed process are shown in Table 2.2.

Table 2.2 Key Comparisons of Existing Versus AECOM's Proposal HOT Lane Modeling

Measurement	Existing COG Process	AECOM's Proposal
Running Time	• Longer running time. Double the run time for model application; similar run time for toll setting	• More time savings when using nonzero toll seed input • Potentially more time saving when using a lookup table to replace the toll decrease function • More settings are offered
Toll Result	• Toll values are underestimated.	• Similar toll pattern to that of MWCOG process. Tolls are underestimated and slightly lower than the MWCOG process.
Traffic Volume Result	• Traffic on HOT lanes is overestimated	• Traffic on HOT lanes is overestimated even more than the MWCOG process
Complexity	• Easier to understand than the AECOM process	• More complicated and harder to follow the structure
	• Multiple runs and two steps are required (longer run time)	• Only one run is needed per scenario
	• A run requires some manual processing work, which could be reduced by automation of the toll setting process proposed by TPB staff. Even in that case, three separate model runs are required to conduct a toll-setting run.	• A normal model run without toll setting also runs once, instead of running a base and a final run like in the COG process
Easy to Use	• More difficult to conduct a toll setting run	• Easier to execute a model run • More difficult to understand if users would like to change the toll setting components
Sensitivity Analysis	• Has been tested on different scenarios over years	• Only one analysis year (2020) has been tested by TPB staff
Others	• Only toll increase adjustment is included	• Both toll increase and decrease adjustment are involved • HOV choice model was only partly calibrated
	• Equivalent toll minutes for converting toll costs to a generalized time for each vehicle class	• Use relationships of toll-choice probability distribution versus different value of time distribution by vehicle class for each peak period

Source: TPB memorandum, Reference *(17)*.

Both the existing COG process and the proposed AECOM process have advantages and disadvantages. Due to the complexity of the process, the limited scenario tests, and the time constraints of the Constrained Long-Range Transportation Plan (CLRP) work, TPB staff did not recommend using AECOM process for the air quality conformity determination of the 2016 CLRP, which is currently underway. The following recommendations were made by TPB staff after their evaluation of the process:

1. Use the existing COG toll-setting procedure including the enhanced automation that has recently been added by TPB staff for the upcoming air quality conformity determination of the 2016 CLRP.
2. If TPB were to decide later to move forward with the AECOM approach:
    a. Incorporate Fix 1 to the AECOM proposed model.
    b. Disregard Fix 2 for the AECOM proposed model, and consider replacing the toll decrease function by lookup table(s) to reduce running time for the future tests.
    c. AECOM consolidated the number of toll groups from 134 to 91. TPB recommended that some of those consolidations be reversed.
    d. Conduct sensitivity tests. Some ideas include conducting tests for different year scenarios and changing the average V/C threshold range from 0.95-1.01 to a wider range, such as 0.90-1.01.

2.4 Segmenting Highway Assignment Using Value of Time

Overview

We are proposing for MWCOG's consideration an alternative approach for modeling managed lanes. The approach is based on the process used in the new Baltimore Metropolitan Council (BMC) model, InSITE, and is documented by Rossi et al. *(14)*. InSITE is an activity-based model, but the 2015 paper describes how this approach could be adapted for a trip-based model. This report adapts concepts from the earlier paper and focuses specifically on how this approach could be applied to the MWCOG model. The original paper provides more details on the derivation of the approach and the concepts that inspired the approach such as the desire to reduce aggregation error, as well as examples of how segmenting mode choice models to include toll and free road choices can lead to errors.

The choice of whether to use a priced roadway is always part of the route choice (highway assignment) component of models, where some trips are assigned to routes using priced roads and some are not. In many models, whether a priced road **may** be used is also considered as part of the mode choice component. In such cases, referred to here as "toll/nontoll segmented" mode choice models, or simply "segmented" mode choice models, the auto mode alternatives are duplicated to provide "toll" and "free" alternatives for existing auto submode alternatives, which are usually defined by vehicle occupancy levels. Those choosing the "free" alternatives are restricted from using priced roadways during highway assignment while those choosing "toll" alternatives may (but are not required to) choose paths that include priced roadways.

Value of Time

A concept that is critical in the estimation of priced road use is the **value of time**, or, more precisely, the value of in-vehicle travel time. In the most aggregate model applications, a single average value of time is used during highway assignment to consider tradeoffs between time and cost in determining best highway paths. It is common practice to have separate values of time for different vehicle types (for example, autos versus trucks). The most sophisticated aggregate assignment models may define several vehicle classes defined by value of time or income levels. A vehicle class with a lower value of time would be less likely to use paths with higher toll costs.

Mode choice models also implicitly use the concept of value of time, represented as the ratio of the in-vehicle time and cost coefficients in the utility function. The value of time is also used in determining the best paths between origins and destinations; it is used to determine tradeoffs between cost and time in the path building process, where the networks are “skimmed” to produce origin-destination travel times and costs. It should be noted that the values of time implied in path building are not always consistent with those implied in mode choice models, especially since mode choice models are segmented by trip purpose while path building is usually segmented only by time of day and mode.

Aggregation and Sequentialization in Travel Models

A well-known issue with travel models is that, for computational reasons, they oversimplify travelers’ decision-making processes by separating and sequentializing choices. In reality, mode and route choice are not separate, sequential choices (nor are mode and destination choice, or route and time-of-day choice, or many other combinations of choices that are nearly always modeled separately). But under the current paradigm, this simplification is necessary to model the process of traveler choices.

The idea of including a priced versus free route choice component in the mode choice model is, therefore, a false premise; it is simply part of the overall decision-making process (which includes mode and route choice) for the traveler. Nonetheless, the choice of using priced roads is sometimes included as part of mode choice to segment the traveler population in an attempt to reduce aggregation error in the model.

In the case of the choice of whether to use priced roadways, including this choice within the mode choice model, as a way of segmenting the population into two groups; one of which is much less likely (or, the way that it is modeled, unlikely at all) to use priced roadways. Segmenting the population in this way allows the model to produce two sets of highway paths for origin-destination pairs where there are viable routes that use priced roads and viable routes that do not. This, in turn, allows the mode choice model to distinguish between the times and costs encountered by travelers in each segment; rather than all auto users having the same time and cost, those willing to use priced roads will have higher costs and lower times than those who are not. The two groups may, therefore, have different utilities in mode choice, in the same way that auto and transit users have different utilities. The advantage to including this choice in the mode choice model is that tradeoffs between auto and nonauto modes can be considered separately for the two segments.

In segmented mode choice models, two sets of highway skims are produced: one assuming priced roads can be used, and one assuming they cannot. The latter set implies a lower value of time, which may be explicitly assumed in determining the best paths; however, the elimination of priced roadways from the path building process in effect ignores the value of time, at least with regard to tradeoffs involving toll costs.

Benefits of Toll/Nontoll Segmentation in Models

The idea of separating “toll” and “free” trips during mode choice has some appeal. The assignment step segments those with lower values of time and makes them very unlikely to use priced roads (in fact, they would never use priced roads unless there were no valid free paths). Furthermore, it extends this segmentation to mode choice so that the value of time can be considered when choosing between auto and nonauto modes. If toll/free segmentation is limited to route choice, then only a single “average” auto path with the same utility function is used in mode choice (within any segmentation scheme unrelated to value of time, such as vehicle occupancy level). This could lead to aggregation error in cases where a scenario with priced roadways does not change the best auto path given the aggregate average value of time assumption.

Note that even in a nonsegmented model, it is possible to segment auto travelers between mode choice and highway assignment by value of time so that the tradeoffs between time and cost are considered during route choice. The advantage of the segmented model is that these tradeoffs are also considered during mode choice.

Challenges to Using Models Segmented by Toll and Nontoll

The main challenges associated with the use of segmented models are:

1. There is a risk of overstating auto utility in mode choice for certain origin-destination pairs and understating it for others based on the utility values of the toll and the free path, the degree of overlap of those routes, and the existence (or not) of other paths that are not included as distinct options. The advantage of not segmenting, therefore, is that the highest utility path is consistently used in the mode choice model.

2. The toll versus free segmentation does not truly separate travelers who use priced roadways from those who do not. While the “free” segment does not use toll roads in assignment, the “toll” segment may or may not use them, because current static assignment methods cannot accommodate a rule that requires use of tolled roadway segments.

3. The sample sizes for toll road users in the surveys used for model estimation may be very small in some regions. For example, in the Baltimore region, only 11 shared ride work tours with a toll paid were reported in the household survey. (Note that this is the same survey data set used in the MWCOG model development, but this number refers only to the Maryland and Washington, D.C. portions of the survey sample.) Small sample size is an issue not only for model estimation, where it can be impossible to get statistically significant parameters for toll utilities, but for model validation also, since the number of travelers in each segment cannot be estimated with statistical significance by expanding the survey data.

4. A related issue is that the segmented mode choice model is made more complex by doubling the number of auto alternatives. This adds computation time to the mode choice model.

5. The binary nature of the toll versus free choice is an oversimplification compared to the alternate approach presented below (though less so than a model with no segmentation at all). There is not necessarily a single “toll” path; there may be multiple viable paths that use priced roads, and the best path may depend on the assumed value of time. Some “toll” paths may use only a small length of priced road while incurring a small toll cost. So the skims used to identify the best “toll” path may not accurately portray the times and costs associated with the paths used by everyone in the “toll” segment.

An Alternative Approach to Segmenting Models by Toll and Nontoll

We propose an alternative approach to segmented mode choice models that addresses some of the challenges and shortcomings associated with the segmented model. This approach was originally developed in the context of the BMC activity-based model although, with some modifications, it could be used in an aggregate trip-based modeling approach as well.

The proposed approach takes advantage of two recent enhancements to travel modeling:

- The use of simulated values of time from a lognormal distribution in a disaggregate model application (see, e.g., Sall et al., in *(15)*); and
- Segmentation of trip tables used in aggregate highway assignment by value of time level.

The proposed approach would define a segmentation scheme based on value of time levels (ranges) to be used for both highway assignment and mode choice. These levels would be defined based on the value-of-time distributions which are assumed to be used in the activity-based model. A set of highway skims would be developed using the implied average value of time for each level. In mode choice application, the skims used for each segment would be those for the corresponding value-of-time range. Highway assignment would be performed using separate trip tables for each value-of-time range segment, and skims for the next iteration of the model would be developed for each segment.

The main differences between this approach and the toll/nontoll segmented mode choice models are:

- The segmentation is not used to create separate alternatives in the mode choice model. Rather, mode choice is applied separately for the travelers in each segment, and the segments are retained for the highway assignment.
- Value of time segmentation is not as limited as toll/nontoll segmentation for mode choice estimation. In Baltimore, five segments are used.
- There is no guarantee that a “free” path will be used in developing travel time skims although the likelihood of a free path would be high for the segment with the lowest value of time.

Implementation of the Value-of-Time Segmentation Method in the MWCOG Model

The steps involved in implementing this approach within a trip-based model framework, along with suggestions on how to do this for the MWCOG model, are described below. We propose to use the value of time distributions from the new BMC model. While that model is activity-based, the procedure can be adopted for use in a trip-based model. The steps are as follows:

Model Estimation

1. **Define a set of value of time ranges**. BMC used five segments, and we suggest that MWCOG use the same ranges. They are (in 2012 $ per hour):

Table 2.3 Value of Time Ranges

Range	Mean
$0.00-$3.93	$2.49
$3.93-$6.82	$5.33
$6.82-$10.74	$8.64
$10.74-$17.93	$13.85
Greater than $17.93	$31.38

Alternately, MWCOG could use fewer segments to reduce the model run time during highway assignment. If that is desired, the value of time ranges would have to be defined anew.

2. **Estimate value of time distributions**. Rather than do this anew, we recommend using the distributions estimated for the BMC model, which used the majority of the MWCOG household survey data set for estimation. The way that the variable value of time was implemented in the BMC mode choice model estimation was to specify a lognormal functional form for the value of time distribution, estimate a base in-vehicle time coefficient to reflect the mean of the distribution and a parameter to represent the standard deviation. Rather than estimating out-of-vehicle time coefficients, the ratio of out-of-vehicle time to in-vehicle time was estimated. Cost coefficients were allowed to vary by income class. In practice, all of the level-of-service coefficients were constrained to produce reasonable results.

   Cambridge Systematics, Inc. describes the BMC mode choice model in its recent documentation of the BMC ABM *(16)*. The relevant details appear in Section 2.14, “Tour Mode Choice,” of the referenced report. Variable value of time is achieved in the tour mode choice models by specifying a distribution for the in-vehicle time coefficient, in this case a log-normal distribution. With a fixed-cost coefficient, the value of time distribution can be described easily. Cost coefficients for the various household income levels were constrained to produce reasonable average values of time.

   Besides the median value for the in-vehicle time coefficient, the other parameter for the log-normal distribution is the standard deviation. This parameter was constrained to equal 0.75 to produce reasonable shapes for the value of time distributions. The value of 0.75 was based on judgment after testing different coefficients in conjunction with various cost coefficients by income and values of time for the work and nonwork tour purposes. This value provided a reasonable distribution across income categories. The distributions are shown in Figures 2.1 and 2.2.

   The value of time distributions would be implemented in the MWCOG mode choice model as part of the reestimation of that model. Based on the estimated (or asserted) in-vehicle time coefficient, the cost coefficients (and the standard deviation coefficient described above) would be asserted to maintain the appropriate values of time.

Figure 2.1 Value-of-Time Distribution

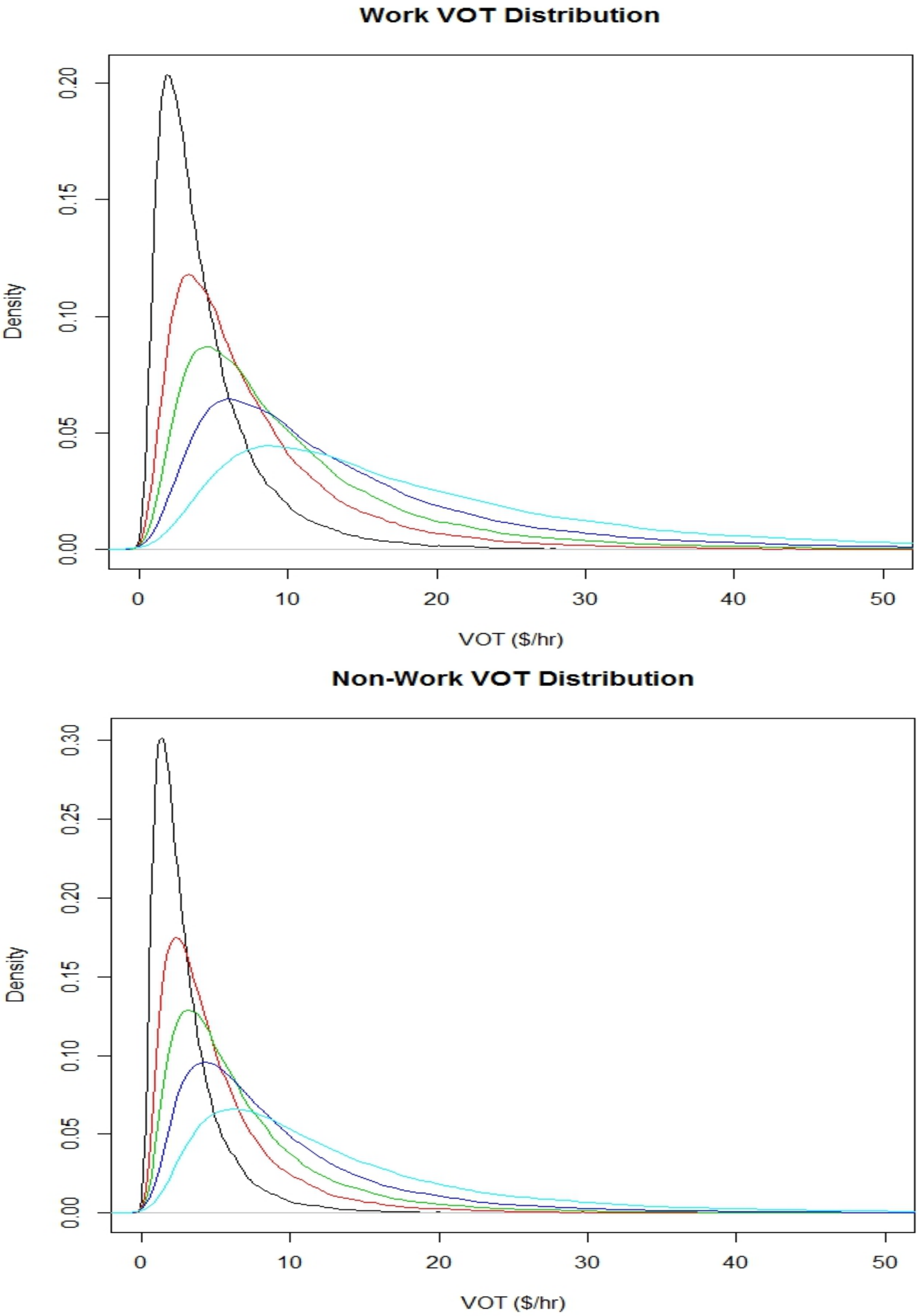
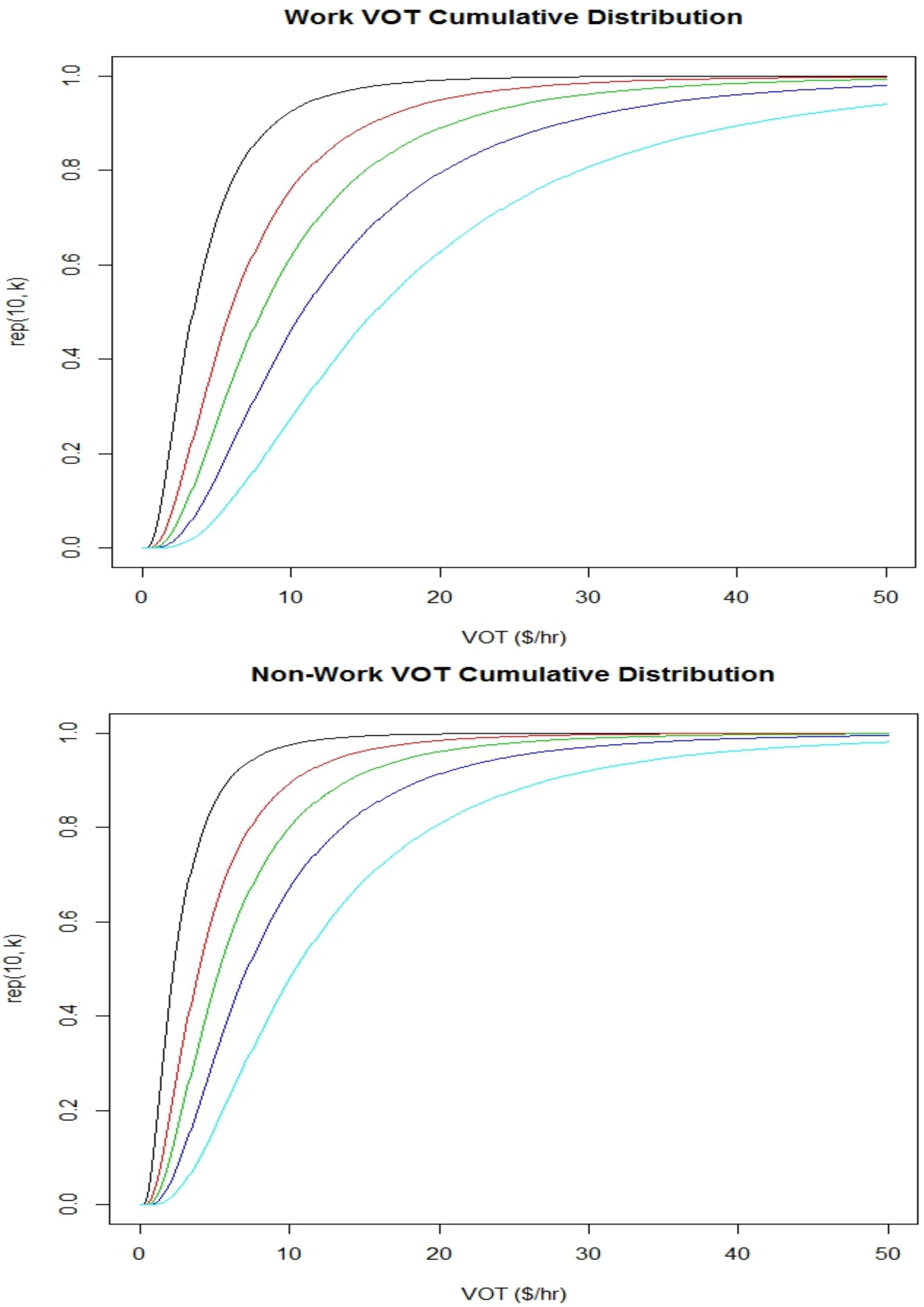


Figure 2.2 Cumulative Value-of-Time Distributions



Model Application

1. **Divide the person trip tables** that are the outputs of the trip distribution model into five segments representing the different value of time ranges. Since we will not be applying trip distribution using value of time ranges, this can be done by applying fixed percentages to the person trip tables for each purpose. If the trip tables are segmented by income level, the percentages will vary by income level. The fixed percentages can be estimated using approximate average values of time for each income level. As an illustration, the Table 2.4 below shows the median values of time for each income level in the BMC model:

Table 2.4 Median Value of Time (BMC)

Income Range	Work	Nonwork
$0-$15,000	$3.42	$2.28
$15,000-$30,000	$5.91	$3.94
$30,000-$50,000	$7.99	$5.33
$50,000-100,000	$10.80	$7.20
Over $100,000	$15.60	$10.40

Note: The values of time are less than the average wage rates implied by the income levels. This is consistent with experience with implied values of time in mode choice models without distributed values of time, where the average implied values of time are usually far less than the average wage rates.

2. **Create skims for each highway mode alternative** in Cube for each value-of time level, using the mean value of time for each range to represent the tradeoffs between time and cost. If five value of time ranges are used, this would result in 15 total skims for the highway modes.

3. **Apply the mode choice model** separately for each segment, using the corresponding skims as inputs.

4. **Perform highway assignment**, using the segmented mode choice model outputs as separate auto vehicle trip tables, with the mean values of time for each segment being used to represent the time-cost tradeoffs. If five value of time ranges are used, this would result in 15 total auto trip tables for the highway assignment, plus the truck trip tables.

2.5 Recommendations

This task order effort provided insight on best practices in managed lane modeling for regional travel demand forecasting models, an understanding of the existing modeling framework, and proposed improvements to the modeling methodology. Given the current state of the existing TPB model, TPB has the advantage of being able to pursue one of these three options:

1. **Continue with improvements to the currently implemented methodology.** The TPB travel model implements HOT-lane scenarios that are developed using two separate model executions: a) the “base” run from which HOV 3+ skims are developed; and b) the “final” run which uses specially developed HOT lane toll rates and the HOV 3+ skims from the base run. One alternative is to move ahead with improvements to the current model which entail enhancements to the model scripts in order to improve overall efficiencies.

There is no explicit toll choice mechanism in the MWCOG toll model. Vehicles using toll facilities or nontoll facilities are determined in the assignment process based on the generalized impedance which consists of travel times and toll charges. In the toll setting procedure, the toll rate is adjusted with a set of rules based on the ranges of the v/c ratio. These “discrete” rules may result in an adjusted toll rate oscillating between two toll levels associated to two neighboring v/c ranges during the toll setting process. Another issue is the fact that there is no guarantee of a unique solution coming from the toll-setting process since a converged user equilibrium assignment is designed to have a unique set of link volumes but not paths.

2. **Adopt an approach that the previous consultant recommended in FY 2014.** TPB staff’s review does not currently recommend going forward with this methodology. Although several improvements were introduced, the overall benefits were not apparent.

3. **Adopt the segmentation of highway assignment using the value-of-time approach,** as described in Section 2.4.

Our short- term recommendation is to implement **segmentation of highway assignment using value of time**, as described in Section 2.4. This approach is consistent in objective with best practices and is possible to achieve within the set timeframe, especially given that data and parameters could be readily borrowed from the Baltimore experience.

Our recommended long-term improvement for the regional model is the gradual **shift to the activity-based modeling framework**. Activity-based modeling is the state-of-the-art in demand modeling in large U.S. metropolitan areas and facilitates the consideration of pricing into the decision hierarchy. While the activity-based model can be implemented using only revealed preference survey data (such as the MWCOG household survey), a combination of revealed and stated preference surveys can also be used, with the stated-preference data allowing for the modeling of choices that do not yet exist.

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3.0 Task Order 16.4 – Non-Motorized Model Enhancements

This report section summarizes activities that CS performed under Task Order 16.4: Non-Motorized Model Enhancements. Specifically, the task activities included:

- Review documentation for the latest version of the COG/TPB model (2.3.57a) as related to non-motorized modeling;
- Provide a review of the latest developments of modeling non-motorized travel in a regional modeling framework;
- Evaluate options for enhancing non-motorized travel modeling; and
- Make recommendations for the preferred approach to enhancing non-motorized modeling in the short and long term.

Section 3.1 presents a summary of the latest practices in non-motorized travel modeling employed by several large Metropolitan Planning Organizations (MPO) in the U.S. Section 3.2 describes two innovative studies on bike travel and pedestrian travel. Section 3.3 discusses options and a proposed approach to enhancing the non-motorized modeling.

3.1 Review of Non-Motorized Travel Modeling in Select Large MPOs

The state of practice on modeling non-motorized travel in the regional modeling framework was summarized in the 2012 TRB paper "Recent Practices in Regional Modeling of Non-Motorized Travel" *(1).* The review found that (at the time) over two-thirds of the 28 large MPOs with trip-based models that were reviewed incorporated non-motorized travel to some extent (so fewer than one-third of the large MPOs did not incorporate non-motorized travel). A subsequent review of 48 large MPOs showed a similar, but slightly higher proportion (38 percent), of large MPOs did not model non-motorized travel and another one-third did not distinguish between walk and bike travel in their non-motorized models *(2)*. The latter study included some urban areas that are somewhat smaller than those in the earlier study, which were less likely to have included non-motorized travel in their models.

Table 3.1 summarizes treatment of non-motorized travel in models maintained by 12 large MPOs, including 5 trip-based models and 7 ABMs either in operation or under development. All have incorporated non-motorized modeling in their model systems. In this sample of MPOs, logit models are the most commonly used model formulation, and non-motorized modes are included in the mode choice model stage more often in the ABM framework than in the trip-based model framework.

Table 3.1 Non-Motorized Modeling in 12 Large MPOs

Metropolitan Planning Organization	Type of Travel Model	Non-Motorized Mode	Non-Motorized Model Formulation	Trip Generation and Pre-Mode Choice	Mode Choice
Boston Metropolitan Planning Organization (CTPS) (3)	Trip-Based	1 (walk)	Logit		✓
Chicago Metropolitan Agency for Planning (CMAP) (4)	Trip-Based	1(bike/walk)	Logit	✓	
Delaware Valley Regional Planning Commission (DVRPC) (5)	Trip-Based	1(bike/walk)	Logit	✓	
National Capital Region Transportation Planning Board (TPB) (6)	Trip-Based	1(bike/walk)	Regression	✓	
Southern California Association of Governments (SCAG) (7)	Trip-Based	2 (bike, walk)	Logit		✓
Atlanta Regional Commission (ARC) (8)	ABM	2 (bike, walk)	Logit		✓
Baltimore Metropolitan Council (BMC) (9)	ABM	2 (bike, walk)	Logit		✓
Houston-Galveston Area Council (H-GAC) (10)	ABM	2 (bike, walk)	Logit		✓
Metropolitan Transportation Commission (MTC) (11)	ABM	2 (bike, walk)	Logit		✓
Metropolitan Council (Minneapolis, MN) (12)	ABM	2 (bike, walk)	Logit		✓
New York Metropolitan Transportation Council (NYMTC) (13)	ABM	1(bike/walk)	Logit	✓	
Puget Sound Regional Council (PSRC) (14)	ABM	2 (bike, walk)	Logit		✓

Over the past few years, modeling practice continues to advance, especially in a disaggregate approach, with some of the largest MPOs in the country moving towards the implementation of the Activity-Based Model framework. As indicated in the previous review *(1)*, activity-based modeling approaches appear more promising than trip-based modeling for addressing non-motorized trip-making. This potential has to do with the more accurate measurements of factors affecting non-motorized travel making behavior, including both disaggregate representation of traveler characteristics and the micro-level depiction of built-environment and urban-form variables. Both areas of interest have been explored in practice, but the full potential has yet to be realized.

Table 3.2 summarizes variables used in 11 large MPO models, which affect non-motorized trip making as well as other modes.[25] These variables can be grouped into different categories: traveler socioeconomic and demographic characteristics, level-of-service characteristics, accessibility, and characteristics of the built

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[25] This is the same list of MPOs as in Table 3.1, minus NYMTC, which is not included in Table 3.2.

environment and urban form (Table 3.3). Although TAZs are still commonly used, smaller geographic units of analysis are increasingly being used to model non-motorized travel, including Chicago's use of quarter-sections (0.5 mile by 0.5 mile) and quarter-quarter-sections (0.25 mile by 0.25 mile) in the central areas, in comparison with usual one-mile section (approximately one square mile) as a zone. Baltimore has recently incorporated parcel-buffer variables in its ABM model development, using point-based employment database and property parcel and point data in Maryland and District of Columbia. A description of the parcel database can be found in Section 1.12 of this report, "Develop Parcel-Level Development Database."

Table 3.2 Variables Affecting Non-Motorized Travel in 11 MPO Models[a]

MPO	TAZ Structure	Variables
Atlanta Regional Commission (ARC)	Regular TAZ	• Household characteristics (income, auto ownership, household (HH) size, # workers, income, etc.)
		• % roads with sidewalks • Travel time/distance • Life stage (child, student, worker, etc.) • Person level characteristics (Age, gender, life stage, etc.) • Accessibility measures (population/employment density)
Baltimore Metropolitan Council (BMC)	Parcel Buffer (0.5 mile) and TAZ	• Household size • Income level • Vehicle availability per trip purpose • Number of vehicles/workers • Number of vehicles/adults • Traveler personal characteristics (full/part time worker, occupation, adult age, child age, gender)
		• Travel time • Intersection density • Employment density • Tour purpose • Number of stops
Boston Metropolitan Planning Organization (CTPS)	Regular TAZ	• Household characteristics (income, auto ownership, HH size, # workers, income, occupation, etc.) • Population density per acre • Trip Purpose • Walk time/out-of-vehicle time
Chicago Metropolitan Agency for Planning (CMAP)	Subzone structure in Trip Generation only (TAZ elsewhere)	• Household and subzone characteristics (income, auto ownership, HH size, # workers, income, etc.)
		• Pedestrian environment factor
Delaware Valley Regional Planning Commission (DVRPC)	Regular TAZ	• Household characteristics (income, auto ownership, HH size, # workers, income, etc.) • Land use density, land use mix, connectivity, transit availability, special attractions, and bike index
Houston-Galveston Area Council (H-GAC)	Regular TAZ	• Traveler personal characteristics (income, gender, age, number of children, household size, auto availability); • Characteristics of the modes of travel available to the trip maker (e.g., travel time, cost of travel);

MPO	TAZ Structure	Variables
		• Density (residential, employment) • Number of stops
Metropolitan Transportation Commission (MTC)	Regular TAZ	• Household characteristics (income, auto ownership, HH size, # workers, income, etc.)
		• Density (HH/acre, employment/acre) • Trip purpose
Metropolitan Council (Minneapolis, MN)	Regular TAZ	• Household Income • Household race • Household size • Traveler personal characteristics (income, occupation, age, gender, employment status, education level)
		• Travel distance • Intersection density • Employment density
National Capital Region Transportation Planning Board (TPB)	Regular TAZ with floating density measurement	• Population and employment density • Street block density
Puget Sound Regional Council (PSRC)	Regular TAZ	• Household size • Household auto availability • Household income • Traveler personal characteristics (income, gender, age) • Characteristics of the modes of travel available to the trip maker (e.g., travel time, cost of travel) • Characteristics of the trip itself (e.g., work versus non-work trips)
Southern California Association of Governments (SCAG)	Density measures - 1/2 mile radius of the TAZ centroid	• Housing/employment density • Travel time/distance • Travel cost • Trip purpose
		• Accessibility (walk distance, employment density)

[a] NYMTC is included in Table 3.1, but excluded from this table.

Table 3.3 Variables Commonly Used in Non-Motorized Models

Data Type	Variable
Socioeconomic and Demographic	• Household size • Household race • Household income • Number of vehicles/workers • Number of vehicles/adults • Age of head of household • Number of workers in household • Number of children
Traveler Personal Characteristics	• Age • Gender • Income level • Occupation (full/part time) • Child age
Level of Service and Accessibility	• Bicycle Access • Access to parks • Transit Access • Distance • Time
Build Environment and Urban forms	• Residential density • Employment density • Intersection density • Network connectivity • Network restrictivity (% roadway network where pedestrians are prohibited) • Sidewalk availability • % streets easy to access • Area type • Block size • Street block density • Path density (distance of paths / zonal area • Retail density • Urban Living Infrastructure

3.2 Innovative Studies in Non-Motorized Travel Modeling

There has been an increasing interest in data collection and modeling of non-motorized travel over the past few years. This section highlights two studies, one in Los Angeles focusing on modeling bike travel demand and the other in Portland modeling pedestrian demand.

Los Angeles Bike Travel Demand Model

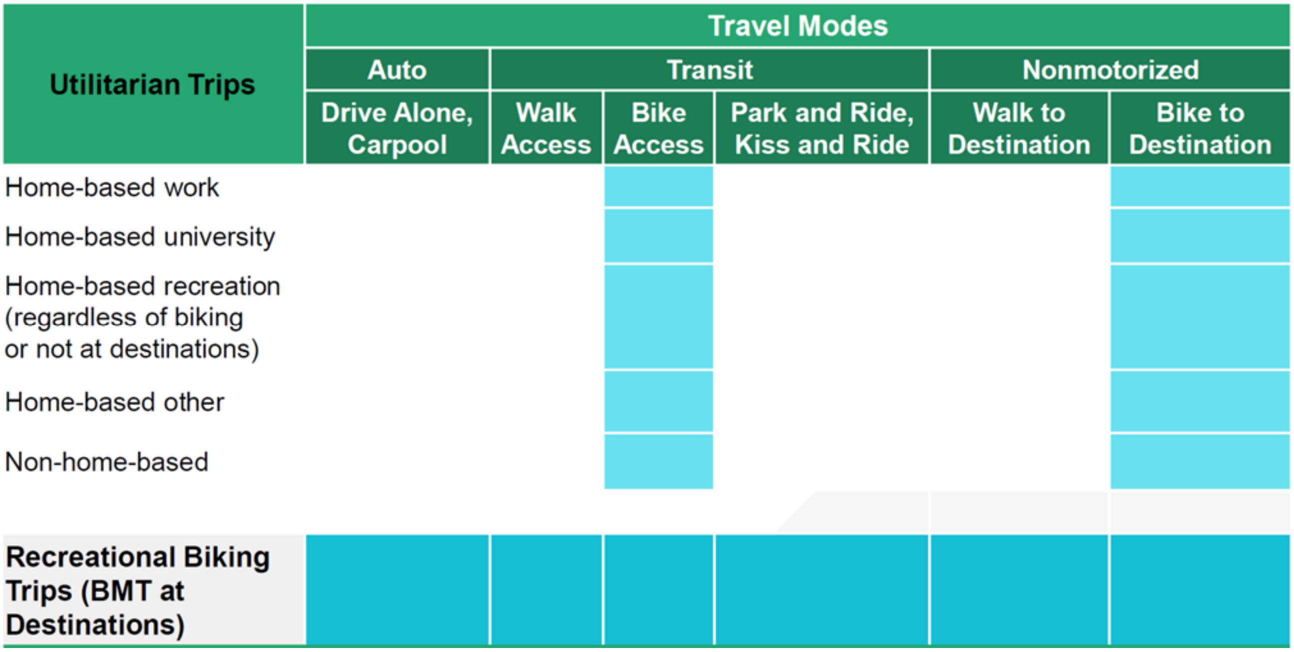
The goal of the Los Angeles Bike Model Development is to provide the Los Angeles Metro with the technical capability to measure the performance of proposed bicycle-related facility improvements and to help prioritize bicycle infrastructure investments, with a tool that has sensitivities to:

- Link-level measures of bicycle infrastructure such as bicycle trails, lanes, and routes, cycle tracks, and bicycle boulevards; and
- Node-level bicycle infrastructure investments (e.g., bicycle share programs, bicycle rental programs)*(15).*

Table 3.4 shows how the new non-motorized model components integrate with and enhance the existing Metro model *(16*), a trip-based travel demand model maintained by the Los Angeles County Metropolitan Transportation Authority with a focus on Los Angeles County. The components in white (automobile and walk modes) were available in the existing Metro model. The model enhancements are those components in blue (bicycle related modes), focusing on recreational biking and the following three types of utilitarian bicycle trips:

- Intrazonal trips;
- Interzonal trips; and
- Bicycle access to transit trips.

Table 3.4 Integration of Bike Model Components into the Existing Los Angeles Metro Model



Utilitarian Trips	Travel Modes					
	Auto	Transit			Nonmotorized	
	Drive Alone, Carpool	Walk Access	Bike Access	Park and Ride, Kiss and Ride	Walk to Destination	Bike to Destination
Home-based work			🟦			🟦
Home-based university			🟦			🟦
Home-based recreation (regardless of biking or not at destinations)			🟦			🟦
Home-based other			🟦			🟦
Non-home-based			🟦			🟦
Recreational Biking Trips (BMT at Destinations)	🟦	🟦	🟦	🟦	🟦	🟦

Note: Elements in blue color are new enhancements as part of the bike model development and integrated into the existing model.

Each of these types is reflected in four utilitarian trip purposes, in addition to estimation of bicycle recreational demand. Major model components include:

1. A new bicycle route choice model that is responsive to the presence and quality of bicycle facilities between origin and destination zones, network attributes, and geographic characteristics.

2. Better representation of the factors underlying bicycle travel in the mode choice model, including secured bicycle storage, bicycle share programs, and the presence and quality of bicycle network routes.

3. Bike access to transit, which serves as a distinct mode in the Metro mode choice model and be responsive to both link-level and node-level measures of bicycle supply variables, as well as land use variables and bike access route choice logsums.

4. A bicycle recreational demand model that is responsive to home-end measures of bicycle infrastructure, recreational bicycle infrastructure beyond three miles of link level bicycle infrastructure, and node-level bicycle infrastructure investments.

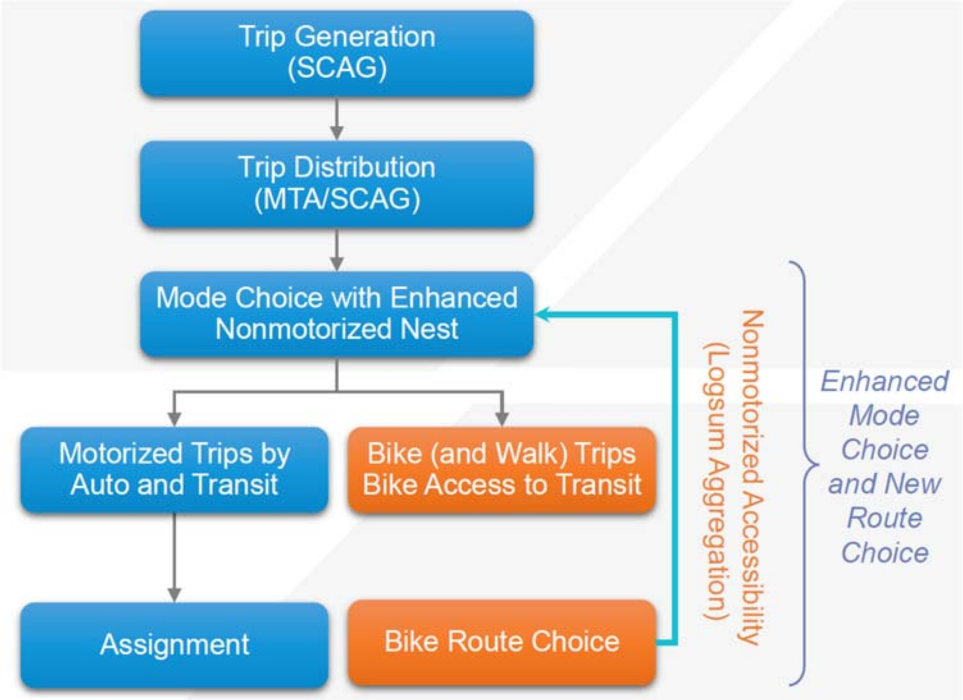
Figure 3.1 shows the utilitarian bicycle travel modeling components and their integration with the existing Metro model:

- The mode choice model is enhanced with a bike mode component with representation of the factors underlying bicycle travel, including secured bicycle storage, bicycle share programs, and bicycle path choice logsum (i.e., an aggregate measure of the presence and quality of bicycle network routes).

- The mode choice model is also enhanced with a new bike access to transit (bike-transit) alternative, which serves as a distinct access mode and is responsive to both link-level and node-level measures of bicycle supply variables, as well as land use variables and bike access route choice logsums.

- A new bicycle route choice model was developed that is responsive to the presence and quality of bicycle facilities between origin and destination zones, network attributes, and geographic characteristics.

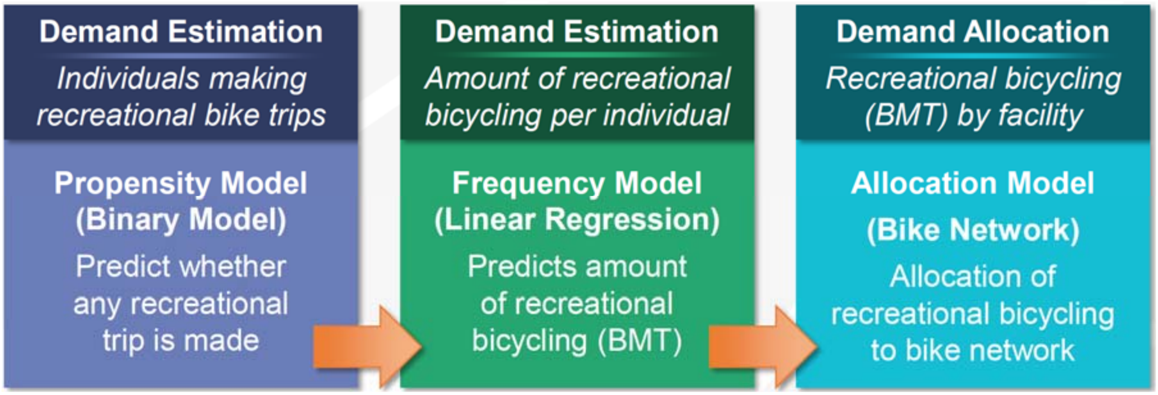
Figure 3.1 Utilitarian Bicycle Travel Model and Its Integration with the Los Angeles Metro Model



Recreational bicycling is defined as bicycling for recreational or exercise purposes; the bicycling alone is considered the motivation for the activity. This is contrasted with utilitarian bicycling, where the cycling is a means to get to a destination. While utilitarian bicycling has an origin and a destination, recreational bicycling may have the same starting and end point and can include laps and loops. Unlike conventional traffic assignment, recreational bicycle miles traveled (BMT) is allocated to roadway links rather than being assigned to a travel path; BMT is allocated based on an algorithm and is not the result of a trip-based assignment process. This means that the model results need not necessarily guarantee conservation of flow.

Recreational bicycling modeling is implemented in a two-stage process: 1) estimate the demand for recreational bicycling, and 2) conduct a network-level-based allocation of the estimated demand. Overall, the goal of this approach is to predict bicycle volumes per link in Los Angeles County. Figure 3.2 shows the framework for the recreational bike model component.

Figure 3.2 Los Angeles Recreational Bike Demand Generation Model Process



As noted earlier, the Los Angles Bike Model is an analytical tool that is responsive to measures of bicycle investments, including:

- Sensitivities to link-level measures of bicycle infrastructure, such as bicycle trails, lanes, and routes, cycle tracks, and bicycle boulevards; and
- Sensitivities to node-level bicycle infrastructure investments (e.g., bicycle share programs, bicycle rental programs, bicycle storage, and security programs, etc.).

As shown in Table 3.5, these bike model capabilities have put the Los Angeles Metro at the forefront of bicycle demand modeling in the regional travel demand modeling framework compared to peer agencies in other metropolitan areas which have developed bicycle modeling capabilities. These cutting-edge analytical capabilities will provide the Metro with a rigorous analytical tool to assist in its transportation planning process, including prioritization of bicycle investments in the region.

Table 3.5 Los Angeles Metro Bike Model Capabilities

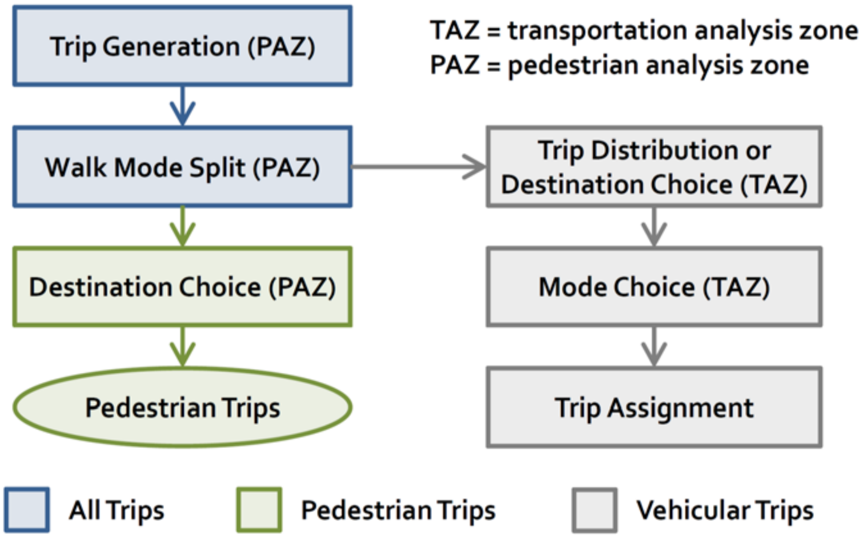
	Capable of Addressing Issues Model Features and Functionality	
Policy Issues	**Mode Choice**	**Route Choice**
Intrazonal, interzonal	Yes	Yes
Bike access to transit	Yes	Yes
Bike sharing	Yes	Yes
Bike parking	Yes	N/A
Recreational	Yes	Yes

Portland Model of Pedestrian Demand (MoPeD): A Pedestrian Demand Estimation Tool

The Portland MoPeD pedestrian modeling framework consists of four main steps, as shown in Figure 3.3 below *(17).*

- Pedestrian analysis zones (PAZs), which are uniform grid cells (in this application they have 264-foot (80m) sides), are used to model walk trips;
- A binary logit walk-mode split model is developed to estimate the number of walk trips produced in each PAZ, using spatially disaggregate built environment and socioeconomic variables that measure relationships between walking and the physical environment;
- Trips by vehicular modes (auto, transit and bicycle) are aggregated to the TAZ level for the distribution to destinations in the regional model; and
- A destination choice model is used to distribute the number of walk trips produced in each PAZ to destinations.

Figure 3.3 Conceptual Framework



Source: Clifton et al., 2016. *(17)*

Walk Trip Binary Logit Model

This binary logit model splits the total trip ends into pedestrian trips and vehicular trips (auto, transit and bike), as a function of household characteristics and pedestrian environment (Clifton, et al., 2016 *(17);* Singleton et al., 2014 *(18).* Traveler characteristics (demographic and socioeconomic) variables include four categories for each of the following variables:

- Age of household head;
- Household size;
- Number of workers;
- Number of children;
- Household income; and
- Number of vehicles.

Pedestrian Index of the Environment (PIE) was developed to represent the built environment as an index that encompasses the following six dimensions:

1. Population and employment density;
2. Block size;
3. Sidewalk extent/density;
4. Transit access;
5. Urban living infrastructure; and
6. Comfortable facilities.

Urban living infrastructure includes shopping and service destinations used in daily life, such as grocery stores, cafes, restaurants, clothing and other retail stores, schools, dry cleaners, and entertainment venues. (See http://johnson-gardner.com/files/Urban_Amenities_Final5.pdf and http://otrec.us/project/407/). Comfortable facilities were represented by bicycle network links weighted based on their classifications such as most suitable, moderately suitable, and less suitable. These six dimensions are measured at quarter-mile (0.4 km) or one-mile (1.6 km) radii around a PAZ's centroid and quantified on a scale of one to five for individual PAZs. Weights were assigned to the six dimensions to account for their relative importance to pedestrian travel. The weights were generated by using household travel survey data to regress the probability of walking on each individual built environment measure and were set to generate a maximum possible weighted PIE value of 100 and a minimum weighted value of 20.

Transportation system variables include the length of freeway miles within an eighth-mile radius of PAZ centroids and the length of trails within a one-half-mile radius of PAZ centroids.

Pedestrian Destination Choice Model

Multinomial logit pedestrian destination choice models were estimated for six trip purposes, using the data from about 4,500 walk trips from a 2011 household travel survey in the Portland, OR, region. Independent variables include:

- Walk-trip distance;
- Size (employment by type, households);
- Supportive pedestrian environments (parks, a pedestrian index of the environment;
- Variable;
- Barriers to walking (terrain, industrial-type employment); and
- Traveler characteristics.

Distance and size (such as employment) have the strongest influence on pedestrian destination choices, with the former being negative and the latter being positive. Travelers in carless or childless households are less sensitive to distance for home-based work (HBW) purposes. More attractive pedestrian environments were also positively associated with pedestrian destination choice after controlling for other factors.

Super-pedestrian analysis zones consist of 5x5 PAZs and were used to model destination choice.

3.3 Findings and Recommendations

As shown in the latest and previous reviews of non-motorized travel modeling in a regional travel demand model framework, non-motorized travel modeling continues to move towards two objectives:

1. More accurate measurements of factors influencing non-motorized travel; and
2. more analytical capabilities, which enable evaluation and prioritization of infrastructure investments on active transportation modes

In order to achieve better representation of variables for non-motorized travel, modelers have taken a more disaggregate approach to geographic units of analysis than the conventional TAZ, including use of fine-grained zone systems such as grid cells, blocks, non-motorized zones, and micro-zones. Another is the use of parcel-based and parcel-point buffer variables.

This disaggregate approach especially applies to demographic and socioeconomic variables that are important in a traveler's non-motorized travel behavior. Population synthesis, which is a part of activity-based models, is particularly useful in providing a wide range of variables at both households and person levels. In general, activity-based modeling approaches appear more promising than trip-based modeling for addressing non-motorized trip-making.

Two options for enhancing non-motorized modeling in the COG/TPB model are:

1. Enhancing binary modal splits at the trip generation stage, and
2. Adding a non-motorized model nest in the mode choice model

Each option has its own advantages and disadvantages. Advantages for Option 1 include:

- It has the potential to be responsive to a variety of variables at the zonal/subzonal level.
- It will have a seamless integration with the existing model framework with minimal disruption to trip distribution models.
- A new trip distribution model is not required to incorporate non-motorized trips in the distribution process.

Advantages of Option 2 include:

- It has the potential for testing variables at the origin-destination level, as well as zonal level. However, some variables may not turn out be significant as distance tends to be a dominating variable at the OD level for affecting non-motorized travel.
- It includes variables at the origin-destination-pair level and thus is responsive to variables specific to an OD pair such as travel distance, cost and time.

Since COG/TPB staff has a longer term goal of developing an activity-based model, it makes sense to defer some of the more detail-oriented work until the more advanced model is developed. Therefore, CS recommends a phased approach to enhancing the non-motorized modeling in the COG/TPB model development program:

- In the short term, improve the trip-based model by enhancing the binary modal splits at the trip generation stage with use of disaggregate model estimation using 2007/8 household travel survey data and the existing database of information related to built-environment and non-motorized facilities.

- In the longer term (i.e., development of an activity-based model), incorporate non-motorized travel as part of the mode choice model nest structure, with full use of disaggregate model estimation and a new, integrated parcel-level database and a non-motorized facility database.

Table 3.6 shows the proposed model specifications for enhancing non-motorized model at the trip generation stage, where trip productions as total person trips are split into motorized and non-motorized trips.

Table 3.6 Enhancing Non-Motorized Model at the Trip Generation Stage

Non-Motorized Model	Description and Specifications
Dependent Variable	• Share of non-motorized person trips by trip purposes
Independent variables for testing	• Land use and urban form variables at the production and attraction ends of the trips including measures such as residential and employment density, land use mix and diversity, and design • Measures of accessibility • Characteristics of non-motorized options, including availability and/or quantity of non-motorized facilities subject to data availability • Respondents' socioeconomic characteristics
Model Formulations	• The model can be a binomial model (Motorized vs Non-motorized)
Data Source	• 2007/8 Household Travel Survey • Socioeconomic data from the MWCOG model, Census, Longitudinal Employer-Household Dynamics (LEHD), and parcel data • GIS data for complete roadway network • GIS data for non-motorized infrastructure at link and node level • Transit/auto skims from the model

A refined geographic unit of analysis is preferred, including consideration of the following options:

- Sub-TAZ structure which can be developed with a combination of TAZ structures used in the existing county-level models in the region (e.g., Fairfax, Montgomery, Prince George's, and Loudoun);

- Census Block geography; and

- Parcel-level or parcel-point-buffer.

Section 1.12 and Section 1.14 of this report describe existing sources related to parcel-level data and non-motorized infrastructure data, respectively. A parcel database is readily available for use in Maryland and District of Columbia. However, work needs to be done to compile existing databases in the Virginia jurisdictions, and then conduct cleaning up and standardization. Therefore, for the short-term model improvements, it is practical to use Census Block geography or a combination of Census Block and parcel-buffer data. For the ABM development, the parcel/parcel-point data is recommended for implementation.

For model estimation in the short term, existing data can be used to measure urban form and built environment variables, accessibility, non-motorized infrastructure, and traveler characteristics at the block and parcel-buffer level. Table 3.7 shows potential variables for testing in model estimation. For example, Census data at the block level can be used for population variables, and Longitudinal Employer-Household Dynamics (LEHD) data can be used for employment. Adjustments will need to be made at the block level so that the block-level data are aggregated to match with the socioeconomic data at the TAZ level.

For model application in the short term, socioeconomic variables at the block level can be developed through allocation of total forecasts at the TAZ level, based on existing distribution and future developments. Variables related to non-motorized infrastructure/programs can be prepared with the information from the local and regional transportation plans. Total person trips generated at the block level can be estimated through allocation of the TAZ-level estimates from the COG/TPB model, based on the block level socioeconomic variables. For example, households can be used to allocate home-based trips from the TAZ to block level, while employment can be used for allocation of non-home-based trips. Once the block-level non-motorized trips are estimated, they will be aggregated to the TAZ level and the calculated motorized trips at the TAZ level will be carried forward to the next step of the model stream.

Table 3.7 Potential Variables for Testing in Model Estimation

Category	Variables
Density	• Employment by categories • Households/population • College and school students
Diversity (Land Use Mix)	• Entropy (measuring homogeneity of land use in a given area, with a value of 0 representing homogeneous land use and 1 indicating evenly distributed land uses) • Simpson's diversity index (an index of the different elements in the zone, in this case, population and employment, with 0.5 representing equal distribution and 1 indicating homogeneous land use in a zone)
Design	• Intersection by types (e.g., 4 leg, 3 leg, dead end) • Street network connectivity
Accessibility	• Distance to nearest transit stop/station • Density of transit stops/stations • Logsum measure of accessibility
Non-motorized infrastructure/programs	• Sidewalk density • Density of bike facilities (by classification) • Availability of bike share station • Distance to nearest trail
Traveler characteristics	• Household income category • Vehicle availability • Household size

3.4 References

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4.0 Task Order 16.5 – Mode Choice Model Enhancements

This report section provides recommendations for enhancements to the MWCOG mode choice model. Specifically, we reviewed practices for handling transit in mode choice modeling employed by several large MPOs in the U.S., as well as reviewed literature related to recent developments in mode choice modeling. We provide recommendations on features to incorporate into the MWCOG mode choice model. Special attention is paid to transit path building and transit assignment and how those procedures will need to be updated to accommodate the recommended enhancements.

4.1 Review of Other MPO Mode Choice Model Structures

The structure and specifications of mode choice models employed by MPOs nationally are varied, depending on a variety of factors, including the MPO’s needs and uses for the model, the funding available for model development, data availability, the consultant retained to develop the model (if one is used), among a number of other factors. Variations on mode choice models can include the following:

- **Structural form of the model.** The most common model form is the nested logit (NL), which is not subject to the independence of irrelevant alternatives (IIA) assumption of the simpler multinomial logit (MNL).

- **Treatment of non-motorized modes.** Many MPO models estimate non-motorized trips prior to the mode choice model, meaning the mode choice model splits trips between motorized modes (e.g., auto and transit). Other MPO models treat non-motorized trips in the mode choice model itself.

- **Treatment of auto occupancy.** Many MPO models treat different auto occupancy categories (e.g., drive alone, shared ride-2, shared ride-3, etc.) as distinct modes in the mode choice model, while others treat auto as a single mode and split auto trips by occupancy later in the modeling process.

- **Treatment of transit technologies.** Some MPO models treat different transit technologies as separate modes in the mode choice models, while other MPO models group them. In the case of the latter, transit trips are split between transit path options later in transit assignment. Regardless of how transit technology is treated, most MPO models consider multiple transit modal options in the mode choice model based upon the mode of access to transit (e.g., walk access, drive access, and sometimes drop-off or bike).

- **Treatment of toll choice.** Toll choice is often treated as separate submodes for auto alternatives. Based on the analysis below, this is more common in combination with separate treatment of transit technology in mode choice, but that need not be the case.

The review of MPO models focused on the treatment of transit technology in order to better identify the approach that should be used for the MWCOG travel demand forecasting model, including mode choice, transit path building, and transit assignment.

Review of Models with Single Transit Technology in Mode Choice

A number of large MPOs in the U.S. use a mode choice model structure that includes modal options for only a single transit technology, though, as mentioned above, in most cases, multiple transit modes are defined based upon the mode of access to transit. Table 4.1 details features of these models for several of the largest MPOs in the U.S.

Table 4.1 Mode Choice Models that Use a Single Transit Technology to Define Mode Alternatives

Region/Agency	Type of Travel Model	Auto Modes	Transit Modes	Non-Motorized Modes	Mode Choice Model Structure
Baltimore, BMC (2016)	ABM	3 (SOV, HOV2, HOV3+)	2 (walk access, drive access)	2 (bike, walk)	NL
Boston, CTPS (2008)	Trip-based	3, 2 (SOV, HOV/HOV2, HOV3+ [work trips only])	2 (walk access, drive access)	1 (walk)	NL
Chicago, CMAP (2011)	Trip-based	1 (all auto)	1 (all transit)	0 (modeled earlier in TDM)	Binary
Houston, H-GAC (2015)	ABM	3 (SOV, HOV2, HOV3+)	2 (walk access, drive access)	2 (bike, walk)	NL
Minneapolis, Met Council (2015)	ABM	3 (SOV, HOV2, HOV3+)	2 (walk access, drive access)	2 (bike, walk)	NL
Philadelphia, DVRPC (2008)	Trip-based	1 (all auto)	2 (walk access, drive access)	0 (modeled earlier in TDM)	NL
Seattle, PSRC (2014)	ABM	3 (SOV, HOV2, HOV3+)	2 (walk access, drive access)	2 (bike, walk)	NL

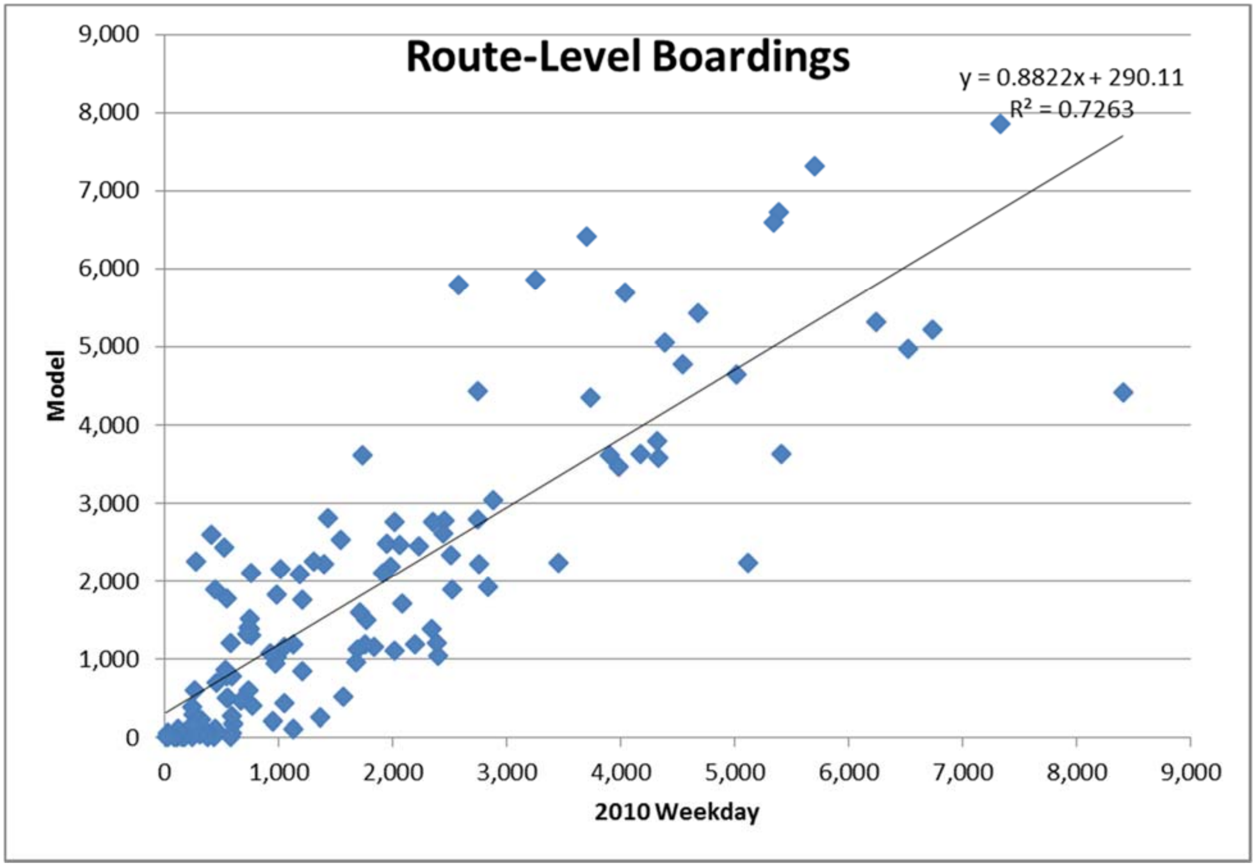
Total regional transit ridership generated by a mode choice model can be validated as closely as one likes by adjusting model constants. Transit assignment validation results provide other evidence as to how well a model is performing. However, these results are also subject to the reasonableness and accuracy of generation and distribution models, not just mode choice models. Moreover, each agency has different objectives and different error acceptance levels. Therefore, it is difficult to make comparisons on a one-to-one basis. Nonetheless, we examine transit assignment validation results for three of the agencies listed in Table 4.1.

The CMAP model validation report (CMAP 2011) contains several metrics of transit assignment performance, including total daily transit boardings, transit boardings by transit mode (heavy rail, commuter rail, bus), and share of transit boardings by transit line (for heavy and commuter rail). Along these measures, the CMAP model performs well. For instance, the CMAP report compares the observed and estimated daily transit boardings for heavy rail (8 lines), commuter rail (12 lines) and all bus (Table 20, page 35, buses are not segmented by line). However, instead of showing the data in terms of absolute boardings, the report compares the estimated and observed data by computing shares (e.g., the Blue Line (heavy rail) has an observed share that is 7.1 percent of the total boardings, and the estimated share was 6.7 percent (so the Blue Line was underestimated by 0.4 percentage points)). For the heavy and commuter rail lines, the observed shares varied from 0.1 to 11.7 percent. The maximum absolute difference in the share of transit boardings between observed and modeled is 0.6 percentage points (though in some cases the percentage difference in these shares was off by as much as -60 or +80 percent).

In the case of DVRPC (2008), transit boardings by transit mode (commuter rail, subway-elevated, bus and trolley) were compared to counts, as were boardings by transit operator and boardings by transit line. Overall, differences by transit mode and transit operator were quite small, all between -5 and +6 percent of observed (Table XIV-7, page 286). On a transit line basis, they found the coefficient of correlation between observed and modeled boardings was 0.97 and the percent root mean squared error (RMSE) was 65 percent (Table XIV-9, page 288).

Finally, in the case of H-GAC (2015b), boardings were compared across transit modes. Relative model error was a bit larger than the previous two models, with a modeled low of -25 percent for local circulator transit and modeled high of +118 percent for park-and-ride to non-CBD areas[26] (Table 3.8, page 3-8). Route-level bus boardings were also compared and are shown in Figure 4.1. In total across all routes, the percent RMSE was found to be 53 percent.

Figure 4.1 H-GAC Model Validation: Observed versus Modeled Route Boardings



Source: H-GAC, 2014a.

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[26] Though the observed total for this mode was small to begin with.

Review of Models with Multiple Transit Technologies in Mode Choice

A number of other large MPOs in the U.S. use a mode choice model structure that includes modal options for multiple transit technologies. Table 4.2 details features of these models for several of the largest MPOs in the U.S.

Table 4.2 Mode Choice Models that Use Multiple Transit Technologies to Define Mode Alternatives

Region/Agency	Type of Travel Model	Auto Modes	Transit Modes	Non-Motorized Modes	Mode Choice Model Structure
Atlanta, ARC (2016)	ABM	6 (by occupancy & by toll)	6 (by walk, PNR, or KNR access & for 2 transit modes: premium versus other)	2 (bike, walk)	NL
Los Angeles, SCAG (2012)	Trip-Based	8 (by occupancy & by toll)	22 (4 access modes [only 2 apply to some transit modes] & 8 transit modes [some are not active in base year])	2 (bike, walk)	NL
New York, NYMTC (2014)	ABM	4 (by occupancy)	4 (by walk or drive access & for 2 transit modes: commuter rail or any other)	0 (modeled earlier in TDM)	NL
San Francisco, MTC (2012)	ABM	6 (by occupancy & by toll)	10 (by walk or drive access & for 5 transit modes: BART, commuter rail, LRT, express, local bus)	2 (bike, walk)	NL
Washington, D.C., MWCOG (2016)	Trip-Based	3 (by occupancy)	12 (by walk, PNR, or KNR access & for 4 transit modes: commuter rail, Metrorail, bus, combined bus/Metrorail)	0 (modeled earlier in TDM)	NL

As was done for the models reviewed that consider only a single transit technology in mode choice, transit assignment validation results of three of the models in Table 4.2 were examined to draw comparisons.

The NYMTC model validation (NYMTC 2014) compared observed and modeled transit trips in and out of the "Hub," which is the term used for the CBD,[27] by mode (commuter rail versus other), finding that the model matched observed trips well (p. 98). Note that NYMTC performs transit assignment for only the AM peak period (page 97). At a more disaggregate level, looking at commuter rail station boardings in the AM peak, much larger disparities between observed and modeled transit boardings were observed (e.g., less than -50 percent or more than +100 percent in a number of cases, pages 101-104). AM peak subway boardings by borough were also compared between the observed and modeled with results suggesting

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[27] The Hub, or CBD, is defined as the portion of Manhattan south of 60th Street, which forms the southern border of Central Park. See, for example, map of the Hub on p. 6 of Hub Bound Travel Data, 2014, New York, New York: New York Metropolitan Transportation Council (NYMTC), November 2015, https://www.nymtc.org/Data-and-Modeling/Transportation-Data-and-Statistics/Publications/Hub-Bound-Travel.

between -14 percent and +31 percent of observed (Table 7-15, page 105). It is worth noting that the New York model is unique in a number of ways. First, the model would fall in between what someone would classify as a trip-based model and an activity-based model (it is a tour-based model). Second, while it enumerates commuter rail separately from other transit modes for mode choice modeling, the other transit category includes many transit technologies, including subway, premium bus, local bus, and ferries. So while the model is listed in this report subsection, it shares certain features with the models discussed in the "Review of Models with Single Transit Technology in Mode Choice" subsection. It is also worth noting that NYMTC uses O-D transit assignment, rather than the more typical P-A transit assignment.

MTC (2012) performed a validation to both year-2000 conditions and year-2005 conditions. Regarding the year-2005 validation, a comparison of observed and modeled transit boardings by transit mode (commuter rail, heavy rail, express, ferry, light rail, local) showed modeled commuter rail boardings being low by about 50 percent (p. 189), while all other transit mode boardings were high by 2 percent (heavy rail) to 12 percent (ferry). Of course, the single worst transit mode performances were for the two least used transit modes (i.e., commuter rail and ferry). Examining results by operator and by route for one specific operator showed a great deal more variability in modeled and observed transit boardings (pages 190-192).

The ARC model validation (ARC 2016) compared observed and modeled transit boardings by operator, with differences ranging from -29 to +40 percent (excluding two little-used operators whose modeled boardings were far too high, see page 214). They also examined bus and rail boardings by transit line and computed correlation coefficients of 0.77 for bus boardings and 0.92 for rail boardings (pages 213-216).

Findings and Recommendations

Based on the models examined above, there is not clear evidence that one approach performs better than the others in terms of transit assignment results. Castiglione et al. (2015, see, p 116) draws basically the same conclusion in a SHRP 2 report reviewing activity-based model practice.

There are advantages and disadvantages of each approach. While the detailed transit mode structure offers more control in matching targets by transit submodes, it might do so at the expense of explaining the choice variation through modal constants, rather than modal attributes. This can make the mode choice model less sensitive to policy variables. The detailed structure also makes logsums sensitive to the effects that multiple attractive transit options can have on mode choice. On the other hand, that sensitivity may not be warranted in cases where transit paths overlap or premium transit options are only used for small portions of a transit path.

There are a couple practical advantages of considering only a single transit technology in the mode choice model. First, the model is simpler in a number of ways. Obviously, there would be fewer modes in the mode choice model, but this also means a simpler nesting structure (if nested logit specification is used) and fewer skims and skimming procedures need be developed. Second, it avoids the notion of labeling paths that use multiple transit technologies as belonging to one or the other of those modes. In reality, such a path is a mixed mode path and is likely perceived differently from a path that uses a single transit mode. Those differences in perceptions can be accounted for using different weights on travel time and other path attributes, depending on transit technology. While this approach could also be employed if the model considered transit technologies as different modes, the differences in perceptions could end up being confounded in transit mode constants (i.e., it may be difficult to separate the impact of perception of travel time by transit mode versus the constants).

Therefore, it is recommended that the MWCOG mode choice model consider only a single transit technology in enumerating mode alternatives. It is worth pointing out that removing the transit technology submode alternatives from the mode choice model does not mean that transit trips will not ultimately be split by transit technology. The split will simply occur in the transit assignment step of the model rather than modal split. Moreover, the model calibration and validation processes will be given the same level of scrutiny no matter which approach is used. In particular, the decision of mode choice structure will play no role in the level of precision with which Metrorail targets will be met.

4.2 Enhancements to Representation of Walk Access for Transit

Typically land development patterns are incorporated into mode choice models in rather simplistic ways. For instance, land use types (e.g., rural, suburban, urban, and central business district) at the origin and/or destination are often used in mode choice models. Typically, one will find that, all else being equal, transit usage is higher for trips made between urban locations compared with more rural locations. Density variables can also be used in this way. Density variables provide the advantage of a continuous variable, which avoids cliff effects that one would see with categorical variables. On the other hand, calibration may be easier if categorical variables are used.

Moreover, because travel models rely on spatial aggregation of land into zones and these zones are typically the basis for computing densities and area types, there can be large variations in density across adjacent zones, simply due to a single highly developed parcel in one zone. These occurrences may cause densities to vary across zones in ways that are unimportant to transit usage. Of course, if land use types are based only on density, this is an issue for those variables also.

Neither land use type nor density variables can measure transit accessibility. One simple way of measuring transit accessibility is through measures of the transit network intensity for an area. For instance, transit stop density at the origin and/or destination is one measure. Spatial aggregation can also impact these variables, though this may be mitigated, to some extent, by choosing density measures that are not related specifically to the zone boundaries (e.g., density of transit stops within 1 mi of the zone centroid).

Accessibility Measures

More sophisticated transit accessibility measures can be used. For instance, the equation below shows one example that is similar to a logsum measure often used in travel models:

$$A_i = \ln\left(\sum_{j \in D_i} S_j \times \exp[\theta \times c_{ij}]\right)$$

Here, A_i represents the accessibility of zone *i*, S_j represents a size measure of zone *j* (e.g., employment), c_{ij} is the generalized cost of using transit to travel between zone *i* and zone *j*, θ is a scale parameter, and D_i is a set of zones relevant to the accessibility calculation (e.g., a distance threshold might be used or one might include all possible destination zones).

This type of measure has several advantages over typical density measures or area types. First, it measures how well the zone is connected to other zones via the transit network, and in this way, it is directly applicable to transit accessibility. Secondly, it is weighted on the basis of the size of each zone. The larger a zone, the more significant that zone's impact on the overall accessibility. By accounting for a zone's connectivity with other zones, this measure avoids some of the issues with spatial aggregation that can occur with density measures[28]. It can also use parameters consistent with the mode choice model.

In practice, relative accessibility measures are often used. This is typically done by computing a similar highway accessibility measure[29] and differencing a zone's transit and highway accessibilities. The result is a measure of the transit accessibility relative to highway accessibility, which better reflects that transit is always a competitor to private auto modes. Both transit and highway accessibilities generally improve as one moves toward the center of a region (where network densities are highest).

Papaioannou and Martinez (2015) found that accessibility at the origin and destination were more important factors for transit usage than the actual connectivity between the origin and destination (e.g., the transit travel time between zones). In other words, improving transit connectivity between an origin and destination will provide larger benefit (in terms of transit usage) if both the origin and destination are perceived to be transit friendly locations (than if they are not). This underscores the importance of transit accessibility at both the origin and destination.

While accessibility measures are often used in MPO travel models, they are more typically found as variables in upper level models, for instance vehicle availability or day pattern models of an activity-based model (ABM)[30]. We recommend using these variables in the MWCOG mode choice model rather than more typical density variables. The basis for this recommendation is that the density variables may be misplaced, and that it is really transit accessibility at the origin and destination that is important for choice of transit. Since density variables typically mimic transit network density, we believe accessibility is really the effect density variables capture. The findings of Papaioannou and Martinez (2015) corroborate this. We recommend that density and accessibility measures be developed and compared to verify the correlation between the two, and ultimately, accessibility variables be incorporated in the mode choice model.

Other Zonal Variables

Kamruzzaman et al. (2015) studied how transit behavior was impacted by transit oriented development (TOD) patterns as compared to transit adjacent development (TAD) patterns. TOD patterns are defined by mixed use development, dense development, good connectivity (e.g., streets in grid pattern), and access to a transit hub. TAD can mimic TOD across one or more of these dimensions, but typically has less mixed use development, lower densities, and poorer connectivity.

One important connectivity attribute identified in this work was measuring the number of cul-de-sacs and dead end streets. Such links are not part of the transportation network defined for MWCOG's travel model, so this would need to be developed using more detailed network data. It is recommended that this data be collected if the cost of doing so is not so high. For instance, there may be ways to extract such information from publicly available databases and/or maps (e.g., OpenStreetMap). Alternatively, MWCOG may have access to all-streets networks from NAVTEQ/HERE, which could be used.

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[28] Though, as long as zones are used at all, some level of spatial aggregation error will persist.

[29] That uses highway skims rather than transit skims, but with the same size terms and scale parameter.

[30] This is the case for the Baltimore ABM as well as all recent CT-RAMP ABM implementations.

One measure of land use mix used by Kamruzzaman et al. (2015) was Simpson's diversity index. It is computed as follows:

$$\lambda_i = \sum_m {p_{im}}^2$$

Here, m is an index of the different elements in the zone, in this case, population and employment, and p_{im} is the share of the total population and employment for that element. For instance, if population and employment had an equal number in the zone, the share of each would be 0.5 and the diversity index would be 0.5. If there was no employment, however, then the population share would be 1.0 and the diversity index would be 1.0.

One appealing aspect of the Simpson's diversity index is that it strips any impact that density has on the measurement[31]. Many so-called land-use mix variables used in practice simultaneously measure land use mix and overall density. That is not the case for Simpson's index, as it will exist between 0.5 and 1.0 for all zones. A couple of slight modifications might be considered to shift the variable by 0.5 so that it exists between 0.0 and 0.5 and to balance population and employment (e.g., there are typically about two jobs per person in most regions).

PEF Methodology

Pedestrian Environment Factors (PEF) were developed as part of the model for WMATA, based on originally the MWCOG/TPB Version 2.2 model and more recently Version 2.3 model. This subsection discusses the PEFs and makes recommendations for how they might be used in the enhanced MWCOG model.

WMATA's version of the MWCOG travel model is a post-processor, which takes the trip tables from the MWCOG model run, creates peak and off-peak trip tables for HBW, HBO, and NHB, calculates zonal Pedestrian Environment Factor (PEF), prepares transit access skims, and performs mode choice and transit assignment. The mode choice model was set up for three trip purposes and two time periods with the use of constants for market segments based on New PEF values instead of the 20 geographic market segments (AECOM 2012).

The New PEF was created for the MWCOG/TPB Version 2.3 model, based on original PEF, zone proximity, transit coverage, and population and employment density. Zone proximity was used to smooth the original PEF values based on a zone's proximity to adjacent zones. The smoothed PEF values were further refined for transit friendly areas, through a quadratic relationship between PEF and percent transit access coverage, which is a composite index of the percentage of long walk to Metrorail, percentage of short walk to peak transit, and percentage of short walk to off-peak transit. For these transit friendly areas, the PEF values calculated based on the quadratic function, if larger than the smoothed PEF values, are used. Finally, these calculated PEF values were refined for high density areas, through a quadratic relationship between PEF and development density index, which includes population and employment.

Original PEF values were developed for the MWCOG/TPB Version 2.2 model and were defined as the number of Census blocks in a TAZ divided by the area of the TAZ in square miles. These original PEF

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[31] Note that this is not to say that density (or accessibility) is not an important variable also. However, isolating diversity and density (or accessibility) is a more appealing approach than creating a variable that measures both simultaneously without necessarily appropriate weighting.

values were adjusted as part of the calibration and validation process. These original and adjusted PEF values were taken as an input to the latest WMATA model.

Cambridge Systematics was unable to replicate the PEF calculation results for the model set provided by WMATA in February 2016. There is a lack of information about the data used to calculate original PEF values and their adjustments. Proximity-based PEF could not be calculated because of missing relevant data.

Cambridge Systematics reviewed the results of PEF calculated as part of the 2015 and 2040 model runs, using thematic maps of PEF values, transit access index, and development density index. Scatterplots were also used to relate PEF to transit access index and development density index. Thematic maps shows reasonable patterns of PEF values in the modeling domain. Scatterplots indicate that one value of transit access index or development density index may correspond to different PEF values, making it difficult to interpret the relationship.

In general, the PEF construct and its use in the mode choice model include:

- Development of a composite index that includes original PEF values based on block density and adjustments, and further refinement based on transit access and development density index; and
- Development of constants based on PEF values at the production and attraction ends of a trip.

Given the nature of this process, it is a challenge to explain the PEF to a planner and the public and to interpret the implication of a policy or project that is related to improving the infrastructure promoting walking and biking. There is neither explicit supply-side variable included for policy evaluation nor direct and explicit relationship between urban form and modal shares.

It is recommended that the PEF construct not be used in the enhanced MWCOG mode choice model components. However, because of the vetting process to which the PEFs have been subjected, it may be a worthwhile validation effort to compare model results from the enhanced MWCOG mode choice model against the PEF construct.

Recommendations

- Accessibility measures should be explored and compared with density variables. Accessibility measures should be added to transit mode choice utility functions in place of density variables, depending on the results of the comparisons.
- Roadway network connectivity variables (e.g., dead end density) should be explored in transit mode choice utility functions.
- Land use mix variables should be considered for the transit mode choice utility functions (e.g., Simpson’s diversity index).
- Compare transit access results against the PEF construct during model validation.

4.3 Representation of Transit Attributes

It is typical for travel models to consider several attributes of modal alternatives in different ways. For instance, out-of-vehicle time (OVT) is usually perceived to be anywhere from 2 to 3 times more onerous than in-vehicle time (IVT) in most studies. OVT components for transit typically include access and egress time, wait time, and transfer time. Transit fare, tolls, auto operating costs, and parking costs also deserve explicit treatment in the model and can be translated into travel time units via value of time (VOT) estimates, which in typical urban models can range from as low as $2 or $3 per hour up to $30 per hour or more, depending on trip purpose, income level, and a variety of other factors. In addition, penalties are often assigned for transit paths that include transfers between different transit routes. Relative weights (like VOT, for instance) are used to translate each attribute into common units and generalized costs are computed for each mode so that they can be compared on even grounds in the mode choice model.

Often many assumptions are used in this process. For instance, it is typically assumed that travelers do not perceive a difference between transit IVT and auto IVT. A number of recent studies, however, suggest that travelers value IVT spent on different modes in different ways (see, e.g., Ettema and Vershuren 2007, Ettema et al. 2012, Vovsha et al. 2012, Frei et al. 2015, among others). With the preponderance of information and communication technologies that have expanded the number and types of activities one can engage in while on transit vehicles, the differences in travel time valuations across modes has become even more important to consider. Because of this, transit usage may be increasingly linked to transit attributes not typically considered in the models, like reliability, amenities, and comfort.

This section, Section 4.3, and its subsections detail recommended enhancements with respect to how transit attributes are represented in the MWCOG model. Generally speaking, these enhancements should be considered in the context of both the transit mode choice utility functions and the transit path-building and assignment procedures, since the parameters of each should be internally consistent. Some specific challenges for transit path-building and assignment are discussed in Section 4.4, below.

In-Vehicle Time Segmentation

As described above, there is ample evidence in the literature to suggest that travel time is perceived differently on different modes of transport. Most of the literature suggests that time spent on certain types of transit is perceived to be less onerous than time spent in an automobile. This is largely a result of the fact that a traveler must commit a certain level of cognitive energy to the task of driving the automobile, which is not required on a transit vehicle. The ability to perform other tasks (such as relaxing or working) on transit vehicles is the primary reason for differences in traveler perceptions.

The Federal Transit Administration (FTA), in fact, provides guidance for valuing travel time differences on different modes for fixed guideway transit technologies. For fixed guideway transit modes[32], FTA permits up to 25 percent discount on travel time spent on transit vehicles for travel forecasts prepared for New Starts applications (relative to bus or auto travel time). The 25 percent discount represents a maximum, and in most cases, a smaller discount would apply. The appropriate discount, according to FTA's guidance (FTA 2008), depends on a variety of attributes of the transit technology, including travel time reliability, seat availability, ride quality, and vehicle amenities.

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[32] This includes commuter rail, heavy rail, light rail, subway, streetcar, and bus-rapid transit (BRT).

In TCRP Report 166 (Outwater et al. 2014), several nontraditional transit attributes were examined, including several on-board features of transit vehicles. Such features included on-board seat availability, seat comfort, temperature, cleanliness of the vehicle, and productivity features. In total, the authors found that the value of these five nontraditional attributes was 5 to 11 minutes of IVT per trip, depending on trip purpose and city. For comparison, a 5 to 11 minute discount would be achieved on trips of 20 to 45 minutes using FTA's guidance of a 25 percent discount on IVT.

In practice, several agencies apply discounts to IVT spent on transit vehicles. For instance, the San Francisco MPO (MTC 2012) applies a discount of 15 to 22 percent on IVT for ferries, commuter rail, and heavy rail, and 8 to 11 percent on IVT for light rail, relative to auto or bus IVT. Atlanta's MPO (ARC 2016) applies an IVT discount of 30 percent for all transit on home-based work tours.

It is recommended that IVT discounts on transit service be considered in the enhanced MWCOG mode choice model. A variety of discount structures should be tested and evaluated both in terms of model performance and in terms of FTA and other experience. Such discounts should also be applied in transit path-building and assignment steps. It is anticipated that this enhancement will improve the model's sensitivities to changes in the transit network.

Nontraditional Transit Attributes

While many nontraditional transit attributes have seen increased attention recently, very few agencies have begun attempting to incorporate new research developments in their urban models, other than in the form of IVT discounts discussed above. We are not aware of any agencies that include such attributes in their model, and only a few (e.g., MTC and SFCTA in San Francisco, PSRC in Seattle, and CMAP in Chicago) that are looking into these topics in this context. This section details some of the developments related to other transit features and makes recommendations for enhancements to the MWCOG model.

FTA guidance for New Starts projects (FTA 2008) allows for adjustments to modal constants (relative to bus service) on the basis of the quality of unmeasured attributes of certain fixed guideway transit technologies. Table 4.3 shows maximum allowable "credits" for different transit features. In total, the maximum adjustment to the modal constant allowable for guideway-only trips is 15 minutes of IVT, and only 7 minutes of IVT for trips that include one or more transfers to transit bus service.

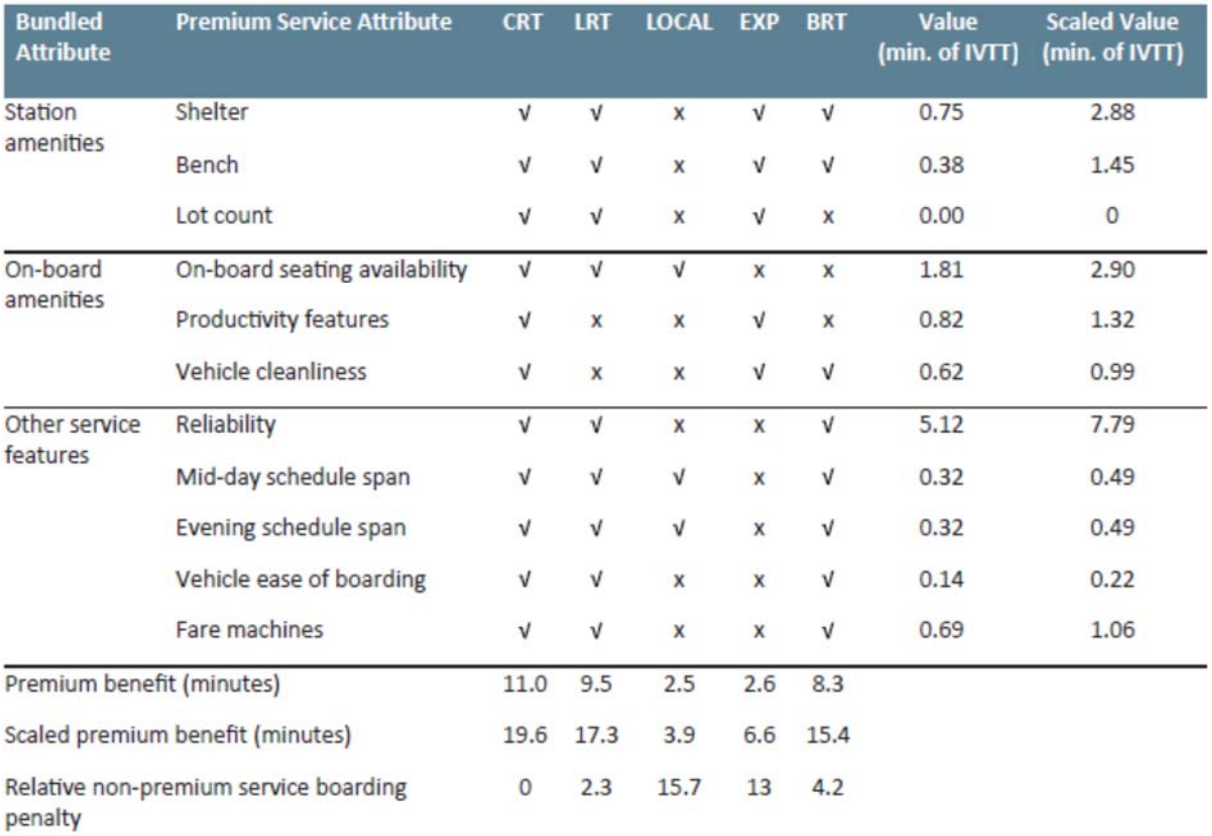
Table 4.3 FTA's Maximum Adjustments for Fixed Guideway Transit Systems

Unmeasured Attribute	Maximum Credit for Guideway-Only Trips (Minutes)	Maximum Credit for Guideway/Local Bus Trips (Minutes)
Reliability of vehicle arrival	4.0	2.0
Branding and visibility	2.0	1.0
Schedule-free service	2.0	1.0
Span of good service (e.g., across times of day)	3.0	0.0
Amenities at stops / stations	3.0	2.0
Dynamic schedule information at stops / stations	1.0	1.0
Total	**15.0**	**7.0**

Note: Adapted from FTA (2008, Table A4.1-1, p A5-4)

In addition to on-board features, the TCRP report referenced earlier (Outwater et al. 2014) also quantified the value of a number of other transit features that are typically ignored by urban models. Figure 4.2 shows the approach taken in that report, which was applied using the Salt Lake City travel model. Premium benefits of each of the attributes were estimated from a stated preference survey conducted in several regions. Those were scaled to recognize that in their model application, several of the attributes for which benefits were measured from the survey, could not be measured in practice.

Figure 4.2 Boarding Penalties Estimated for Different Transit Technologies[a]



Bundled Attribute	Premium Service Attribute	CRT	LRT	LOCAL	EXP	BRT	Value (min. of IVTT)	Scaled Value (min. of IVTT)
Station amenities	Shelter	√	√	x	√	√	0.75	2.88
	Bench	√	√	x	√	√	0.38	1.45
	Lot count	√	√	x	√	x	0.00	0
On-board amenities	On-board seating availability	√	√	√	x	x	1.81	2.90
	Productivity features	√	x	x	√	x	0.82	1.32
	Vehicle cleanliness	√	x	x	√	√	0.62	0.99
Other service features	Reliability	√	√	x	x	√	5.12	7.79
	Mid-day schedule span	√	√	√	x	√	0.32	0.49
	Evening schedule span	√	√	√	x	√	0.32	0.49
	Vehicle ease of boarding	√	√	x	x	√	0.14	0.22
	Fare machines	√	√	x	x	√	0.69	1.06
Premium benefit (minutes)		11.0	9.5	2.5	2.6	8.3		
Scaled premium benefit (minutes)		19.6	17.3	3.9	6.6	15.4		
Relative non-premium service boarding penalty		0	2.3	15.7	13	4.2		

a CRT stands for commuter rail transit, LRT stands for light rail transit, LOCAL stands for local bus, EXP stands for express bus, and BRT stand for bus rapid transit. Note that subway/heavy rail was not an available transit technology in Salt Lake City. The premium benefits for heavy rail are probably less than those for CRT, since productivity features such as Wi-Fi access and outlets would not be applicable, but would be at least as high as those for LRT.

Source: Outwater et al., 2014, pages J-6 to J-7.

Each premium feature was then examined with respect to the five transit technologies available in the region and assigned as being present or not. The benefits were then summed for each transit technology, transformed into relative penalties, and applied as boarding penalties. That is, for each boarding of a particular transit technology, a lump-sum penalty was applied specific to that technology.

Applying premium features as boarding penalties is debatable, since the premium attributes were measured at the trip level. Nonetheless, it seems like a reasonable approach for mixed technology trips and builds in a transfer penalty to the model, which is specific to the transit technology used.

A similar approach could easily be adapted for the MWCOG model. However, the other transit features could be evaluated for each transit service offered in the MWCOG region, and boarding penalties could be determined for each. This would require the generation of additional variables by the skimming procedure. One would need to know the number of boardings by transit technology. One could extend the approach to allow for differences within different services as well (e.g., across routes within the same service). This would require new attributes be added to the transit network and for those attributes to be skimmed in the skimming procedures. Since on-board amenities will be captured through a discount applied to the IVT coefficient, those attributes would be ignored here. The primary advantage of pursuing this recommendation would be to reduce the model's reliance on modal constants and to improve the model's ability to anticipate the ridership on new transit modes or changes to the transit network.

Seat Availability and Crowding

One approach to dealing with the impact of seat availability and crowding was detailed in under "In-Vehicle Time Segmentation," above. That section suggests that seat availability and crowding be accounted for by discounting IVT for premium service (e.g., when there is ample seat availability and little crowding). However, it is not capable of dealing with how service performance may change over time or for its effects to be automated in the modeling process. This section describes ways in which automating the procedure may be possible.

The "In-Vehicle Time Segmentation" subsection, above, suggests that the IVT discount be specific to transit technology. In the case of seat availability and crowding, this suggests that service of each transit technology is uniform across the region and across time periods. Moreover, while it would be possible to change the discount level for future years to accommodate changes in service level across time, it would be preferred to have an automatic procedure that accounts for changes in demand and compares to supply.

In order to allow for variability in the discount level, three things are needed. First, the IVT discount associated with premium seat availability and crowding service must be segmented from the IVT discount associated with other premium attributes. Based on FTA's guidance (FTA 2008), the approximate discount of premium seat availability and crowding is 10 percent, though this could be refined. Second, a crowding function is needed to relate congestion level to IVT discount level.[33] Third, a feedback mechanism is needed between supply and demand.

The Cube-PT program provides the function of analyzing crowded conditions in transit vehicles during the transit assignment process. The PT crowd model is an iterative multi-path loading process that allocates excess demands to alternative feasible paths. It employs a "damping" mechanism to stabilize assignment results in the iterative loading process, where results are obtained from the final iteration.

The PT program supports two types of crowd modeling: link travel time adjustments and wait time adjustments. The link travel time adjustment model examines passengers' perceived travel times through a crowd factor curve, which is a function of utilization level of transit vehicles. The crowd factor is applied to the travel time of a transit link to reflect the perceived travel time due to crowding. The wait-time adjustment model adjusts the wait times of passengers at boarding stations. The program evaluates the arriving demand and the available capacity of transit vehicles at each station. The excess demands are allocated to other services resulting in additional wait time.

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[33] For instance, this might range between 0 and 0.1 if the discount for premium seat availability was 10 percent.

The PT program also generates two types of skim matrices relevant to crowd modeling: the average perceived additional link time and the average additional wait time. These skim data can be used by the mode choice model to reflect the transit service level under crowding.

The crowd modeling function of the Cube-PT program would support the proposed mode choice framework in several ways. First, it has a built-in travel time adjustment model that reflects the impact of crowding on perceived travel time, and it also has the capability of updating wait times due to crowding. Second, it provides crowd-related skim data for the mode choice model. Third, as the PT program performs transit assignment and provides relevant skim data for the mode choice model under crowding conditions, it ensures the consistency of transit service level being used in the mode choice process and the transit assignment process. Finally, with the consistency of transit service level between the mode choice and assignment processes, the number of iterations required to achieve equilibrium conditions in the feedback process would be reduced.

To our knowledge, there are no agencies currently using the crowd modeling capabilities of Cube-PT. As such, a significant amount of testing and calibration may be needed in order to tune the approach and ensure it works well. In addition, new data would be needed. Information from transit providers on effective capacities would be needed as well as information on the level of congestion that currently exists, especially during peak periods. Due to the vast extent of the transit network in the region, it is recommended that the approach be limited to Metrorail for its initial deployment. For other transit providers, the simpler static discounting approach discussed under “In-Vehicle Time Segmentation,” above, can be used.

Variable Value of Time

As part of Task Order 16.3 on improving MWCOG’s modeling capabilities related to managed lanes, it has been proposed to develop and use value of time (VOT) distributions and segmentation in the MWCOG model. This has important implications for the mode choice model.

In mode choice models, typically VOTs are implied by estimated or derived coefficients on the IVT and cost variables. The quotient of the IVT coefficient and the cost coefficient yields the implied VOT. For the MWCOG mode choice model, trip tables from trip distribution will be split by VOT segment. Each VOT segment will have a distinct VOT. VOT differences will be a result of differences in the assumed IVT coefficient.[34] However, income segmentation is an important component of the mode choice model as well. Typically, each income segment is assumed to have a distinct cost coefficient, with low income households having larger magnitude coefficients and high income households having lower magnitude coefficients. Therefore, the mode choice model application must be segmented by both VOT segment and by income segment.

As described in Section 2.0, “Task Order 16.3 – Managed Lanes,” the highway skimming procedures will generate separate skim tables for each VOT segment. Each will be used for the appropriate VOT segment here. Each income segment within a particular VOT segment will use identical skims. For instance, a low VOT traveler can come from a low income household or a high income household. It will be assumed that all low VOT travelers have the same value of time, for instance $3 per hour. However, cost sensitivities will be segmented by income level, so the cost coefficient in the mode choice model for low income travelers will have a larger magnitude than that of high income travelers. This means that there must be a similar relative

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[34] An IVT coefficient of larger magnitude implies higher VOT, while an IVT coefficient of smaller magnitude implies lower VOT.

difference between IVT coefficients of these travelers in order that VOTs be the same. So if value of time for low VOT travelers is $3 per hour, a low income household may have time and cost coefficients of -0.02 and -0.4, while a high income household may have time and cost coefficients of -0.01 and -0.2. Both sets of coefficients imply the same VOT. In general, low VOT travelers from high income households will be the least sensitive to changes in network level-of-service characteristics (since both time and cost coefficients will be low). On the other hand, high VOT travelers from low income households will be the most sensitive to changes in network level-of-service characteristics (since both time and cost coefficients will be high). However, these two groups will make up two of the smallest groups of travelers, as the majority of low income households will have lower VOTs and the majority of high income households will have higher VOTs. Table 4.4 provides an illustration of how the joint VOT and income segments might look in terms of cost and time coefficients and overall market shares (note that the table is purely hypothetical).

Table 4.4 Example Joint Distribution of VOT and Income Segments

Segment	Income 1	Income 2	Income 3	Income 4	Total
VOT 1	β_{cost} = -0.400 β_{ivt} = -0.015 Share = 0.120	β_{cost} = -0.300 β_{ivt} = -0.011 Share = 0.050	β_{cost} = -0.200 β_{ivt} = -0.008 Share = 0.020	β_{cost} = -0.100 β_{ivt} = -0.004 Share = 0.010	VOT = $2.25 Share = 0.200
VOT 2	β_{cost} = -0.400 β_{ivt} = -0.030 Share = 0.100	β_{cost} = -0.300 β_{ivt} = -0.023 Share = 0.060	β_{cost} = -0.200 β_{ivt} = -0.015 Share = 0.030	β_{cost} = -0.100 β_{ivt} = -0.008 Share = 0.010	VOT = $4.50 Share = 0.200
VOT 3	β_{cost} = -0.400 β_{ivt} = -0.050 Share = 0.020	β_{cost} = -0.300 β_{ivt} = -0.038 Share = 0.100	β_{cost} = -0.200 β_{ivt} = -0.025 Share = 0.050	β_{cost} = -0.100 β_{ivt} = -0.013 Share = 0.030	VOT = $7.50 Share = 0.200
VOT 4	β_{cost} = -0.400 β_{ivt} = -0.080 Share = 0.008	β_{cost} = -0.300 β_{ivt} = -0.060 Share = 0.032	β_{cost} = -0.200 β_{ivt} = -0.040 Share = 0.080	β_{cost} = -0.100 β_{ivt} = -0.020 Share = 0.080	VOT = $12.00 Share = 0.200
VOT 5	β_{cost} = -0.400 β_{ivt} = -0.133 Share = 0.002	β_{cost} = -0.300 β_{ivt} = -0.100 Share = 0.008	β_{cost} = -0.200 β_{ivt} = -0.067 Share = 0.070	β_{cost} = -0.100 β_{ivt} = -0.033 Share = 0.120	VOT = $20.00 Share = 0.200
Total	**β_{cost} = -0.400** **Share = 0.250**	**β_{cost} = -0.300** **Share = 0.250**	**β_{cost} = -0.200** **Share = 0.250**	**β_{cost} = -0.100** **Share = 0.250**	

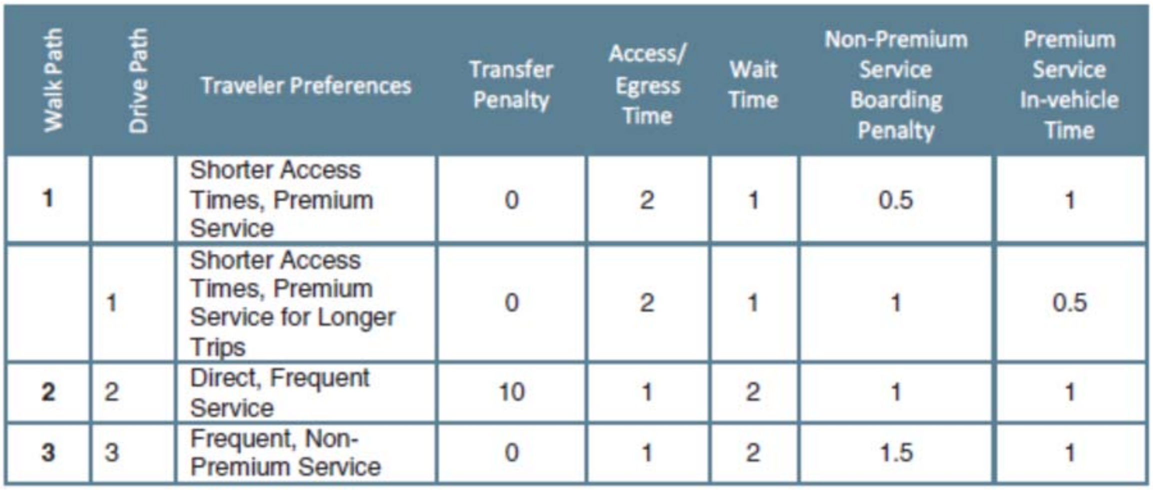
For transit modes, skimming procedures will not be segmented by VOT, since other transit attributes are of greater importance to transit travelers (see Section 4.4 for more details). Nonetheless, transit utility calculations must be computed carefully. Since much of the literature has measured sensitivities to out-of-vehicle times and nonstandard transit attributes in a relational framework to in-vehicle time, relationships that are defined for the enhanced mode choice model should be done similarly and applied in the same way. For instance, the OVT coefficient can be defined as 2 or 3 times the IVT coefficient, so that as the IVT coefficient varies across VOT and income segments, the OVT coefficient varies proportionally.

The approach is described in Section 2.0 of this report, "Task Order 16.3 – Managed Lanes."

Path Choice Component

The TCRP study described above (Outwater et al. 2014) also examined the impact of transit path options on transit mode choice preferences. Instead of defining transit skims by specific transit technologies (as the existing MWCOG model does), they generated transit skims using three different sets of weights (as shown in Figure 4.3, which reflect preference structures that differ across travelers. By doing so, separate transit path options were identified and were treated as explicit alternatives under the walk- and drive-access transit alternatives in the mode choice model. Basically, instead of choosing between rail, premium bus, and standard bus, the model presumes the choice is between three separate path options, where each path option is defined by a set of weights used for skimming the transit network.

Figure 4.3 Path-Building Weights for Transit Path Options in Mode Choice Model



Walk Path	Drive Path	Traveler Preferences	Transfer Penalty	Access/ Egress Time	Wait Time	Non-Premium Service Boarding Penalty	Premium Service In-vehicle Time
1		Shorter Access Times, Premium Service	0	2	1	0.5	1
	1	Shorter Access Times, Premium Service for Longer Trips	0	2	1	1	0.5
2	2	Direct, Frequent Service	10	1	2	1	1
3	3	Frequent, Non-Premium Service	0	1	2	1.5	1

Source: Outwater et al., 2014, page 25.

Before settling upon the three sets of path-building parameters shown in Figure 4.3, Outwater et al. (2014) examined a number of different path-building parameter sets. They settled on the final ones based upon their match with observed data. By incorporating the path choice component in the mode choice model, they found that path building parameters were more accurate and there was a reduced reliance on modal labels in the model.

In theory, the approach should improve the representation of transit in the mode choice model by better capturing the transit mode’s composite utility. When transit technology is used to represent transit submodes, many suboptimal transit paths are enumerated and included in the utility functions, simply because the paths represent the best path that uses a specific transit technology (e.g., commuter rail). This can artificially inflate the composite utility of transit overall when there truly is only one reasonable path, but can also artificially deflate the composite utility of transit when there are multiple good transit path options that all use the same transit technology submode. When no transit submodes are included in the mode choice model (which is the recommended approach), only the single best transit path option is included in the overall transit composite utility. When the second best transit path option is close in utility to the best option, the approach will serve to deflate the composite utility by ignoring that second best option.

Unfortunately, the approach has a number of implementation issues that would need to be worked out. These issues are described below.

1. **Path choice probability splits**. The approach generates three path options that are treated as submode options in the mode choice model. In theory, one should treat those as distinct alternatives and split transit demand between the three path options. However, it is not clear how these path option splits would be reconciled with the transit assignment model. Moreover, observed data on path splits is not available, so there would be no way to validate that model subcomponent.

   An alternative would be to ignore the path choice demand splits and only carry forward the overall transit trips to transit assignment. In this case, it would be important that there be internal consistency between the path choice component of the mode choice model and the transit assignment model, so that paths represented in the mode choice model are actually paths chosen by transit assignment.

2. **Setting the parameters for path-building.** The TCRP report offers guidance in the way of transit path-building parameters, but additional data may be needed to support testing of different parameter sets.

3. **Identical transit paths**. One issue that will arise in areas with limited transit accessibility will be cases where all three transit paths are identical. Correction factors must be added to the utility functions in such cases to avoid overstating transit's composite utility.

4. **Maintenance of additional skims**. One advantage identified earlier for the recommended approach of using only a single transit submode was that the number of skims needed by the model is reduced. The transit path submode approach would nullify that advantage, and would require distinct skims be generated for each path option.

5. **Model calibration**. Model calibration will be more challenging simply by adding degrees of freedom without any additional constraints.

6. **Experience**. Possibly the biggest issue is that there is only one implementation of the approach, and that was for a research project, not a model used in practice. There would assuredly be other issues that come up that cannot be foreseen at present and the relative improvement of the approach over another is not clear at this time.

Overall, there is a fair amount of risk in pursuing the transit path choice logsum component in the mode choice model. As such, a transit path choice logsum is not recommended for the updated MWCOG mode choice model at this time.

Recommendations

- IVT discounts on premium transit service should be implemented. A variety of discount structures should be tested and evaluated both in terms of model performance and in terms of FTA and other experience.

- Consideration should be given to adding nontraditional transit attributes to the model. There are multiple options for implementing this, as described in Section 4.3. The goal of including such attributes is to reflect the underlying determinants of transit path choice, rather than relying on constants.

- Crowding effects on Metrorail may be incorporated in the model. Cube-PT can be used to generate crowding variables (as described in more detail in Section 4.4). However, this is seen as a lower priority enhancement.

4.4 Transit Path-Building and Assignment

As mentioned at the beginning of Section 4.3, many of the recommended enhancements to the MWCOG mode choice model affect how transit path-building and transit assignment are performed as well. Some of these affects were discussed in the body of Section 4.3. Section 4.4 addresses transit path-building and assignment directly.

Transit Path-Building

Transit path-building procedures will need to be updated in several ways, as described below:

1. Only a single best path procedure will be needed, rather than distinct procedures for each transit technology submode.
2. Transit path building parameters will be updated to be consistent (to the extent possible) with weights used by the mode choice model. This will ensure that the best path options (according to mode choice utilities) are truly the best paths.
3. Several new variables will need to be included in the path building procedures, including terminal times at Metrorail stations, number of boardings by transit technology, in-vehicle travel times by transit technology, and crowding levels.

The transit path-building will be handled in Cube-PT. One issue will be that multi-path processes must be used with Cube-PT, and skim variables generated by the process will be slightly different than those typically generated by a best-path algorithm. Specifically, the skim variables will represent average levels of the variables across the different paths used for any i-j pair. However, the averaged variables can be used in mode choice models without modification.

Transit Assignment

The transit assignment process will also be revised to accommodate the enhanced mode choice model structure. The assignment process segmented by transit technology as implemented in the current MWCOG model will be simplified. In the current MWCOG model, transit trips are divided into 12 segments by transit submode and access mode. These trips are assigned to the transit network independently.

With the enhanced mode choice structure, transit trips will be segmented by access mode only. The enhanced mode choice structure will not segment by transit technology, and instead, the path choice (assignment) component will split transit trips between transit technology. The entire transit system consists of various transit service types with different service characteristics and fare structures. As such, the variable weights used to assign transit trips across paths will need to be considered carefully. Moreover, testing will be performed to determine if the VOT segmentation discussed in “Variable Value of Time,” above, should be carried forward to transit assignment (see “Value of Time,” below, for more details).

To analyze crowd condition, it will be necessary to assign all the transit trips of various segments in a single unified loading process such that the overall demand and loading condition of the transit system can be evaluated during the assignment process. This can usually be handled using the “multi-class” assignment process, which assigns transit trip tables of different classes simultaneously. The Cube-PT program provides the multi-class assignment function, with separate sets of path-building parameters for different segments of transit trips.

The transit assignment process is used not only to predict the passenger volumes on the transit network, but also to provide important service and demand data that are fed back to the mode choice model. Most of the service related variables of a transit path can be retrieved using the PT skimming process. For some of the demand related variables, e.g., as the number of Metrorail boardings and vehicle congestion level at the initial station, etc., special "post-assignment" processes can be developed to retrieve these data.

Feedback of Congestion Levels

To the extent that supporting modeling of seat availability and crowding on Metrorail is desirable moving forward, it is recommended that congestion levels from transit assignment be fed back to the demand model via the transit skims. This requires several new features be added and developed as described in Section 4.3. First, Metrorail lines must be coded with capacity values by time period. Second, once the full model runs once, resultant transit assignment link volumes need to be updated on the transit network. Third, the congestion level at initial boarding of Metrorail must be skimmed as well as the maximum congestion level experienced on Metrorail for the trip. Fourth, a relationship between congestion levels and in-vehicle time discount must be developed. The relationship should take a value of the maximum discount level when congestion is low and a value of zero when congestion is very high (or possibly even a negative discount for extreme crowding). Last, the IVT discount is applied in the calculation of transit mode choice utilities.

Value of Time

As discussed in "Variable Value of Time," under Section 4.3, above, segmentation of value of time will be incorporated in the enhanced MWCOG model to support modeling of managed lanes. For transit path-building and assignment, it is anticipated that a single representative VOT can be used rather than segmented values. It is not anticipated that VOT segmentation would result in significantly different transit paths being built, nor is it anticipated that VOT segmentation would result in differences in transit assignment results. However, VOT segmentation in transit assignment will be explored to verify this. If it is found that VOT segmentation is important in transit assignment, VOT segmentation for this model and the path-builder will be reconsidered. Separate transit skims for each VOT may be required and additional trip table segmentation may be required for loading trips to the transit network in assignment.

Recommendations

- Transit path-building and assignment should be updated to use Cube-PT's crowding capabilities for Metrorail;
- Other nontraditional transit attributes that are used in the enhanced mode choice model should be included in the path-builder and assignment processes;
- Transit skim feedback should be implemented in the model, much like highway skims are fed back to distribution and mode choice models; and
- VOT segmentation in transit assignment should be explored to verify (or refute) the idea that it will have only small impacts.

4.5 Data Needs

Much of the data needed to make the recommended enhancements to the MWCOG model system already exists. However, several additional data items will be needed or useful to have. This section details those data needs.

While no specific data is needed to measure the recommended land use mix variables, finer-grained spatial data (e.g., parcel level data) would be useful in generating land use mix variables. Being able to identify where in a zone employment is located compared to population could impact how the land use mix variables are computed and applied.

Local street-level data will be needed to measure dead end and cul-de-sac density variables. This data may be available through publicly available data sources, like OpenStreetMap or similar.

In order to estimate and calibrate the models, additional data related to seat availability and crowding on Metrorail will be necessary. Presumably, this information could be collected from the transit operator. A number of pieces of information related to crowding on transit vehicles would be useful, including:

1. Effective capacities at different times of day by route;
2. Observed demand at different times of day by route and by station; and
3. Any additional qualitative or quantitative information that Metrorail can provide.

Reliability information related to each transit service will be useful, including on-time arrival performance, reliability of travel times (e.g., standard deviations), and any other measures that transit operators can provide. It is preferable to obtain such information at different times of day and across different routes, if available. Ultimately, reliability will likely be quantified somewhat qualitatively, but more detail will allow for refinement of the measurements.

The existence of other transit attributes by transit technology will be important. This includes information like vehicle cleanliness, amenities provided on board transit vehicles (e.g., Wi-Fi service, power outlets, etc.), fare machine information, station/stop shelter and security information, as well as other information. Accurate terminal times for Metrorail (i.e., time between entering station to arriving at the platform) by station should also be collected.[35]

4.6 Model Estimation, Calibration, and Validation

This section discusses some of the issues involved with model estimation, calibration, and validation.

Model Estimation

Model estimation will be needed to implement the enhanced features of the mode choice model. This will be necessary to obtain a good baseline level for each of the model parameters. However, it may be necessary to assert some of the relationships. For instance, value of time distributions will likely be asserted and based on the distributions used for the BMC activity-based model (this is described in more detail in Section 2.0 of

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[35] This information was assembled as part of Task Order 16.2.

this report, “Task Order 16.3 – Managed Lanes”). In addition, it may be difficult to measure some of the new variables that are recommended for the model in the year relevant to the model estimation data.

Moreover, it is anticipated that many of the recommended new variables are inter-related (e.g., land use mix, dead end density, and transit accessibilities).[36] Typically, given a limited sample of data, it is difficult to estimate precise coefficient values for multiple variables that exhibit correlation. This is typically a case of allowing too many degrees of freedom and the model consequently overfitting the data. As a result, in practice, variables are often simply dropped from the model in such circumstances. Instead of dropping variables, however, it is recommended that engineering judgment and experience from elsewhere (e.g., the sources described above) be considered to assert coefficient relationships among the related variables. The model calibration step will be used to refine the asserted relationships in order to match observed targets better.

It is recommended that model estimation work be performed for the MWCOG mode choice model. While it may not be possible to estimate all of the parameters we have recommended with a high level of precision and/or statistical significance, estimating the models with revealed preference data will create a baseline for the overall scale of the utility functions to use in the model (which is something that is not easily calibrated).

Model Calibration and Validation

It is recommended that a great deal of attention be paid to model calibration and validation. The main objective of the proposed model enhancements is to improve the model sensitivities, both in terms of the number and types of policies to which the model is sensitive. As described above, model estimation work will be limited in that it will be based on a limited survey sample and it is likely that a number of assertions will need to be made anyway. As such, extensive calibration and validation will be much more valuable to determine that the model is working appropriately and responding to the needs of MWCOG. This will require an iterative process of calibrating mode choice and transit assignment to ensure that changes made in one model component do not result in unintended results for the other.

For model validation, a number of validation measures are recommended, including comparisons to transit boarding data, district-level transit trip interchange comparisons, among others. In addition, more localized validation measures should be examined, like comparisons of the model to observed transit corridor level data using mapping tools.

Sensitivity testing should also play an important role in model validation to ensure model sensitivities are appropriate in a variety of settings. Sensitivity tests should range in scope from system level to local level. For instance, one test may be to examine how the model responds to changes in demographics, while more localized changes might be to look at how the model responds to changes in the characteristics of one specific station or Metrorail line.

It is recommended that a backcast year be developed to verify model results. Alternatively, if a backcast dataset cannot be developed, it may be possible to hold out a certain part of the validation data for validation

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[36] Cross correlation of the independent variables in a model is typically something one would like to avoid, but is something that is inherent in travel models. For instance, auto travel times and costs (which are highly dependent on distance) are highly correlated variables that are almost always considered in mode choice models. It is our experience that cross correlation often leads to poor parameter estimates, since the effects of variables are confounded with one another. This can be mitigated with larger datasets and improved data. In practice, however, it often leads to making assertions about the values of parameters, though this isn’t necessarily a bad thing and can ensure the model is properly sensitive to a variety of policy variables.

purposes. For instance, validation targets for 1 or 2 routes for each transit operator might be used solely for validation checks and not for calibrating the model.

Recommendations

- Mode choice models should be estimated with existing household and transit on-board survey data and the newly developed transit attribute variables. The relationships between some coefficients may need to be constrained or asserted. Those relationships can be adjusted during model calibration.
- Model validation should compare the model along traditional transit validation measures, but also more localized measures (e.g., at the corridor level).
- Model calibration and validation of mode choice and transit assignment should be handled as a joint process to ensure consistency in parameters and weights between the two model components.
- A list of sensitivity tests should be developed and performed.

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