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16. Abstract

The travel demand models developed and applied by the Transportation Planning and Programming Division (TPP) of the Texas Department of Transportation (TxDOT) are daily three-step models (i.e., trip generation, trip distribution, and traffic assignment sequentially invoked). Currently, TxDOT TPP does not have a procedure to account for existing or planned toll roads in the urban travel demand models. TxDOT TPP has been operating under guidance established when toll roads existed as planned facility improvements in either the interim or forecast year model applications. Although the larger urban areas in Texas have embraced tolled facilities for quite some time (i.e., Dallas-Fort Worth, Houston, and Austin), roads that charge users a fee to bypass congestion or provide alternative routes have only been implemented recently in a select few small to medium-sized urban areas still under the purview of TxDOT TPP model development. In order to calibrate base year travel models with operational toll roads or models with planned tolled facilities, TxDOT TPP needs a procedure to account for facilities that charge fees to the user. For the tolled facilities currently operational in small to medium-sized study areas, the fees are fixed and are not dynamic by time of day or congestion levels.

The technical objective of this research report is to provide TxDOT TPP with a menu of potential procedures that could be selected for implementation in the current Texas Package suite of travel demand models to reasonably estimate toll road demand, primarily for the small to medium-sized urban areas. Nationally, generally two approaches are used: a path-based system and a choice-based system. Researchers reviewed both approaches as well as different supplemental techniques (i.e., time of day, market segmentation, and mode choice) implemented nationally and within the state that are complementary to any toll demand estimation techniques. Challenges and considerations for each of the approaches are reviewed and presented. The procedures and applications reviewed in this project are not intended to replace or compete with existing toll-financing-level analysis.

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DEVELOPING TOLLED-ROUTE DEMAND ESTIMATION CAPABILITIES FOR TEXAS: OPPORTUNITIES FOR ENHANCEMENT OF EXISTING MODELS

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DISCLAIMER

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- Mike Schofield, transportation analyst with TxDOT TPP.
- Greg Lancaster, team leader with TxDOT TPP.
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- Michael Bolin, transportation engineering supervisor and the North Region coordinator with TxDOT.
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CHAPTER 1: INTRODUCTION

BACKGROUND

The Texas Department of Transportation's (TxDOT's) Transportation Planning and Programming Division (TPP) has been involved in travel demand model development and applications since the early 1960s. Initially, TxDOT was responsible for developing all urban travel demand models in areas exceeding 50,000 persons. TxDOT TPP still maintains full model development responsibilities for 21 of the state's 25 study areas and shared development responsibilities with two of the remaining larger metropolitan planning organizations (MPOs).

The North Central Texas Council of Governments (NCTCOG) and the Houston-Galveston Area Council of Governments (H-GAC) are responsible for modeling the state's two largest regions: the Dallas-Fort Worth and Houston-Galveston metro areas, both with populations exceeding 5 million. In the Austin and San Antonio areas, mode-choice and traffic assignment responsibilities have migrated to the local area MPOs: Austin's Capital Area Metropolitan Planning Organization (CAMPO) and the San Antonio-Bexar County Metropolitan Planning Organization (SAMPO). TxDOT still coordinates trip generation and trip distribution activities for these two regions. Therefore, procedures for modeling current or planned tolled facilities are under the direction of the local area in both Austin and San Antonio. The mode-choice model and the approach to toll modeling are accomplished through consulting contracts.

The state's four largest urban areas now use tolled facilities as a means to address budget shortfalls in the face of rising congestion. Such facilities can generally be built more quickly than traditional capacity-expansion projects due to toll revenues covering a portion of project costs. These four regions' MPOs have had to address tolling's impacts on travel demand patterns and model predictions earlier than other regions in the state.

Under House Bill 3588, TxDOT must conduct toll viability studies for all future capacity enhancements and new facilities to determine if tolls are appropriate for implementation. This policy, which has been in place since 2003, emphasizes TxDOT's need for appropriate tools and procedures to anticipate tolled-highway volumes and associated revenues. Some flat-fee toll projects have advanced beyond the planning stages and have already been built, including Tyler's Loop 49 and Brownsville's SH 550. Laredo's Camino Columbia Tollway is now under TxDOT management and exists as a facility in Laredo's 2003 travel demand model (although it is not currently treated as a tolled facility in the models). Similar to actual travel conditions, the Camino Columbia Tollway receives very little in the way of traffic in the models because of the juxtaposition of the facility relative to the urbanized area.

The El Paso region is considering variably tolled managed lanes in its Border Highway expansion project as a potential means to relieve downtown congestion along IH 10. In order to address the planned variable-priced facility in El Paso, a generalized cost assignment was quickly implemented for the interim years that the facility would appear. The generalized cost approach was adopted without the benefit of the process being present during the base year calibration portion of model development.

Before such facilities were built, TxDOT TPP had been operating under agreed-upon guidance (between TPP and the Toll Operations Division [TOD], formally known as the Texas Turnpike Authority [TTA]) that was established when tolled facilities were simply planned improvements and did not exist in any base year model networks. Such planned facilities were added to either interim- or forecast-year network geographies and simply treated as free route alternatives. Within TxDOT TPP, the forecast volumes produced by the TPP models were essentially considered a maximum-flow benchmark for comparisons to corridor-level analysis estimates developed by TPP. Refined traffic volume estimates were previously developed by TTA as a part of the toll and revenue development process. TxDOT TPP, to date, has not been engaged in either the estimation or basic accounting of tolled facilities as a part of the travel demand model structure or traffic forecast procedures.

This approach is no longer viable since TxDOT TPP is now involved in another five-year model update cycle that coincides with the updates to each urban area's Metropolitan Transportation Plan (MTP). TPP is currently involved in updating existing travel demand models for the Tyler, Brownsville, and Laredo urbanized areas (with Brownsville modeled as a part of the Lower Rio Grande Valley region). The existing base-year models are being updated using revised demographics and networks that coincide with the count collection year (travel surveys have not been collected since the previous count collection cycle). Thus, each of these three study areas' models must address existing toll roads in the model updates in order to accurately reflect current traffic conditions as a part of standard model validation and calibration.

Additionally, given the uncertain status of traditional funding options, toll roads, whether implemented as static or dynamically priced facilities, will probably be given greater consideration to address mobility needs moving forward in the state. Therefore, TxDOT TPP needs mechanisms to address existing tolled facilities and have the capability to analyze as of yet future tolled facilities in study areas without existing planned priced system network improvements. The research undertaken in this study is not of the level of refinement associated with toll revenue forecasting and analysis. The methods and approaches described are intended to provide TxDOT with a spectrum of options that could be given consideration within the existing TxDOT travel demand model development process for small to medium-sized urban areas.

TxDOT's Current Travel Demand Model Structure

TxDOT maintains a traditional three-step, sequential 24-hour travel model (Figure 1) for the 21 small to medium-sized study areas still fully under TPP's purview. TxDOT refers to the 24-hour models as daily models. TxDOT generates, distributes, and assigns daily vehicle trips for these 21 areas. The Beaumont and El Paso models initially generate person trips as inputs for a meso-level high-occupancy vehicle (HOV) model that separates (and aggregates to the sector-level geography) transit-based trips, before creating vehicle trip tables by trip purpose, as used in traffic assignment.

TxDOT TPP relies on the Texas Package suite of programs, hereafter referred to as the Texas Package, for model development and application activities. TripCAL5 is used to generate trip ends (productions and attractions), while ATOM2 turns these into trip matrices by trip purpose. The trip tables created by ATOM2 are converted to origin-destination (OD) format and are assigned to the network using the TransCAD software (commercially available software developed by the Caliper Corporation). A single OD matrix is assigned to the coded network using the equilibrium assignment procedure and 24-hour link-level capacity estimates. As a part of the network geography intelligence, TPP develops estimates of daily speeds that represent a congested-weighted 24-hour speed based on a generalized cost procedure using posted speeds provided by the MPO as input to the trip distribution and traffic assignment models.

TransCAD is a multi-functional geographical information system (GIS)–based program designed to effectively model as many trip purposes, zones, links, times of day, modes, and traveler classes as users specify, with stochastic (logit-based) or deterministic (shortest-path) traffic assignment, with (and without) full feedback of travel times and costs, to achieve tight system convergence (based on precisely specified gap criteria). In Texas, TransCAD's application is limited to well-defined roles. It is heavily used as a GIS tool to manipulate, display, and analyze features of spatial data, including complex networks, extensive zone systems, and corresponding attributes (e.g., link performance parameters, household demographics, and other features of urban systems). TransCAD is also used to convert production-attraction matrices to the OD trip table format, and applies the basic Fratar method to distribute external-through trips. Finally, TransCAD is used to equilibrate traffic across complex network geographies in order to find minimum-travel-time paths. All other utilities used in TPP's travel demand modeling pursuits are contained within the Texas Package (as generally shown in Figure 1).

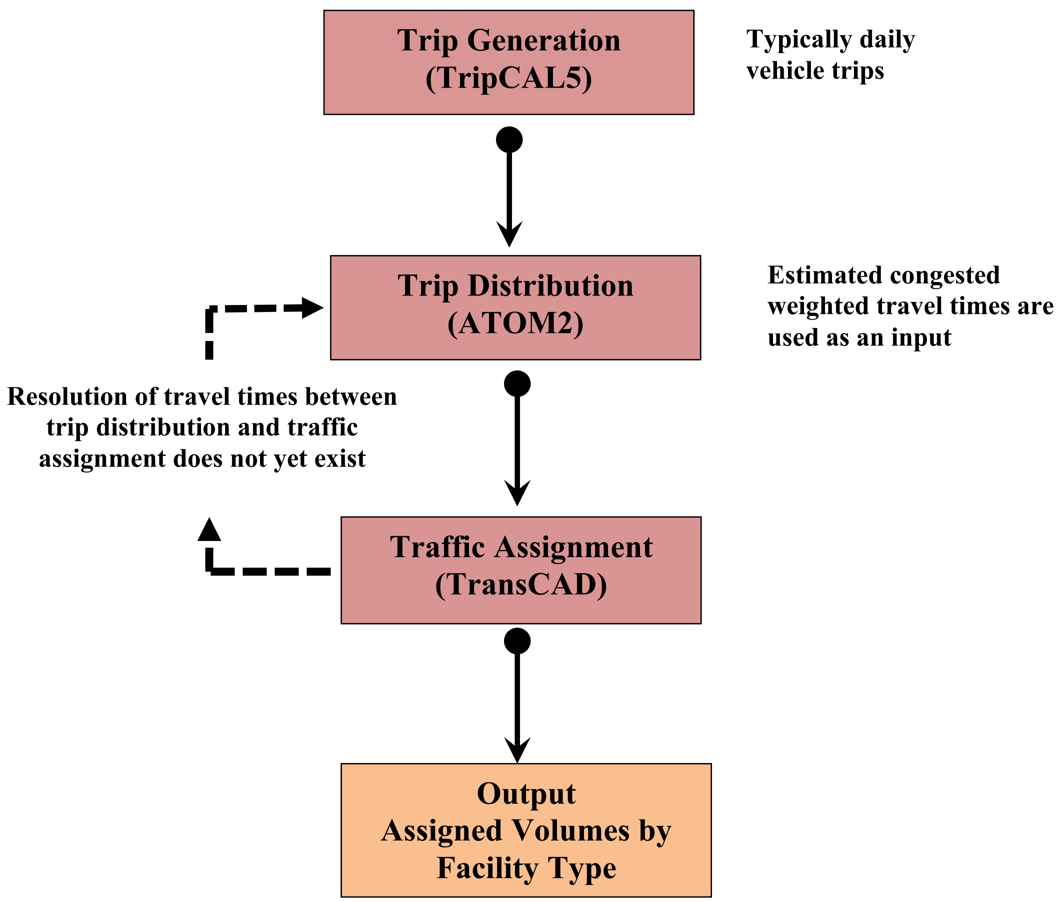


Figure 1. TxDOT TPP's Sequential Travel Demand Model Process.

Since most of study areas demonstrate relatively little to no traffic congestion (with some exceptions, such as San Antonio and Austin), TxDOT TPP has not implemented a congestion feedback mechanism to resolve congested weighted travel times output from TransCAD's traffic assignment routine with those assumed/used in trip distribution. CAMPO recently implemented a feedback mechanism through a consulting contract so that the times used for trip distribution are consistent with the final traffic assignment travel times. Since TPP develops daily travel models, the models do not recognize distinct travel patterns (and travel times) for peak versus off-peak (and other) times of day, with the exception of the San Antonio and Austin study areas. For example, CAMPO assigns the home-based work trips to a morning peak period to develop peak-period estimates of travel time for input into its own mode choice models. But, eventually, all trips are assigned to the network using the 24-hour period.

With respect to tolling, time-of-day modeling is seen as essential to the process. Given that toll roads, such as Loop 49 and the Camino Columbia Tollway, exist where existing congestion is lacking and free alternatives are abundant, time-of-day considerations may not be as relevant in the near term. In addition, Loop 49 was designed to provide a bypass alternative for logging trucks and external related travel to Loop 323, which is closer to the actual urbanized area of Tyler. The facility, at least initially, does not appear to be targeting peak-hour work trips. Future congestion levels for this example or any other example should not be dismissed when determining when to invoke temporal periods in the base year modeling structure.

In the case of tolling, time-of-day modeling is often considered essential since traffic is not uniformly distributed over the course of a day. This is similar to why feedback loops are implemented for time-of-day periods rather than 24-hour conditions (to capture the effects of travel as a result of congestion during specified time periods). Time-of-day modeling can simply involve fixed shares by time of day (if analysts wish to avoid a time-of-day choice model).

In addition to historical reliance by local and state decision makers on daily demand to prioritize and size roadway infrastructure investment, the 24-hour focus of travel models is often tied to a lack of time-of-day counts (for validation of model predictions), rather than lack of survey data that could be used to develop such models (e.g., trip shares by time of day). However, such data are commonly unavailable in many U.S. regions. It is quite possible and common to rely on travel survey data for time-of-day shares and proceed with 24-hour validation (by summing up the model-predicted time-of-day volumes).

Current and Coming Approaches

Nationally, there are generally two distinct approaches to estimating toll demand estimation—a path-based system and a choice-based system. Tolling is nothing new to U.S. networks, but more and more cities and states are pursuing this option as a method of adding much-needed revenues, moderating growing congestion, and introducing market mechanisms in the allocation of scarce transportation resources. To anticipate the effects of such network changes, URS (2010) recently made four important changes to Baltimore's demand model specification and process; these involve modification of the trip tables' preparation, toll road diversion, or route choice within the traffic assignment stage (for splits across best tolled and non-tolled routes, for every OD pair), customized volume-delay functions for tolled facilities, and testing of traffic pattern response to multiple tolling scenarios. The modified process applies by time of day and trip purpose for both single-occupant vehicle (SOV) and HOV modes. The tolled versus non-tolled route splits rely on the following binary-logit specification:

$$\text{Toll Share} = 1/\ (1 + \exp(\alpha * \Delta T + b * Cost/\ln(Inc) + c + ETCbias) \qquad (1.1)$$

where:

- exp( ) stands for the exponential function.
- ΔT is the time savings afforded travelers by the tolled route.
- *Inc* is the median zonal income.
- *c* and *ETCbias* are constant terms to reflect any traveler-perceived biases for or against tolled and electronic toll collection (ETC) facilities (since toll collection can add driver effort, e.g., via maintenance of toll tag accounts).

Values of time involve the implied cost-time tradeoff of $\alpha/\beta*\ln(Inc)$ and range from $11 to $17 per hour for automobile travel. Interestingly, general toll road bias or use reluctance was deemed negligible (making *c* effectively zero [URS 2010]), and electronically (plus manually) tolled facilities were viewed favorably (making *ETCbias* negative).

Transponder-ownership shares and commuter-discount rates are also incorporated in the revised Baltimore model (and assumed to apply at 70 and 80 percent, respectively). A $3 surcharge was added for trips not carrying a transponder (on two of the region's three tolled facilities), along with toll-rate ratios for medium- and heavy-duty trucks (relative to passenger vehicle rates). Link-performance functions for the tolled facilities suggest earlier onset of congestion-reduced speeds (with serious drops in the neighborhood of volume-capacity (v/c) = 0.75, rather than 0.8 for freeways). Baltimore's new model results were reported last year (Pandey and Ryder 2011), under a variety of toll settings, using four times of day and six trip types, over a 20-year horizon. The model sequence is shown in Figure 2.

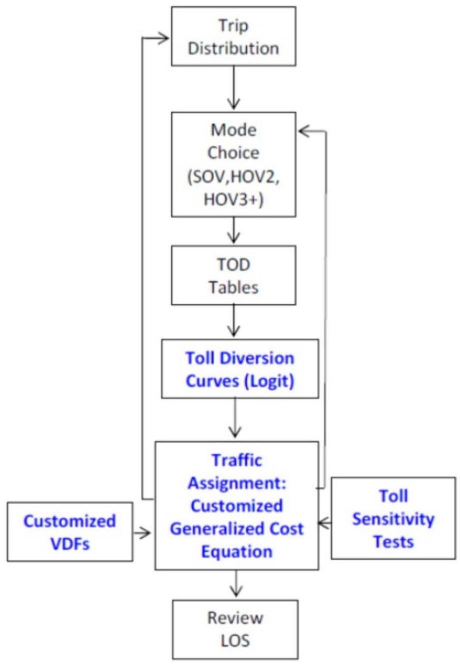


Figure 2. URS (2010) Proposed Travel Demand Model Process for Baltimore's Tolled Network.

Vovsha et al.'s (2012) National Cooperative Highway Research Program (NCHRP) report identified a serious potential issue with the now-common use of toll-diversion models, at least where multiple tolled routes exist and tolled-route users are flagged by a simple "tolls paid > 0" indicator. It seems that modelers are assigning toll-route users to the full network (since tolled routes are too limiting), while non-toll users are assigned only to the non-tolled network. Thus, the tolled users are able to avoid the tolled routes, while non-tolled users have no chance of choosing tolled routes. This can represent a fairly significant loss of potential toll users and can affect the equilibrium process, which can contribute to challenging interpretation issues. Moreover, this setup results in tolls and tolled-link flows that can never fully equilibrate. Use of generalized costs, rather than diversion models with a special constant term for toll choice, avoids such issues but may not be as realistic.

Other techniques that may be of interest include Klodzinski et al.'s (2010) post-processing of demand estimates for express lane use, and Thompson-Graves et al.'s (2008) description of the Delaware Department of Transportation's new toll-modeling process (which nests the tolled-route/non-tolled-route choice within Delaware's existing logit choice structure, and includes EZPass and non-EZPass market segmentation). Brebbia et al. (2005) describe how CUBE Voyager's model specifications can tackle a variety of tolled settings, and Vovsha et al.'s (2005) earlier work describes the variety of modeling options that exist and are needed for multiple tolling considerations.

Recently, URS (2011) also developed a synthesis of "best (toll modeling) practices" for Phoenix's Maricopa Association of Governments (MAG), along with a recommended implementation plan. The consulting team first surveyed modelers at 17 North American agencies (including Austin, Houston, Dallas-Fort Worth, and San Antonio MPOs) where tolled facilities already existed or were planned. Almost all were then using a four-step model, with seven planning to rely on activity- or tour-based models in the near future. Six relied on TransCAD, and eight relied on CUBE Voyager. Nine relied on gravity models for trip distribution, six relied on logit-based models, and three (all of them Texas MPOs: Austin, Houston, and San Antonio) reported reliance on an "atomistic" distribution approach. Eight relied on both time and cost for their impedance terms, and almost all (including the four Texas MPOs) claimed use of a nested logit model for mode choice (CAMPO has since migrated to a generalized cost approach to account for tolls). Only three out of the 17—Austin, San Antonio, and Denver—reported reliance on a 24-hour (full-day) trip table and assignment (with the remainder recognizing different times of day—even though few, if any, have access to counts by time of day for later validation). The report's recommended model modifications are similar to those URS (2010) implemented for Baltimore (as described above). A related 2011 proposal by URS (for MAG) also indicates that a Geographic Information System Developer's Kit (GISDK) tolling routine was being developed by URS staff for Austin's CAMPO, and that URS was studying tolling along US 1604 and managed lanes along IH 35 in San Antonio.

With respect to time of day, an NCHRP report on the topic of appropriate methods for toll modeling (Vovsha et al. 2012) states that "Introduction of a time-of-day choice and/or an incremental peak-spreading model…is essential for urban toll roads."

More recently, MAG hired HDR (2012) to produce a related report, with modeling recommendations for traffic and revenue studies. The HDR consulting team noted that tolls come in various form—including cordons versus point based versus link based, flat versus variable, dynamic versus pre-set, and in the form of managed lanes (alongside regular lanes). Evidently, NCHRP Synthesis 364 (HDR 2007) looks at these and other, relatively specific variations on the tolling theme. For example, the "culture" of tolling in a region or state can have significant impact on splits. Trucker behaviors can be critical to use and revenues. Ramp-up periods, risk, and peak spreading (of traffic) responses can have significant impact. The HDR (2012) report reviews 32 sources of traffic and revenue modeling practices, covering 15 in depth. Such reviews and reports are of interest to the research team, particularly for the proposed synthesis.

Caliper's Slavin et al. (2009, 2010) have identified issues relating to gap criteria used in full-feedback approaches (where trip distribution, mode, and time-of-day choices are consistent with the network assignment results, for all traveler classes). Their work shows how gap targets of 0.01 and even 0.0001 routinely fail when adjustments to a network are relatively minor (especially when the starting trip table is "cold" rather than close to final and thus "warm"). Such work is important for different toll model specifications and processes in rooting out the most important enhancements that TxDOT and Texas MPOs can make in anticipating the impacts of tolled projects, along with other network changes and transportation policies.

As tolling implementations, model applications, and output validations become more common, in New York, Dallas-Fort Worth, Austin, Houston, San Francisco, Chicago, and elsewhere, more opportunities for appreciating what works best, even in small, relatively uncongested regions, will become available. It is an excellent time to consider improvements to TxDOT TPP's practices for enriching the forecasts and evaluations that Texas must pursue because it addresses air quality, congestion, road safety, and transportation budget issues, while optimizing transport investment and policy decisions.

REPORT ORGANIZATION

The remainder of this report is organized as follows. The first two chapters examine and review national and state practice with respect to toll demand estimation techniques and approaches. Chapter 2 is dedicated to a review of national practice, while Chapter 3 examines how the state's four largest urbanized areas approach toll demand estimation. Although these cities generally differ in density and levels of congestion in comparison to the remaining small to medium-sized cities in the state, the approaches used and lessons learned can provide experience in this particular aspect of demand modeling. Chapter 3 also examines how toll demand estimation is accomplished in the Texas Statewide Analysis Model (SAM) and also documents how representatives of the TxDOT TOD approach traffic and revenue estimation for toll roads under consideration in the state. Traffic and revenue analysis has been performed for not only the largest study areas in the state but also for smaller areas, such as Tyler, that are constructing fee-based roads. Both chapters take care to frame the discussion relative to small to medium-sized study areas.

Based on the information provided from the state and national review of practices, Chapter 4 summarizes the potential options and corresponding considerations for addressing toll demand estimation in the existing Texas Package. Given that there is no single technique used but usually a series of complementary options employed, such as time of day, market segmentation, and iterative feedback, to address the dynamics of fee-based travel and the effects on travelers, the chapter reviews how the supplementary techniques could be pragmatically addressed in the current Texas modeling framework.

Critical to the approaches enumerated in the preceding chapter, Chapter 5 evaluates how these sometime complementary and potentially competing options address toll demand estimation. As a part of the process, the research team used the existing Tyler, Texas, urban area model as a case study to examine each of the sequential steps as well as considerations for mode choice, time of day, iterative feedback, additional market segmentation of the trip table, and traffic assignment considerations. Tyler currently has a low-volume fixed-fee toll road, Loop 49, which is being incrementally opened in segments. Given the low volume on this facility, the research team tested tolling on the more congested Loop 323, which is located 3 miles from the urban core. The result of using specific techniques as well as combinations of techniques are presented in this chapter.

Chapter 6 provides a matrix of toll demand estimation options for consideration by TxDOT TPP. To support the matrix of options, a number of context-sensitive issues by study area were examined, such as vehicle miles of travel, truck mix, population growth, and air quality attainment status to name a few. In this manner, TxDOT can identify what approaches could be considered practical for reasonably addressing toll demand estimation for small to medium-sized study areas. To date, TxDOT has chosen a common approach to travel demand modeling to enhance technology transfer and training among TxDOT staff and local end users, such as the MPOs. Ultimately, it will be TxDOT's decision about whether to continue this approach by implementing any forthcoming change for all urban areas or selecting specific approaches by study area given the context-sensitive nature of the region or the toll facility.

CHAPTER 2: REVIEW OF TOLL MODELING APPROACHES AT THE NATIONAL LEVEL

INTRODUCTION

A National Perspective

Texas' population grew by more than 20 percent between 2000 and 2010 (Texas Department of State Health Services 2011), yet construction of new roadway infrastructure to serve that population has lagged. As a result, roadways are becoming increasingly congested, resulting in traveler delays, wasted fuel, and harmful emissions (Schrank and Lomax 2011). Meanwhile, Texas' state gas tax has not been raised since 1991 (Hall 2012), and as a result, inflation has depressed the original spending power by more than 40 percent over those 21 years (Bureau of Labor Statistics 2012). To address these challenges, Texas has pursued the construction of tolled facilities in addition to non-priced roadways. This has enabled the state to pursue many more projects that would otherwise go unfunded without raising the gas tax.

Texas looks to continue building new tolled facilities and managed lanes for the foreseeable future. However, TxDOT's existing transportation planning models do not adequately incorporate tolling. This chapter describes the best practices used around the United States, with a focus on those conducted in smaller communities (less than 1 million persons) because in Texas' larger urban areas, MPOs and regional tolling authorities typically conduct their own studies.

Literature Review and Interviews

To understand toll modeling practices around the United States, researchers reviewed literature, especially travel demand model (TDM) documentation, and interviewed a number of modelers (in public and private practice). Interviewees included:

- Greg Giaimo of the Ohio Department of Transportation's Office of Statewide Planning and Research.
- Brian Gregor and Becky Knudson of the Oregon Department of Transportation's Transportation Development and Planning Division.
- Howard Slavin, president of Caliper Corporation.
- Rick Donnelly, senior engineering partner at Parsons Brinckerhoff (PB).

- Yong Zhao,[1] senior transportation planner at URS Corporation.
- Christopher Mwalwanda, vice president of CDM Smith.
- Phil Eshelman, toll and project manager at Jacobs Engineering.

Eshelman and Mwalwanda were interviewed together and largely agreed on most issues, as were Gregor and Knudson. Therefore, this report refers to both of these interviews as joint two-person sources, rather than four separate ones.

Best Practices

From the literature review and interviews, researchers identified eight key areas of toll-modeling best practices:

- Data relevance: currency and context.
- Network and link attributes.
- Toll choice models and trip assignment.
- Times of day and other temporal considerations.
- Traveler classes and values of time.
- Mode choice and nonmotorized travel.
- Outer feedback loops and convergence.
- Model validation.

DATA RELEVANCE: CURRENCY AND CONTEXT

Appropriate data are critical to modeling and forecasting traveler behaviors. This is particularly true of tolled facilities, which introduce extra choice complexity: instead of travelers simply choosing their shortest paths, they must now also estimate how much time they can save by taking tolled routes, and decide if those routes are worth their extra (monetary) cost. Travel behaviors and patterns in Brownsville may be quite different from those in Tyler, which will differ from those in Waco. Also, travel patterns and behaviors shift over time, particularly in a state experiencing rapid population growth, like Texas. The data set may be five years old, and

[1] Dr. Yong Zhao started working with Jacobs Engineering in August 2013. Other interviewees may have changed their work locations since the 2012 and early 2013 interview dates.

then the agency has to wait another 4 to 10 years before funding is secured, environmental clearance is granted, and the project is designed, constructed, and opened to the public.

Donnelly (2013) notes that understanding the travel markets is the most important aspect of toll modeling: "who—by income, trip purpose, auto availability, vehicle occupancy, etc.—are presently using the corridor and how those markets are forecasted to change over time." By ensuring that data better reflect the actual population to be affected by new tolling options (in time and location), analysts can have a greater degree of confidence in predicted outcomes and modeling forecasts. Multiple sources, including Donnelly (2013) and Gregor and Knudson (2012), agree that ensuring that data are both current and local is critical (while also including longer, external trips since these are often important for tollway traffic and revenues [T&R]).

Key variables to track in such data sets include trip-maker and local-area demographics, (estimated) values of travel time (i.e., trip makers' willingness to pay to save travel time), nearby and trip-end-related land use and employment patterns, and freight flows. Slavin (2012) notes that data used to generate the truck trip table are very important, particularly if heavy trucks are anticipated to be a solid share of toll revenues and/or volumes.

Corridor-focused surveys may be conducted to gather much of this information, including household and commercial travel surveys to assess travel patterns and stated-preference (SP) surveys to help create estimates (Donnelly 2013). Gregor and Knudson (2012) note that the U.S. Census Bureau's Longitudinal Employer-Household Dynamics data program is a key source that Oregon modelers use for obtaining relevant and current employment data for model inputs.

Related to data collection efforts are the future assumptions fed into the model. Perez et al. (2012) note that population and employment growth, as well as specification of the transportation network, are key inputs that ultimately impact model predictive accuracy as much as the quality of the model itself. Similarly, Wachs et al. (2007) identify reliability of exogenous forecasts as an inherent weakness within the modeling process. For example, Wachs et al. compared population, household, and employment forecasts to actual data in six major metropolitan areas between 1980 and 2000, finding regional forecasts versus actual values differing by −23.8 percent (San Francisco employment) to +8.1 percent (Chicago household counts). As Perez et al. (2012) correctly note, however, these assumptions are more closely related to "the planning domain, rather than in the field of modeling." Therefore, while it is important to ensure that forecasting models enjoy substantial analytical rigor, improvements to many key inputs to the models (like future-year gas prices and population and jobs forecasts, by traffic analysis zone) lie outside the scope of this TDM research project.

NETWORK AND LINK ATTRIBUTES

Not only is it important to ensure that data are relevant, but links along the tolled facility and along competing and complementary routes need to be properly calibrated. Donnelly (2013) notes that travel time estimation accuracy is critical, particularly on an OD basis, and such times are greatly impacted by link-level performance assumptions. This includes free-flow speeds, link capacities, and link performance or volume-delay parameters (e.g., α and β in standard Bureau of Public Roads [BPR]–type functions), which determine how quickly travel speeds fall when volume-capacity ratios rise on a given link.

To calibrate link attributes, Zhao (2013) recommends conducting speed studies on existing corridors that will serve as competing facilities to new tollways. When speed data are used in combination with traffic counts taken throughout the day, analysts should be able to accurately estimate the link performance function parameter values.

For arterials, Wachs et al. (2007) suggest a different approach. The BPR link performance function models freeway volume-capacity-speed relationships well but often falls short for lower classes of arterials, where intersection delays and queuing complicate matters. Implementing strategies to model intersection delay better represents the actual delay that will likely be encountered by travelers.

Additionally, Giaimo (2012) notes that tolled links should reflect multiple toll rates for distinctive traveler types. For example, travelers with electronic toll tags generally receive a discounted fare, and heavy vehicles are charged more than passenger cars. Giaimo stated that Ohio's statewide model uses 12 rates based on vehicle weight, plus another nine rates based on vehicle class, because different facilities toll differently. However, models in several small and medium-sized regions of Ohio use just two toll rates (light-duty vehicles versus heavy-duty trucks). Perez et al. (2012) also recommend that toll plazas and access ramps be coded with realistic delay functions, though this aspect is less important than other features.

TOLL CHOICE MODELS AND TRIP ASSIGNMENT

Once the network and link parameters have been defined and calibrated, it is crucial to identify the process that will be used to determine which travelers choose paths with tolled links, as opposed to entirely free routes. Modelers assign traffic to a tolled network in at least three ways (Zhao 2013):

- Standard **deterministic user equilibrium** (DUE) or shortest-path assignments, which are based on travelers choosing routes to minimize their own generalized cost (tolls plus travel time costs plus other operating costs).
- **Stochastic user equilibrium** (SUE) assignments, which assign travelers to the better routes (i.e., those with lower generalized costs), according to logit probabilities, typically.
- **Cost-ratio** (CR) assignments (Zhao and Zhao 2008), which consider just the lowest-cost non-tolled versus tolled paths and are regularly referred to as toll diversion models or route choice models.

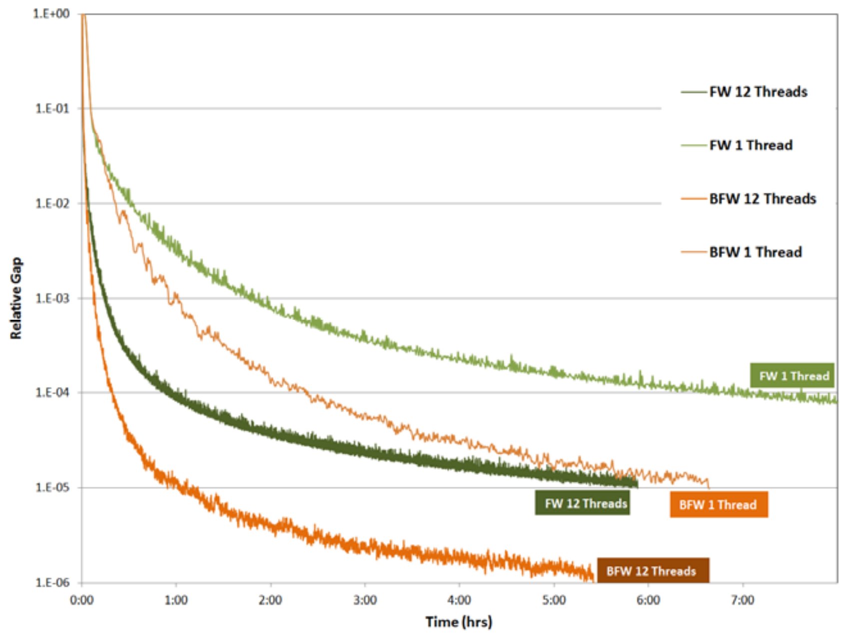
According to Zhao and Zhao (2008), SUE traffic assignment is typically not conducted in networks where there is a degree of complexity, as it requires enumeration of every potential path between every origin-destination pair, and analysis to estimate the share of travelers taking each path. Moreover, this must be conducted numerous times until equilibrium conditions are achieved, making SUE impractical for implementation. For this reason, this report discusses DUE and CR methodologies for trip assignment, but does not discuss SUE beyond this introduction.

DUE Implementation

Ohio's regional planning models use a DUE implementation when accounting for tolling impacts, suggesting that such implementations should be suitable for Texas applications in small and medium-sized regions (Giaimo 2012). Moreover, as discussed in Chapter 3, the MPOs from Austin, Dallas, Houston, and San Antonio all use a network assignment process using a DUE framework that incorporates tolling costs.

Slavin (2012) suggests that TxDOT should use a bi-conjugate Frank-Wolfe (BFW) algorithm (Daneva and Lindberg 2003) for the network assignment, which is similar to the Franke-Wolfe (FW) algorithm currently implemented but should reach convergence much faster.

An example of this is shown in Figure 3, comparing times required to reach convergence under different network assignment algorithms for a transportation network in Washington, D.C.



Source: Slavin et al. (2012)

Figure 3. Washington, D.C., Regional Afternoon (PM) Multi-class BFW and FW Assignments.

CR Implementation

In contrast to advocates for DUE implementations, CR methods use a pre-assignment step, where two paths are identified between each OD pair: one minimum-cost path with no tolled links and one minimum-cost path (excluding tolls) that can include tolled links. For OD pairs where the two minimum-cost paths are not the same (i.e., the second path includes one or more tolled links), a logit function is applied to determine the proportion of travelers taking each route. This is conducted by adding tolling costs back into the tolled path's generalized costs, and applying a binary logit model to determine the probability of a given traveler taking the tolled and non-tolled paths. Finally, a DUE algorithm may be applied for network assignment, with non-toll travelers choosing the lowest-cost path with no tolled links, and tolled travelers choosing the lowest-cost path (excluding tolls) and able to use tolled links. One formulation of the binary logit function is as follows (URS 2010):

$$Tolled\ Route\ Share = \exp(V_{tolled\ route})/(1 + \exp(V_{tolled\ route}))$$

$$\text{where } V_{tolled\ route} = \alpha * \Delta T + b * Cost/\ln(Inc) + c_{toll} + ETCbias \quad (2.1)$$

where:

- exp( ) stands for the exponential function.
- ΔT is the time savings afforded travelers by the tolled route.
- *Inc* is the median (household) income of travelers.
- c_{toll} and *ETCbias* are constant terms to reflect any traveler-perceived biases for or against tolled facilities (in general) and ETC facilities, respectively (because toll collection requires some driver effort, e.g., maintenance of toll tag accounts).

Interestingly, URS (2010) found general toll-road bias or user reluctance negligible for its Baltimore application—due to residents' familiarity with other tolled facilities (making *c* effectively zero [URS 2010])—and ETC facilities viewed favorably. In some contrast, others have estimated toll road bias to vary by vehicle type, time of day, and trip purpose. An alternative form for Equation 2.1's embedded systematic utility, noted by Livshits et al. (2012) in the Chesapeake Expressway Study, is as follows:

$$V_{route\ i} = Toll_i + TT_i \cdot VOT + D_i \cdot VOC + f \cdot FB \quad (2.2)$$

where:

- The $V_{route\ i}$ term represents the (systematic) utility of choosing route *i*.
- *TT* is travel time.
- *VOT* is the value of travel time.
- *D* is the distance along the route.
- *VOC* is the per-mile operating cost.
- *f* is a freeway indicator variable (taking a value of 1 if the route includes a freeway link).
- *FB* is freeway bias.

In this context, the comparative utility of a tolled route could be contrasted with a non-tolled route (or even multiple tolled and non-tolled routes) in order to determine the fraction of travelers choosing each. This may be conducted by using a logit function, such as that seen in Equation 2.1.

According to Zhao (2013), for the purposes of small networks and MPOs with small populations, CR models are useful and relatively straightforward in their implementation. Zhao and Zhao (2008) note that a key factor for ensuring accuracy in these models is proper calibration of the logit parameters (e.g., in Equation 2.1 or 2.2), including, ideally, validation of share forecasts when applied to existing tolled facilities (presumably in the same region to help control for other factors at play). Zhao and Zhao also note that a CR model may result in some inconsistencies when implemented as a pre-assignment step to a DUE network assignment algorithm, though these inconsistencies would likely have less impact in smaller and less-congested regions.

Perez et al. (2012) suggest that while CR assignments may be suitable for competing route alternatives in relatively simple intercity flow forecasts (with few competing paths), such models can produce questionable results if the tolled facility is expected to impact trip-making, mode, destination, and time-of-day choices. Thus, Perez et al. (2012) and Livshits et al. (2012) recommend that such models be incorporated in a pre-assignment step, such as a lower-level nest in the mode-choice step. Also, to address these concerns, it is recommended that CR methods be avoided in complex networks where multiple paths may exist that all have the same or near-same travel costs.

For implementation, Zhao (2013) notes that a CR model may be much more difficult to implement in TransCAD (which TxDOT uses in its models) than in other travel demand modeling software such as Cube. However, Zhao has successfully implemented a CR model after reaching convergence using DUE network assignment.

Slavin (2012) argues that standard DUE models are generally superior to CR or toll diversion models. Slavin finds that CR implementations may generate inconsistencies between TDM outer-loop iterations and believes that DUE models are generally more consistent for estimating traffic flows. Two examples quickly illustrate how such inconsistencies arise with this methodology when competing parallel routes exist:

- Assume that a new tolled route is added to a corridor with the exact same uncongested travel times and toll costs as an existing tolled route. The CR method pulls too much traffic from the other, non-tolled routes and thus raises the average travel costs of these shifted travelers, even though it is an exact substitute for an existing tolled route. If the analyst simply uses DUE (with generalized travel costs), any traffic shifts will come entirely from the tolled route (assuming a fixed trip table), and traveler costs remain unchanged, as expected and desired.

- Assume the Figure 4 network applies, with two tolled links, a single origin, and a single destination. Here, T or NT<Link#> [TimeCost, TollCost] stands for tolled (T) or non-tolled (NT) links' travel times and monetary costs (in equivalent units). Under DUE, all travelers take T1 and NT2 links, offering the lowest generalized cost, though other classes of travelers (with values of travel time and thus costs) may take different paths. However, using the standard CR or toll diversion method, the shortest-time (but highest-toll) path (T1 + T2) will *always* be chosen as the tolled path, and the two non-tolled links (NT1 + NT2) as the non-tolled path. Shares of travelers would then be allocated to each of the two paths based on differences in generalized costs (via a binary logit equation). The problem here is that T2 *should* have much lower volumes than T1 (because some or even most drivers should pick T1 and NT2), but instead the CR or toll-diversion approach sends them equal flow volumes.

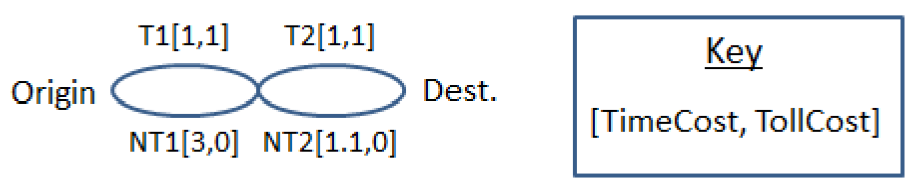


Figure 4. Simple Network Resulting in Cost-Ratio Errors.

Other CR model implementations are also possible and can partly address some of the limitations evident in this second example. Pulipati (2013) suggests using a CR model where three paths are always identified (for every OD pair) instead of just two: the shortest-time path using any set of tolled links, the shortest-time path using no tolled links, and the lowest-generalized-cost path (if distinct from the two other paths). After the three routes are identified, a multinomial logit model is applied, using the full generalized costs of each path, in order to assign traveler shares to each path.

Cost-Ratio Factors

While time and toll costs are standard and relatively straightforward inputs for models of travel demand, operating costs introduce a variety of issues. Gregor and Knudson (2012) note that Oregon's models account for per-mile operating costs. While they do not segment operating costs by fuel efficiency (e.g., a Toyota Prius and a Ford F-350 have the same per-mile operating costs), operating costs are modeled differently for heavy trucks.

Eshelman and Mwalwanda (2013) recommend using full per-mile operating-cost values provided by the American Automobile Association (AAA) (2013) for household vehicle travel, which ranges from $0.46 to $0.75 per mile, depending on household vehicle type. These costs include fuel, tires, depreciation, maintenance, and insurance—which are far more than the marginal (per-new-trip or per-added-mile) cost of travel that travelers often consider when making individual trips (after acquiring a vehicle and insuring it). In contrast, economists argue that travelers ignore fixed costs of travel when making single-trip decisions, and many travelers ignore most (if not all) vehicle operating costs.

Slavin (2012) counsels leaving all operating costs out of the model since they are generally based on link lengths alone, rather than how the link is driven (fast or slow) and vehicle fuel economy (with hundreds of fuel-economy classes). Phoenix's modeling framework takes a middle ground (Livshits 2012) by applying travel costs but at a much lower $0.16 per mile operating cost to account for only marginal operating costs, like fuel. Slavin (2012) notes that such distance-based metrics correlate highly with travel times, creating a much flatter objective function and slowing model convergence in the network assignment stage.

Other cost factors may also be included in the network assignment stage of forecasting, like travel time reliability (Brownstone and Small 2005), though such factors are relatively rare in T&R studies, as affirmed by Zhao (2013) and the researchers' own experience. Ultimately, it is difficult to know what travelers really consider when making trip decisions. Many are habituated to certain modes, routes, and times of day, and few have access to good information on competing travel times. Electronic tolls are also relatively hidden to travelers. For example, how many people know exactly what they were charged last week when taking Austin's SH 45N for several miles?

TIME OF DAY AND OTHER TEMPORAL CONSIDERATIONS

While the traffic-assignment and toll-choice process is a critical step, the relative utility of a tolled route (and an individual's ultimate decision of whether to use it) may often depend on travel time savings, particularly if a viable alternative route exists. If congestion is present on the non-tolled route, it will inevitably vary by time of day. Gregor and Knudson (2012), Giaimo (2012), and Zhao (2013) all recommend modeling multiple times of day to reflect congested and uncongested states, which can affect travel times dramatically in busy urban regions. As Perez et al. (2012) note, time-of-day choice modeling should ideally be incorporated into the TDM structure (e.g., after mode and destination choices), rather than assuming fixed splits by time of day. In this way, as generalized costs rise during peak times of day, travelers can switch to lower-cost (less-congested or lower-toll) times of day, rather than simply switching routes, modes, or destinations.

Times of day typically include four periods: morning (AM) peak, midday, PM peak, and off peak. Giaimo (2012) notes that Ohio's models generally use such a four-period framework and then conduct a peak-spreading post-processing subroutine for network links where the v/c ratios exceed 1.0. However, Zhao (2013) believes such efforts are unnecessary when congestion is not excessive. Peak-spreading models operate by first identifying links where demand exceeds capacity. Next, excess demand is shifted onto the shoulders (the time intervals immediately before and after peak periods) until demand no longer exceeds capacity. A curve-smoothing function is then applied so that in the most congested hour, the links' demands equal capacity but taper off in both time directions, across one-hour bins (used for post-processing peak spreading). All this is done after network assignment routines converge; it simply requires a post-processing of link flows where volume to capacity values exceed 1.0.

While Perez et al. (2012) note that such spreading can be better reflected by more explicit time-of-day choice modules in activity-based model (ABM) settings, it is unlikely that TxDOT's TDMs will be updated to full ABMs in the foreseeable future. If multiple times of day are adopted in TxDOT TDMs, post-process peak spreading could be used for the highly congested links (e.g., the IH 35 and MoPac freeways in Austin during AM and PM peak periods), though such processes may be less relevant in small and medium-sized communities where congestion is less prevalent.

For certain managed lane applications, Donnelly (2013) prefers to use micro-simulation or dynamic traffic assignment with demand estimated in 15-minute increments (for daytime hours, at least). While this detailed level of resolution will not be a component of this project, it is instructive for future model improvements in case TxDOT wishes to pursue managed lane projects in these locations at some future date.

For T&R studies, it may be important to model non-work days, as supported by Perez et al. (2012). With 52 weekends each year, 10 federally recognized holidays, and another 11 Texas-recognized holidays, over a third of all days per year are either holidays or weekends. This potentially has important implications for congestion, toll revenues, emissions, air quality, crash statistics, quality of life, the Texas economy, and other transport-related phenomena. Kriger et al. (2006) note that in some locations, seasonal variations are quite noticeable, particularly in locations with strong tourism influences. Consequently, modeling weekends, holidays, and seasonal variations can provide meaningful results (particularly when forecasting tolling revenues).

Kriger et al. (2006) also note that truck and other commercial traffic may exhibit distinctive peak-demand profiles and have important impacts on T&R forecasts. For example, toll roads are generally most attractive during the most congested times of day. If trucks make up 5 percent of the traffic stream during the most congested peak period but 10 percent of the stream during other times of day, the total share of trucks on the tolled facility will likely be lower than the model may predict.

According to Wachs et al. (2007), ramp-up periods at the beginning of a new tolled facility's opening can also significantly impact demand. After the opening, traffic volumes may be low, reflecting users' unfamiliarity with the new highway (and its time-savings benefits) and a potential reluctance to pay (or subscribe for ETC services, for example). During ramp-up periods, Wachs et al. note that traffic growth is typically rapid, eventually stabilizing to levels that would be expected on similar tolled facilities. Wachs et al. cite three primary factors influencing ramp-up: scale (how much initial estimates are off by), duration (how long ramp-up takes), and extent of catch-up (how close volumes are to forecasts after ramp-up is complete). Without incorporating ramp-up impacts, forecasts may suffer from optimism bias: Lemp and Kockelman (2009) found that low-risk projects, on average, realized actual-to-forecast traffic volumes of 0.8 to 0.9 (bank commissioned versus others) the opening year, with two years required for forecasted volumes to catch up to actual volumes. On high-risk projects, volume ratios were just 0.45 to 0.7 (bank commissioned versus others), with eight-year ramp-up durations. With this in mind, TDMs may benefit by incorporating methods that reflect the ramp-up phenomenon.

TRAVELER CLASSES AND VALUES OF TIME

While travel patterns vary by time of day, they also inevitably vary by the type of traveler and corresponding travel purpose. Certain travelers are willing to pay more than others to save time, distance, and fuel. Ultimately, values of time (VOTs) vary by traveler, trip type, day of week, and driver's state of mind. Thus, VOTs are regularly segmented in many different ways, including by household income, trip purpose, vehicle occupancy, vehicle class, and even time of day (Perez et al. 2012).

Giaimo (2012) notes that the Ohio Department of Transportation relies on household income levels (key for trip generation) in combination with just two trip purposes (commute versus non-commute) to assign VOTs, with VOTs for non-commute trips valued at half of those for commute trips. While Zhao (2013) notes that just two VOTs—one for autos and the other for heavy trucks—may be sufficient for preliminary analyses in small communities, Gregor and Knudson (2012) segment VOTs into three income bins for their (the Oregon Department of Transportation's) home-based work (HBW) trips. For truck trips, Gregor and Knudson note that regional Oregon models typically assume a fixed share of non-home-based (NHB) trips to be heavy trucks (versus the Ohio Department of Transportation's statewide model, which incorporates a commodity flow component).

Perez et al. (2012) recommend segmenting VOTs across at least four or five travel purposes, three or four income groups, and multiple vehicle classes (such as passenger versus commercial vehicles, heavy trucks, and taxis). URS (2010) distinguishes between HBW, home-based non-work (HBNW), and NHB purposes for distinct personal trip-making VOTs, with additional VOT values for commercial vehicles, medium-duty trucks, and heavy-duty trucks. Slavin (2012) recommends that two distinct truck types be modeled, such as owner-operator versus fleet-driven trucks. Livshits et al. (2012) say that visitors and other infrequent network users may be more likely to use tolled facilities (due to a perception of their relative simplicity). Ultimately, segmentation decisions can come down to the tolled corridor's purpose, with some segmentations making more sense than others, depending on congestion levels and the types of travelers expected to use the corridor.

Household incomes and the corresponding wage rates may be used as proxies when estimating VOTs (Outwater and Kitchen 2008). The Puget Sound Regional Council found a nonlinear relationship between income and VOT, particularly at lower incomes, though the relationship becomes approximately linear with household incomes above $50,000, as shown in Figure 5 (Outwater and Kitchen 2008).

Source: *Outwater and Kitchen (2008)*

Figure 5. Relationship between VOT and Household Income.

For more refined analyses, stated preference (SP) surveys may be used prior to the construction of tolled facilities, and revealed-preference (RP) studies may be used after tolled facility openings. Kriger et al. (2006) note the utility of SP surveys for conditions that do not exist locally, though the authors note that when conditions do exist, RP studies are preferable.

In addition to allowing distinctive/heterogeneous VOTs through discrete segmentation, Perez et al. (2012) suggest introducing further heterogeneity by applying random coefficient choice models (typically the mixed logit) for wider, continuous, and ultimately more realistic VOT distributions. If conducted, this could be implemented during the network assignment step, though if a mode-choice model is present, the same modeled variation should also be applied to other steps, such as destination and mode choice. The application of such variation across VOTs should help ensure model consistency and avoid potential issues with convergence.

To estimate VOTs (as a function of traveler incomes and trip distances), Livshits et al. (2012) suggest that the following formulation may apply, as used by the United Kingdom's Department for Transport (2007):

$$VOT = K\left[\frac{\beta_\tau}{\beta_c}\right]\left(\frac{Inc}{Inc_0}\right)^{N_{inc}}\left(\frac{D}{D_0}\right)^{N_c} \tag{2.3}$$

where:

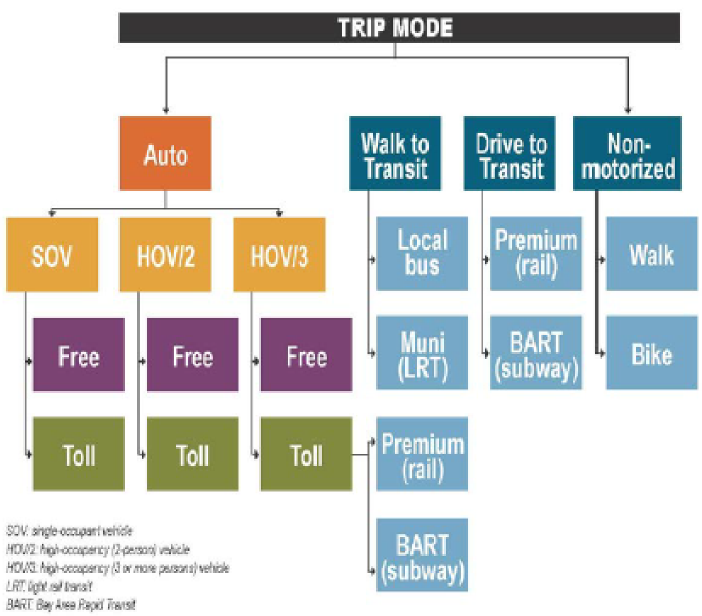
- β_τ and β_c represent coefficients of travel time and cost in both the route-choice and mode-choice models.
- *Inc* is the traveler's household income.
- Inc_o is the region's average area income.
- *D* is the trip distance.
- D_o is the average area trip distance.
- *N* is the elasticity of income or cost.
- *K* is the inflation factor between when the β values were estimated and the analysis year.

While the Department for Transport (2007) provides values for K, N_{inc}, and N_c, these parameters may need to be estimated from Texas data to be accurate for the purposes of this project if this approach is pursued. As an alternative, VOTs may come from Equation 2.1's implied cost-time tradeoff: $\alpha/\beta \cdot \ln(Inc)$ if appropriate route-choice data exist (to allow the analyst to estimate these behavioral parameters). This would likely be a less difficult endeavor (though possibly less accurate).

Giaimo (2012) notes that tolls are applied at the vehicle level in the Ohio model's network assignment stage, rather than at the traveler level. Gregor and Knudson (2012) concur that when modeling travel during the assignment stage, routes were chosen that minimize vehicle travel cost, rather than individual traveler cost (i.e., splitting toll fares among all occupants). However, mode, destination, and other choices (upstream in the demand model system) reflect individual traveler choices, so tolls should ideally be split in some thoughtful way among vehicle occupants, possibly even after the assignment step, to reflect full per-person travel costs. Giaimo acknowledges that it would be better to identify and split any tolls among carpoolers, while applying toll costs for families as a whole undivided value. Zhao (2013) notes that in small communities, carpooling is not a large factor, so a single VOT can be used at the individual vehicle level, rather than dividing it among vehicle occupants. Such cost-assignment details relate very closely to the upstream model of mode choice.

MODE CHOICE AND NONMOTORIZED TRAVEL

The mode-choice step is typically implemented after trip distribution (gravity or destination choice) in a traditional four-step TDM. When implementing tolling in a regional planning model, a mode-choice step may be used to either distribute travelers between various travel modes (e.g., SOV, high-occupancy vehicle with two occupants [HOV2], high-occupancy vehicle with three or more occupants [HOV3+], transit, pedestrian), or incorporate the actual decision of whether a traveler chooses to use a toll road. In the second type of application, the toll choice may be incorporated into a lower nest of a nested logit model, as implemented in San Francisco (see Figure 6).



Source: Livshits et al. (2012)

Figure 6. San Francisco Toll Model Structure.

While the implications of incorporating the toll choice into the mode-choice or pre-network-assignment step were discussed previously (in the section "Toll Choice Models and Trip

Assignment”), this section primarily focuses on different mode-choice models and implementations.

Perez et al. (2012) strongly recommend that all TDMs incorporate a mode-choice step, preferably using a logit or nested logit specification. For example, a three-level nested logit model can consistently and rigorously reflect mode choice, vehicle occupancy, and route type (tolled or non-tolled). Donnelly (2013) suggests separating SOV, HOV2, and HOV3+ travelers during the mode-split step, rather than relying on average vehicle occupancy values. Even if tolled facilities do not distinguish between vehicle occupancies, future managed lane applications may do so, so implementing this step during near-term model updates will facilitate future improvements in the TxDOT model.

In contrast, Zhao (2013) believes that many small and medium-sized communities do not necessarily need a logit model for mode choice, and that other aspects of the TxDOT model merit treatment sooner. Indeed, Gregor and Knudson (2012) note that Oregon’s models do not incorporate a mode-choice step in regions of 70,000 persons or fewer. Instead of ignoring mode choice, Zhao proposes converting person trips (once distributed to destination zones) into vehicle trips using fixed proportions based on distance. For example, a given percentage of shorter trips could be assumed to be walk/bike trips, with a similar approach used for transit trips. To increase spatial resolution for trip-distance measurements, Wachs et al. (2007) suggest setting walking distances to 0.5 miles or less between traffic analysis zone (TAZ) centroids in the urban cores of regions. Eshelman and Mwalwanda (2013) recommend a context-specific approach to mode choice: rural regional models do not need a mode-choice step, whereas transit trips should be reflected in TDMs for urban regions.

Regardless of whether a detailed, logit-based mode-split step is used (as recommended by Perez et al. [2012]) or a simpler approach is pursued (as recommended by Zhao [2013]), mode split appears to be a component of many TDMs in use elsewhere, at least for areas with larger populations. Even if a simple approach is adopted now, such a placeholder could facilitate future model enhancements.

OUTER FEEDBACK LOOP AND CONVERGENCE

An outer feedback loop and a network assignment convergence criterion represent two final TDM specification components. The top TDMs today use full feedback loops in order to ensure consistency in travel times and costs that serve as inputs to destination and mode-choice equations, with travel times and cost skim as outputs of the network assignment stage. Such consistency allows the model equations to equilibrate or stabilize, ultimately achieving convergence and a unique, stable transport-system solution for policymakers and the public to rely on.

Convergence in network assignment is typically measured using the concept of a relative "gap" value, which compares the current context to a new preferable context that could be achieved with an additional iteration. For example, Morgan and Mayberry (2010) use the following formulation:

$$Gap = \frac{\sum_{i \in I} \sum_{k \in K} f_k t_k - \sum_{i \in I} d_i t_{min,i}}{\sum_{i \in I} d_i t_{min,i}} \tag{2.4}$$

where:

- I is the set of all OD pairs.
- K_i is the set of all paths used by trips traveling between OD pair i.
- f_k is the number of trips taking path k.
- t_k is the travel time on path k.
- d_i is the departing demand.
- $t_{min,i}$ is the travel time on the shortest (or minimum-cost) path between OD pair i.

While Morgan and Mayberry (2010) use this formulation at the assignment step, similar formulations may be used for other steps, or when testing for convergence at the outer feedback loop after all modeling steps have been conducted.

Giaimo (2012) notes that some of Ohio's models do not use any feedback loop at all and may have no need to, and Gregor and Knudson (2012) note that Oregon's regional models typically run three to four full/outer feedback loops. Since there is no real congestion in these regions, with the exception of a few minor intersections or segments within the network, the shortest paths are based on travel times and costs, or past skim values, which are presumed close to final, converged results. For regions with minor congestion, Giaimo notes that Ohio's modelers sometimes use a "warm start," conducting a preliminary loading of the model to get a sense of likely congestion and speeds, before progressing through the full TDM.

In contrast, Perez et al. (2012) stress the importance of full-model feedback in achieving a stable equilibrium solution (rather than spurious, intermediate solutions), at least in regions with congestion, where travel times and costs can vary a great deal (versus free-flow skimmed values) from iteration to iteration. Models that stop early, before reaching convergence, regularly report erroneous results at the link level, especially in congested networks (Slavin et al. 2012). Zhao (2013) has noticed many regional TDMs that are not run until convergence. Instead, one full feedback iteration is regularly run, and all model results are then assessed. Most regions appear to now be applying a fixed number of full feedbacks (like the Oregon models), to avoid the very long convergence times needed to reach the gaps now recommended by experts (see, e.g., Boyce and Xie [2012], Slavin et al. [2012], and Morgan and Mayberry [2010]), which are 10^{-4} or fewer and ideally 10^{-6} or fewer.

As in the methods currently used in Oregon and Ohio's models, Zhao (2013) agrees that use of outer feedback loops depends on the presence of congestion. In regions with little congestion, all three consultants (Zhao, Mwalwanda and Elschelman) note that such efforts may not be necessary. However, congestion is likely to grow in many regions over time, especially with the 20-year model runs typical of State Implementation Plan practice. And accurate speed estimates can be important to emission rate estimates for many pollutant criteria in the growing number of non-attainment regions in Texas (as ozone and other standards tighten). Unfortunately, none of the respondents were able to provide specific v/c values or other thresholds to look for when conditions are likely to be congested enough to warrant feedback loops.

For actual implementation of an outer feedback loop, Slavin et al. (2012) suggest a method of successive averages (MSA) implementation. Slavin et al. recommend that such implementations average link flows across iterations, rather than across link travel times. Averaging travel times may lead to lower convergence and is not theoretically consistent because traffic volumes have a nonlinear relationship with travel delay, and therefore may produce travel times that do not correspond to any actual travel patterns estimated during network assignment. Additionally, beginning with good estimates of congested link travel times and skims should reduce the total number of feedback loops required and speed convergence.

Slavin et al. (2012) recommend using a percent root mean squared error (RMSE) criterion for exiting the outer loop, though other criteria are also possible. These recommendations note using each zone-to-zone value as observations for calculating percent RMSE. In Washington, D.C., Caliper Corporation used a 0.1 percent threshold (Slavin et al. 2012).

MODEL VALIDATION

The final modeling feature relates to validation of TDMs, which Perez et al. (2012) and many others consider critical to creating reliable traffic (and revenue) estimates along new tolled facilities. Such validation can take on multiple forms. First, model forecasts and changes in those forecasts must be intuitively reasonable. For example, simply introducing tolls on a link should not add traffic to that link. Similarly, if speeds fall on a link, travel demand should also fall on that link, absent other changes.

Additionally, the same model ideally should be applied to similar contexts, where traffic results are available for comparison to more forecasts. Such comparisons help verify model accuracy and support model reliability. One caveat is that analysts should take care not to "overfit" the data to the similar, already observable context.

Local travel survey data (of households and businesses), traffic counts, SP surveys, and other data sets are important in the process of model validation (and regularly essential for model-parameter estimation and model calibration). These and other sources may be used (as described previously) to check model accuracy in traffic volumes, time-of-day splits, traveler VOTs, volume-speed relationships, and other important behaviors along tolled routes (and elsewhere in the modeled networks).

Wachs et al. (2007) identify two methods of model validation: forward validation (where a model calibrated based on past data is used to forecast current travel patterns) and backcasting (where the current model is used to estimate travel patterns from prior years). In both methods, analysts compare actual travel data with the model-predicted results to determine whether the proposed model is valid (i.e., achieves validation). Wachs et al. note that many agencies conduct such forecasting efforts for model updates, though backcasting is much less common.

Wachs et al. (2007) also note that sensitivity testing (where inputs and model parameters are varied) can be helpful in establishing the reasonableness of model predictions and understanding potential variations in outcomes. Eshelman and Mwalwanda (2013) also indicate their use of such strategies in their corridor-focused T&R work, as described in greater detail in

Chapter 3. Fagnant and Kockelman (2012) offer an example of such simulations for tolled corridor analysis (with an abstracted Austin network and more than 100 model runs). Fagnant and Kockelman drew from log-normal distributions over more than 20 input parameter sets, simultaneously, and generated relatively smooth distributions for tolled-link flow rates, project benefit-cost ratios and internal rates of return, toll revenues, crashes, emissions, and other impacts. Kriger et al. (2006) identify the area's/region's growth rate, VOTs, and planned toll rates as particularly important parameters to toll-project success, while Fagnant and Kockelman (2012) identify link capacity and link performance parameters as critical model inputs. Kriger et al. (2006) and Livshits et al. (2012) also identify economic downturns as another key source of risk.

Tolled-road volumes and revenues will remain uncertain and harder to forecast than flows along non-tolled links; fortunately, model validation and analyst illumination of risk and variance are valuable strategies for addressing such unknowns (Lemp and Kockelman 2009).

SUMMARY AND CONCLUSIONS

This document reviews current practices and techniques used around the United States for incorporating tolling into TDMs, along with general recommendations for TDM specifications and applications. The team interviewed a variety of state department of transportation modelers and modeling consultants, and reviewed a number of technical articles and research reports on recommended practices for incorporating tolling in TDMs. While the findings reveal overlap across recommendations and practices among the sources interviewed and cited, there was also a degree of disparity. The distinctions may stem largely from the modeling context: larger regions have greater needs, more resources, and more complex networks than smaller regions, and investment-grade T&R studies for new tolled facilities tend to focus on single-corridor details and data, while regional models seek to provide solid forecasts for an entire metropolitan area. All interviewees seemed to agree on at least one thing: travel demand modeling needs differ across contexts, and a one-size- (one-model-) fits-all solution is generally not the best approach.

With this in mind, eight key components were identified as areas in which TxDOT's TDMs could be improved when incorporating tolls. Highlights of these components are as follows:

- **Data relevance: currency and context**: Current and locally collected data are very helpful for proper model calibration. These include demographic details and traveler VOTs, land use and employment patterns, and commercial trip-making patterns. When improving regional TDMs to incorporate tolling impacts, TxDOT should take steps to ensure that these data are collected and input into the model.
- **Network and link attributes**: Link performance function parameters, including link capacities, should be carefully calibrated for tolled facilities and substitute routes. Toll prices may vary by user class, time of day, and method of collection; and these features should factor into the modeling equations.
- **Toll-choice models and trip assignment**: Many toll road modelers are using a deterministic user-equilibrium route assignment methodology, with each traveler minimizing generalized costs between origins and destinations. Others use logit models or diversion curves for all tolled links, with route utility a function of generalized travel costs, including (at a minimum) toll price, vehicle operating costs, and monetized travel time. Both frameworks are theoretically defensible and widely used, though it is important that generalized travel costs be comprehensive in their assessments.
- **Time-of-day and temporal considerations**: Multiple times of day should likely be given consideration when approaching the toll paradigm. Even with low levels of network congestion, tolled facilities can rely on travel time savings to remain competitive routes, and therefore tolled link volumes should reflect different levels of congestion and travel patterns.
- **Traveler classes and values of time**: Multiple traveler classes with different VOTs should be established to enable more realistic and smooth demand predictions. VOTs can be segmented by user type (e.g., trucks versus passenger vehicles), trip purpose (e.g., commute versus non-commute trips), income levels, and possibly time of day. Depending on the context, models may also include additional VOT segmentation by time of day and truck type, though such improvements would likely be a lower priority in most instances.
- **Mode-choice and nonmotorized travel**: A mode-choice model could be constructed as a logit or nested logit specification. A lesser but still meaningful improvement

could split trip tables across modes on the basis of inter-zonal distances. However, many experts note that this step may add limited value for small and medium-sized communities. Mode-choice models are typically implemented for the larger travel models, while for smaller study areas, implementation should probably be context sensitive.

- **Feedback loops and convergence**: An outer feedback loop could be incorporated between trip distribution, mode choice, and final network assignments, to ensure skimmed trip times and costs are consistent throughout the model chain. As noted in the review of national practice, the use of an outer feedback loop depends on the presence of congestion. Without congestion, implementing feedback may not be necessary. Implementing this change to the structure of the models would be done in concert with link performance (or volume-delay) functions and time-of-day traffic splits, to help travel times reflect actual traffic loads. A convergence gap criterion should be reached before the model exits, though the number of iterations required presumably will be quite small for regions with little congestion.
- **Model validation**: Model outputs and behaviors should be tested against observed conditions (forward and/or backwards in time), compared against non-tolled conditions, and double-checked for reasonableness. Sensitivity testing of parameter and input impacts is also a very valuable strategy when examining and presenting model forecasts.

These recommendations for TxDOT's TDMs with tolling are based on current national practices and recommendations, with emphasis on medium-sized and smaller urban areas. This information helps identify which model improvements might generate the greatest corresponding forecasting improvements for small to medium-sized study areas. By ensuring TxDOT's TDM specifications and practices reflect best U.S. practices for similar settings, TxDOT can look forward to improved transportation planning, project analysis, and decision making in Texas.

CHAPTER 3: REVIEW OF TOLL MODELING APPROACHES AT THE STATE LEVEL

INTRODUCTION

This chapter provides:

- A review and summary of toll modeling approaches used by Texas MPOs that are engaged in modeling tolled facilities.
- A categorization of Texas MPO procedures.
- A review of methods, approaches, and considerations used by representatives engaged in the estimation of T&R projects on behalf of TTA within TxDOT.
- A brief summary of the toll modeling approach implemented within the Statewide Analysis Model (SAM).

Through in-person interviews and reviews of supporting TDM documentation provided by MPOs, researchers obtained background information and details on the overall TDM approaches and structure at select MPOs. The MPOs interviewed are the four largest MPOs in the state, which have been engaged in toll modeling practices for a number of years:

- Austin.
- San Antonio.
- Dallas-Fort Worth.
- Houston.

Consequently, these MPOs have had to address toll consideration during the base-year model calibration process. Specific toll modeling methods and in-process enhancements were identified as part of this process. This information can provide TxDOT TPP with potential options and implementation considerations for small to medium-sized urban travel models.

While these MPO areas are not comparable to the small and medium-sized urban areas in the TxDOT TPP models from a geographic and demographic scale or in terms of congestion (sometimes a key factor in toll road consideration), the process for developing and using toll modeling procedures in these areas could ultimately be instructive to TxDOT TPP.

It is no coincidence that the four MPOs performing toll demand analyses are located in four of the five largest urban areas of the state and have the state's most robust regional transport systems. As a result, these regions have been leading the state's MPO modeling practitioners in investigating, developing, and applying methods of toll demand modeling. Travel models for two of the regions (Austin and San Antonio) have been developed cooperatively with TxDOT TPP and are largely based on TxDOT's Texas Package. While the models for the Houston region have been developed in consultation with but independent of TxDOT, portions of the Texas Package are used in the current set of Houston models. The models for Dallas-Fort Worth have been developed independent of TxDOT but contain similarities to the other trip-based models in the state. NCTCOG provides loaded networks to TxDOT TPP from time to time to support corridor-level analyses.

This chapter provides the individual findings from the four large MPOs in the state. The summaries include general background information regarding the urban TDMs, as well as specific information regarding the approach taken within these models to account for toll demand. Although not as refined as the approaches used by TTA to conduct T&R studies, specific modeling techniques in these areas and lessons learned serve as valuable foundations for TPP's eventual consideration. Similarities and differences between the urbanized models are discussed as well.

METROPOLITAN AREA TOLL MODELING APPROACHES

Austin Region (CAMPO)

Toll demand modeling for the Austin region is performed using a trip-based model collectively developed by CAMPO and TxDOT. The CAMPO TDM is a trip-based model that contains the four traditional steps of trip generation, trip distribution, mode choice, and traffic assignment. The CAMPO model set also includes, as part of the post-mode-choice assignment trip table preparation step, procedures for creating AM and PM peak-period trip tables.

Trip generation is performed using TxDOT software incorporated by CAMPO into customized application procedures for different trip purposes:

- HBW trips (direct, strategic, and complex).
- HBNW trips (retail, other, school, university, and University of Texas).
- Non-work airport trips.
- NHB trips (work, other, and external-local).
- Truck/taxi (TRTX) trips.
- External trips (local auto, local truck, through auto, and through truck).

Household income, household size, and workers-per-household submodels facilitate segmentation of rates among five household incomes, five household sizes, and three workers-per-household groups.

Trip distribution is performed using TxDOT software implemented through a CAMPO-developed application procedure that is part of a feedback process. The process initially uses skims built from link free-flow times, and thereafter uses travel times from an AM peak assignment for subsequent iterations of CAMPO's work trip distribution. All other trip purposes are distributed first with skims based on free-flow times and subsequently, in iterative fashion, link travel times from a 24-hour assignment. This is also part of the iterative feedback process.

The mode-choice model is a nested logit model that separates motorized travel into auto modes among three occupancy levels (SOV, HOV2, and HOV3+) as well as toll/non-toll. Transit demand is estimated among three bus modes and two rail modes. The mode-choice model also separates nonmotorized travel into walk and bike modes. The mode-choice modeling process includes an auto ownership submodel to facilitate segmentation among three auto ownership levels (0, 1, and 2+ vehicles).

The toll-separated auto modes are combined back to occupancy levels (SOV, HOV2, and HOV3+) to facilitate the use of the traffic assignment step for estimating toll demand. AM peak travel times are used to provide level of service (LOS) data for the HBW mode-choice model, while daily travel times serve as LOS inputs for all other purpose mode-choice models.

A generalized cost (GC) multimodal multi-class assignment (MMA) is performed for the AM peak and 24-hour period to facilitate the feedback process. Travel times from these assignments are fed back for distribution of the three HBW purposes and all non-work purposes, respectively, and through mode choice. The traffic assignment output travel times used in the feedback process are derived from either 1) the method of success averages (MSA) of either current and prior assignment times or 2) times from a single assignment of constant weight-factored AM peak and 24-hour trip tables. The choice of which of the two methods is used is made by the modeler. Upon declaration of convergence,[2] PM peak-period trip tables are created from the 24-hour final trip tables, and a PM peak-period assignment is performed.

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[2] Based on values of travel time skim RMSE, trip table total misplaced flow (TMF), and the link-based GEH statistic determined from the base-year model application of feedback.

The end result of this assignment process is that time-of-day toll demand is estimated for three periods: the 24-hour daily period, AM peak period, and PM peak period. For each time period, the toll demand is segmented among autos and trucks. The assignment procedure makes use of TransCAD's generalized cost assignment methodology, and segments vehicle operating costs and values of time (VOT) among auto and truck vehicle classification designations. Generalized cost is calculated for each link of the highway network and includes link travel time, link operating cost, and any applicable tolls. Link travel time is based on the link distance and either a free-flow speed (on the initial iteration of the traffic assignment) or a congested speed based on the volume-to-capacity ratio of the link (between iterations of an individual traffic assignment).

The auto and truck operating costs are based on values reported by Barnes and Langworthy (2004) and converted to 2005 dollars. The VOT used for the auto class is consistent with that of the CAMPO mode-choice model, while a 3.5 multiplier, cited by CAMPO staff as typical, is used to estimate the truck class VOT. Table 1 presents the auto and truck operating costs and VOTs used in the CAMPO models.

Table 1. Campo Toll Cost-Related Inputs.

Mode	VOT	Auto Operating Cost
Auto	$0.20/minute	$0.136/mile
Truck	$0.70/minute	$0.476/mile

Sources: CAMPO (2010)

Link-specific toll costs are used for existing toll facilities where toll collection points and amounts are known and for future facilities where it can be confidently estimated. A toll-cost-per-mile value is used to calculate toll costs on future facilities in which tolling points and costs are not known.

The generalized cost assignment method of estimating toll demand replaced a mode-choice-based procedure following a Travel Model Improvement Program (TMIP) Peer Review Panel recommendation to move toll demand estimation from the mode choice to the route choice level. The structure of the mode-choice model that contains toll/non-toll nests was retained for model recalibration purposes; consequently, the output toll-segmented auto-mode trip tables are simply combined following mode choice. The retaining of the toll/non-toll nests offers the advantage of retaining sensitivity among the auto/transit upper mode choice to tolling costs.

Toll road volumes are reviewed along with all other network roadway volumes against observed traffic counts as part of the regional model validation. VOT and auto operating cost, along with toll cost, values are calibrated such that assigned toll demand matches observed traffic volumes.

Consideration was given to several activities geared toward the enhancement of toll modeling capabilities at CAMPO:

- SP surveys.
- The ability to model variable-priced facilities.
- Consideration of VOT in route choice.
- Diversion curves.

Additionally, CAMPO is working toward developing procedures for conducting sensitivity testing of the toll demand modeling process.

San Antonio Region (SAMPO)

Toll demand modeling for the San Antonio region is performed using the trip-based model collectively developed by SAMPO and TxDOT and referred to as the San Antonio Multimodal Model (SAMM). The SAMM is a traditional trip-based four-step model of trip generation, trip distribution, mode choice, and traffic assignment. The model set also includes a time-of-day component for use in the mode-choice step only. The trip generation and trip distribution steps are performed using TxDOT software and procedures, while the traffic assignment model uses TxDOT procedures within TransCAD. The mode-choice model was independently developed and integrated into the model stream by SAMPO.

Trip generation is performed for:

- HBW trips.
- HBNW trips (retail, other, school, and university).
- Non-work airport trips.
- NHB trips (work related, other, and external-local).
- Internal truck trips.
- External trips (local commercial, local non-commercial, through commercial, and through non-commercial).

Trip distribution is performed using travel time skims based upon 24-hour average speeds from a look-up table. The resulting person trip tables are summed, converted to vehicle trips, and then merged with the vehicle trip-generated trip purposes to obtain a total 24-hour trip table for use in a pre-mode-choice assignment performed to develop congested mode-choice input travel times.

The segmented HBNW and NHB purposes are combined for input into mode choice. The HBW, combined HBNW, and combined NHB trip tables are each segmented into 5.5-hour peak and off-peak (rest-of-day) trip tables for input into the peak and off-peak mode nested logit choice models for each purpose. Peak mode-choice models receive highway LOS inputs from the assignment times of the previously mentioned 24-hour assignment. The off-peak mode-choice models use highway travel times based on the 24-hour look-up table estimated speeds. The mode-choice models estimate demand for each trip purpose among three highway modes segmented by occupancy, two transit modes segmented by mode of access, and walk and bike modes.

The seven mode-choice output trip tables are converted to vehicle trips and then combined with the trip tables created directly by the trip generation and distribution processes into a 24-hour automobile trip table and a 24-hour truck trip table. These trip tables are assigned to the modeling network using the TransCAD user equilibrium (UE) GC MMA technique. Toll demand for a 24-hour period among auto and truck classes is estimated as part of this assignment routine. The traffic assignment makes use of three different BPR-based assignment functions in which the alpha and beta values differ among generic roadway type. Figure 7 graphically portrays the SAMM assignment functions.

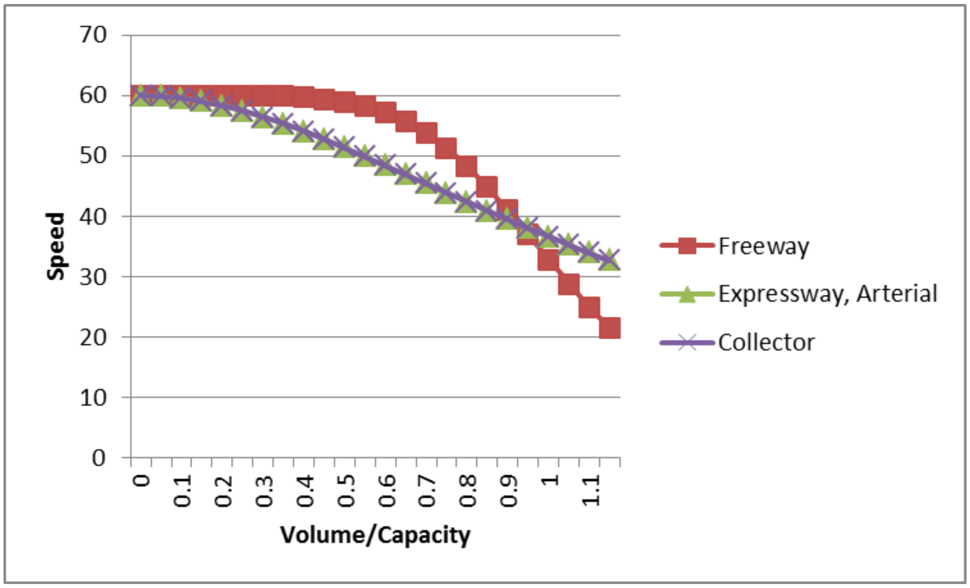


Figure 7. SAMM Assignment Functions.

Link impedances for the assignment include the link travel time along with the applicable toll (converted to time values through VOT) but do not include auto operating costs. Link toll costs are based on a per-mile toll on all toll facilities except direct-connector ramps between toll roads, which have a fixed toll cost. Both sets of costs are segmented among auto and truck classes. These toll costs are converted to time values for the MMA assignment based on VOTs segmented among auto and truck classes. Table 2 presents link toll costs and VOTs used in the SAMM assignment-based toll demand estimation process.

Table 2. SAMM Toll Cost-Related Inputs.

Class	Toll Cost		VOT
	Toll Links	Toll Ramps	
Auto	$0.15/mile	$0.50	$16.50/hour
Truck	$0.40/mile	$1.00	$40.00/hour

Source: SAMPO (2012)

Dallas-Fort Worth Region (NCTCOG)

Toll demand modeling for the Dallas-Fort Worth region is performed using the trip-based travel models developed by NCTCOG. The models are structured as a set of traditional trip-based travel models that include feedback of time-of-day travel times to trip distribution.

The trip generation model estimates trips for:

- HBW trips (segmented by income).
- HBNW trips.
- NHB trips.
- Airport trips (DFW Love Field).
- Internal truck trips.
- External trips (local auto, local truck, through auto, and through truck).

Trip distribution is performed with a model that uses a gravity model formulation incorporating free-flow times in the initial iteration of the model set and then AM peak roadway skims for the income-segmented work trips and off-peak roadway skims for the non-work, NHB, and internal truck purposes during iterative feedback. Trip tables for airport trips (both home-based and NHB) as well as all external trips are developed through factoring of base year tables.

The NCTCOG mode-choice models include nested logit models for HBW and HBNW purposes and a multinomial model for the NHB trip purpose. The models estimate trips for these purposes among three auto modes and two transit modes using AM peak highway and transit LOS inputs for HBW trips and midday off-peak LOS inputs for HBNW and NHB trips.

The resulting daily trip tables are combined into trip tables segmented among four occupancy classes: drive alone, shared ride HOV lane, shared ride non-HOV lane, and truck. These trip tables are factored to AM peak-period and off-peak-period trip tables during the iterative portion of the model and assigned to the networks with a UE GC MMA that iterates for either 5,000 iterations or until a gap of 0.00001 is achieved. The assignment makes use of customized volume-delay functions (VDFs) developed and calibrated to match observed speeds and travel times by NCTCOG. The assignment VDFs include congestion delay and traffic control delay components. Toll costs are represented as both link-based costs for known tolling and unit costs per miles for future toll facilities, and are adjusted to convert toll costs to the base year 2007. Table 3 presents the cost-related inputs to the NCTCOG MMA general-cost assignment.

Table 3. NCTCOG Toll Cost-Related Inputs*.

Mode	VOT	Vehicle Operating Cost
Auto	$0.233/minute	$0.15/minute
Truck	$0.283/minute	$0.15/minute

** 2007 dollars*
Source: NCTCOG (undated)

Figure 8 presents the functions used in the NCTCOG generalized cost assignment.

Generalized Cost = Operating Cost + (VOT)(Travel Time)

Where: Operating Cost = (Length)(Cost per Mile) + Adjusted Toll,
Adjusted Toll = [Fixed Toll + (Toll per Mile)(Length)](Adjustment Factor_{yr}), and
Travel Time = $T_0 + C_d + S_d + U_d$.

Where: T_0 = free-flow travel time, C_d = volume-dependent congestion delay,
S_d = volume-dependent approach delay at signalized intersection, and
U_d = volume-dependent approach delay at unsignalized intersection.

NCTCOG (undated)

Figure 8. NCTCOG Traffic Assignment Function.

Following completion of five iterations of feedback of AM and off-peak travel times from the traffic assignment to trip distribution, a last set of AM peak-period and off-peak-period trip tables, along with PM peak-period trip tables, are created through diurnal factoring and assigned to the appropriate network. In this way, toll demand estimates are developed for three times of day among four different vehicles classes. Because the trip tables are segmented by occupancy, toll demand for managed lane facilities can be estimated in addition to fixed-toll facilities.

Houston Region (H-GAC)

Toll demand modeling for the Houston region is performed as part of the trip-based models developed by H-GAC and the Metropolitan Transit authority of Harris County (Houston METRO) with collaboration from TxDOT. The H-GAC travel models are traditional four-step models consisting of trip generation, trip distribution, mode choice, and traffic assignment as well as post-mode-choice time-of-day trip table development to facilitate time-of-day assignments and iterative feedback of congested time-of-day travel times to the trip distribution submodels.

The trip generation models estimate trip ends for:

- HBW trips (across five income groups).
- HBNW trips (for retail, other, school, university, and airport trips).
- NHB trips (work based and non-work based).
- Internal truck trips (local and through).
- External trips (involving local auto, local truck, through auto, and through truck trips).
- NHB external trips for internal travel made by non-residents.

First-iteration trip distribution for all trip purposes with TxDOT's ATOM2 gravity-analogy-based model is performed using impedances based on 24-hour average speeds from a look-up table. For subsequent iterations of the model set, composite impedances representing AM peak-period highway and transit travel times are used in the distribution of the income-segmented home-based work trip purpose, while highway impedances from a 24-hour assignment are used for distribution of all other trip purposes.

The nested logit mode-choice models estimate daily demand by trip purpose among eight auto modes segmented by occupancy and toll status and six transit modes segmented by mode of access and local/non-local bus mode. These models are applied separately for income-segmented work trips, the combined HBNW purposes, and the combined NHB purposes. In this way, toll demand is sensitive to changes in transit LOS and vice versa. As part of the mode-choice modeling process, highway cost as well as time skims for paths that include toll roads and paths that do not include toll roads are built. Based on the utility of the "mode" that includes use of a toll facility—which is based on, among other things, trip purpose, time saved, cost, operating cost, and various household characteristics—toll "mode" trips are estimated.

The motivation for placing the toll demand estimation portion of the regional travel models within the mode-choice model was the theory that the choice to use a toll road is not simply a route choice, but a behavioral decision made jointly with the choice of driving alone, sharing a ride, or riding transit. The approach used in H-GAC's model assumes that the use of a toll road or HOV facility is a user choice with certain user biases in that choice. This allows for explicit inclusion of socio-economic characteristics such as household size and income of trip makers along with trip purpose, trip length, and LOS attributes. Since the development of this mode-choice model, advancements have enabled inclusion of zonal socio-economic characteristics such as income (and hence VOT) in traffic assignment software. H-GAC will be transitioning to a traffic-assignment-based method of toll demand estimation with the adoption of new models in the near future.

Daily modal demand, including toll demand for the HBW trip purposes, is estimated using peak highway and transit LOSs and off-peak highway and transit LOSs for the combined HBNW purposes and the combined NHB purposes. Toll costs are represented either through a specific link-based cost where tolled locations and costs are known (i.e., existing facilities) or on a per-mile basis on future toll facilities. Table 4 presents the per-mile toll cost values used in the creation of toll cost skims. The toll cost per mile is based on the system average toll cost per mile among auto and truck toll tag and cash-paying customers. Both the link-specific and distance-based toll costs reflect the differential toll cost among cash and tag-based toll patrons through calculation of an average toll cost weighted by the system average proportion of tag-based versus cash toll patrons. Because toll demand is segmented by occupancy level, the differential cost reflected through managed lane pricing can be captured in a straightforward manner through the use of occupancy-segmented cost skims.

Table 4. H-GAC Per-Mile Toll Costs*.

Toll Road	Managed Lane	
	Peak	Off-Peak
$0.16	$0.35	$0.14

** 2011 dollars*

The modal trip tables for HBW income-segmented trips, total HBNW trips, and total NHB trips are summed to create combined purpose trip tables by six auto modes: drive alone, share ride 2, and share ride 3+, which are all segmented into toll and non-toll markets. These trip tables are converted to vehicle trip tables, and along with the vehicle-generated trip purposes (internal truck and external auto and truck), they are factored into AM peak trip tables. AM peak travel times for the assignment of these trip tables, as well as those from a parallel 24-hour assignment, are evaluated for convergence among trip table and link travel time measures. If convergence is achieved, the 24-hour trip tables are factored into PM peak, midday, and overnight periods, and multi-class assignments for these time periods are performed for the final iteration of the model set.

Assigned toll road volumes are treated as all other assigned volumes in that the 24-hour volumes are compared to counted toll volumes as part of the regional model validation at both the facility type (i.e., toll roads) and corridor level. As mentioned, H-GAC is transitioning to an assignment-based method of toll demand estimation. This transition is part of a new model development project in which H-GAC is developing a new set of activity-based models.

CATEGORIZATION OF TEXAS MPO PROCEDURES

Model Context

Table 5 provides a general overview of the four metropolitan areas and shows the context in which tolls have received consideration.

Table 5. Study Area Characteristics.

Model Area	2010 Regional Population (Million)	Geographic Size (Square Miles)	2010 Delay* (Hours)
Austin (CAMPO)	1.8	4,300	38
San Antonio (SAMPO)	2.1	4,000	30
Dallas (NCTCOG)	6.4	5,000	45
Houston (H-GAC)	5.9	8,800	57

** Per person, per year*
Source: Schrank et al. 2010

The MPOs in the four metropolitan areas use the following travel models:

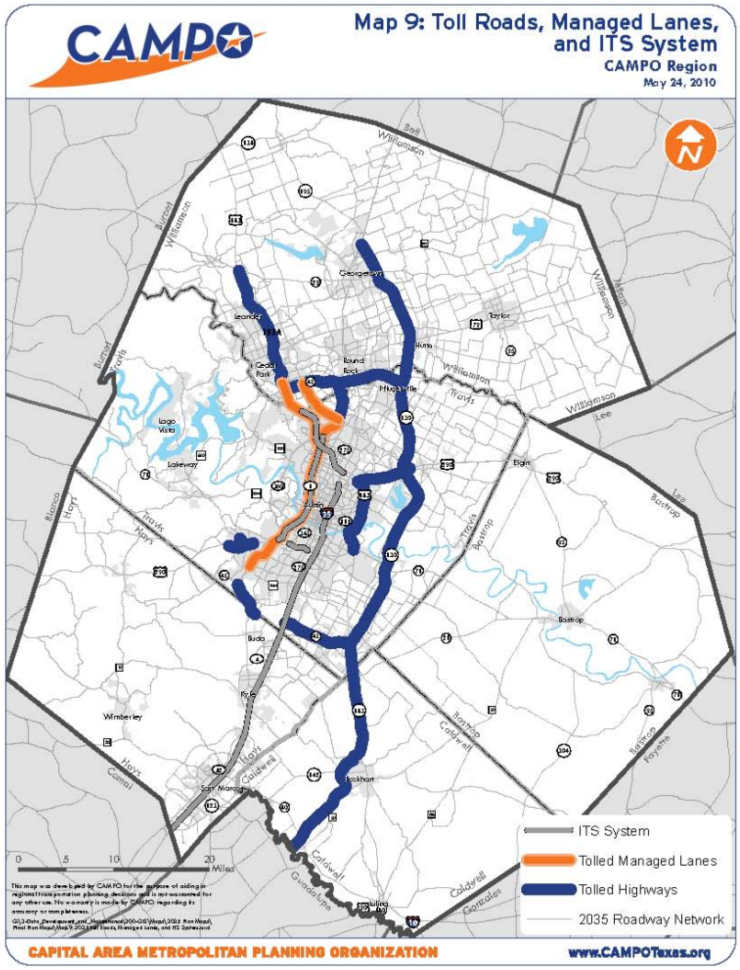
- CAMPO (Austin) uses a trip-based regional travel model for the five-county metropolitan area, which has nearly 2 million residents and moderate to severe region-wide peak-period congestion.
- SAMPO (San Antonio) uses a trip-based regional travel model for the five-county metropolitan area, which has over 2 million residents and moderate to severe corridor-level peak-period congestion.
- NCTCOG (Dallas-Fort Worth) uses a trip-based regional travel model for the 12-county metropolitan area, which has 6.3 million residents and severe region-wide peak-period congestion.
- H-GAC (Houston) uses a trip-based regional travel model for the eight-county metropolitan area, which has 5.9 million residents and severe region-wide peak-period congestion.

Toll Facility Setting

During the information-gathering stage, several of the MPOs mentioned that toll demand modeling techniques were influenced by the location and function of the existing and planned tolled corridors in the region relative to the regional transportation system. For instance, toll roads that compete in corridors with non-toll facilities might result in toll demand modeling procedures that have different characteristics than a region in which toll roads do not compete with non-toll facilities. The following subsections highlight the regional setting of the existing and planned toll roads in the four major metropolitan areas reviewed.

CAMPO

There are four (i.e., SH 130, MoPac North, US 183A, and SH 45N) traditional fixed-fee toll facilities built on new-location corridors within the region. One of these facilities (SH 130) exists in the undeveloped portions of the region but parallels a heavily congested freeway facility (IH 35), while the other connects suburban areas among congested arterial facilities. Figure 9 presents toll and managed lanes in the CAMPO region.

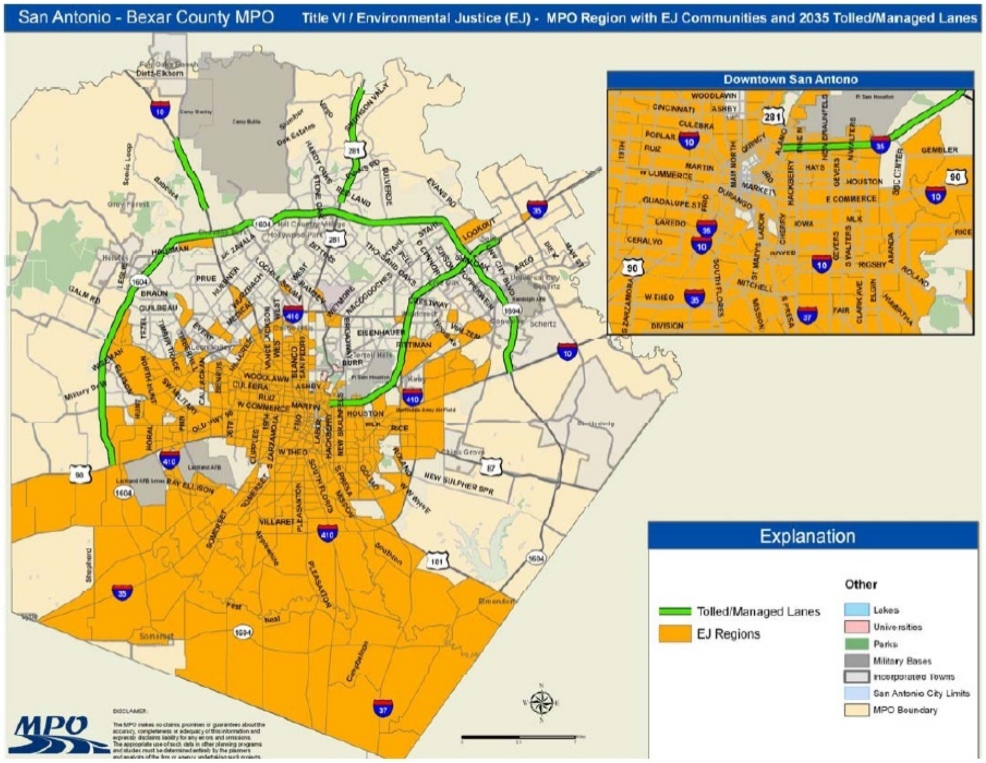


Source: [CAMPO (2010)]

Figure 9. Planned Toll/Managed Facilities in the Austin Region.

SAMPO

There are no current toll facilities within the SAMPO model area. Future fixed-fee toll facilities are being planned as part of several freeway expansion projects in the congested portions of the region. Figure 10 presents planned priced facilities for the San Antonio region.

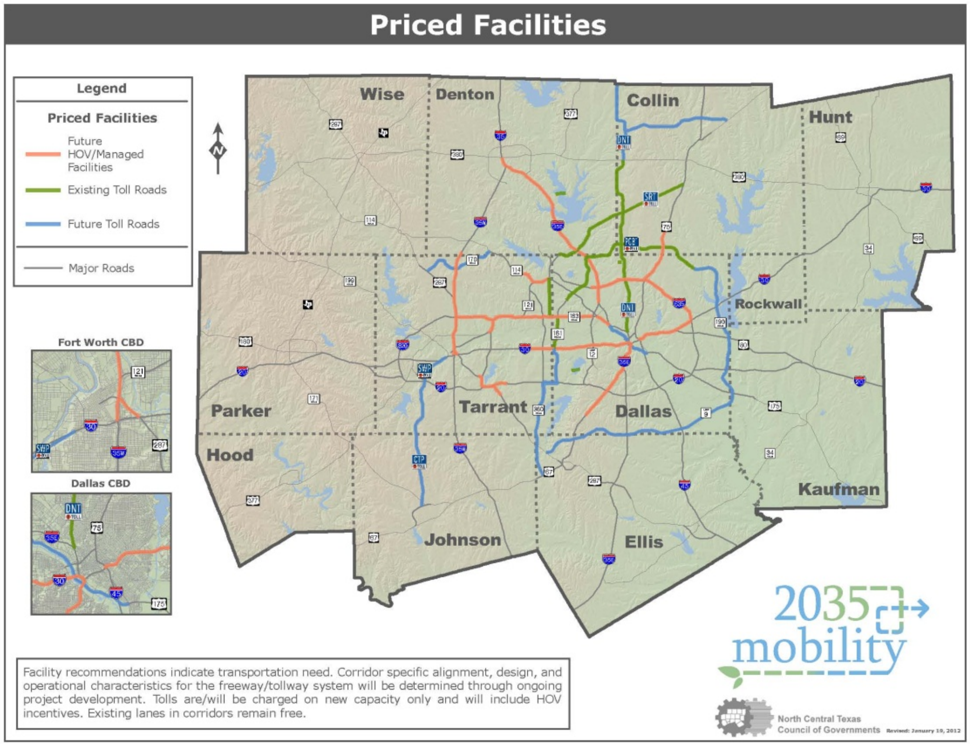


Source: *SAMPO (2011)*

Figure 10. Planned Toll/Managed Facilities in the San Antonio Region.

NCTCOG

There are three traditional fixed-fee toll large-scale facilities in the region. These facilities were built in new-location corridors rather than on existing right-of-way and exist within the congested urban and suburban portions of the region. There are also two fixed-fee toll bridges and a small-scale arterial connection toll facility. Numerous fixed-fee toll roads and managed lane facilities in the urban and suburban portions of the region are planned. Figure 11 presents a map of these existing and planned facilities in the Dallas-Fort Worth region.

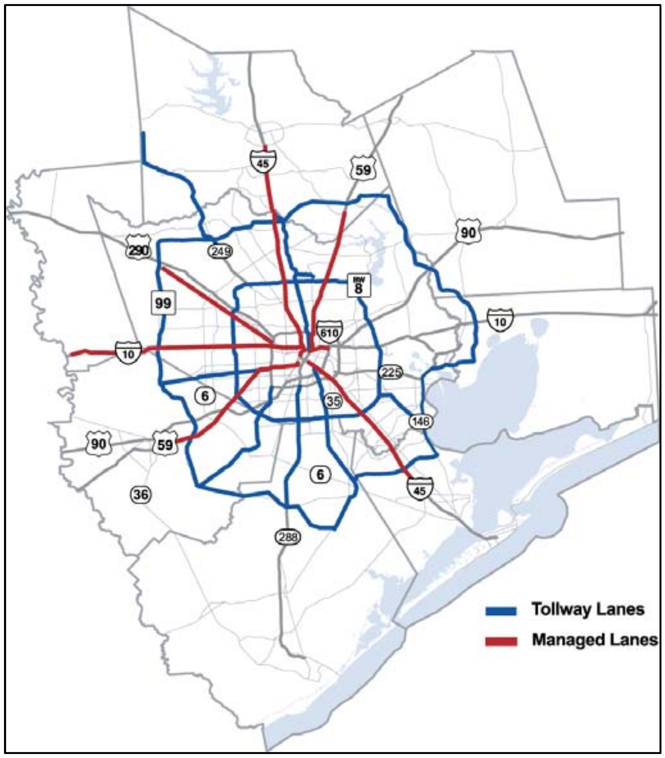


Source: NCTCOG (undated)

Figure 11. Priced Facilities in the Dallas-Fort Worth Region.

H-GAC

There are four fixed-fee toll facilities in the urban and suburban portions of the region, with one facility being an entire loop facility. Two of these facilities do not directly compete with any high-capacity non-toll facilities, while one competes with a moderately congested freeway/HOV facility. The fourth facility was constructed in the midst of densely developed urban arterials and extends into less-developed suburban areas. Additionally, managed/high-occupancy toll (HOT) lane facilities exist within IH 10W, IH 45N, IH 45S, and US 59S freeway corridors. Figure 12 presents existing and future toll and managed lanes facilities in the Houston region.



Source: H-GAC (2013)

Figure 12. Existing and Planned Tollways and Managed Lanes in the Houston Region.

Toll Analysis Need

The primary need among all four areas is to accurately account for toll demand in the model base year and to estimate toll demand in forecasts in future-year scenarios. This information is used for MTP development and as inputs to more detailed corridor studies that are conducted by others. Additionally, all four regions make use of toll demand estimation procedures to develop data used in the environmental justice evaluation process.

Toll Modeling Step

Table 6 summarizes the step in the model stream in which toll demand is estimated. All but the Houston region estimate toll demand in the traffic assignment step. The Houston region is transitioning to an assignment-based method currently in development. Although not used to estimate toll demand, the CAMPO models retain toll/non-toll nests in the mode-choice model so as to preserve sensitivity of modal choice to toll costs. The new Houston model will have this same feature.

Table 6. Toll Demand Estimation.

Region	Toll Demand Estimated in Which Step of Model	
	Mode Choice	Traffic Assignment
Austin (CAMPO)		✓
San Antonio (SAMPO)		✓
Dallas (NCTCOG)		✓
Houston (H-GAC)	✓	

Traffic Assignment Characteristics

Table 7 presents a summary of the variables used in the traffic assignment step among the models reviewed.

Table 7. Traffic Assignment Variables.

Region	Shortest Path Variables in Traffic Assignment			
	Travel Time	Toll Cost	Operating Cost	VOT
Austin (CAMPO)	✓	✓	✓	✓
San Antonio (SAMPO)	✓	✓		✓
Dallas (NCTCOG)	✓	✓	✓	✓
Houston (H-GAC)	✓			

These characteristics reflect that two of the four regions use a generalized cost version of the user equilibrium (GC-UE) approach in traffic assignment. The San Antonio models incorporate cost, but only toll cost, which is converted to time using VOTs segmented by vehicle class. The Houston models use only travel time because toll demand is not estimated by the assignment step. The use of variables as presented in Table 7 shows the type of traffic assignment performed, as summarized in Table 8.

Table 8. Traffic Assignment Characteristics.

Region	Traffic Assignment				
	Method		VDF		
	UE	GC-UE	BPR	Conical	Customized for Toll/ Managed Facilities
Austin (CAMPO)		✓	✓		
San Antonio (SAMPO)	✓		✓		
Dallas (NCTCOG)		✓		✓	✓
Houston (H-GAC)	✓		✓		

Time-of-Day Modeling

Each of the four study areas performs time-of-day modeling. The motivation for this is different by study area. Table 9 presents a summary of the scope to time-of-day modeling in the reviewed TDMs.

Table 9. Time-of-Day Modeling.

Region	Time-of-Day Modeling		
	Trip Distribution	Mode Choice	Traffic Assignment
Austin (CAMPO)			✓
San Antonio (SAMPO)		✓	
Dallas (NCTCOG)			✓
Houston (H-GAC)			✓

The MPOs follow the following modeling processes:

- The CAMPO modeling process includes an AM peak-period assignment as part of the iterative feedback process. After achieving desired feedback convergence, a PM peak-period assignment can be performed.
- SAMPO performs time-of-day modeling, but it is limited to the mode-choice step (peak and off-peak). Toll demand is represented only for 24-hour demand.
- NCTCOG performs time-of-day modeling for purposes of feedback and assignment. AM peak-period (6–9:30 a.m.) and off-peak-period (non-AM or PM peaks) assignments are performed for purposes of trip distribution (peak for work and off-

peak for other purposes). The assignment step adds the PM peak period (3–6:30 p.m.) to the other periods.

- H-GAC performs time-of-day modeling to develop inputs for mode choice, traffic assignment, and feedback. AM peak-period (6:30–8:30 a.m.) assignments are performed to develop LOS skims for HBW mode choice and HBW trip distribution. Following establishment of stability/convergence in feedback, a final AM peak-period assignment along with midday (8:30 a.m.–3:30 p.m.), PM peak-period (3:30–6:30 p.m.) and overnight (6:30 p.m.–6:30 a.m.) assignments are performed with the modal trip tables to establish volumes on the toll facilities by these four times of day.

In summary, all four regions perform some level of time-of-day modeling. In all cases, though, the motivation for the time-of-day modeling capability is not related to toll demand modeling but for use in other steps of the process (i.e., mode choice) or to facilitate an iterative feedback process.

Use of Cost-Related Variables

Two key variables used in the estimation and forecasting of toll demand are network link toll costs and VOT. VOTs are used in both mode choice and traffic assignment to represent costs in terms of travel time. As part of the development of toll modeling procedures, consistency among mode-choice VOT and generalized cost traffic assignments VOT is evaluated. Table 10 and Table 11 provide information on use of toll cost and VOT, respectively, in the reviewed models.

Table 10. Use of Cost-Related Variables.

Region	Which Step Uses			
	Toll Cost		VOT	
	Mode Choice	Traffic Assignment	Mode Choice	Traffic Assignment
Austin (CAMPO)	✓	✓	✓	✓
San Antonio (SAMPO)	✓	✓	✓	✓
Dallas (NCTCOG)	✓	✓	✓	✓
Houston (H-GAC)	✓		✓	

Table 11. VOT Segmentation.

Region	VOT for Toll Demand Segmented by	
	Vehicle Class	Trip Purpose
Austin (CAMPO)	✓	
San Antonio (SAMPO)	✓	
Dallas (NCTCOG)	✓	
Houston (H-GAC)		✓

In comparison, the Houston models estimate toll demand at the mode-choice step rather than the traffic assignment step.

Feedback

All study areas reviewed include some form of congested travel time feedback rather than unresolved sequential model steps. Table 12 summarizes the characteristics of the feedback processes for these models.

Table 12. Characteristics of Feedback.

Region	Steps Included in Feedback	
	Assignment and Mode Choice	Assignment, Trip Distribution, and Mode Choice
Austin (CAMPO)		✓
San Antonio (SAMPO)	✓	
Dallas (NCTCOG)		✓
Houston (H-GAC)		✓

CAMPO, NCTCOG, and H-GAC currently employ iterative feedback of congested travel times to trip distribution. SAMPO employs limited single iteration feedback of loaded assignment times from a 24-hour assignment for use in peak mode choice and 24-hour look-up-table-based times for the off-peak mode choice.

SUMMARY OF TEXAS MPO FINDINGS

Although possessing some level of uniqueness in overall model application procedures, the modeling processes specific to toll demand estimation among the regional travel models reviewed have similar approaches. All but one of these large and congested metropolitan regions estimate toll demand through traffic-assignment-based procedures, and the one region that does not is moving toward such a procedure. Of the metropolitan regions practicing toll demand estimation through traffic assignment, two of the three use generalized cost UE with specification of vehicle operating cost and VOT segmented among auto and truck class. Three of the four metropolitan areas estimate toll demand in a time-of-day fashion through diurnal factoring of post-mode-choice trip tables to defined time periods. Feedback of congested travel times, although present in models for three of the four metropolitan areas surveyed, was not implemented for reasons having to do with the need to estimate or forecast toll demand. However, sensitivity of toll to time-of-day congested travel times is a characteristic of the models in the three regions that engaged in iterative feedback.

TEXAS TURNPIKE AUTHORITY CONSULTANT TEAM INTERVIEW

As a part of the effort to document current approaches to toll modeling within the state, the research team met with the three consulting firms that conduct detailed T&R studies on behalf of TTA. The three consulting teams are CDMSA, Jacobs, and Stantec. The research team provided a list of potential questions and discussion items in advance of the meeting in an effort to focus the discussion. The list of potential questions is included in the Appendix.

Because this was an effort intended to gather basic information based on informal discussions, the information summarized in this section is more general in nature than the previous detailed model documentation and interviews with MPO staff.

General Overview

TTA created two separate technical memorandums detailing guidelines for conducting T&R studies to perform toll feasibility analyses. TxDOT was only able to provide the second of the two technical memorandums—*Technical Memorandum 2005-2: Guidelines for Conducting TTA Traffic and Revenue Studies* (TTA 2005). According to this report, the first technical memorandum prescribes a more detailed approach to conducting feasibility studies in the state (TTA 2005). Both technical memorandums are referenced in other national literature on the subject (HDR 2012, National Cooperative Highway Research Program 2006).

Key to the second memorandum is the description of the three-level industry standards for T&R studies:

- Level 1—sketch.
- Level 2—intermediate.
- Level 3—investment grade.

The second TTA memorandum also refers to a conceptual level that occurs prior to Level 1. A more thorough description of the four main levels is provided in the technical memorandum (TTA 2005). A general description of the process, including steps, is described in a short information document also distributed by TTA (TTA 2007).

The discussion with the consulting teams focused primarily on model data uses and model practice to support the most detailed of the three TxDOT categories of T&R studies—investment grade. This type of study requires a more refined approach, one that relies heavily on travel demand modeling for screening the potential of a corridor to support a tolled facility.

Requested Input Data

Once a specific corridor in a study area is identified as a potential tolled facility candidate, the consulting teams gather as much existing data as possible. The data are primarily obtained from TxDOT TPP and can include any of the following data sets (depending on availability):

- Local urbanized travel demand modeling, including:
  - Base, interim, and forecast network geography(s).
  - TAZ geography.
  - Trip generation and trip distribution models.
  - Socio-economic data used as a primary input to the TDMs.
  - Model documentation (if available).
  - Trip tables (daily trip tables from TxDOT TPP).
- Software (Texas Package):
  - TripCAL5 (trip generation software).
  - ATOM2 (trip distribution software).
- Count data:
  - Annual count data.

- Urban count data.
  - Vehicle class data.
  - Permanent count data.
- Survey data, which can include the results of the following surveys typically performed by TxDOT TPP:
  - Household.
  - Workplace.
  - Commercial vehicle.
  - External.
  - Special generator.

Additional local data that are not specific to TxDOT TPP include transponder data for travel time information (distribution of travel by time of day) and toll transaction data for urbanized areas that have existing toll facilities. These two locally specific data sets, in conjunction with count and vehicle classification information, are used to prepare toll diversion methodologies (when applicable).

TDM Network(s)

Specific elements of the network databases critical to toll analyses that are reviewed and potentially modified during the T&R analysis appear to include the following attributes.

Speed. TxDOT TPP uses estimates of daily speeds in the small to medium-sized urban area travel models. Regionally, the approach used during the T&R studies is to continue to maintain the existing speeds annotated in the network geographies. The networks, though, are enhanced with corridor-specific speeds based on supplemental travel time and delay studies conducted in the affected corridor. It appears to be standard practice to develop corridor-specific speeds relative to different congestion levels by time of day (sometimes referred to as speed distribution curves). In this manner, the existing calibrated speeds for the region (and subsequent trip length frequency distribution curves and friction factors) are maintained, and the need to revisit the trip distribution and traffic assignment steps is limited. The consulting teams referred to this practice as "drilling down" to the study corridor. In this manner, the T&R firms characterized the analysis of existing speeds and modified corridor speeds as performing a diagnostic of the network. These firms seek to identify the likelihood of a travel time occurring during a specified time period for trips from zones i to j.

Capacities. Similar to the discussion relative to speeds, each of the firms indicated that the daily capacities annotated in the network geographies by TxDOT TPP are generally used. Only corridor-specific capacities are used as a part of their process. This is especially true for the rural or small to medium-sized study areas. As noted, the corridor-specific capacities will pivot off of the existing daily estimates of capacity. This also extends to studies where time of day is introduced to the existing model structure in the rural models. For larger urbanized areas, such as Austin and Dallas-Fort Worth, these models already have time-of-day considerations within the model structure and capacity logic.

Counts. In addition to the supplemental travel-time and delay studies, each firm indicated that the networks are populated with additional count data. Two primary reasons are noted for this practice. Initially, the defined base year for the toll analysis may be incongruent with the base year travel model for T&R analysis; therefore, additional counts relative to the analysis year need to be collected as a means to benchmark the model's performance. Secondly, additional counts are targeted in and around the corridor of study to help determine how well the trip tables created from supplemental travel surveys are performing relative to these special counts. It was also noted that the time needed to process counts by TxDOT TPP is, in many instances, inconsistent with the timeframe of T&R studies.

Volume-Delay Function. The practice for T&R studies is to create a VDF using speed-flow data obtained from supplemental traffic studies in the region. The modified VDF is applied at the corridor level and not regionally. The existing BPR alpha and beta parameters are maintained for non-corridor-specific links.

Toll Costs. TxDOT networks do not currently have a cost attribute annotated with the network database since TxDOT TPP does not account for tolls in the existing models. For the T&R studies, toll costs are either expressed as fixed (e.g., at ramps or at gantries) or as an average cost relative to link lengths. To achieve further market segmentation and depending on the approach used, toll costs can be expressed by vehicle class (e.g., non-commercial versus commercial vehicle toll rates). The base toll rate used for passenger cars is approximately 12.0 cents per mile (as expressed in 2003 dollars), while commercial vehicles use the "N-1" weighting approach (where N is the number of axles on the vehicle) (TTA 2005). Future toll costs are dependent on whether there is a policy in place locally to address future toll increases. As noted, in some instances a policy did not exist. In these cases, a toll policy must be developed in order to accurately capture anticipated future revenues.

Socio-economic Data and TAZ Geographies

Each firm indicated that a comprehensive independent review of the existing base and forecast demographics is performed as a part of the analysis. It is common practice to revise the demographics along the corridor as a part of the investment community criteria, given that changes to socio-economic data along the corridor are likely to occur. The success of the toll road is primarily determined by whether the forecasted change to demographics and roadway-system levels of service are achieved. Either together or separately, changes to demographics and roadway-system levels of service can contribute to both the success and failure of the toll road. As a part of the revisions to the socio-economic inputs, concurrent modifications may also occur to the affected TAZs in the corridor to better approximate network loadings.

Trip Tables and Time-of-Day Approaches

The firms noted that on occasion they may or may not receive trip tables by trip purpose—either from the local MPO or TxDOT. Consequently, the only trip table that might be available to work with may be the final 24-hour OD table. Trip tables by trip purpose are preferable. The ability to further segregate the existing trip table(s) is highly dependent on whether supplemental data are available. Depending on the data available, the firms noted that the trip tables can be segregated by:

- Trip purpose.
- Vehicle class.
- Income group.
- Payment method (e.g., cash or ETC).
- Time of day.

The following subsections give additional information regarding three of the different trip table permutations.

Vehicle Class. Whether or not the daily trip tables are refined to capture greater market segmentation and/or time segments is highly dependent on the characteristics of the study area (as well as the scope, budget, and schedule of the toll analyses). The decision to refine the trip tables into finer market segments is highly dependent on the characteristics of travel in the affected corridor. As an example offered during the interviews, if only 2 percent of the existing vehicles are trucks, then there may be no justifiable reason to distinguish the trip tables by vehicle type because the auto-to-truck ratio is so imbalanced. Conversely, if vehicle class counts (either existing or supplemental) identify potential heavy truck usage in the corridor, distinguishing by vehicle type will be a critical element of understanding the market with respect to revenue (e.g., axle multipliers applied to multi-axle vehicles).

Within the count data collection activities, an approach specifically used to address segmenting the external trip tables into commercial and non-commercial purposes is the use of vehicle class data collected at these stations. Vehicle class data collected near external stations can be used to capture truck-related external traffic when the initial external seed matrix simply represents vehicles. National freight data were also mentioned as another source for segregating external trip tables in the absence of external commercial and non-commercial market trip tables.

Payment Method. When toll roads were not as prevalent in the state as they are today, considerable attention was given to ETC methods when cash and ETC were used simultaneously. However, the bias against ETC is fading with the retirement of the cash option in the state. The subject of ETC segmentation is further justified in urban areas with existing tolled facilities. It was noted that even with 100 percent transponder toll roads, there will be violators and drivers that intentionally choose to pay the higher mail-in cost associated with infrequent or intermittent use rather than obtain a transponder. As much as 30 percent of the transactions on a 100 percent ETC facility will not be transponder based. Although it was agreed that there probably needs to be a mechanism to capture this dynamic to accurately predict potential revenue, it was not clear how this might be achieved in current practice. For study areas that are still maintaining a cash/ETC mix as a toll collection method, there is a ramp-up period given consideration with respect to the travelers of that corridor. As more users switch to ETC, there appears to be less sensitivity to the daily costs associated with toll usage. It was not clear how often the payment method is captured within the trip tables. Anecdotally, segregating the trip tables into ETC and cash options is probably limited to the larger urbanized regions.

Time of Day. Time-of-day characteristics were also noted as a potentially critical modification to the trip tables for understanding not only the traveler characteristics of the corridor but also the peaking characteristics of the facility. The potential for conveying travel time reliability as a measure against competing facilities is another dividend to refining the daily trip tables that TxDOT TPP continues to use in the small to medium-sized study areas. The travel time savings can be analyzed by direction as well, which is a critical element to any revenue study. Time-of-day considerations are not addressed in either the sketch or conceptual levels. Time of day is addressed in the level-two and -three feasibility analyses. If the existing travel model framework lacks time of day, the methodology used to achieve temporal-related trip tables is dependent on available data. The two most critically mentioned data sources are the household travel survey and time-of-day counts. The typical time periods include AM and PM peaks, midday, and off-peak. The household travel survey can provide the diurnal factors, but the counts can illuminate when and where the breaks should occur relative to each period. Supplemental counts are typically collected to help calibrate the models by time of day. Time-of-day speeds are used to help calibrate the network. These are collected with supplemental travel time/speed studies in the region and corridor. Depending on the analysis level, creating period trip tables may or may not be necessary. It was noted that initial estimates of traffic can be considered a benchmark to move to period tables.

Additional Data Collection Activities

Each of the consulting teams noted the need to collect additional data to support the toll feasibility analyses. The motivation included the need for more timely data (there can be a 12 to 18 month processing time associated with the traditional count collection program) and focused information on the corridor being studied. Additional data collection activities are found in Table 13.

Table 13. Additional Data Collection Activities.

Activity	Purpose
Travel surveys (SP)	• Obtain VOT
OD surveys	• Ascertain model performance relative to additional counts • Obtain travel patterns
Travel time/speed studies	• Obtain travel times by time of day • Obtain speeds relative to volume
Counts	• Assist with time-of-day breaks for each period • Calibrate model in specific corridor • Obtain vehicle class counts

The focus of these activities center on the study corridor. As noted previously, the purpose of these studies is to drill down to the corridor-level analysis. These are not intended as a means to usurp the existing models (e.g., trip rates and trip lengths).

Approaches

Because of the proprietary nature of the approaches implemented by the three different consulting teams, some of the information is limited. All three firms were forthcoming, but there is a limit to the detail that can be published. That being said, the approach undertaken to conduct a toll feasibility analysis appears to reflect several criteria:

- The size of the study area. A rural (versus urban) area model often refers to the small to medium-sized study areas for which TxDOT TPP still maintains model development purview (e.g., Tyler, Longview, Laredo, and Hidalgo County).
- The general level of congestion in the study area.
- The level of congestion in the identified corridor under study.
- The anticipated growth of the network, demographics, and traffic for the region.
- The existing model structure (e.g., three step versus four step).

Three approaches were discussed in the meetings with the TTA consultants:

- Generalized cost assignment technique.
- Toll diversion curves.
- Route-choice model imbedded in the assignment software.

The two most common approaches appear to be the generalized cost and toll diversion methodologies. Generalized cost is implemented during the traffic assignment step by defining toll costs, VOTs, and auto operating costs. The likelihood or utility of choosing a route relative to other routes is determined by the cost of that route weighted by the time and distance of that route. Travel time is expressed as minutes per mile, VOT in dollars per minute, and auto operating costs in dollars per mile.

A second approach alluded to in the meetings but documented in the TTA technical memorandum (TTA 2005) is the toll diversion approach. Zone-to-zone VOTs are developed based on the median zonal income (as reported in the TxDOT TPP zonal socio-economic data) and the median household income for the region. Each zone is assigned a VOT relative to its income level. In this manner, zones that have lower median incomes, and hence lower VOT, have far fewer interactions than pairs from higher-income zones. Therefore, the likelihood is that a lower-income zone producing a toll trip will be significantly lower than a higher-income zone.

The third approach is a route-choice model imbedded in the traffic assignment approach. This appears to be specific to the CUBE travel demand software. The route-choice model is a logit model (probabilistic curve). During assignment, the two shortest-path SKIMs between zone pairs using time and cost are built—toll and non-toll. The demand between the two zone pairs is weighted based on a probabilistic function that splits the demand between non-toll paths and toll paths.

The implementation of a feedback mechanism within the existing rural models is not standard practice. Because congestion levels in the corridor study and the region are minimal, the need to introduce a feedback mechanism to resolve the speeds between those created by traffic assignment and those input into the trip distribution models is considered meaningless for these study areas. More robust areas with greater levels of congestion have already addressed the feedback issue. The following subsections give specific discussions regarding VOT and auto operating costs.

Value of Time

VOT is a measure that can be used to establish the VOT savings relative to the cost of travel. These data are not obtained from traditional household or commercial vehicle surveys. Practices for obtaining estimates of VOT include:

- Reviewing what other study areas of similar size and characteristics are using.
- Using the average wage rate in the study area as a proxy—typically 50 to 70 percent of the average wage rate.

Another deterministic approach can be a review of existing toll roads in the study area since this will provide locally known quantities. Without an existing toll road, though, the preferred method appears to be an SP survey where the opinions of the travelers as well as their income and trip purpose can be collected relative to their likelihood to pay for travel. SP surveys also appear to be used even in areas with existing toll roads where locally specific known qualities exist.

Concerning trucks, a number of potential considerations must be given due diligence during the toll feasibility process:

- Payment method (driver or company).
- Priority of commodity that is being moved.
- Whether the driver is reimbursed or not.
- Independent versus contract drivers.

The VOT for commercial vehicles is significantly higher than general-purpose vehicles. This is typically on orders of magnitude of 2.5 to 3 times the value for automobiles.

Auto Operating Cost

Auto operating cost, which is another input variable to the generalized cost assignment technique, attempts to quantify the operating cost of the vehicle in terms of cost per mile. Typically, auto operating costs are segmented into commercial and non-commercial vehicle types. The most common source of these data is AAA.

Summary

A key finding is the degree of use regarding the existing TxDOT urban travel models and input data. The desire for extensive modifications to the existing models is incongruent with the scope and timing of the toll feasibility analysis. Therefore, the consulting teams will generally work within the existing model framework as much as possible or as much as necessary (depending on the modeling approach criteria). The teams noted that the existing models will be augmented to some degree, such as developing time-of-day demand through the use of directional count data and diurnal factors obtained from the travel surveys. However, this is not always the case since some of the rural models under TxDOT's purview are relatively uncongested, and rapid demographic and concurrent traffic growth is not anticipated.

Modifying, updating, and changing the existing trip length frequency distributions and friction factors that are part of a standard delivery from TxDOT TPP do not appear to be a part of the T&R-level analysis performed by TTA. This honors working within the existing TPP models as much as possible.

Since the primary objective is to determine potential revenue that could be generated by a toll facility, most of the refinements occur within the affected corridor and not at the regional level. Using this approach generally obviates the need to reevaluate model calibration in most instances. In the most basic terms, T&R studies attempt to:

- Replicate existing traffic.
- Assess the likelihood of the forecast network and demographics to occur.

Given that these firms are ultimately responsible for providing project construction cost estimates and potential return on the project, these approaches may or may not be necessary for TPP to consider implementing in the planning models. As noted by the consulting teams, the objectives of the TPP models are different from and should not be confused with models that are necessary for toll feasibility and economic viability studies.

TOLL MODELING IN TEXAS SAM

TxDOT's SAM-V2 (Version 3 was released later in the project) estimates toll demand through the use of the TransCAD GC MMA technique. The implementation of this technique is highlighted by BPR-based volume delay functions that incorporate link delay, intersection delay, and VOT segmented by trip purpose and household income. The VOTs are used in the assignment model to convert toll cost to time equivalents. The VOTs used in SAM-V2 were derived through an analysis of data from the 2009 National Household Travel Survey (NHTS), along with those documented in TDM-related literature and case studies on a national level regarding the relationship of VOTs to wage rates. Reviews of literature, other modeling efforts, and case studies also assisted with the decision of VOT segmentation and appropriate ranges for VOTs in those segments.

The assignment methodology does not appear to incorporate auto operating cost, leaving operating cost sensitivity to the mode-choice component of SAM-V2. With respect to the assignment functions, SAM-V2 uses four different BPR curves for links that vary by road type and three different BPR curves for intersections that vary by intersection control.

Traffic assignment is also part of a model feedback procedure that involves the trip distribution, mode choice, and traffic assignment steps of SAM-V2. As the MMA technique used in SAM-V2 converts tolls to time equivalents, sensitivity to toll costs—in addition to travel time—is brought to the trip distribution and mode-choice components of SAM-V2. In this way, through feedback, equilibrium between post-assignment travel times and travel times used in trip distribution and mode choice is achieved.

CONCLUSIONS

All toll demand modeling performed directly by public agencies in Texas other than for traffic and revenue studies make use or are being modified to make use of a generalized cost traffic assignment to estimate toll demand. Additionally, all but one of the modeling practices among these entities includes feedback of congested impedances to create consistency among assignment travel times and trip distribution impedances. There are differences among these entities as to the type and degree of segmentation among times-of-day, vehicle classes and/or trip purposes that are largely the function of the general transportation planning support that the travel demand model plays in the region (i.e., air quality, transit analysis).

The traffic and revenue-oriented toll demand studies conducted by private consultants attempt to use the existing regional models in an as-is condition as much as possible and supplement the models with data from the corridor being studied. As needed, the consultant-based traffic and revenue modeling will augment the existing regional model to some degree, such as developing time-of-day demand through the use of directional count data and diurnal factors obtained from the travel surveys. However, this is not always the case since some of the rural models under TxDOT's purview are relatively uncongested, and rapid demographic and concurrent traffic growth is not anticipated.

CHAPTER 4: POTENTIAL CHALLENGES TO TOLL MODELING IN CURRENT TXDOT TDM STRUCTURE

INTRODUCTION

This chapter reviews TxDOT's model structure within the context of accounting for tolling in the existing TDM architecture. An element of this review is a discussion of the methods that TxDOT can consider to enhance the tolling capabilities of its current model structure for small to medium-sized study area travel models. The discussion of methods particularly highlights challenges and potential opportunities for consideration by TxDOT TPP associated with the different approaches. The two widely adopted approaches to modeling or accounting for tolls are:

- The generalized cost assignment technique.
- The application of toll diversion curves.

The toll diversion approach uses a probabilistic function to compare non-tolled and tolled paths between zone pairs. Based on information in the origin zone, such as median income, the likelihood of a traveler choosing path A or path B is determined by the cost of the competing routes relative to the zones' distribution of income. Some recent reviews of the toll diversion method suggest issues with convergence when there are competing toll facilities and, hence, the reasonableness of toll-related traffic and revenue estimates. Irrespective of any possible issues with the toll diversion methodology, there is no readily available capability to implement this technique with TxDOT's current modeling software platform. Consequently, this research focused on those aspects of tolling associated with implementing a generalized cost assignment technique, which is gaining greater traction as the preferred method for handling toll-related demand estimates.

As noted previously, a sizeable number of study areas nationally and in Texas have adopted or are moving toward the generalized cost assignment approach. In Texas, three of the four largest study areas (i.e., Austin, San Antonio, and Dallas-Fort Worth) estimate toll demand using an assignment-based technique. The fourth study area, Houston, is moving toward this procedure to replace a mode-choice-based toll demand estimation process. In addition, SAM-V2 estimates toll demand on facilities via the GC multimodal multi-class assignment function (i.e., the MMA technique) available in the TransCAD modeling software platform.

Although the small to medium-sized study areas for which TxDOT develops travel models differ in many characteristics (e.g., study area size, population, urban density, level and amount of recurrent traffic congestion, number of modes being analyzed, temporal segmentation of trip tables) from the four large metropolitan regions, there is strong appeal for considering the same common generalize-cost-based assignment approach used by the four largest urban areas. The generalized cost approach, along with other potential enhancements, appears to be rather portable regardless of study area size. Experience from these earlier applications in the state may prove informative to TxDOT TPP if and when toll considerations are addressed as enhancements to the existing Texas Package.

Many of these enhancements including supplementary improvements, such as time-of-day and speed feedback, can be incorporated into the existing Texas small to medium-sized study area models (when appropriate). Ultimately, it will be TxDOT TPP's decision on the approach and accompanying enhancements adopted. This chapter describes some of these considerations as well as potential challenges associated with each technique.

CONTEXT

With respect to small to medium-sized study areas, three primary concerns are associated with study area suitability:

- Study area characteristics.
- Transportation planning needs.
- Technical/software-related challenges.

Study Area Characteristics

Currently, TxDOT TPP develops and maintains travel models for two study areas—Tyler and Laredo—that contain operational toll roads. Both examples are static fixed-toll facilities. A third study area, Brownsville, is currently constructing SH 550, which will also be a fixed-fee toll facility. However, this facility is not open, nor does it exist in any of the existing Brownsville TDM networks maintained by TxDOT TPP. The current toll road in Tyler is a portion of a larger multi-region facility that will be a part of the adjacent Longview study area. Other urbanized areas, such as Hidalgo County, are considering toll roads, but these are in the planning stages at this time. The Corpus Christi study area is also considering a southern reliever route and possibly managed lanes on the Crosstown Expressway (SH 286) and South Padre Island Drive (SH 358).

El Paso is constructing a variable-priced facility as parallel lanes to the existing Border Highway, which is a fairly uncongested facility that is located between the Rio Grande River and IH 10. However, the approaches and considerations for estimating toll demand on facilities with variable-pricing schemes require additional considerations and further refinements that go beyond fixed-fee toll modeling techniques. This is not to say that some of the approaches and enhancements could not be considered natural links to eventually support and achieve variable-pricing demand estimation capabilities. One example may involve considering the implementation of a mode-choice model as a means to obtain vehicle trips by occupancy levels. Vehicle trips by occupancy can be achieved without the benefit of a mode-choice model, but this approach does not yield transit or nonmotorized trips.

Tyler

The toll road in Tyler, known as Loop 49, is being incrementally constructed in segments and is eventually envisioned as a relief route around the combined Tyler and Longview urbanized cores. The first 5-mile portion (also known as Segment 1) was open and operational in 2006. Subsequent segments west and south of Tyler have since been built, creating a 26-mile loop from IH 20 to SH 110. The initial loop is a two-lane undivided highway, but there is enough right-of-way to accommodate the planned upgrade to a four-lane divided highway. Future segments are in the planning stages with no timeline for completion. The facility is envisioned as a new connection between Tyler, Longview, and Marshall that will intersect with IH 20 at three locations, as illustrated in Figure 13.

The 2007 count on Segment 1 was 700 daily vehicles (adjusted for axles and season). Since 2007, a second count location was added to a newly opened segment of the toll road just beyond Segment 1. The daily count for this location is reported at 2,000 vehicles. Daily traffic volumes on the newly opened sections beyond the two existing segments are not yet available. With improved connectivity, it is reasonable to anticipate that usage will continue to rise. Even with the increase from 700 to 2,000 vehicles per day, this represents only 0.08 percent of the total modeled trips in the recently updated 2007 TDMs. Currently, the level of demand on the existing Loop 49 sections is of little consequence relative to overall vehicle demand in Smith

County. The proportion of travel occurring on Loop 49 would be further diminished if the total trips in the existing 2007 models for the combined region (e.g., Longview and Tyler) were to be examined in aggregate. A portion of the planned Loop 49 alignment in Longview is outside of the existing model area boundary (MAB).

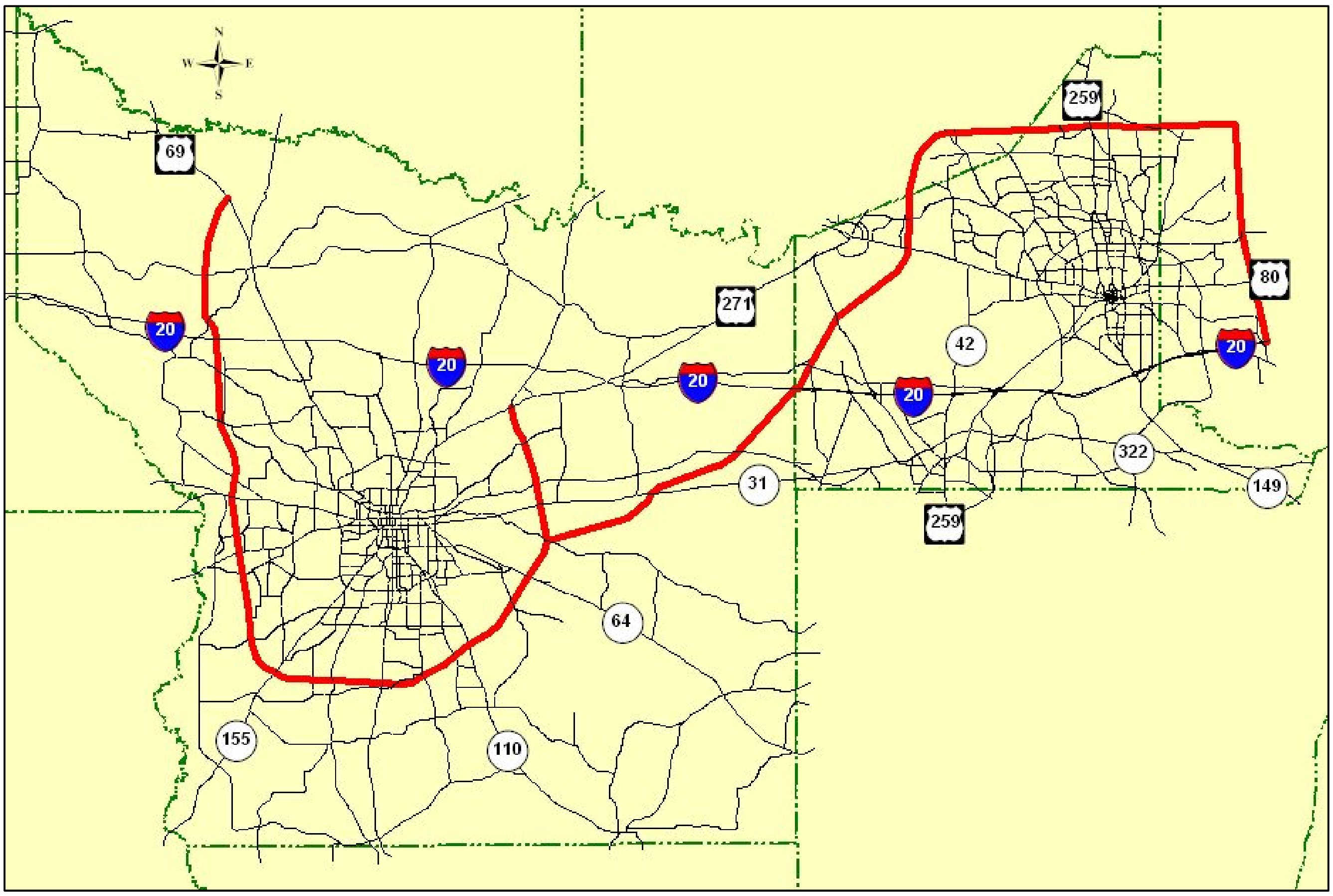


Figure 13. Loop 49 in Tyler/Longview, Texas.

Laredo

TxDOT purchased the Camino-Columbia toll road in Laredo in 2004 after the toll road, which was originally developed by a private consortium of landowners, filed for bankruptcy in 2003. The route is known as SH 255 on the state system, and begins at the Columbia Solidarity International Bridge on the U.S.-Mexico border and terminates at the intersection of IH 35 approximately 16 miles north of Loop 20 inside the urbanized portion of the model area (see Figure 14). The toll road has intersections with FM 1472, FM 338, and US 83, moving west to east to IH 35. For large portions of the facility, the cross section is a two-lane undivided highway with an exception at select intersections where the road becomes divided and additional directional lanes are added.

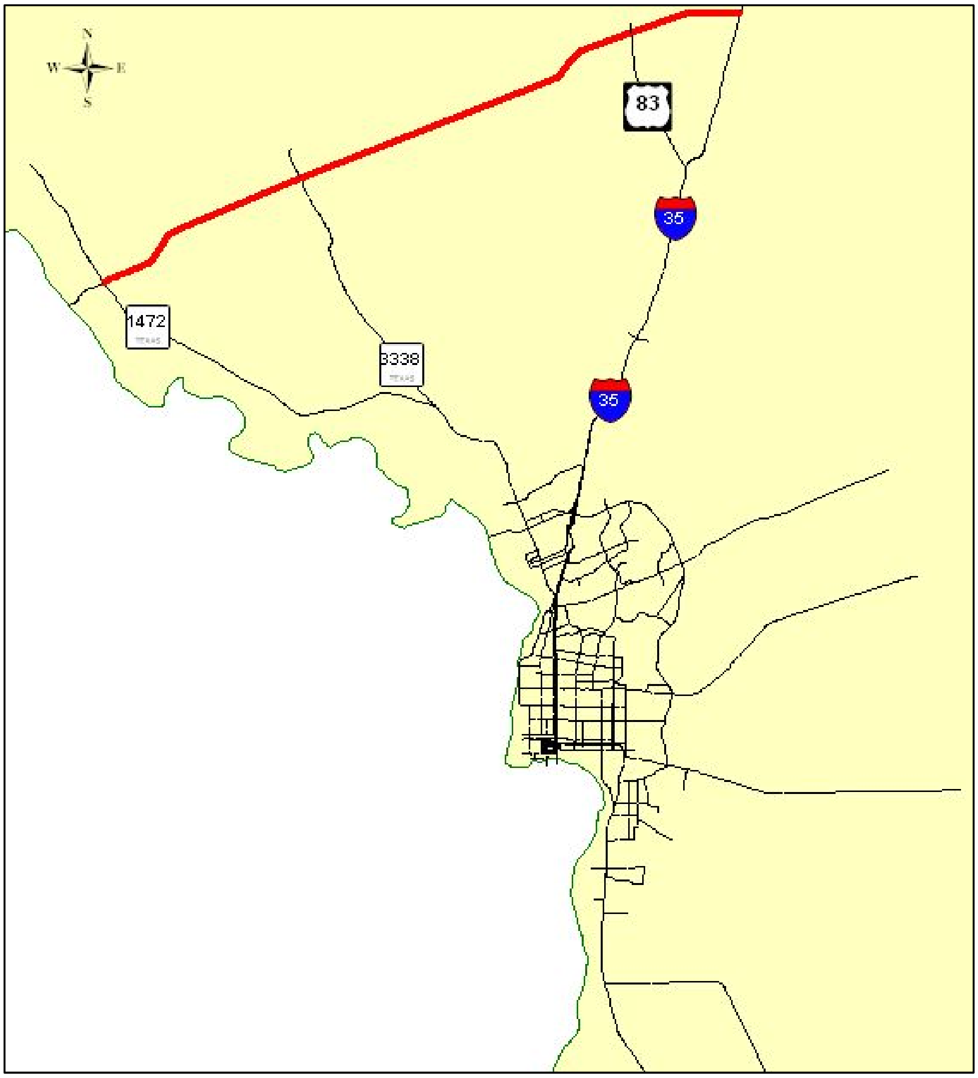


Figure 14. Location of Camino-Columbia Toll Road in Laredo, Texas.

The road was originally intended to serve as a truck bypass to incentivize trucks to not enter the relatively congested urbanized area of downtown Laredo. The facility has a fixed fee for autos and a per-axle fee for trucks, and is completely electronic. At least partially due to U.S. regulations that limit operation of Mexican trucks to an 8-mile radius from the U.S. border, the toll road has been limited in its ability to serve the originally envisioned purpose. For the previous base year travel model, which was 2003, the typical daily count on the Camino Columbia toll road was 600. This represents 0.09 percent of the total modeled 2003 trips in the base year Laredo model. The 2010 count is 630 at the same count location. In either case, this facility is not carrying a significant amount of traffic by any enumeration—daily or by time of day (if the latter was to be estimated).

Similar to Longview, the toll road in Laredo crosses outside of the MAB. Therefore, the network and zone structure are incompatible for portions of the toll road. This would have to be addressed to ensure that intersections/interchanges and zonal loading are addressed appropriately. These two study areas should consider expanding the MAB to improve network compatibility and completeness.

Brownsville

The third study area, Brownsville, is currently constructing a fixed-fee toll road. The Brownsville study area is part of a larger regional MAB that also includes the Harlingen-San Benito and Hidalgo County study areas. The regional model that combines these three MPOs extends beyond the collective MPO boundaries to incorporate all of Cameron and Hidalgo Counties. The original motivation for combining the three individual models was rooted in a potential toll road that would bypass all three study areas and serve as a reliever route to US 83, which begins at the U.S.-Mexican border in Brownsville and runs parallel to the Rio Grande River but through each study area. This planned project has since been temporarily shelved, but Brownsville is constructing SH 550 in the hopes of providing a faster and more reliable connection between the Port of Brownsville with US 77/US 83 (see Figure 15). Similar to the SH 255 toll road in Laredo, SH 550 is intended to reduce the number of trucks bound to and from the port inside the relatively congested urbanized portions (i.e., international port of entries) of the study area in terms of existing demand and anticipated demand as a result of several planned port expansion projects. Once completed, SH 550 will be a four-lane divided highway with frontage roads. The project bypasses existing portions of FM 511 (Indiana Avenue) near the port but eventually merges with the existing alignment for FM 511. The project will add dedicated main lanes, grade-separated interchanges, and frontage roads.

In addition, Brownsville is considering an additional toll road west of US 77/US 281. TxDOT is currently updating the existing 2003 travel models to 2009. Since the toll road is still not open, the SH 550 toll facility will be limited to the 2040 network coding to be included in the forecast application of the updated 2009 model.

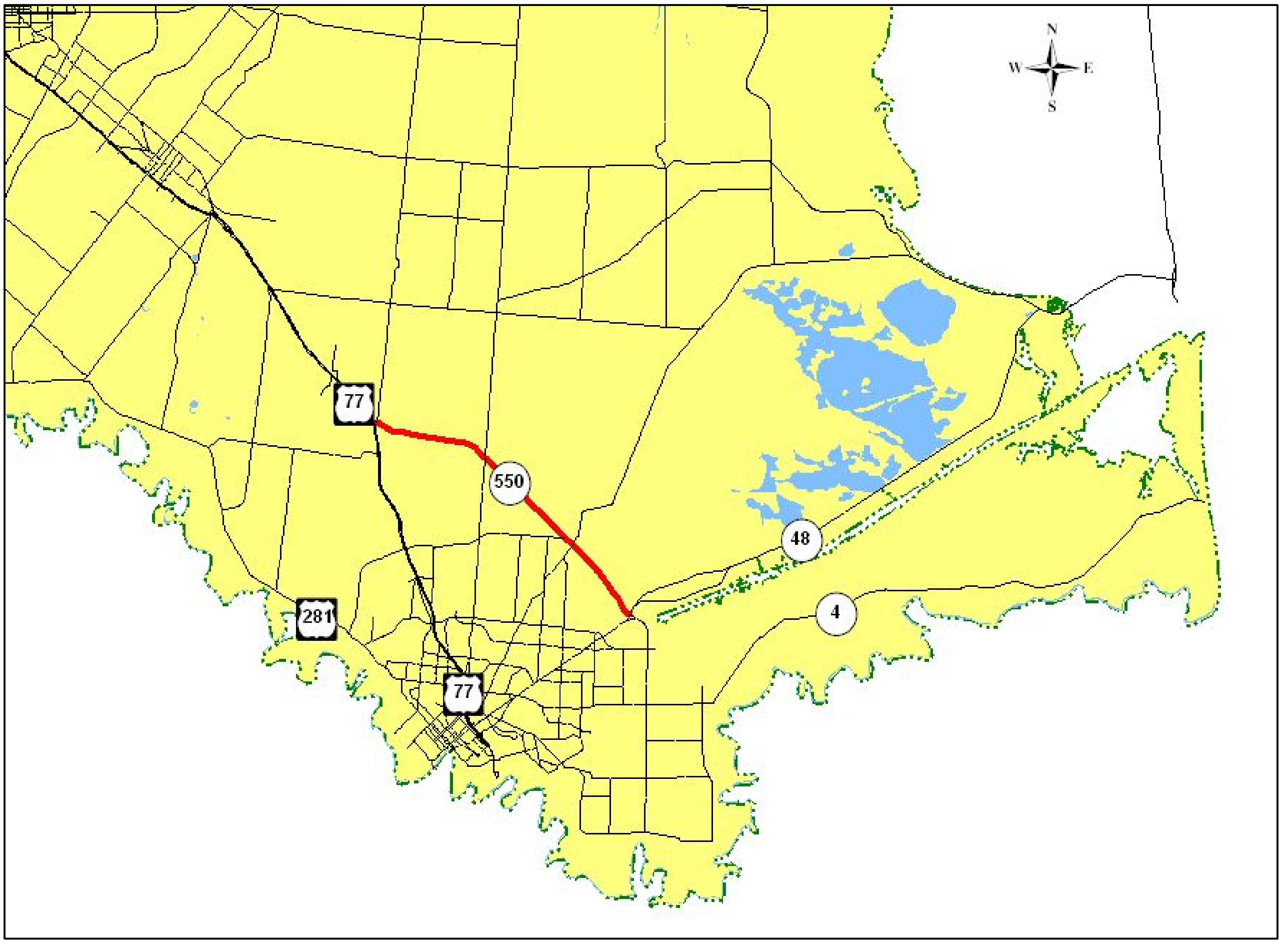


Figure 15. Location of SH 550 in Brownsville, Texas.

Study Area Characteristic Analysis

As evident in the Tyler and Laredo toll road vehicle count data, the level of congestion on the two existing toll roads is of little consequence to relative travel, delay, and congestion. Table 14 compares the base year count on Loop 49 and the Camino-Columbia toll road relative to the corresponding total trips for the base year modeled.

Table 14. Toll Demand Relative to Total Demand (Tyler and Laredo).

Study Area Name	Model Base Year	Sample Toll Count	Total Study Area Modeled Trips	Percent of Toll Trips Relative to Total Trips
Laredo (Comino-Columbia)	2003	600	632,631	0.09%
Tyler (Loop 49 Segment 1)	2007	700	825,806	0.08%

The assigned vehicle trips, when modeled as free facilities, reasonably replicate counts on both facilities. This is probably attributable to the rural nature of the facilities, the number of free uncongested alternatives nearby, and the juxtaposition to any measurable level of congestion. Obtaining reasonable traffic loadings on new facilities in rural portions of the small to medium-sized study areas has typically presented a challenge given location, zone size, and limited demand characteristics. In these instances, though, the free treatment of the toll roads, thus far, has not produced poor results. This, however, cannot be interpreted as the appropriate means with which to account for future demand on these facilities when congestion on competing free alternatives and overall regional demographic growth will most likely occur. In all likelihood, the attractiveness of toll roads will increase with greater levels of congestion elsewhere in the region.

As a means to communicate the challenge associated with modeling rural facilities in small to medium-sized study areas, the total number of zone pairs that contribute trips to existing toll links can be examined. This is accomplished by assigning a trip table containing cell values of ones to the network. The accumulated total on the link is the number of zone pairs that could possibly contribute a volume on the counted links noted previously. In the Tyler and Laredo networks, relatively few zone pairs traverse the counted link in the toll corridor (as measured at the counted link in the network). Table 15 identifies the number of zone pairs contributing trips to the toll links in Tyler and Laredo relative to the total number of zones. The total number of potential zone pairs is obtained by squaring the total number of zones. The number of zone pairs is not uniform across all toll links. Only those with counts are reported in Table 15.

Table 15. Number of Zones Contributing Trips to Counted Toll Links.

Study Area	Zone Pairs	Total Zones	Comment
Laredo	24	229	
Tyler	620	452	Section 1
Tyler	1816	452	Section 2

The lack of demand as measured by the zone pair analysis is probably due in large part to the fact that the type of congestion exhibited in the typical peak periods of the large metropolitan areas in the state simply does not exist in these two study areas, at least relative to the portions of the region served by these toll facilities.

Given the juxtaposition of Loop 49 and SH 255 relative to existing development in the region, it may be quite some time for meaningful toll demand to appear at the currently expected pace of demographic growth in these corridors as well as growth in congested parallel corridors (e.g., Loop 323 in Tyler). Anecdotally, current users of the toll system are using these roads for the access and mobility they provide, not necessarily as a means to bypass diurnal or daily levels of congestion. This may not be true in the forecast model applications given assumed growth projections (see Table 16).

Table 16. Population Growth by Study Area.

County (Study Area)	2013	2040	Absolute Growth	Percent Growth
Smith (Tyler)	216,343	280,634	64,291	29.72%
Greg (Longview)	125,185	160,540	35,355	28.24%
Cameron (Brownsville)	427,195	641,376	214,181	50.14%
Webb (Laredo)	265,932	433,503	167,571	63.01%

Source: Texas State Data Center (TSDC) (2013)

Given current volumes and the incremental expansion, the immediate need for an extremely robust toll schema is not pressing, but as evident in changes to forecast population in Table 16, that may not always be the case.

Transportation Planning Needs

The primary purpose of the TDMs developed by TxDOT TPP is to support the development of MTPs, which are updated on a five-year cycle for most MPOs. Ideally, each MPO would use the travel model as a means to inventory network and demographic information, report vehicle miles traveled (VMT) for the base and forecast application(s), and examine different alternative impacts relative to multiple measures. The travel models have also been used to identify funding gaps between the financially constrained plans and what would be necessary to achieve a certain LOS across all facilities in the region.

The small to medium-sized study areas typically have limited staffing and experience in the development and application of travel models. Additionally, the financial agent in most instances is with the host city. Therefore, resources and demands are often split between MPO and city responsibilities and tasks.

For this reason, care should be given to develop an approach that can satisfy current planning needs and can be easily applied in the context of alternatives analysis among MPOs that are characteristically small with respect to staffing levels. In Texas, refined estimates of toll demand and revenue are performed by third-party contracts typically administered by TxDOT TOD.

Technical/Software-Related Challenges

With respect to the technical context, there are relatively few hurdles for TxDOT TPP to incorporate at least the most minimum enhancements to the existing Texas Package to account for toll roads. At a minimum, a generalized cost assignment technique could be incorporated in small to medium-sized urban area models with existing or planned toll projects. With a few changes to the network attributes, such as toll costs and estimates of VOT (by class segmentation), and some level of trip table stratification, TxDOT TPP should reasonably expect fairly decent estimates of toll demand. Furthermore, TxDOT TPP may want to incorporate time-of-day models for some of the study areas to capture work-related peak travel relative to toll usage.

The more significant enhancements would be associated with the derivation of time-of-day trip tables and how many classes would be sent through the assignment step. For example, TPP may wish to consider stratifying HBW trips by income categories to be able to apply different VOTs during assignment because of the strong correlation between peak-period travel and work-related travel on toll roads. Of course, each of these considerations brings challenges not yet currently encountered in the existing suite of models. These challenges and reasons why TPP may wish to consider potential enhancements are discussed in the next section.

CONSIDERATIONS, CHALLENGES, AND OPPORTUNITIES

The Texas Package is an independent collection of programs that has been integrated into the TransCAD TDM software, which is the adopted TDM platform for TxDOT. With few exceptions, the travel models developed by TxDOT TPP are sequential three-step daily models—trip generation, trip distribution, and traffic assignment. The first two steps in the sequential model platform are performed in the Texas Package, while traffic assignment is accomplished using TransCAD. Trip generation is performed using the TripCAL5 software, while ATOM2 is used to create trips by trip purpose prior to applying traffic assignment (Pearson et al. 1990, 1995; Benson and Hall 1999; Bell and Benson 1991).

With few exceptions, the models are 24-hour or daily models where vehicle trips are generated, distributed, and assigned to a network geography cooperatively developed by TxDOT TPP, the local MPO, and the local TxDOT District Planning Office. The process for applying the Texas Package is documented in an applications manual created for TxDOT TPP by the Texas

A&M Transportation Institute (TTI) (Hall 2007). Specific challenges, opportunities, and considerations regarding the Texas Package relative to iterative speed feedback approaches are thoroughly documented in two additional research reports cooperatively developed by TTI and the Center for Transportation Research at the University of Texas (Reeder et al. 2011, 2012). Many of the issues highlighted in the speed feedback reports are relevant to the tolling considerations in the context of potentially adopting time-of-day modeling and iterative feedback to resolve initial free-flow speeds with congested weighted speeds. Rather than replicating existing documents, this report highlights potential enhancements that TxDOT may wish to adopt in the existing Texas Package, ways these enhancements can be implemented, and any challenges or considerations that TxDOT may wish to take under advisement associated with these enhancements, as described in the following subsections.

Network Geography

The TransCAD modeling software package, like many others, makes it relatively straightforward to perform a generalized cost assignment with the provision of a few key pieces of network information related to the cost of traversing the modeling network.

In the context of TxDOT's standard network database management within TransCAD, the move to generalized cost assignment would have limited effect on the overall structure and content of the standard TxDOT TransCAD network dataview—primarily the inclusion of additional attributes. These fields are relevant for the eventual creation of a network file (*.NET) that is used during two model application steps—trip distribution and trip assignment. The discussion of the impact on the network dataview assumes a model operating in TransCAD version 6.0. Variations of impacts that would be present for models operating in version 4.5 are noted.

Capacity/Speed

The effect of explicit treatment of toll roads as priced facilities on network dataview content may include the need to create one or more dedicated toll road facility types. Either approach can be used to the same effect. If TxDOT uses existing facility types rather than explicitly creating new toll facilities types, it would probably have to use the unique speed and capacity fields to address any possible changes to these two operational characteristics. The speed-capacity utility available in the TransCAD add-on menu item uses the data annotated in the unique speed and capacity fields by overwriting the standard speed and capacity data for the corresponding facility type, lane, and area type definition. The toll links are identified as those links having a cost greater than zero in a new toll cost attribute field. This is consistent with how toll roads were initially addressed in the existing El Paso travel models when a toll road was not explicitly included in the initial list of facility types (current or planned). The specific speeds for these facilities were annotated in the unique speed field in the network dataview. The toll road speeds in this example are significantly higher than the corresponding daily speed for the same facility type. This approach was an attempt to address travel time reliability and corresponding attractiveness that should be inherent with a managed lane, albeit in a daily environment.

If TxDOT chooses to add an additional facility type to further distinguish toll roads in the network geography, the existing facility type/functional classification has room to expand beyond the current 22 facility types and 8 functional classes. Capacities and initial speeds specific to toll roads (freeways and/or arterials) could be developed and used in network specification. To the extent daily modeling of toll facilities is performed as part of any toll demand analysis procedures, sets of capacities will need to be developed that distinguish toll roads from functionally equivalent non-toll roads. When discussing daily capacities, which are used in the current practice at TxDOT TPP, TxDOT may wish to adopt different assumptions involving the following factors that affect capacity derivation, such as the "K" factor (ratio of peak-hour volume/daily volume), percent trucks, and lane use.

For small to medium-sized study areas that have limited daily congestion, reducing the capacity assumptions for toll links would probably be done to achieve greater diversion of travel from toll roads to other roadways. This is partially done to offset the attractiveness of these facilities that are the results of assumed higher (relative to non-toll road) speeds. The balance of higher speeds but lower capacity assumptions is also done to allow the toll road to operate at a higher LOS than traditional freeways. Where congestion is limited, the higher speeds may make the toll road overly attractive relative to competing facilities.

An approach that would forgo daily modeling of toll demand in favor of a move toward time-of-day models would still require speeds and capacities to be estimated for the toll road facility type(s) in addition to all other roadway classes. The existing TxDOT method for estimating daily capacities has its roots in hourly capacity assumptions. Therefore, the ability to estimate peak-period capacities for existing TxDOT roadway classes would likely be straightforward. In the context of resolving speeds in the sequential model process, TxDOT may wish to consider the implementation of free-flow speeds as a part of the standard practice (when feedback is justified based on congestion levels in the region).

Impedance Function Inputs

Although impedance functions are a characteristic of assignment, the nature of the functions and the method of assignment in which they are invoked impact the network dataview with respect to data items that would need to be created, populated, and maintained for some or all links in a network line layer.

Currently, TxDOT TPP traffic assignment practice uses a traditional BPR function but with estimated congestion-weighted speeds rather than free-flow speeds. The link impedance is based solely on the link travel time that is derived from speeds obtained through a facility type/area type cross-classified look-up table. The speeds in the network geography represent daily speeds and are based on a generalized cost function that tries to minimize speed differences in the functional class hierarchy because of the lack of congestion in most of the small to medium-sized study areas. Two additional fields in the VDF are also annotated in the network dataview—alpha and beta. TxDOT, through the use of capacities and alpha/beta, attempts to mimic LOS E capacities. TxDOT can modify the alpha and beta to simulate different LOS conditions when warranted. For small to medium-sized study areas with limited capacity-related issues, it is sometimes necessary to modify the alpha and beta parameters of the standard BPR volume-delay function to achieve diversion. Modifying these variables is limited on a case-by-case basis. In addition, alpha and beta can be varied by functional class. Examples include changing these parameters on centroid connectors to achieve desired loadings for a given area type. This could be done on toll road links to mimic a higher LOS (e.g., LOS C). The speed-based link impedance is stored in a dataview field labeled as TIME, as shown in Figure 16.

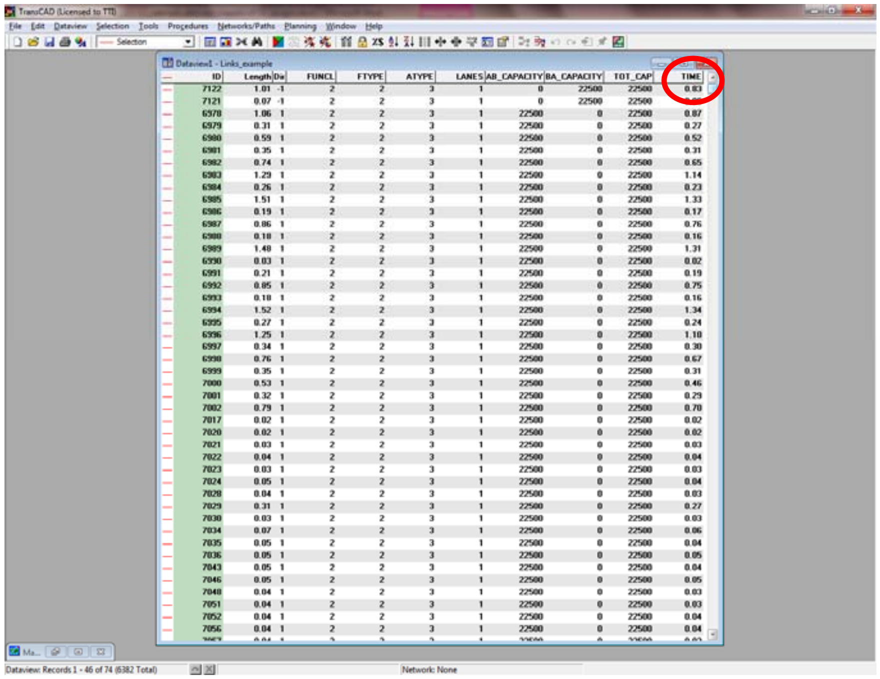


Figure 16. Standard TxDOT Model Dataview.

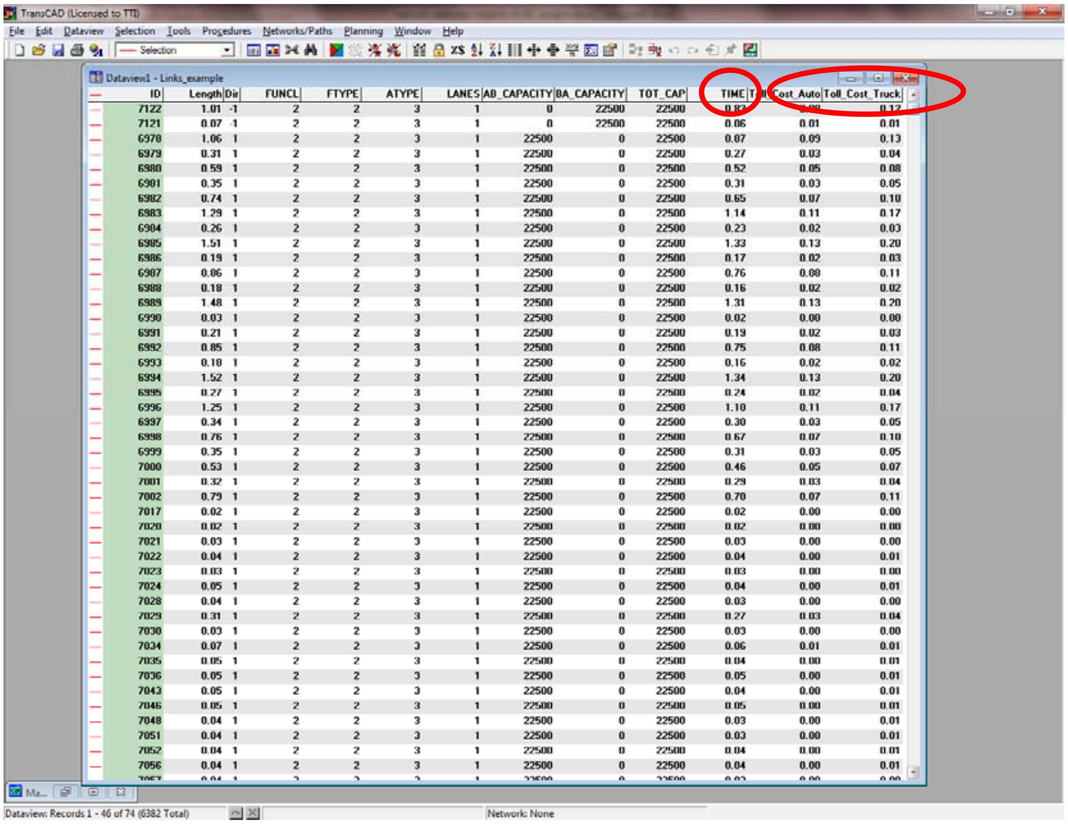
In addition to time, two additional fields to distinguish whether the link intersection is signalized or unsignalized could be added to the dataview (e.g., NCTCOG). These are used to support NCTCOG's customized VDF equation that incorporates traffic control delay and traditional link congestion delay. Adoption of such an approach would require fundamental changes to how TxDOT inventories roadways and calibrates models to account for delay. This would be an additional MPO responsibility during the travel model network geography update process. This also assumes that the delay characteristics at the intersection are consistent in the forecast application(s).

Toll Cost

In order to expand the definition of link impedance to include toll cost, the standard TxDOT network dataview would have to be modified to include a field to carry the toll cost for tolled links. If toll costs were segmented in any way, for instance among vehicle class (e.g., passengers cars, commercial/heavy-duty trucks, or service/light-duty trucks), the network dataview would need to be expanded further to include dedicated toll cost fields that mirror the desired segmentation. The total link impedance would then be derived using the following generic expression of cost-based impedance (generalized cost), which is expressed in dollars:

$$\text{Impedance} = \text{Travel Time} * (\text{VOT}) + \text{Toll Cost} \qquad (4.1)$$

An example of such a modification in which there is segmentation of auto and truck tolling is shown in Figure 17.



ID	Length	Dir	FUNCL	FTYPE	ATYPE	LANES	AB_CAPACITY	BA_CAPACITY	TOT_CAP	TIME	Toll_Cost_Auto	Toll_Cost_Truck
7122	1.01	-1	2	2	3	1	0	22500	22500	0.83	0.08	0.12
7121	0.07	-1	2	2	3	1	0	22500	22500	0.06	0.01	0.01
6978	1.06	1	2	2	3	1	22500	0	22500	0.07	0.09	0.13
6979	0.31	1	2	2	3	1	22500	0	22500	0.27	0.03	0.04
6980	0.59	1	2	2	3	1	22500	0	22500	0.52	0.05	0.08
6981	0.35	1	2	2	3	1	22500	0	22500	0.31	0.03	0.05
6982	0.74	1	2	2	3	1	22500	0	22500	0.65	0.07	0.10
6983	1.29	1	2	2	3	1	22500	0	22500	1.14	0.11	0.17
6984	0.26	1	2	2	3	1	22500	0	22500	0.23	0.02	0.03
6985	1.51	1	2	2	3	1	22500	0	22500	1.33	0.13	0.20
6986	0.19	1	2	2	3	1	22500	0	22500	0.17	0.02	0.03
6987	0.86	1	2	2	3	1	22500	0	22500	0.76	0.08	0.11
6988	0.18	1	2	2	3	1	22500	0	22500	0.16	0.02	0.02
6989	1.48	1	2	2	3	1	22500	0	22500	1.31	0.13	0.20
6990	0.03	1	2	2	3	1	22500	0	22500	0.02	0.00	0.00
6991	0.21	1	2	2	3	1	22500	0	22500	0.19	0.02	0.03
6992	0.85	1	2	2	3	1	22500	0	22500	0.75	0.08	0.11
6993	0.18	1	2	2	3	1	22500	0	22500	0.16	0.02	0.02
6994	1.52	1	2	2	3	1	22500	0	22500	1.34	0.13	0.20
6995	0.27	1	2	2	3	1	22500	0	22500	0.24	0.02	0.04
6996	1.25	1	2	2	3	1	22500	0	22500	1.10	0.11	0.17
6997	0.34	1	2	2	3	1	22500	0	22500	0.30	0.03	0.05
6998	0.76	1	2	2	3	1	22500	0	22500	0.67	0.07	0.10
6999	0.35	1	2	2	3	1	22500	0	22500	0.31	0.03	0.05
7000	0.53	1	2	2	3	1	22500	0	22500	0.46	0.05	0.07
7001	0.32	1	2	2	3	1	22500	0	22500	0.29	0.03	0.04
7002	0.79	1	2	2	3	1	22500	0	22500	0.70	0.07	0.11
7017	0.02	1	2	2	3	1	22500	0	22500	0.02	0.00	0.00
7020	0.02	1	2	2	3	1	22500	0	22500	0.02	0.00	0.00
7021	0.03	1	2	2	3	1	22500	0	22500	0.03	0.00	0.00
7022	0.04	1	2	2	3	1	22500	0	22500	0.04	0.00	0.01
7023	0.03	1	2	2	3	1	22500	0	22500	0.03	0.00	0.00
7024	0.05	1	2	2	3	1	22500	0	22500	0.04	0.00	0.01
7028	0.04	1	2	2	3	1	22500	0	22500	0.03	0.00	0.00
7029	0.31	1	2	2	3	1	22500	0	22500	0.27	0.03	0.04
7030	0.03	1	2	2	3	1	22500	0	22500	0.03	0.00	0.00
7034	0.07	1	2	2	3	1	22500	0	22500	0.06	0.01	0.01
7035	0.05	1	2	2	3	1	22500	0	22500	0.04	0.00	0.01
7036	0.05	1	2	2	3	1	22500	0	22500	0.05	0.00	0.01
7043	0.05	1	2	2	3	1	22500	0	22500	0.04	0.00	0.01
7046	0.05	1	2	2	3	1	22500	0	22500	0.05	0.00	0.01
7048	0.04	1	2	2	3	1	22500	0	22500	0.03	0.00	0.01
7051	0.04	1	2	2	3	1	22500	0	22500	0.03	0.00	0.01
7052	0.04	1	2	2	3	1	22500	0	22500	0.04	0.00	0.01
7056	0.04	1	2	2	3	1	22500	0	22500	0.04	0.00	0.01
7057	0.04	1	2	2	3	1	22500	0	22500	0.03	0.00	0.00

Figure 17. Example TPP Model Dataview (Modified for Inclusion of Segmented Toll Cost).

Vehicle Operating Cost

Recently, there has been debate among model practitioners about the need or advisability of including vehicle operating costs in the generalized cost assignment procedure, especially when demand is segmented among multiple modes, vehicles classes, trip purposes, and/or times of day. Indeed, TransCAD itself does not include the ability to directly specify segmented vehicle operating cost in the MMA assignment option. To include estimates of auto operating costs by class, the network dataview would have to be modified to include additional composite cost fields (by class). These fields would store the combined toll and vehicle operating cost across the link. The composite approach, as noted previously, is similar to the approach used by NCTCOG.

The composite cost field would be annotated as a "total_cost" field, and the number of additional fields would be determined by the number of segmented trip purposes. For example, if the trip table is simply segmented into auto and truck, then there would be two additional "total_cost" fields added for the corresponding market segmentation in the network dataview. Without any segmentation, there would only be one "total_cost" field. The derivation of impedance by class would be represented by the following formula:

$$\text{Auto Impedance} = \text{Travel Time} * (\text{VOT}) + \text{Total\_Cost\_Auto} \quad (4.2)$$

or

$$\text{Truck Impedance} = \text{Travel Time} * (\text{VOT}) + \text{Total\_Cost\_Truck} \quad (4.3)$$

where:

- Total_Cost = Auto Operating Cost + Toll.

Figure 18 provides an example of how cost could potentially be segmented by class. In this example, only two classes are used—autos and trucks.

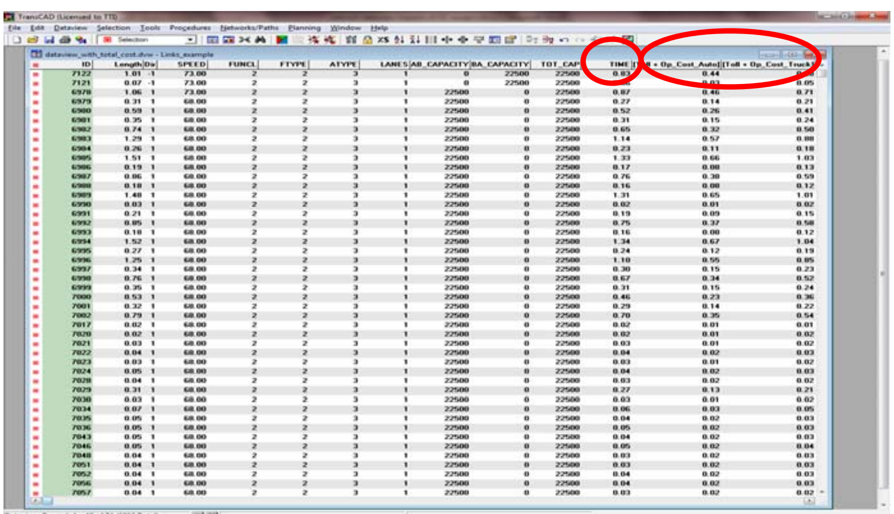


Figure 18. Example Network Dataview to Include a Composite Cost (Auto Operating Cost).

Figure 19 illustrates the impact on the network dataview if vehicle operating costs are included but not segmented. The cost impedance in the single demand table would be represented by the following generic terms:

$$\text{Impedance} = \text{Travel Time} * (\text{VOT}) + \text{Total Cost} \qquad (4.4)$$

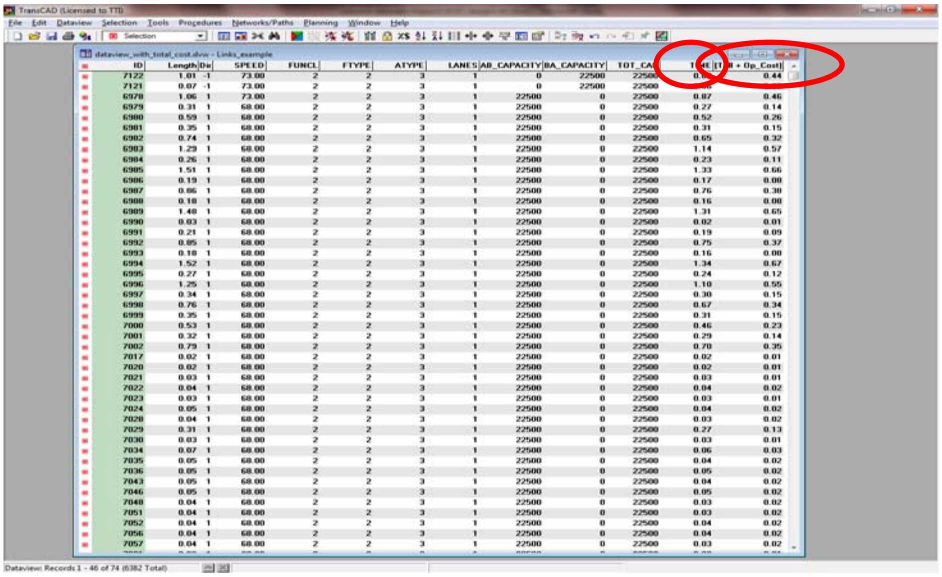
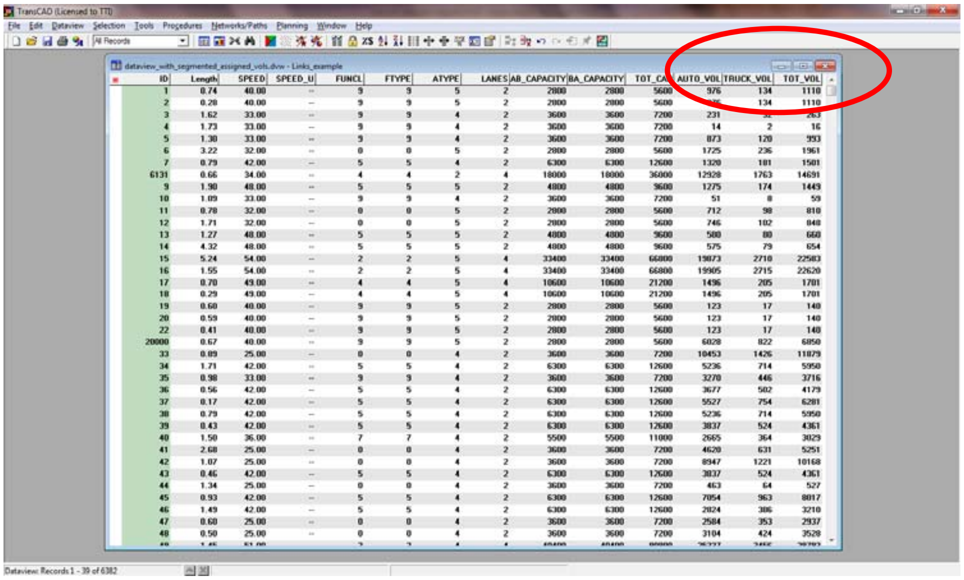


Figure 19. Example Network Dataview with Unsegmented Total Cost.

Assignment Volumes

Using multiple demand tables (e.g., auto and trucks), the MMA option produces assigned link volumes (LINKFLOW) for each demand segment. TxDOT can choose to publish these results as a single link volume by summing the total, which is provided in the binary output file, or TxDOT can preserve each segment volume field in the network dataview. An example of what such a modified dataview would look like appears in Figure 20.



ID	Length	SPEED	SPEED_U	FUNCL	FTYPE	ATYPE	LANES	AB_CAPACITY	BA_CAPACITY	TOT_CA	AUTO_VOL	TRUCK_VOL	TOT_VOL
1	0.74	40.00	--	9	9	5	2	2800	2800	5600	976	134	1110
2	0.28	40.00	--	9	9	5	2	2800	2800	5600	[illegible]	134	1110
3	1.62	33.00	--	9	9	4	2	3600	3600	7200	231	[illegible]	263
4	1.73	33.00	--	9	9	4	2	3600	3600	7200	14	2	16
5	1.30	33.00	--	9	9	4	2	3600	3600	7200	873	120	993
6	3.22	32.00	--	0	0	5	2	2800	2800	5600	1725	236	1961
7	0.79	42.00	--	5	5	4	2	6300	6300	12600	1320	181	1501
6131	0.66	34.00	--	4	4	2	4	18000	18000	36000	12928	1763	14691
9	1.90	48.00	--	5	5	5	2	4800	4800	9600	1275	174	1449
10	1.09	33.00	--	9	9	4	2	3600	3600	7200	51	8	59
11	0.78	32.00	--	0	0	5	2	2800	2800	5600	712	98	810
12	1.71	32.00	--	0	0	5	2	2800	2800	5600	746	102	848
13	1.27	48.00	--	5	5	5	2	4800	4800	9600	580	80	660
14	4.32	48.00	--	5	5	5	2	4800	4800	9600	575	79	654
15	5.24	54.00	--	2	2	5	4	33400	33400	66800	19873	2710	22583
16	1.55	54.00	--	2	2	5	4	33400	33400	66800	19905	2715	22620
17	0.70	49.00	--	4	4	5	4	10600	10600	21200	1496	205	1701
18	0.29	49.00	--	4	4	5	4	10600	10600	21200	1496	205	1701
19	0.60	40.00	--	9	9	5	2	2800	2800	5600	123	17	140
20	0.59	40.00	--	9	9	5	2	2800	2800	5600	123	17	140
22	0.41	40.00	--	9	9	5	2	2800	2800	5600	123	17	140
20000	0.67	40.00	--	9	9	5	2	2800	2800	5600	6028	822	6850
33	0.89	25.00	--	0	0	4	2	3600	3600	7200	10453	1426	11879
34	1.71	42.00	--	5	5	4	2	6300	6300	12600	5236	714	5950
35	0.98	33.00	--	9	9	4	2	3600	3600	7200	3270	446	3716
36	0.56	42.00	--	5	5	4	2	6300	6300	12600	3677	502	4179
37	0.17	42.00	--	5	5	4	2	6300	6300	12600	5527	754	6281
38	0.79	42.00	--	5	5	4	2	6300	6300	12600	5236	714	5950
39	0.43	42.00	--	5	5	4	2	6300	6300	12600	3837	524	4361
40	1.50	36.00	--	7	7	4	2	5500	5500	11000	2665	364	3029
41	2.68	25.00	--	0	0	4	2	3600	3600	7200	4620	631	5251
42	1.07	25.00	--	0	0	4	2	3600	3600	7200	8947	1221	10168
43	0.46	42.00	--	5	5	4	2	6300	6300	12600	3837	524	4361
44	1.34	25.00	--	0	0	4	2	3600	3600	7200	463	64	527
45	0.93	42.00	--	5	5	4	2	6300	6300	12600	7054	963	8017
46	1.49	42.00	--	5	5	4	2	6300	6300	12600	2824	386	3210
47	0.60	25.00	--	0	0	4	2	3600	3600	7200	2584	353	2937
48	0.50	25.00	--	0	0	4	2	3600	3600	7200	3104	424	3528

Figure 20. Example Modified Network Dataview Maintaining Volumes by Class.

Trip Generation

TxDOT TPP uses the TripCAL5 software to generate daily vehicle trip ends by trip purpose. The maximum number of trip purposes for any given TriPCAL5 control file is limited to 10. Additional control files can be created if the number of trip purposes exceeds 10. A modification that TxDOT may wish to consider as a part of accounting for tolls is trip table segmentation (i.e., different vehicle classes). Segmentation by time of day could be developed at the trip generation level, although this sort of segmentation has historically been performed after trip distribution. Rarely are trip tables generated by time of day.

The trip tables are generated by the TripCAL5 software and carried through the sequential model process for eventual inclusion in a generalized cost assignment procedure. In the context of generalized cost, different VOTs and toll rates can be applied to different classes in a multimodal assignment procedure.

Sensitivity to tolling is generally influenced by the traveler's perceived VOT, the cost of the toll, and auto operating costs (expressed in marginal terms, such as cost of fuel, parking, or other out-of-pocket expenses). VOT is a perceived measure that can be used to equate travel time savings based on the cost of travel between competing routes. VOTs are heavily influenced by the income level of the traveler, trip purpose, time of day, and perceived travel time reliability. It is not a uniform value across all users, classes, or time. In the case of the existing toll roads in small to medium-sized study areas, the cost of the tolls is uniform for all autos, regardless of vehicle occupancy levels, but different for commercial vehicles based on the number of axles.

TxDOT will need to consider class segmentation that focuses on separation of trucks from autos if vehicle class segmentation is desired for modeling of existing toll roads. Trucks could be further stratified into internal and external commercial vehicle classes since the internal truck-taxi trip purpose commonly used in Texas typically captures delivery trucks and other types of heavier vehicles excluding the large 18-wheel cargo carriers normally associated with long-haul external freight. Segregating external trucks may eventually lead to further segmentation into ownership classes as a means to refine estimates of VOTs by truck characteristic. This is in and of itself challenging, and national practice reveals an array of VOT estimates that are not consistent from region to region. In addition to having sensitivity to real differences in VOT, further stratification of truck classes aligns with the different toll costs of trucks by axle. Given the challenges of estimating VOT for truck segments, TxDOT may wish to segment autos by occupancy class. Even though the toll roads are currently fixed for autos, regardless of occupancy, this may not necessarily hold true for the forecast.

Figure 21 is an example of what the trip table hierarchy might look like using the stratification of internal and external truck trips. In this instance, there would be three tables assigned using the MMA in TransCAD—autos, internal trucks, and external trucks.

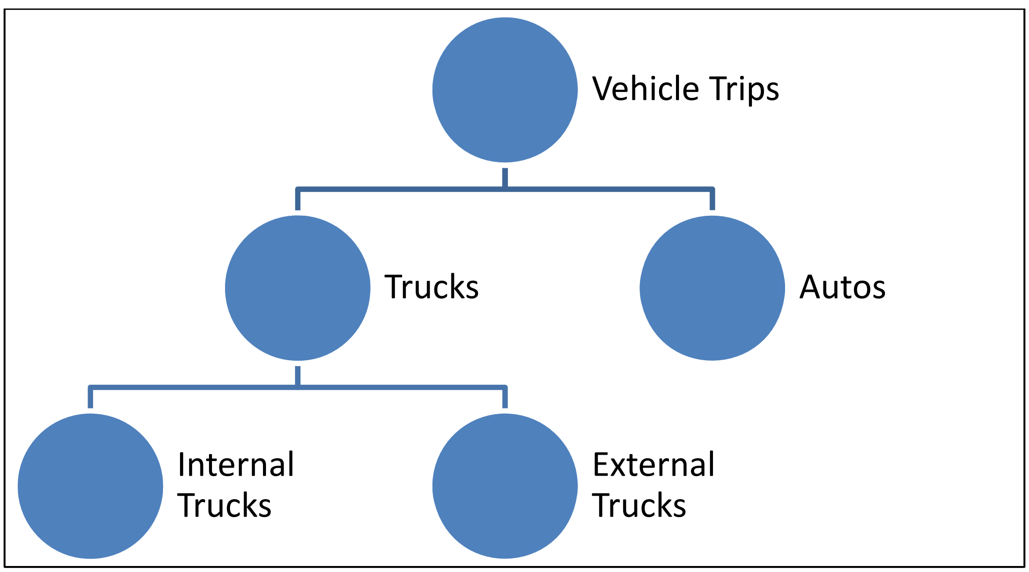


Figure 21. Potential Truck Partition.

As noted in the summary of Texas practice, the decision to migrate to finer market segmentation, especially for trucks, could be based on the percent of truck trips as a part of overall travel in the region or, more likely, the anticipated travel in the specific corridor of study. The decision to pivot to additional truck purposes or classes could be based on corridor-specific information, which would be consistent with the approach used by TTA during toll demand and revenue estimation. If it is anticipated or observed that there are a significant number of trucks in the general area of the planned toll road, additional stratification of trucks may occur to better capture the axle-based costs.

With respect to the four regions currently with toll roads or that will shortly have operational toll roads, Figure 22 provides the percent of internal truck-taxi trips for *internal* travel only (i.e., it does not include external travel). In all cases, internal truck travel is fairly insignificant to overall travel compared to other internal travel (e.g., summation of HBW, HBNW, NHB, and non-home-based external-local [NEXLO]).

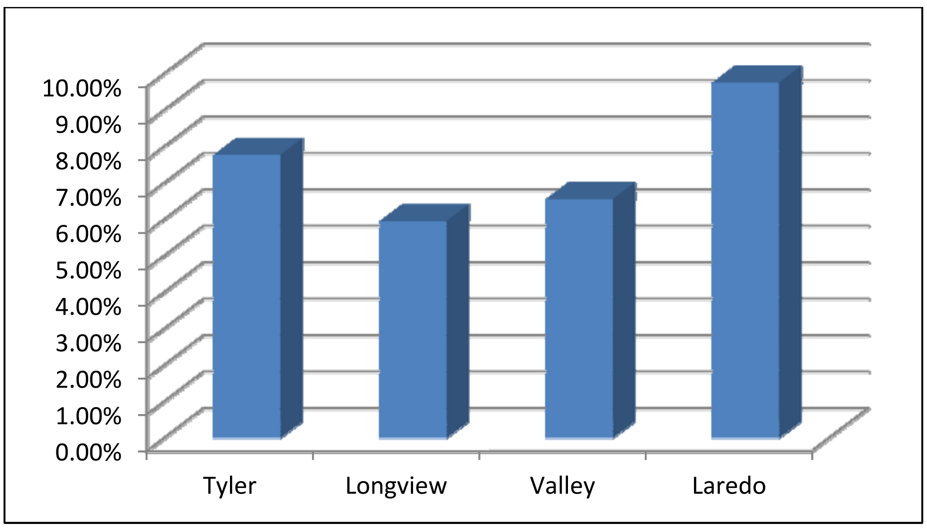


Figure 22. Percent of Internal Truck-Taxi Trips Relative to Total Internal Travel (Base Year Model).

Further consideration could be given to segregating external travel by class if the data are available to support such an endeavor. Three of the four study areas distinguish between commercial truck and auto-related external travel. In Tyler, Longview, and the Lower Rio Grande Valley, where Brownsville is one of the three MPOs in the joint region model, both the external-local and external-thru trip tables are distinguished by auto or commercial vehicles. This capability is derived directly from external station survey data gathered specifically to support the development of the base year models in these study areas. The gathering of these segmented external travel data has been put on hiatus due to concerns about the roadside interview approach to data collection. Testing of alternative data collection methods is being undertaken; however, currently there is no active data collection of data on the part of TxDOT that would allow for the segmentation of external travel into two aggregate classes—autos and trucks.

Within the current Laredo travel models, only external-local travel is divided into the two classes—autos and trucks. The external-thru trip table represents total vehicles. However, TxDOT may wish to consider preserving the external trip tables by class as another means to differentiate toll costs and VOT by external class. Figure 23 reveals what the hierarchy of trips may look like in instances where robust external data exist. In this instance, four trip tables are assigned. In the auto hierarchy, the internal auto trip table represents HBW, HBNW, NHB, and additional non-resident travel, NEXLO.

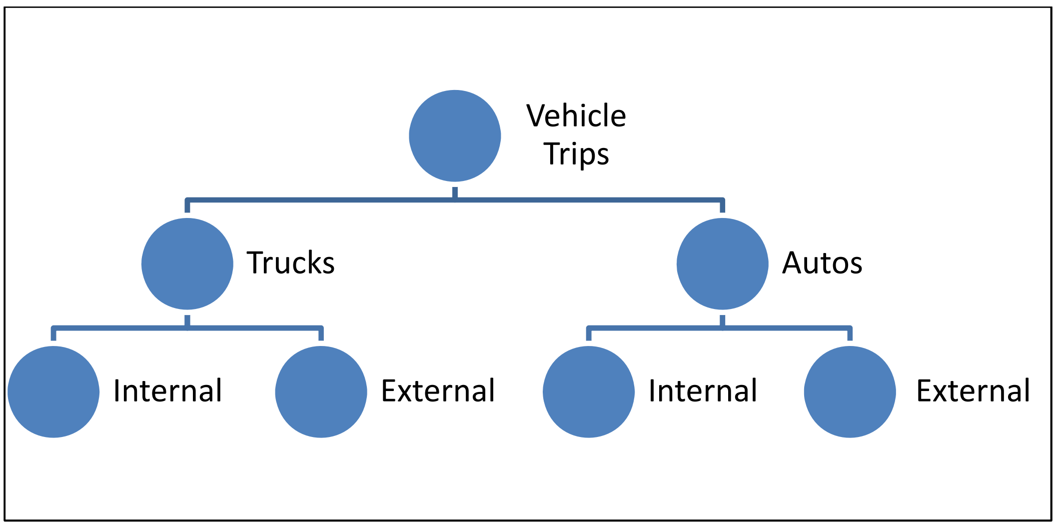


Figure 23. Potential Trip Table Configuration for Assignment.

Figure 24 shows the percent of external-local (EXLO) and external through (EXTHRU) auto and truck trips relative to total trips in each study area based on the latest available base year model data. Of interest is the amount of external travel in each of these study areas since long-distance trips are sensitive to time and cost. Of particular note is the overall percentage of external travel (not including additional internal trips made by non-residents) in the Longview study area. External travel represents a significant proportion of overall trips as well as subsequent VMT. As noted previously, consideration should be given to expanding the MAB of this study area to minimize the influence of external travel on overall travel and to capture the future proposed alignment of Loop 49.

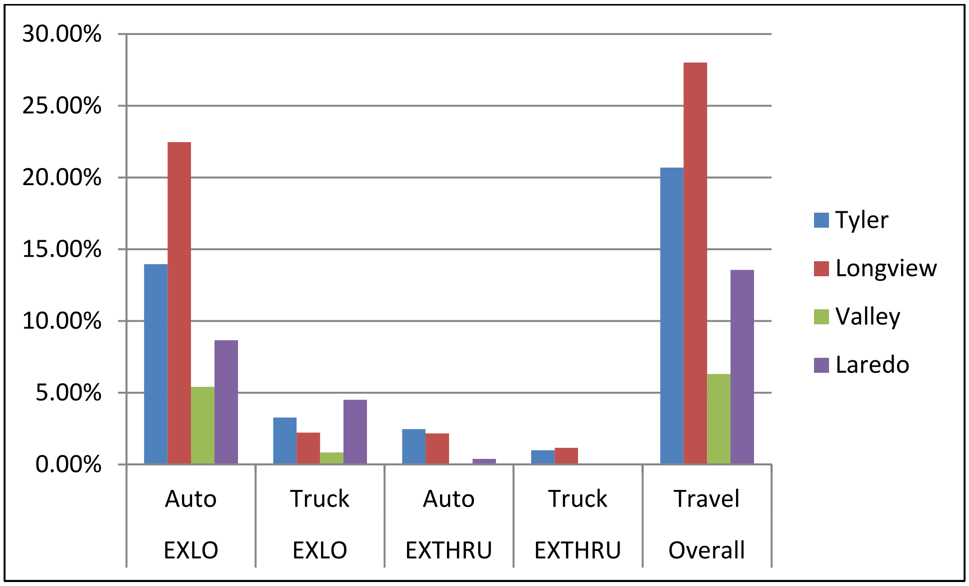
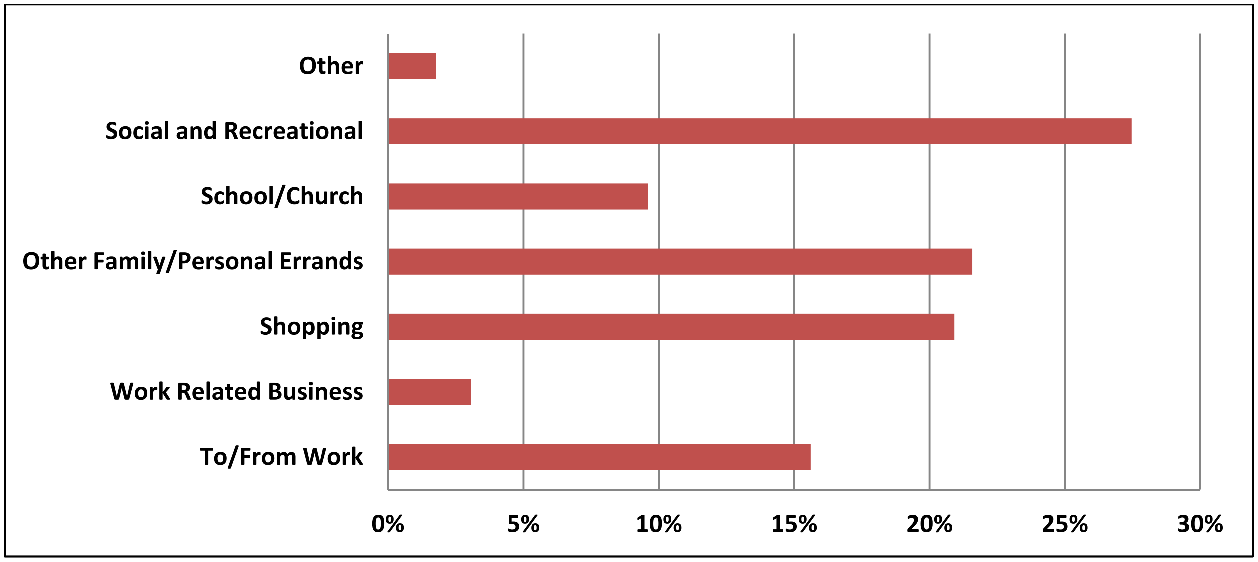


Figure 24. External Travel Relative to Overall Travel for Tyler, Longview, Rio Grande Valley, and Laredo.

Figure 25 depicts the 2009 NHTS distribution of trips by trip purpose. Although the trip purposes in Figure 25 are labeled slightly differently than those presented for Texas-specific trip purposes, the observations are similar to those presented for Texas study areas. In Figure 25, the highest number of trips is associated with non-work-related purposes, such as social/recreational, errands, and shopping, which are commonly referred to as HBNW and NHB trip purposes. In the four Texas examples, HBNW and NHB trip purposes represent the two highest daily trip types (excluding additional internal trips made by non-residents), and truck-taxi typically represents the least prevalent trip type. Figure 26 illustrates the distribution of trips by trip purpose for the four study areas—Tyler, Longview, the combined Rio Grande Valley area (including Brownsville), and Laredo. The model data years used for this analysis for the four study areas are 2007, 2007, 2004, and 2003, respectively.



Source: *Santos et al. (2011)*

Figure 25. 2009 NHTS Trip Distribution by Trip Purpose.

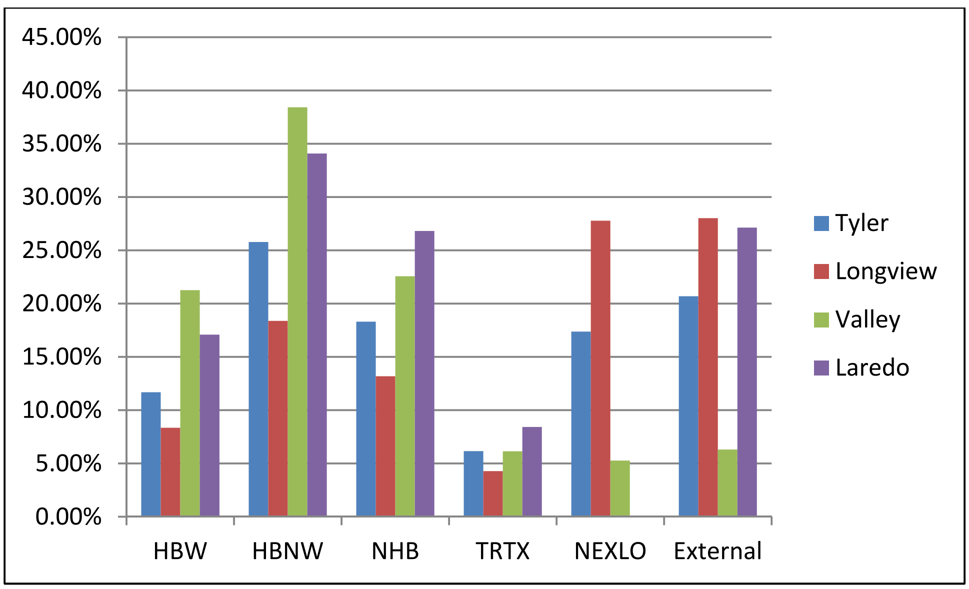
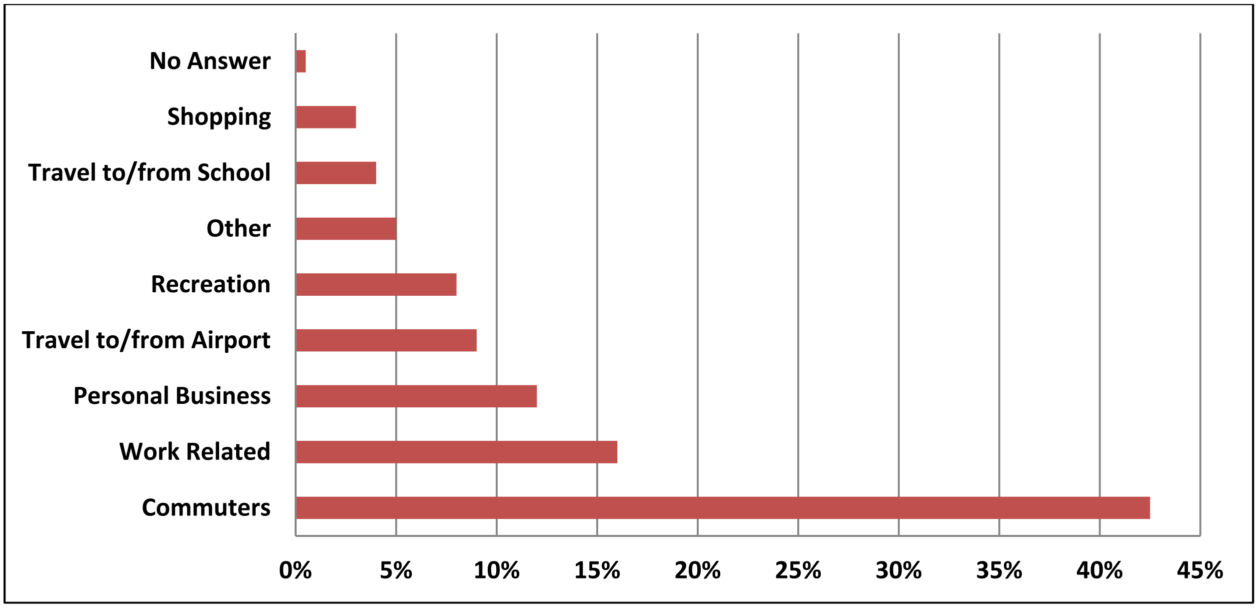


Figure 26. Distribution of Trips for Tyler, Longview, Rio Grande Valley, and Laredo.

With respect to toll roads, this information is significant relative to the orientation of trips on existing toll roads in Texas. Based on data originally obtained from TxDOT-TTA, Figure 27 illustrates the types of trips being made on toll roads. The top two trip types on toll roads are associated with work-related travel.



Source: TTA (undated)

Figure 27. Trip Distribution by Activity on Toll Roads.

Given this knowledge, TxDOT could give further consideration to an additional segmentation among internal auto trips. Having already segregated TRTX trips to preserve this trip as an individual trip table during an MMA assignment, the remaining auto trips could be divided into HBW and all other remaining internal trip purposes combined (i.e., NHB, HBNW, and NEXLO) as a means to account for the information presented in Figure 27. In this manner, a VOT could be estimated for the work-related trip purpose. It is unclear how meaningful segregating work trips is in a daily model, given that most work trips primarily occur in the morning and evening peak. Therefore, having a VOT variable for work trips in a 24-hour model may not be as beneficial in the absence of temporal distribution of these trips.

The toll costs for work and other internal non-truck travel would be consistent with other two-axle vehicles—fixed. Consequently, toll costs have little bearing on this discussion. A more meaningful segmentation may be stratifying the work trip purpose into income classes by preserving the production and attractions by income group from the trip generation models. The Texas Package trip production model is a cross-classification procedure that uses five income and five household size categories. TripCAL5, though, could support any number of income stratifications. It is a matter of how the travel survey data are processed and structured. Such income segmentation would acknowledge that a traveler's VOT is sensitive to cost relative to that traveler's income level.

The trip table segregation could look similar to that presented in Figure 28, where eventually nine trip tables (shown in yellow) are generated, distributed, and assigned (assuming that production rates continue to be stratified by five income categories). The added benefit of preserving income segmentation (and not only for work-related trips) is the ancillary capability to perform income-related analyses at greater degrees of sensitivity by tying trips to income levels and to zones that contribute those trips on specific corridors (i.e., toll roads). Given the time-of-day variability of work-related trip purposes, TxDOT may wish to consider developing time-of-day models to capture the trip-making characteristics of this trip purpose to produce more meaningful results.

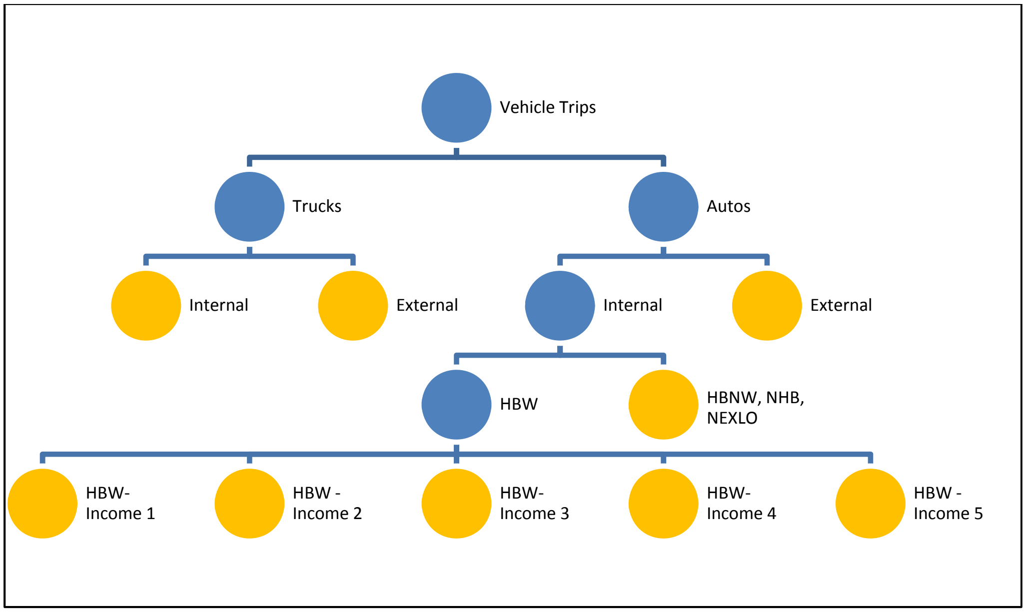


Figure 28. Example HBW Trip Table Stratification by Income Group.

As demonstrated by Figure 28, any number of permutations of the purpose segmentation could conceivably be created and generated. The different colored trip purposes (i.e., yellow) represent a departure from traditional trip purposes at TxDOT TPP. For example, the work-related trip purpose could be segmented into different income categories. In addition, the external truck traffic could be further divided into local and thru if the data are available (not shown in Figure 28). This could aid in the analysis of truck routing or exclusions during the planning process. Ultimately, the question is whether this additional level of detail is beneficial to support the long-range planning needs of most small to medium-sized study areas, given that most of these study areas are primarily interested in simply having a tool to support the development of MTPs on a five-year cycle. Only when significant capital projects or environmental reviews are engaged does a more robust model become relevant in most instances.

The mechanics of actually creating this type of segregation is relatively straightforward. For example, to stratify HBW trips, the following changes would have to occur to create a TripCAL5 control file:

- Additional trip purpose (TP) records would need to be created (i.e., HBW-Income 1, HBW-Income 2, etc.). See Table 17 for an example of TP record modification.
- Production rates for each income category would be input as a separate production trip rate (PT) record. Only that income category by trip purpose would have a corresponding production rate. All other rates would be zeroed out. An example of how the PT record could be modified to preserve production by income category is in Table 18.
- Corresponding attraction rates for each work-related income stratification by area type would have to be developed. Unlike production rates, each area type, household, and employment category would have a corresponding attraction rate by work income category.

Table 17. Additional TP Records for Income Stratifications.

TP 1	NON HOME BASED	A D P N	
TP 2	HBW – INCOME 1	A D P	
TP 3	HBW – INCOME 2	A D P	
TP 4	HBW – INCOME 3	A D P	
TP 5	HBW – INCOME 4	A D P	
TP 6	HBW – INCOME 5	A D P	
TP 7	HOME BASED NON WORK	A D P	
TP 8	TRUCK TAXI	D P T	53350

Table 18. Example HBW Production Rate Stratification by Income Category.

PT	1	1	0.209	0.594	1.045	1.232	1.298	
PT	1	2	0.616	1.166	1.727	2.101	2.288	
PT	1	3	0.946	1.76	2.343	2.783	2.97	
PT	1	4	1.155	2.101	2.838	3.333	3.586	
PT	1	5	1.309	2.398	3.212	3.828	4.081	
PT	2	1	0.253	0.814	1.166	1.32	1.463	(HBW Income Group 1 Productions)
PT	2	2	0	0	0	0	0	
PT	2	3	0	0	0	0	0	
PT	2	4	0	0	0	0	0	
PT	2	5	0	0	0	0	0	
PT	3	1	0	0	0	0	0	(HBW Income Group 2 Productions)
PT	3	2	0.638	1.243	1.628	1.804	1.947	
PT	3	3	0	0	0	0	0	
PT	3	4	0	0	0	0	0	
PT	3	5	0	0	0	0	0	
PT	4	1	0	0	0	0	0	(HBW Income Group 3 Productions)
PT	4	2	0	0	0	0	0	
PT	4	3	0.99	1.617	1.98	2.178	2.332	
PT	4	4	0	0	0	0	0	
PT	4	5	0	0	0	0	0	
PT	5	1	0	0	0	0	0	(HBW Income Group 4 Productions)
PT	5	2	0	0	0	0	0	
PT	5	3	0	0	0	0	0	
PT	5	4	1.144	1.837	2.266	2.541	2.662	
PT	5	5	0	0	0	0	0	
PT	6	1	0	0	0	0	0	(HBW Income Group 5 Productions)
PT	6	2	0	0	0	0	0	
PT	6	3	0	0	0	0	0	
PT	6	4	0	0	0	0	0	
PT	6	5	1.232	1.98	2.442	2.706	2.827	
PT	7	1	0.55	1.496	2.31	2.695	3.047	
PT	7	2	1.023	2.266	3.168	3.872	4.323	
PT	7	3	1.243	2.673	3.894	4.708	5.137	
PT	7	4	1.331	2.981	4.323	5.126	5.588	
PT	7	5	1.419	3.135	4.807	5.676	6.039	

It would not be necessary to add a third dimension to the distribution of households by income and size in the production cross-classification record since income is already a category.

Since a single TripCAL5 control file is limited to a total of 10 trip purposes, additional control files may need to be created if the total trip purpose limit is exceeded. This is typical when external-local productions are handled directly in TripCAL5. At a minimum, a second-generation card is created with the application of TripCAL5 (if the 10 trip purpose limit is not reached but additional production and attractions exceed the total allowable pairs in the initial generation deck).

This type of trip table stratification becomes a sampling problem. This is further amplified if the trip tables are to be further stratified by time period (e.g., five HBW income trip tables by four time periods). General concerns about trip table stratification include but are not limited to the following potential issues:

- Estimating attraction rates based on the income of the employee could create a number of challenges since attraction rates are stratified by area type, trip purpose, and employment type. For a study area with four area types, five sets of attraction rates by each income category would need to be created (if work trips are preserved by the standard five income categories). A general concern with this approach is whether there are enough observations in the workplace survey to create attraction rates without having to impute a large number of cells (for each area type, household, and employment category).
- A secondary concern with creating attraction rates by income category is the likely potential of creating large production and attraction imbalances within study areas. This may very well prove to be true in rural areas where housing outnumbers workplaces. Conversely, the reverse may be created in downtown areas where jobs/worksites typically exceed households in small to medium-sized study areas.

Trip Distribution

Once the production and attraction trip ends are created by the TripCAL5 trip generation software, the next step in the sequential travel model chain at TxDOT is trip distribution. The ATOM2 software, which is a spatially disaggregate trip distribution model that considers zone size in the gravity analogy, is applied to create trip tables that are readied for application in the traffic assignment step. A control file for each trip purpose is created and applied using the following input variables:

- A separation matrix of network zone-to-zone impedances, based on initial estimates of daily speeds.
- Zone radius values for the zone. Radius represents the average travel time of all centroid connectors associated with each zone. Radii serve as surrogates for zone size in the ATOM (atomistic application of the gravity model.
- Productions and attractions by zone for each trip purpose.
- Sector equals record, which is a table of equals between individual zone numbers and a larger sector geography. Bias factors are applied via sectors in ATOM2 rather than at the zonal level. Additionally, different sector structures may be used by different trip purposes (e.g., the education trip purpose may use a district-level geography representing school districts).
- Trip length frequency distribution by trip purpose.
- Calibrated friction factors for each trip purpose.
- Bias factors (i.e., K-factors in traditional gravity models), which are judiciously applied.

There are relatively few concerns associated with the trip distribution step with respect to accounting for tolls. Potential concerns are enumerated in the context of greater changes to the model architecture, such as modeling additional trip purposes (e.g., HBW by income category), time of day, and iterative feedback. Specific considerations and issues include the following:

- The creation of survey-expanded trip tables could be problematic based on the limited number of observations by category. This is not mere hyperbole with respect to the number of household and workplace surveys conducted for any one study area. The finer the trip tables, the fewer the number of observations exist to support this type of activity. Therefore, estimating trip length frequency distributions (and subsequent friction factors if using the gravity analogy) would represent a fairly significant challenge. With limited observations, it is fully anticipated that the survey-expanded trip tables will yield ragged distribution curves from which to obtain initial estimates of average trip lengths and shape. This will present challenges for smoothing the distribution curves by trip purpose and the subsequent calibration of friction factors.
- Introducing temporal segregations of trip tables could also present additional challenges and considerations. Depending on the approach used to develop time-of-

day trip tables (if implemented), TxDOT may wish to consider introducing a feedback mechanism in the sequential model chain to resolve the congested weighted travel times with those that are introduced into trip distribution. A previous research report documented software-related concerns associated with ATOM2 that would have to be addressed prior to implementing a feedback mechanism (Reeder et al. 2011, 2012).

- Introducing iterative feedback has a number of software-related issues, but this discussion could include expanding the definition of impedance. In most cases, the cost that is fed back to trip distribution is simply travel time. However, at H-GAC, a composite travel time is recycled through the sequential model process (transit and vehicle). TxDOT needs to understand the units that are recycled through the trip distribution phase (e.g., time versus costs) if iterative feedback is adopted.

Mode Choice

Currently, only the largest study areas in the state have developed and implemented a mode-choice model to develop estimates of travel by person, trip purpose, and mode. These include Austin, San Antonio, Dallas-Fort Worth, and Houston. H-GAC models currently estimate toll demand via the mode-choice model but is migrating toward an assignment-based approach in the current model update. In the Texas Package, TxDOT TPP has the option of invoking a mezzo-level HOV model that develops estimates of transit travel by sector based on locally developed sector mode shares. Inputs to the mezzo-HOV model include the following files:

- Person trip tables by trip purpose.
- Sector equals record.
- A separation matrix of highway travel times.
- Transit mode shares by trip purpose.
- Auto occupancy factors by trip purpose.

The mezzo-HOV model has been used in the El Paso models but does not require a transit network geography to apply.

The significant advantage of a mode-choice model is the development of trip tables by occupancy level (as well as the capability to account for nonmotorized trips). However, trip tables by auto occupancy can be obtained using travel survey data to obtain occupancy rates by trip purpose. This can be achieved by generating person trip tables by trip purpose, distributing these trips, and then creating the vehicle trip tables for each occupancy level after distribution. The number of vehicle occupancy tables is typically three—one-person vehicle, two-person vehicle, and 3+ vehicle trip tables. Consequently, an auto occupancy model or set of software would need to be developed to address multiple trip purposes. The general process for obtaining occupancy levels is depicted in Figure 29.

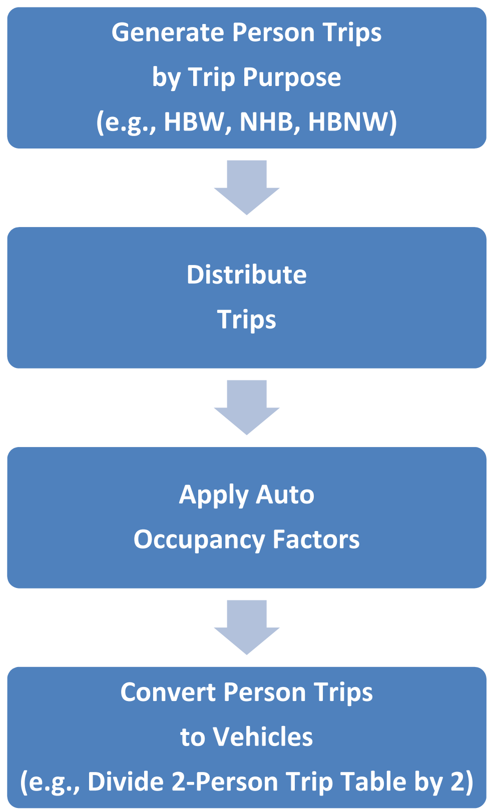


Figure 29. Potential Approach for Acquiring Trip Tables by Auto Occupancy.

This approach means that the trip tables by occupancy are fixed in that they are insensitive to zone-to-zone changes in travel impedances. A mode-choice model would provide this type of sensitivity. For small to medium-sized study areas, however, it is not clear how sensitive the users are to changes in zone-to-zone impedances since there tends to be a number of uncongested free alternatives.

For study areas considering variable-pricing policies, the capability to develop trip tables by occupancy level and time of day is extremely relevant. The small to medium-sized study areas currently under the purview of TxDOT TPP have little to no transit use of any consequence to justify a robust mode-choice model (at this time). Additionally, since the toll roads under consideration are fixed fee for all autos, the motivation to develop trip tables by auto occupancy level is obviated in most instances. However, the capability exists to derive the trip tables by occupancy through further travel survey processing. Another option that would require software enhancements would be to preserve the internal estimates of 1, 2, and 3+ auto occupancy trip tables from the mezzo-HOV model. Currently, these are estimated based on the input average auto occupancy by trip purpose, but these are not preserved as output. Using locally available travel survey data would probably represent the best option to determine percent of trips by auto occupancy level for each trip purpose. Table 19 provides the latest vehicle occupancy rates for select trip purposes from the 2009 NHTS.

Table 19. 2009 Vehicle Occupancy Rates for Select Trip Purposes.

Select Trip Purpose	Vehicle Occupancy Rate
To or from work	1.13
Shopping	1.78
Other family/personal errands	1.84
Social and recreational	2.20
All purposes	1.67

Source: Santos et al. (2011)

With respect to transit use by study area, the following tables provide the latest estimates of commute to work by mode for the counties under consideration in this report. Table 20 depicts the percent of travelers commuting to work by mode, and Table 21 expresses the data in terms of real numbers. The information was obtained from the five-year American Community Survey (ACS) data. The data are exclusive to the work orientation and do not capture other trip purposes.

Table 20. Summary Estimates of Commuting Trends by County (Percentages).

Commute to Work	Hidalgo County Estimate	Cameron County Estimate	Greg County Estimate	Smith County Estimate	Webb County Estimate
Workers 16 years and over	269,223	137,740	54,438	91,262	94,770
Car, truck, or van—drove alone	77.2%	78.4%	80.9%	80.7%	76.9%
Car, truck, or van—carpooled	12.7%	13.8%	12.2%	9.9%	14.3%
Public transportation (excluding taxicabs)	0.3%	0.7%	0.5%	0.4%	1.7%
Walked	1.5%	2.3%	0.9%	1.1%	1.8%
Other means	4.2%	2.2%	2.8%	2.6%	1.2%
Worked at home	4.1%	2.6%	2.7%	5.3%	4.1%
Mean travel time to work (minutes)	21.3	19.9	20.6	21.5	21.5

Source: U.S. Census Bureau (2013)

Table 21. Summary Estimates of Commuting Trends by County (Absolute Values).

Commute to Work	Hidalgo County Estimate	Cameron County Estimate	Greg County Estimate	Smith County Estimate	Webb County Estimate
Workers 16 years and over	269,223	137,740	54,438	91,262	94,770
Car, truck, or van—drove alone	207,879	107,921	44,034	73,620	72,886
Car, truck, or van—carpooled	34,271	19,056	6,645	9,032	13,524
Public transportation (excluding taxicabs)	759	1,023	249	373	1,622
Walked	3,975	3,103	497	1,026	1,689
Other means	11,415	3,064	1,545	2,414	1,145
Worked at home	10,924	3,563	1,468	4,797	3,904
Mean travel time to work (minutes)	21.3	19.9	20.6	21.5	21.5

Source: U.S. Census Bureau (2013)

Table 22 and Table 23 depict the same five-year ACS commuter data but by the corresponding city geography. As can be seen in both the county and city geography, transit-related activity is insignificant by almost any measure.

Table 22. Summary Estimates of Commuting Trends by City (Percentages).

Commute to Work	McAllen City Estimate	Brownsville City Estimate	Longview City Estimate	Tyler City Estimate	Laredo City Estimate
Workers 16 years and over	52,684	61,316	35,676	42,968	90,322
Car, truck, or van—drove alone	77.2%	78.2%	80.4%	81.0%	77.3%
Car, truck, or van—carpooled	11.7%	15.1%	12.1%	9.4%	14.3%
Public transportation (excluding taxicabs)	0.7%	1.2%	0.6%	0.6%	1.7%
Walked	2.1%	2.5%	0.7%	1.5%	1.7%
Other means	3.2%	2.1%	3.5%	3.0%	1.2%
Worked at home	5.2%	2.9%	2.7%	4.5%	3.9%
Mean travel time to work (minutes)	19.1	19.2	19.7	18.4	21.0

Source: U.S. Census Bureau (2013)

Table 23. Summary Estimates of Commuting Trends by City (Absolute Values).

Commute to Work	McAllen City Estimate	Brownsville City Estimate	Longview City Estimate	Tyler City Estimate	Laredo City Estimate
Workers 16 years and over	52,684	61,316	35,676	42,968	90,322
Car, truck, or van—drove alone	40,670	46,703	28,689	34,819	69,778
Car, truck, or van—carpooled	6,139	9,272	4,324	4,005	12,884
Public transportation (excluding taxicabs)	366	713	220	249	1,536
Walked	1,094	1,554	238	642	1,503
Other means	1,671	1,295	1,254	1,300	1,096
Worked at home	2,744	1,776	951	1,953	3,525
Mean travel time to work (minutes)	19.1	19.2	19.7	18.4	21.0

Source: U.S. Census Bureau (2013)

TxDOT TPP is currently sponsoring research on the development of a generic mode-choice model. Additional research was sponsored by the department in the mid-1990s that examined the development of a standard mode-share model as well (Shunk 1995). This approach used the TRANPLAN software but was never adopted by the department.

Time of Day

As illustrated in the information on toll road users in Figure 27, over 40 percent of the toll road users are commuters. Given that work-related travel typically occurs in two defined peaks—morning and afternoon—TxDOT TPP may wish to give further consideration to time-of-day models as a part of an overall schema to better account for toll demand. In most examples noted nationally, there are four distinct periods—morning peak, midday, afternoon peak, and overnight. With respect to small to medium-sized study areas, the typical peaking characteristics encountered in larger urban areas that produce significant congestion, delay, and diversion to alternative paths and/or modes simply do not exist to the extent that there are meaningful differences between peak and off-peak speeds. This, however, should not prevent TxDOT from considering adoption of some form of time-of-day modeling capability. Options could include:

- Continuing daily models without sensitivity to time of day.
- Making a simplifying assumption that HBW trips occur during the peaks, and modeling this single trip purpose temporally in the presence or absence of iterative feedback.
- Modeling four distinct time periods.

There are several techniques that could be used to bring time-of-day modeling capability to the Texas Package models in the small and medium-sized urban areas. As with most approaches, the different techniques vary in complexity, sophistication, and ease of use. There are typically three approaches used to model peak-period conditions (Benson et al. 1988):

- Trip table factoring.
- Trip end factoring.
- Direct generation.

Trip table factoring is typically applied after trip distribution (in three-step models), while trip end factoring is applied after trip generation but prior to trip distribution. In direct generation, trip ends are generated directly in trip generation by time of day. Trip table factoring is the most common form of peak-period modeling, where 24-hour trip tables (by purpose) are factored to create trips by time period. Once the factored trip tables are created, the production-and-attraction trip tables are converted to origin-to-destination (OD) format by applying the directional factors (dominant and non-dominant directionality). A more complex version of this approach is to develop factors by zone rather than using a single factor. This approach means that both the time period and directional factors vary by each zone in the system. A third trip table factor approach is to apply the factors to the person trip tables prior to mode choice as a direct input into mode choice to produce time-of-day trip tables after mode choice. Figure 30 depicts the general trip table factoring to achieve time-of-day trip tables.

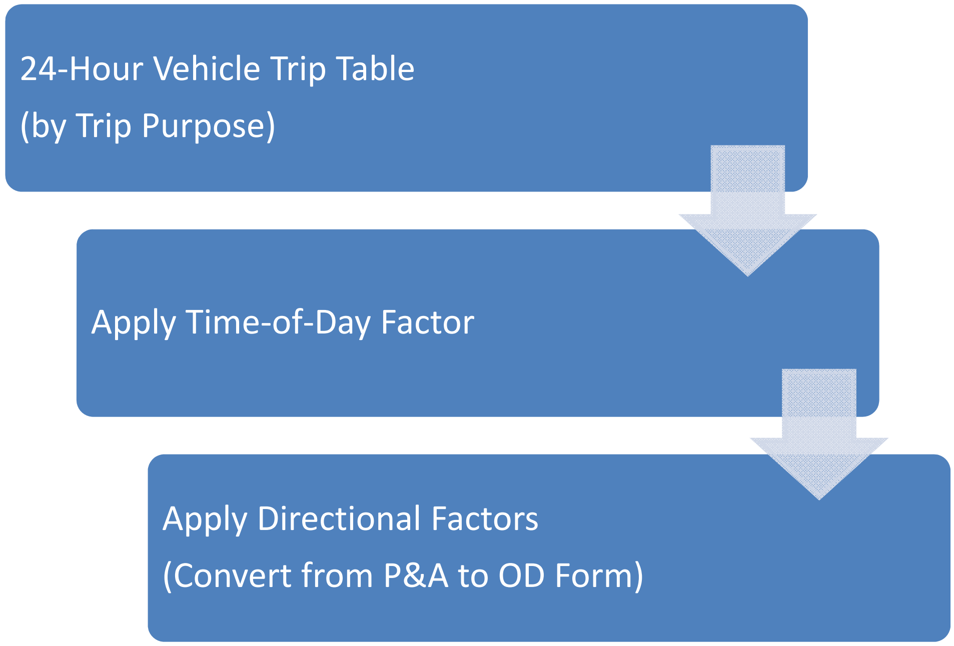


Figure 30. Trip Table Factoring Approach (from Trip Productions and Attractions [P&A] to Trip ODs).

If additional trips are to be modeled to account for tolling, TxDOT TPP would need to acquire the time-of-day factors from the travel surveys as well as the directional factors to convert the trip tables to OD format prior to applying the traffic assignment step. Regardless of whether time periods are modeled, TxDOT TPP can choose to calibrate using daily assignment by summing the time periods into one time period and comparing the results to the 24-hour counts. Alternatively, TxDOT could choose to populate the network with time-of-day counts and attempt to benchmark against these measures during calibration. In either scenario, the accompanying network database needs to be expanded to include time-of-day counts (if possible), capacities, speeds/travel times, and, potentially, additional VDFs. For the assignment step, different VOTs have to be created to account for different VOTs by trip purpose. For instance, the HBW trip purpose would most likely have a higher VOT during the two peak periods versus a home-based shopping or retail trip.

Feedback

Speed/travel time feedback attempts to resolve the congested weighted speeds produced by traffic assignment with those used as input into trip distribution. The process is repeated until some measure of convergence is achieved (i.e., changes in trip tables or travel times). In the immediate term, most of the study areas do not have any congestion of consequence. Therefore, there is a lack of any significant peak-period congestion in most of these study areas to produce meaningful impacts with respect to congestive feedback. This does not preclude the effects of future growth on network supply, though, which should not be dismissed. Currently, however, the motivation for capturing peak changes in travel time appears to be relatively insignificant. This was noted in the interviews with the TxDOT-TOD consultants performed for this project where special speed studies revealed little to no differences between peak and off-peak conditions (in the affected corridor). As mentioned during these interviews, iterative feedback was not introduced to address toll estimates.

Traffic Assignment

The decision to account for tolled facilities in traffic assignment would have some impact on the standard method of traffic assignment used by TxDOT analysts. Some of these changes require additional fields in the network geography, and additional specifications in the network of *.NET files and in the traffic assignment approach used. Using the generalized cost method of assignment, TxDOT would need to move toward the MMA option of traffic assignment.

The generalized cost formula typically used by most agencies and software vendors is expressed as:

$$GC = OpCost * (Length) + Travel\ Time * (VOT) + Tolls \quad (4.5)$$

where:

- GC is the generalized cost (expressed in dollars).
- OpCost is the vehicle operating cost.
- VOT is the value of time.

The operating cost typically represents the cumulative cost of owning and operating a vehicle (e.g., gas and parking). Usually the marginal or immediate out-of-pocket costs are used rather than the total cost of travel, which would include depreciation, maintenance, and insurance. For instance, an individual driver will probably not account for the cost of depreciation and insurance when considering the cost of a particular trip. Since operating cost is applied to length and can vary by class (particularly for truck and freight), the unintended consequence may be to overstate the effects of operating costs when comparing two competing network alternatives with different lengths when considering traveler costs (e.g., toll versus non-toll). As revealed in the national research, there is great variance in the estimates of auto operating cost by class. Because auto operating costs are sometimes overstated and this variable is a function of the length of a network link, path choice can be overweighted simply based on this operating cost alone, regardless of toll cost. In TransCAD version 6.0, this variable is no longer defined in the MMA dialog box. This placeholder was removed in the current version of the software.

In the Dallas-Fort Worth models, the network geography contains an attribute field that represents the composite costs of travel on the link. This composite cost also includes auto operating costs. Consequently, there is a process to continue the use of the auto operating variable, but this may no longer be advisable given the wide degree of differences with estimating auto operating costs.

In the current MMA assignment approach within TransCAD, there are two variables that need to be defined—VOT and toll cost. The toll cost is annotated in the network geography and will be identified via a selection set in the support TransCAD network (*.NET) file. Depending on the amount of market segmentation in the models, this value many not be static in the absolute sense. As noted in the CAMPO interview, the toll cost is varied to account for potential vehicle mix. Since TxDOT currently models vehicles rather than average daily traffic, the need to define passenger car equivalents is obviated in most instances. VOT is associated with the trip table (and time) being assigned. These values would have to be estimated for each trip purpose. Similar to auto operating costs, there appears to be great variance in the derivation and interpretation of VOT in existing practice. The SAM-V2 models have developed one process that may be informative to the small to medium-sized study areas.

The process for applying the MMA assignment technique and corresponding modifications are described in the following subsections. This description presumes the transition of the TxDOT urban models to version 6.0 of TransCAD. Earlier versions of TransCAD also contain the generalized cost assignment option within the MMA method, but exact menu specifications are slightly different than what is portrayed here.

Creation of Network (.NET) File*

One impact to TxDOT standard assignment procedures would be to the process for creating the TransCAD network (*.NET) file that is a required support file to apply the traffic assignment models. The network file links the attributes of the network geography to the assignment models. If the user is specifying network tolls through a network data item such as toll cost, then a selection set of links in which the toll cost is greater than zero would need to be created and specified in the network creation/settings process. In Figure 31, a selection set called “toll links” has been created and is specified as shown during the network creation process.

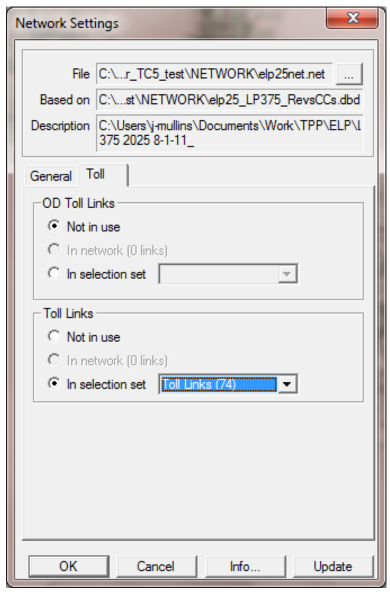


Figure 31. Example Specification Network File (Toll Considerations).

The MMA procedure also supports the use of node-to-node toll specification, referred to as OD tolling. In this method, the user creates a network node-oriented matrix that contains toll cost (if any) for movement through toll facility entry/exit points. The node-oriented approach is common for historical toll roads where the cost is based on where the user entered the toll road and where the user exited the toll road. In this manner, there are specific toll charges between the entry and exit nodes. The links that make up these tolled entry/exit locations are identified through a selection set and then specified as part of the creation of the *.NET file as indicated in Figure 31.

It is presumed that TxDOT procedures would make use exclusively of the "toll link" option within MMA assignment, but the option to alternatively or additionally use OD toll links is available to TxDOT if the payment method is tied to entry and exit points.

Assignment Setup

The major impact of moving to the MMA technique would be in the specification of inputs for the segmented demand tables and the associated link toll cost inputs. An example specification for an MMA assignment is presented in Figure 32 where autos and trucks are segmented into two separate classes. Currently, TxDOT uses a single OD table that does not distinguish by class or trip purpose. There is nothing to prevent adopting the MMA technique. In fact, maintaining information about the trip purposes traversing a link would create a mechanism by which to characterize the users of corridors and/or projects.

In the example highlighted in Figure 32, the demand is segmented by vehicle classification along with, for required consistency, link toll costs. With the adoption of the MMA technique for conducting traffic assignments to obtain toll demand, a VOT would have to be specified for the same level of segmentation that is used for the trip table demand. The method for determining level of segmentation and results of VOT determination is perhaps the most researched and debated aspect of toll demand estimation. It is widely understood that VOT is dependent on a multitude of variables including purpose, time of day, and mode. With respect to the assignment itself, the model process would be impacted strictly in the sense that the user would have to provide information on VOT for each demand segment, as indicated in Figure 32.

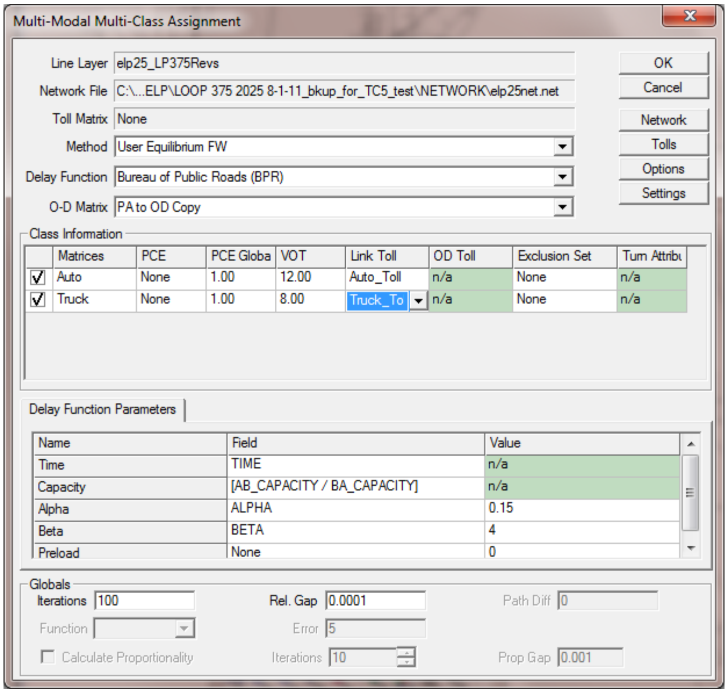


Figure 32. Example MMA Specification.

Another consideration for TxDOT in the arena of traffic assignments for toll demand estimation, although not directly tied to the MMA technique or toll demand estimation, is increasing the number of iterations performed. Research and comparative practice in non-TxDOT models and in areas outside of Texas suggest that the current standard of 24 iterations may be not satisfactory to produce high degrees of equilibrium, even in relatively non-congested traffic assignments. TxDOT may want to consider specifying an increased number of iterations—100 or more. Increasing the number of iterations may also contribute to increased stability when comparing network alternatives. Applying additional iterations requires a different measure of relative gap, which is one of the two benchmarks the software uses to determine whether equilibrium has been achieved. The current relative gap is defined as 0.001 or 10^{-3}. In order to achieve additional iterations, a relative gap of 10^{-4} or greater will need to be defined during the assignment application. Given that a majority of the small to medium-sized study areas have limited regional congestion, performing even as many as 200 iterations would not appreciably increase traffic assignment times.

Should TxDOT's desire to maintain the practice of assigning a single demand matrix and not segment demand by either vehicle class or trip purpose, the option does exist to proceed with generalized cost assignments for estimating toll demand without segmentation. This would mean that single values for toll costs and VOTs would be assumed. There are definitely tradeoffs in making such simplifying assumptions, but such an application can be made using TxDOT's current modeling software. In fact, the same MMA technique used is the only method available in TxDOT's software to conduct generalized cost assignments that consider toll cost. The specification of input in such an assignment by the model user would appear as shown in Figure 33.

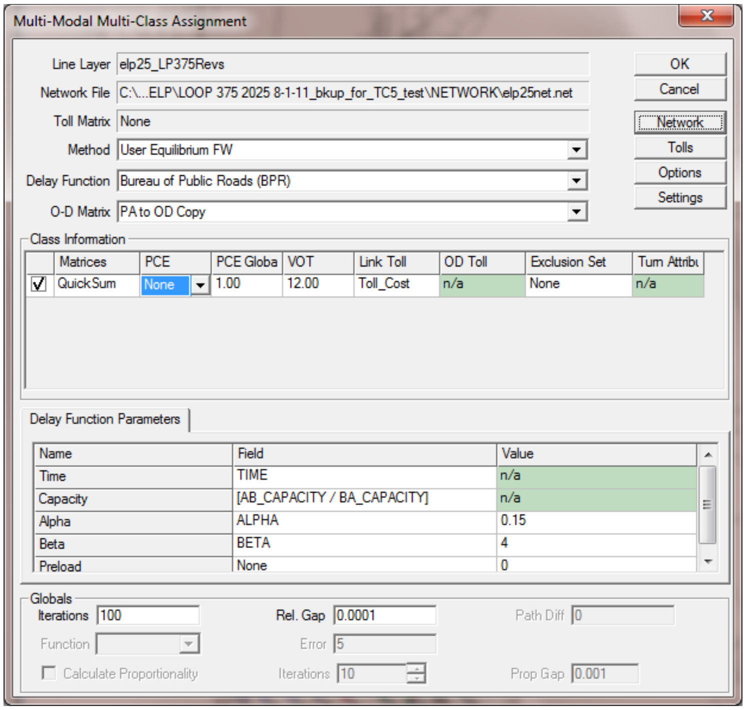


Figure 33. Example MMA Setup (Single-Class Assignment).

CONCLUSION

Based on national and state experience, a majority of the MPOs have or will be addressing toll road demand in the traffic assignment step of the sequential travel model process. Consequently, this approach requires a review of the following enhancements that could be used to support this approach:

- Developing enhanced market segmentation of trip ends and/or trip tables.
- Developing time-of-day modeling to address travelers' reaction to congestion (e.g., work-related travel relative to existing toll use in the state).
- Developing or considering development of trip tables by occupancy level (when appropriate).

- Implementing iterative feedback (if necessary to resolve travel times in the sequential model process).
- Estimating VOTs by traveler classes.
- Estimating auto operating costs for inclusion in a composite cost field (if auto operating costs are deemed appropriate for consideration).

In the context of the generalized cost traffic assignment technique, TxDOT may wish to consider applying an MMA approach using some form of trip table segregation. At a minimum, two trip tables of autos and trucks could be applied to acknowledge the inherent differences in toll costs and VOTs. Further segregation could provide additional opportunities to address toll demand (e.g., segmenting work trips by income categories). However greater segmentation requires larger amounts of data (e.g., trip rates, trip length frequency, time-of-day factors, directionality, and estimates of VOT). This is especially true for truck-related travel where ownership characteristics and commodity type could be accounted for to address different VOTs and toll costs by axle.

More sophisticated approaches that are common in larger study areas may not necessarily be as beneficial for small to medium-sized study areas where toll roads are being primarily constructed in rural portions of the study area with inconsequential levels of current congestion. Forecast scenarios may eventually change these constraints, but currently, the justification for complex enhancements may not be fully recognized. Much of the enhancements require input data that TxDOT does not currently process from existing data collected (i.e., survey data) or does not collect using other methods (e.g., SP surveys). As noted in an earlier TTI report on time-of-day models, more sophisticated approaches with languid input data will not contribute greatly to the quality of the results (Benson et al. 1988). This may be especially true in the Laredo example where a majority of the trips on the toll road are occurring as a result of external station interchanges.

CHAPTER 5: DEMONSTRATION AND EVALUATION OF COMPETING MODEL SPECIFICATIONS

INTRODUCTION

TDM techniques have grown progressively more sophisticated since the introduction of the traditional four-step model in the 1950s. During that same time, the gap in modeling complexity between large MPOs with abundant resources and those smaller in size or with fewer assets has also increased. In Texas, as discussed in Chapter 3 of this report, the four largest MPOs (Austin, San Antonio, Dallas-Fort Worth, and Houston) use various forms of behavioral and temporal disaggregation in TDM models to better reflect traveler heterogeneity while helping anticipate toll road demand. TxDOT's current base model serves as the primary framework for travel demand modeling in small to medium-sized Texas regions. However, with growing congestion in these regions and the introduction and planning of tolled facilities, a TDM technique with more levels of behavioral disaggregation (e.g., user class differentiation, time-of-day segmentation) may well be needed.

Travel demand modelers have strongly recommended several types of travel demand modeling changes in contexts and settings similar to those of the small to medium-sized regions. These changes may improve TxDOT's current framework and procedures, particularly in the context of toll road forecasts. The specific TDM improvement strategies evaluated as part of this research are as follows:

- Incorporating tolls in route choices.
- Incorporating mode choice (via logit and fixed-share strategies).
- Enabling multi-period time-of-day analysis.
- Allowing multi-class assignment of users on the network (based on traveler income levels and trip purposes).
- Incorporating a feedback loop (allowing congestion to play an endogenous role in the behavioral equilibrium).

These model enhancements were tested in different combinations using TransCAD on the 2002 Tyler network geography provided by TxDOT to determine which TDM modeling strategies (and their combinations) offer the most effective accounting of travel behavior and, in particular, toll demand in the context in the model form used by TxDOT and Texas regions. The assumptions behind these extensions of TxDOT's base model and the results of these test runs are discussed below.

MODEL IMPROVEMENTS

Currently, 23 of Texas' 25 MPOs use the Texas Package Suite of Travel Demand Models, a three-step 24-hour vehicle trip-based model (Hall 2011). The Texas Package includes trip generation (using TripCAL5), trip distribution (using ATOM2), and traffic assignment (using TransCAD). The current adopted model architecture does not include a mode-choice step, time-of-day element, or full equilibration feedback loop. Each of these items, as noted previously, may warrant further consideration as a means to enhance toll demand estimation. The current assignment convergence criterion is set at 24 iterations, which may also need to be adjusted (e.g., a 200 iteration or tighter convergence criterion) to achieve greater assignment convergence. Regardless of whether an alternative route being studied is tolled or not, greater assignment convergence contributes to enhanced alternative network analysis and comparison.

This project considered various additions to the Texas Package, including the inclusion of a mode-choice step, disaggregation of time-of-day periods and user classes, and implementation of tighter convergence criteria (for network assignment) along with an outer feedback loop that updates travel times and costs for every OD pair (and mode and time-of-day for each user class, potentially) back to the trip distribution step. The various components of these model improvements are discussed in detail in this chapter. The overall modeling process, including these enhancements, is shown in Figure 34.

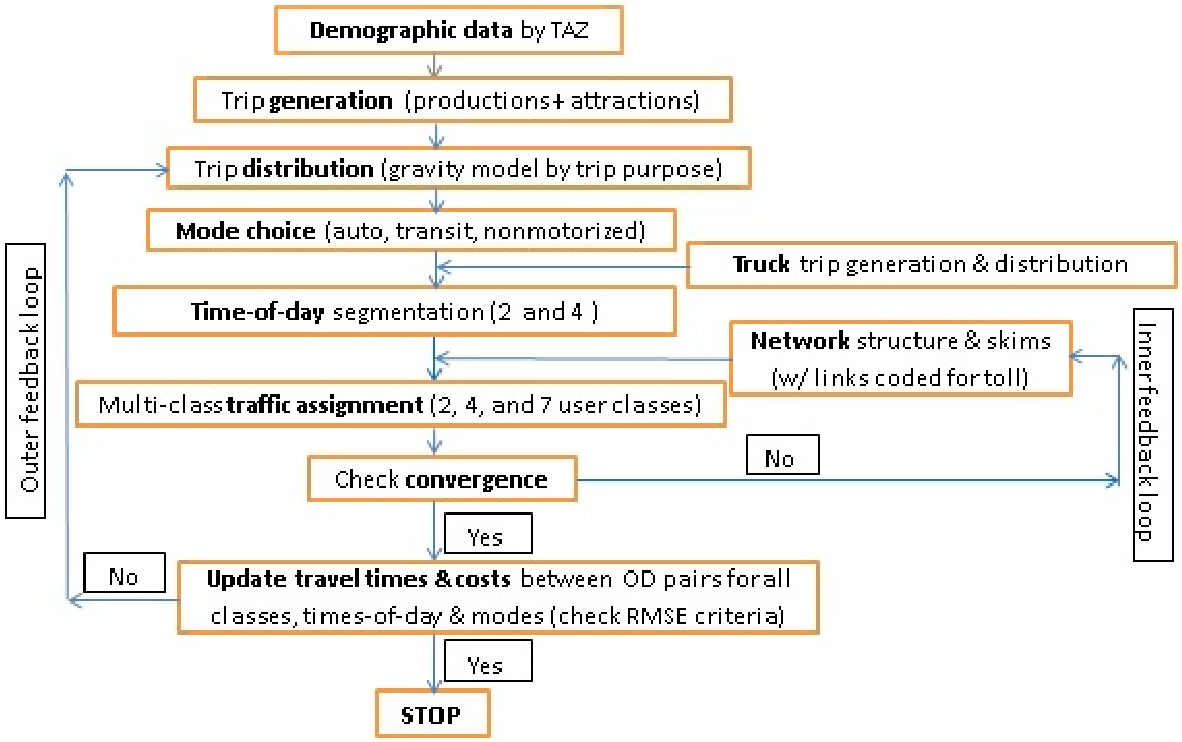


Figure 34. Enhanced TDM Process.

Time-of-Day Considerations

In congested networks, time-of-day considerations are critical in TDMs because of driver responses to congestion (e.g., alternative routes and/or alternative departure times). The relative utility of a tolled route largely depends on toll cost and perceived travel time savings, both of which can vary by time of day. Typically, time-of-day segmentation is incorporated into TDMs after the mode-choice step to reflect generalized travel costs that vary across different times of day (PB et al. 2012).

For this demonstration, two types of time-of-day segmentation are considered. The first is a simple peak (6 to 9 a.m. and 3 to 6 p.m.) versus off-peak (9 a.m. to 3 p.m. and 6 p.m. to 6 a.m.) structure, a setup sufficiently granular for networks where congestion is not excessive (Zhao 2013). The second time-of-day segmentation considered here includes four periods: AM peak (6 to 9 a.m.), midday (9 a.m. to 3 p.m.), PM peak (3 to 6 p.m.), and off-peak (6 p.m. to 6 a.m.). Hourly distributions for personal and commercial trip making in the modeling scenarios used here are based on NCHRP 187's default rates with HBW, HBNW, home-based other (HBO), and NHB trip purposes, as shown in Table 24 (Sosslau et al. 1978).

Table 24. Hourly Trip Distribution by Purpose (Based on NCHRP 187).

Hour Beginning	Percent of Vehicle Trips by Trip Purpose			
	HBW	HBNW	HBO	NHB
Midnight	0.7	0.4	0.7	0.6
1:00 a.m.	0.2	0.2	0.3	0.2
2:00 a.m.	0.8	0	0	0
3:00 a.m.	0.1	0.2	0.1	0
4:00 a.m.	0.1	0.4	0	0.1
5:00 a.m.	1	2.7	0.5	0.4
6:00 a.m.	3.2	7.9	2	1.5
7:00 a.m.	8.9	19.2	5.8	6.6
8:00 a.m.	4.1	9.2	3.4	4
9:00 a.m.	3.2	3	3	3.6
10:00 a.m.	3.9	0.7	4.4	5.6
11:00 a.m.	4.1	0.6	4.4	6.3
Noon	5.2	2.1	4	10.2
1:00 p.m.	4.8	2	4.8	7.2
2:00 p.m.	4.9	3.8	4.2	6.9
3:00 p.m.	6.7	6.3	6.2	8
4:00 p.m.	9.3	13.7	8.1	8
5:00 p.m.	8.5	12.4	8	6.2
6:00 p.m.	6.4	3.7	8.5	4.7
7:00 p.m.	7.9	2.3	11.2	6.3
8:00 p.m.	5.9	1.6	7.9	5.8
9:00 p.m.	4.8	2.9	6	3.9
10:00 p.m.	3.2	2.8	3.9	2.4
11:00 p.m.	2.1	1.9	2.6	1.5

Average auto occupancy rate assumptions are based on the 2009 NHTS, as shown in Table 25.

Table 25. 2009 NHTS Auto Occupancy Rates.

Trip Purpose	Auto Occupancy
HBW	1.1
HBO	1.75
NHB	1.66

Mode Choice

In most four-step TDMs, mode choice is a step implemented after trip distribution (with a gravity-based or other destination-choice model), using either a logit or nested logit model specification (PB et al. 2012). In small and medium-sized regions, such models may require more data than are currently collected or more technical expertise than the current staff have. For example, mode choice is excluded in models for regions in Oregon with fewer than 70,000 in population (Knudson and Gregor 2012). Alternatively, this study tested a mode-choice model with fixed splits based on trip distance, giving higher shares of nonmotorized and transit use for shorter-distance trips and higher shares of auto use for longer-distance trips, as in Lima, Ohio's TDM (Bernardin-Lochmueller and Associates, Inc. 2005).

In this project, two mode-choice models were applied. The first is the fixed-share model, where preference for nonmotorized modes and transit decreases as trips lengthen, as shown in Table 26. The mode shares shown were approximated from the Lima, Ohio, model.

Table 26. Fixed-Share Mode Splits.

Trip Distance	Auto Share	Transit Share	Nonmotorized Share
< 1 mile	75%	5%	20%
1–5 miles	94%	5%	1%
> 5 miles	98%	2%	0%

The auto share estimates assumed here are close to the actual Tyler work-trip area mode splits according to the 2012 ACS, where approximately 92 percent of commute trips were reported to typically be served as auto trips. However, the transit shares used here are more reflective of an area with a more extensive and better-used transit system. In Tyler, there are only four bus-service routes, and the actual transit share for work trips is less than 1 percent.

The second mode-choice model used here, in the framework in Figure 35, is a multinomial logit (MNL) model to split trips across three modes. The MNL model uses the theory of utility maximization to calculate the probability of each trip using a particular mode.

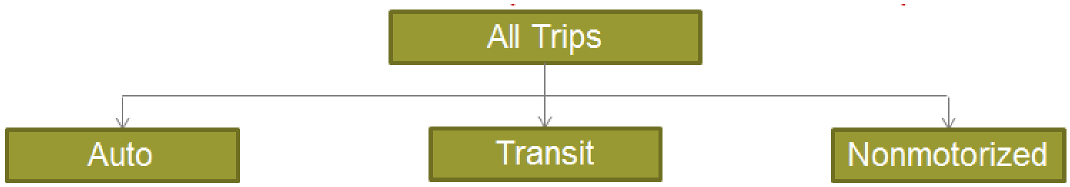


Figure 35. Mode-Choice MNL Structure.

The utility functions for each of the modes used in this simplified MNL model are based only on travel time. The parameters chosen, as shown in the equations below, yield similar mode splits as the fixed-share assumptions.

$$V_{auto} = -0.2AutoTT \quad (5.1)$$

$$V_{transit} = -2.5 - 0.2TransitTT \quad (5.2)$$

$$V_{nm} = -1.0 - 0.2nmTT \quad (5.3)$$

Since the original Tyler network files include only a travel time skim for the auto mode, some assumptions had to be made for the transit and nonmotorized mode travel times, to feed into the first iteration of the MNL mode-choice model. Travel times for each mode and time-of-day period were assumed to be multiples of the region's base off-peak auto travel times (which are derived from existing network travel times), as shown in Table 27 and Table 28. The multipliers for transit and nonmotorized modes from the auto mode were derived from two simple linear regressions of 30 trips of varying distances in Austin as projected by the Google Maps Directions tool (for driving versus transit versus walk travel times).

Table 27. MNL Travel Times by Mode for Two Times of Day.

Time Period	Auto	Transit	Nonmotorized
Peak (6 to 9 a.m., 3 to 6 p.m.)	1.5*AutoTT	2.5*AutoTT	7.5*AutoTT
Off-peak (9 a.m. to 3 p.m., 6 p.m. to 6 a.m.)	AutoTT	2.5*AutoTT	7.5*AutoTT

Table 28. MNL Travel Times by Mode for Four Times of Day.

Time Period	Auto	Transit	Nonmotorized
AM peak (6 to 9 a.m.)	1.5*AutoTT	2.5*AutoTT	7.5*AutoTT
Midday (9 a.m. to 3 p.m.)	1.2*AutoTT	2.5*AutoTT	7.5*AutoTT
PM peak (3 to 6 p.m.)	1.5*AutoTT	2.5*AutoTT	7.5*AutoTT
Off-peak (6 p.m. to 6 a.m.)	AutoTT	2.5*AutoTT	7.5*AutoTT

Currently in most small to medium-sized regions in Texas, transit and nonmotorized travel have extremely low shares as compared to the auto mode. However, carpool can be a mode of interest to transportation planners in these regions, especially when the potential introduction of tolled facilities includes managed lane facilities. A mode-choice model accounting for auto vehicle occupancy is typically structured as a nested logit (NL) model and requires additional assumptions about the order of choices made by travelers as they choose modes, travel times, and routes. It also requires a decision about how to add occupants' values of travel time and splitting monetary costs when sharing the ride and selecting routes (in addition to the mode and travel time of day). These issues related to carpooling add complication normally not found in the other mode options.

For example, San Francisco's NL model for incorporating vehicle occupancy is shown in Figure 36. This is a relatively extreme example that reflects a great many facets of the mode-choice decision. In many studies and modeling practices, the passengers' value of time is only partially (or not at all) reflected in the mode or route choices (see, e.g., Vickerman [2000] and Outwater and Kitchen [2008]), partially since a large number of HOVs are intra-household (with children) and not inter-household. A simplistic approach would be to multiply driver VOT by occupancy, but from a behavioral perspective, this approach tends to overestimate VOT by vehicle; thus, a reduction factor (typically around 0.5) is employed (Gupta 2013). VOT differentiation between drivers and passengers (if the passenger is of a different income group than the driver) is beyond the scope of typical current TDM practices (Gupta 2013). To avoid such complications, this study assumes that only the driver's costs and time value matter in the route choice, and everyone selects destination, mode, and time of day based on the single-user costs of each mode.

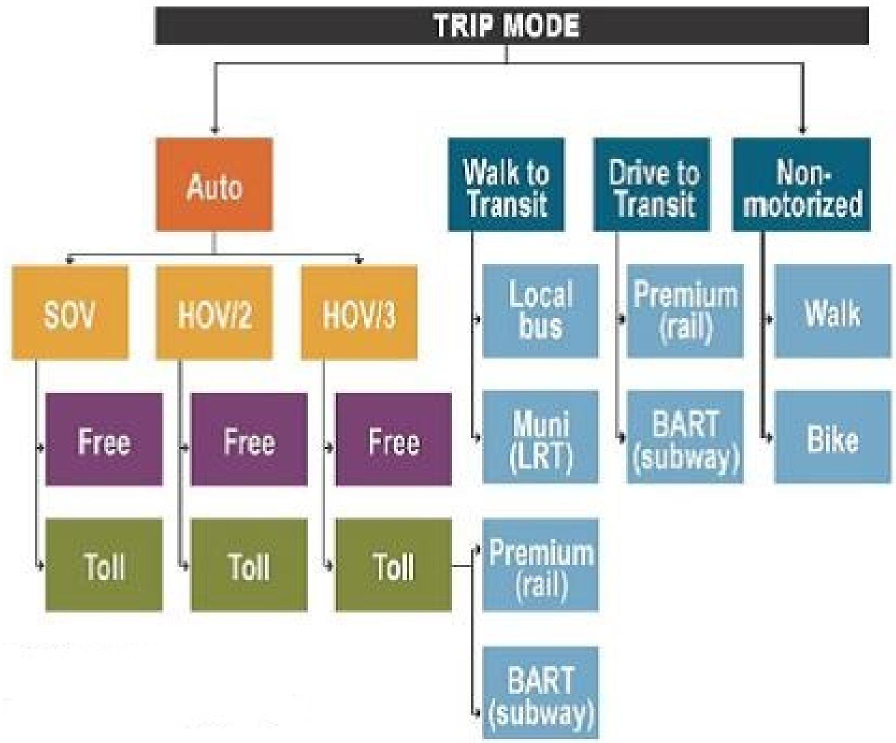


Figure 36. San Francisco Toll Model Structure (HDR, Inc. 2012).

User Class and Values of Time

While the utility of a tolled route varies by time of day, its appeal to a user also depends on specific characteristics of a specific traveler and trip. This project considers three types of user class segmentation:

- Light-duty vehicles (LDVs) and heavy-duty trucks, sufficient in preliminary analyses and for small communities (Zhao 2013).
- LDVs segmented by three income categories and heavy-duty trucks, similar to the practice in Oregon (Parsons Brinckerhoff Quade and Douglas, Inc. 1995).
- Heavy-duty trucks and LDVs segmented by three income categories and two (personal) trip purposes.

Truckers' hourly VOT is assumed to be $40 per hour, and the single-class LDV VOT is assumed to be $12 per hour based on current CAMPO values (CAMPO 2010). In reality, according to the 2007–2011 ACS's five-year estimate, Tyler's median household income is $42,279 and so 18 percent lower than Austin's median household income ($51,596). Thus, the

CAMPO VOT values applied here, as shown in Table 29 and Table 30, may be biased slightly high for the model scenarios that rely on just one income class.

Table 29. VOTs by Income Segmentation.

Household Income	VOT
< $30,000	$8/hour
$30,000–$75,000	$12/hour
> $75,000	$16/hour

Table 30. VOTs per Vehicle by Traveler Income and Trip Purpose Segmentation.

Household Income	VOT for Work Trips	VOT for Non-work Trips
< $30,000	$10/hour	$6/hour
$30,000–$75,000	$14/hour	$10/hour
> $75,000	$18/hour	$14/hour

According to data from the 2010 ACS for the Tyler region, 37 percent of households fall into the low-income group, 36 percent fall into the medium-income group, and 27 percent fall into the high-income group, as defined by the income thresholds shown in Table 29 and Table 30. Hourly distributions of work and non-work trip purposes are based on NCHRP 187 default rates, as shown in Table 24. In current TDM practices, treatment of VOT per vehicle in traffic assignment is typically consistent with that in the model's mode-choice step (Gupta 2013). Again, the VOTs assumed here consider only the driver's income class.

Feedback Loops and Behavioral Convergence

Two types of model convergence improvements are considered here. First, convergence within the **network assignment** step is measured as a gap between the results of consecutive iterations of assignment model runs. TransCAD uses a measure called the relative gap to estimate the difference between the current assignment solution and the equilibrium solution, as defined by:

$$Rel.Gap = \frac{\sum_{\forall links} x_i^{UE} t_i - \sum_{\forall links} x_i^{AON} t_i}{\sum_{\forall links} x_i^{UE} t_i} \quad (5.4)$$

where:

- x_i^{UE} is the current flow on link i.
- x_i^{AON} is the all or nothing flow on link i.
- t_i is the current (model-estimated) travel time on link i.

In the current Texas Package, the convergence criterion for the gap in network assignment is (less than) 0.001 or a maximum of 24 iterations, whichever is achieved first. The preferred convergence criterion for U.S. TDM modeling practice is 0.0001 (Morgan and Mayberry 2010). The network assignment convergence is achieved for each time-of-day period analyzed here.

The second type of convergence improvement considered is an **outer feedback** loop. This loop recycles the congested network's lowest impedance (in this evaluation, generalized cost) routes for all traveler types, shortest-path travel time, and cost skims (for all OD pairs) resulting from the network assignment step back to the trip distribution step. This feedback ensures consistency, allowing the travel patterns to reach a behavioral equilibrium (in theory) and the model system of equations to achieve convergence. Convergence for the outer feedback loop is measured by calculation of the RMSE criterion, which compares the difference between the generalized travel cost originally used in trip distribution (GC'_j) to the generalized travel cost as calculated after trip assignment ($GC°_j$), as shown in the following equation:

$$\%RMSE = \frac{\sqrt{\sum_j (GC'_j - GC°_j)^2 / (\#OD\ Pairs)}}{\sum_j (GC°) / (\#OD\ Pairs)} * 100 \quad (5.5)$$

Convergence is established when the RMSE summed over all ODs is 1 percent or less. In this study, as in general practice, the RMSE for convergence is calculated for a single time of day (when multiple periods exist) for a specific mode (e.g., AM peak period for auto mode, as used in this analysis).The outer feedback loop is particularly important for achieving a stable solution in regions with congestion (Perez et al. 2012).

MODELING SCENARIOS

Tyler Network

Tyler was chosen as the demonstration setting and network for these modeling scenarios, thanks to its small to medium size (a 2012 Census MSA population estimate of 214,821 persons) and recent introduction of a tolled facility (Loop 49). The 2002 network includes 452 zones, 1475 nodes, and 2291 links, as obtained from TxDOT. The 2002 zonal demographic data (also obtained from TxDOT) were used as input for trip generation that is simpler than TripCAL, in order to streamline TransCAD calculations and facilitate rapid TransCAD model runs and result comparisons. For non-commercial person trips, trip generation was performed using standard NCHRP 365 rates for each of three personal trip purposes (HBW, HBO, and NHB trips) (Martin and McGuckin 1998). The person trip attraction rates are calculated as functions of the number of households (HH), whether a zone is in the central business district (CBD), and the numbers of retail, service, and basic jobs in the zone, as shown in the following equations:

- HBW attractions in all zones = 1.45 × Jobs (in zone).
- HBO attraction in CBD zones = (2.0 × CBD Retail Jobs) + (1.7 × Service Jobs) + (0.5 × Basic Jobs) + 0.9 × HHs).
- HBO attraction in non-CBD zones = (9.0 × non-CBD Retail Jobs) + (1.7 × Service Jobs) + (0.5 × Basic Jobs) + (0.9 × HHs).
- NHB attraction in CBD zones = (1.4 × CBD Retail Jobs) + (1.2 × Service Jobs) + (0.5 × Basic Jobs) + (0.5 × HHs).
- NHB attraction in non-CBD zones = (4.1 × non-CBD Retail Jobs) + (1.2 × Service Jobs) + (0.5 × Basic Jobs) + (0.5 × HHs).

For commercial-truck trips, an average of trip rates provided by the Northwest Research Group for Southern California and Seattle's MPO (the Puget Sound Regional Council) was used, based on NCHRP 716 (Cambridge Systematics 2012). Productions and attractions were calculated as functions of the total number of households and total number of jobs, as shown in the following equations:

- Truck trip productions = (0.014 × HHs) + (0.062 × Jobs).
- Truck trip attractions = (0.020 × HHs) + (0.065 × Jobs).

Trip distribution for three trip purposes (HBW, HBO, and NHB) was done via a gravity model using friction factors generated from NCHRP 365's gamma impedance function, shown in the following equation:

$$F_{ij} = a \times t_{ij}^{b} \times e^{c \cdot t_{ij}} \quad (5.6)$$

where:

- F_{ij} is the friction factors between zones *i* and *j*.
- t_{ij} is the travel time between zones *i* and *j*.
- e is Euler's number (2.718).
- a, b, and c are model parameters that vary by trip purpose, as shown in Table 31.

Here, the gravity model is doubly constrained by productions and attractions in each zone, for each of the three trip purposes. In the Texas model, ATOM2 uses a "*triply* constrained" gravity model approach to reflect not just zone-level estimates of trip productions and attractions, but also closely mimic the overall trip length distribution by percent of trips by one minute of separation (Hall 2011).

Table 31. NCHRP 365 Gamma Impedance Function Parameters.

Trip Purpose	a	b	c
HBW	28,507	0.02	0.123
HBO	139,173	1.285	0.094
NHB	219,113	1.332	0.10

Gravity models are typically calibrated to highly aggregated metrics, like trip-length frequency distributions (as currently employed in ATOM2). Singly constrained destination choice models are generally considered more behaviorally defensible for almost all trip purposes and can be applied in a disaggregate manner when compared to gravity models. However, gravity models are more readily available in standard modules in many modeling software packages and therefore remain a popular choice.

While Loop 49 is Tyler's current toll corridor, its distance from the region's downtown and current (very low) traffic volumes (below 2,000 AADT on at least two segments) make the route an unsuitable candidate for testing the sensitivities of the previously described criteria (see Figure 37). For example, any percentage change in Loop 49's low flows may easily overstate the sensitivity of such results to the alternative modeling approaches being tested here. Thus, Loop 323, which is a 19.7-mile four- to six-lane major arterial about 3 miles from the region's primary downtown, was used as a (hypothetical) tolled corridor to test the alternative model specifications. Loop 323 is one of the most congested corridors in the region, due to its relative abundance of retail destinations and proximity to existing urban development. In fact, Loop 49 is viewed as a potential reliever route for inner Loop 323. In these test scenarios, distance-based tolls of $0.20 per mile for autos and $0.50 per mile for trucks were assumed.

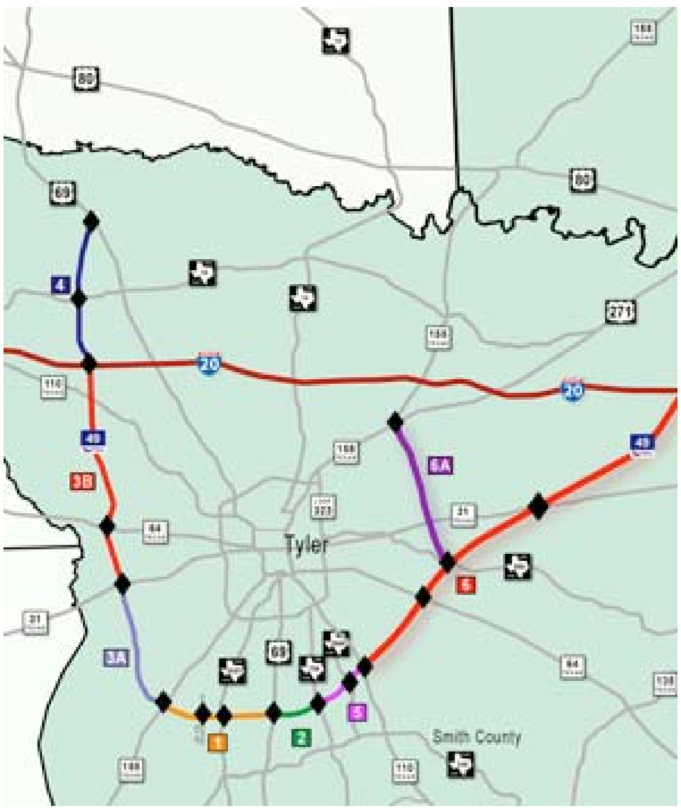


Figure 37. Relative Locations of Loop 49 and Loop 323 in Tyler, Texas.

Scenario Results

The various model improvements discussed previously were incorporated into test runs using the Tyler network. NCHRP Report 365's daily trip generation and attraction values were increased 50 percent to help reflect a moderately congested network, and those volumes were then increased another 50 percent (or 125 percent versus 2002 volumes) to help reflect a severely congested network. As a reference, the trip counts on Loop 323 on the moderately congested network are about 80 percent of the actual 2012 daily traffic volume, whereas traffic counts on Loop 323 in the severely congested network are about 120 percent of the 2012 trip counts.

Texas' current modeling framework is approximated here as the base model: it is a non-tolled 24-hour assignment (no times of day) model with a single user class, no mode-choice step, 0.001 network assignment convergence (gap) criterion, and no outer feedback loop. Building on this base model, two alternative base models (Base Alt 1 and Base Alt 2) that recognize two user classes (commercial trucks and LDVs) are also considered, the first untolled and the second tolled. To give a sense of the level of congestion in the moderate versus severely congested networks, Figure 38 and Figure 39 contrast the daily v/c ratios on each link of the test network under the Base Alt 1 scenario for the two congestion levels. The dark green represents limited congestion (a v/c ratio less than 0.85), light green represents moderate congestion (a v/c ratio between 0.85 and 1.0), orange represents heavy congestion (a v/c between 1.0 and 1.15), and red represents severe congestion (a v/c ratio exceeding 1.15).

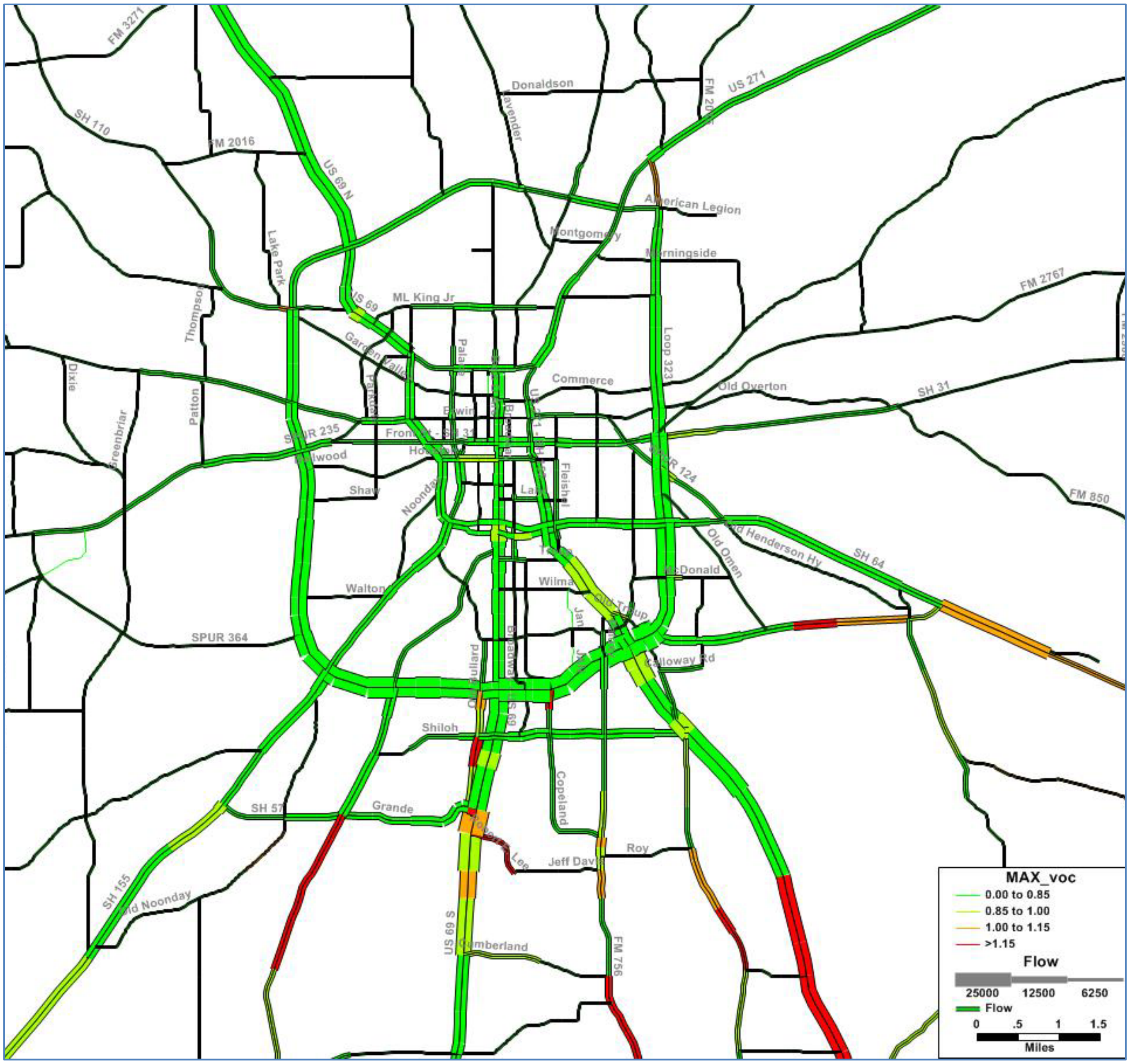


Figure 38. Max V/C Ratios under Moderate Congestion, Base Alt 1 Scenario.

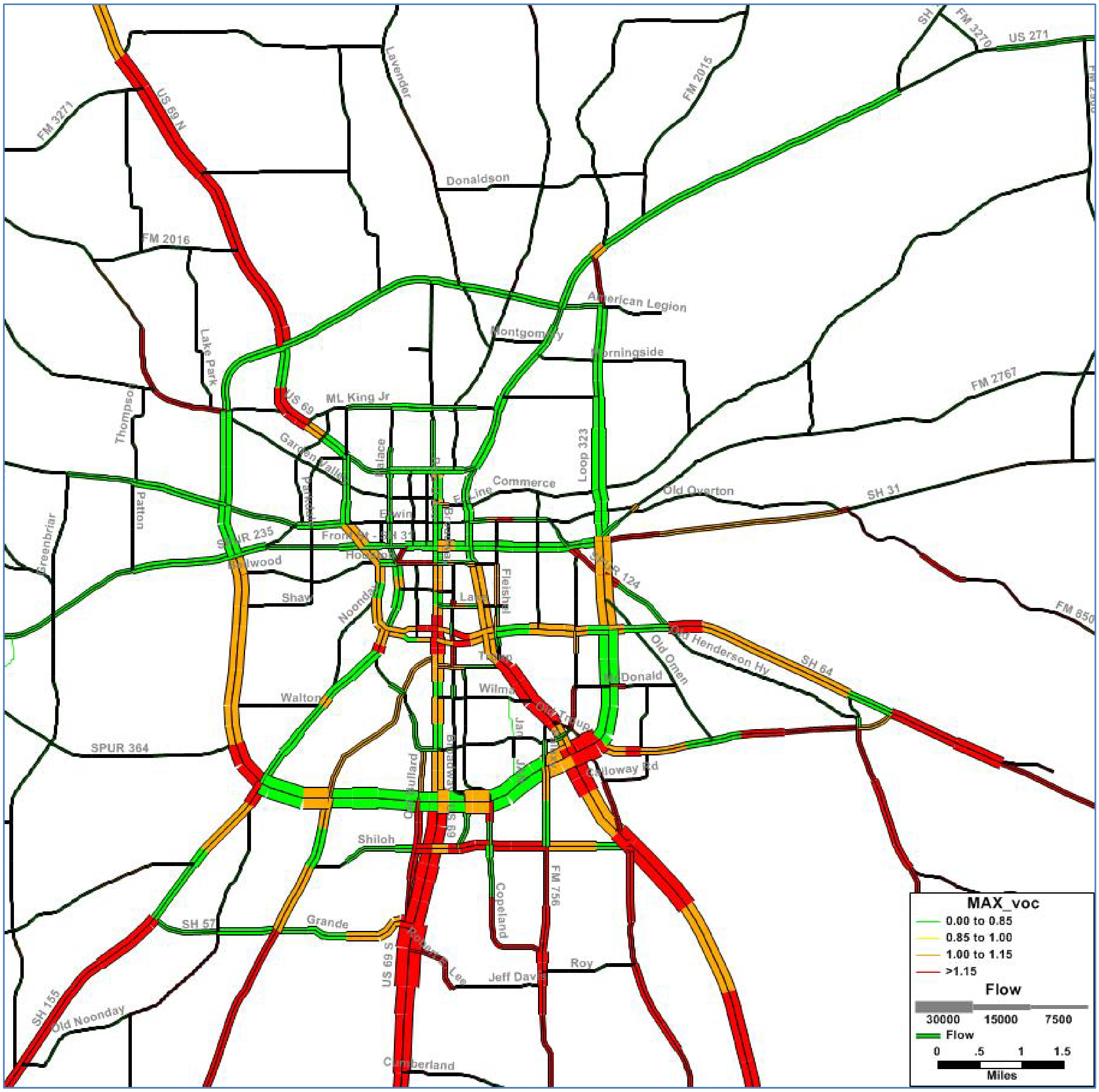


Figure 39. Max V/C Ratios under Severe Congestion, Base Alt 1 Scenario.

From these alternative base-case models, the model improvements were first tested individually and then in various combinations (of two or more changes/extensions), with full-network and Loop 323 VMT and vehicle hours traveled (VHT) values compared to the base model's values (as shown in Table 32 and Table 33).

Table 32. Network and Tolled Route Metrics with Moderate Congestion.

							Network Results				Loop 323 Results			
SCENARIO	**Toll**	**No. Times of Day**	**User Classes**	**Mode Choice**	**Network Assignment Convergence**	**Feedback Loop**	**VHT**	**Percent Change**	**VMT**	**Percent Change**	**VHT**	**Percent Change**	**VMT**	**Percent Change**
Base	N	1	1	-	0.001	N	159,266	-	4.662M	-	10,793	-	436,920	-
Base Alt 1	N	1	2	-	0.0001	N	162,953	2.32%	4.736M	1.57%	11,028	2.18%	445,900	2.06%
Base Alt 2	Y	1	2	-	0.0001	N	161,065	1.13%	4.683M	0.46%	10,785	−0.07%	436,501	−0.10%
Time of Day 1	Y	2	2	-	0.0001	N	164,000	2.97%	4.736M	1.57%	11,059	2.47%	446,193	2.12%
Time of Day 2	Y	4	2	-	0.0001	N	179,308	12.58%	4.742M	1.71%	11,040	2.29%	444,739	1.79%
User Class 1	Y	1	4	-	0.0001	N	159,918	0.41%	4.689M	0.58%	10,917	1.15%	441,683	1.09%
User Class 2	Y	1	7	-	0.0001	N	159,443	0.11%	4.757M	2.02%	10,818	0.23%	437,917	0.23%
Mode Choice 1	Y	1	2	Fixed share	0.0001	N	153,261	−3.77%	4.606M	−1.22%	10,730	−0.58%	434,653	−0.52%
Mode Choice 2	Y	1	2	MNL	0.0001	N	159,966	0.44%	4.464M	−4.24%	10,473	−2.96%	421,688	−3.49%
Feedback Loop	Y	1	2	-	0.0001	Y	151,445	−4.91%	4.464M	−4.24%	10,473	−2.96%	421,688	−3.49%
Combination 1	Y	4	2	-	0.0001	N	179,308	12.58%	4.742M	1.71%	11,040	2.29%	444,739	1.79%
Combination 2	Y	4	4	-	0.0001	N	178,057	11.80%	4.596M	−1.43%	10,516	−2.57%	438,946	0.46%
Combination 3	Y	4	7	-	0.0001	N	169,104	6.18%	4.550M	−2.41%	10,437	−3.30%	414,405	−5.15%
Combination 4	Y	4	7	Fixed share	0.0001	N	168,186	5.60%	4.322M	−7.30%	10,412	−3.53%	410,872	−5.96%
Combination 5	Y	4	7	MNL	0.0001	N	166,120	4.30%	4.512M	−3.22%	10,503	−2.69%	399,549	−8.55%
Combination 6	Y	4	7	MNL	0.00001	Y	158,515	−0.47%	4.406M	−5.50%	9,779	−9.39%	380,283	−12.96%

Table 33. Network and Tolled Route Metrics with Severe Congestion.

							Network Results				Loop 323 Results			
SCENARIO	**Toll**	**No. Times of Day**	**User Classes**	**Mode Choice**	**Network Assignment Convergence**	**Feedback Loop**	**VHT**	**Percent Change**	**VMT**	**Percent Change**	**VHT**	**Percent Change**	**VMT**	**Percent Change**
Base	N	1	1	-	0.001	N	458,246	-	7.068M	-	16,497	-	636,701	-
Base Alt 1	N	1	2	-	0.0001	N	473,362	3.30%	7.178M	1.55%	16,871	2.27%	648,374	1.83%
Base Alt 2	Y	1	2	-	0.0001	N	471,066	2.80%	7.170M	1.43%	16,768	1.64%	643,386	1.05%
Time of Day 1	Y	2	2	-	0.0001	N	479,311	4.60%	7.187M	1.68%	17,122	3.79%	652,769	2.52%
Time of Day 2	Y	4	2	-	0.0001	N	589,349	28.61%	6.467M	−8.51%	17,212	4.33%	651,264	2.29%
User Class 1	Y	1	4	-	0.0001	N	458,012	−0.05%	7.105M	0.52%	16,695	1.20%	642,965	0.98%
User Class 2	Y	1	7	-	0.0001	N	457,218	−0.22%	7.081M	0.18%	16,539	0.26%	638,037	0.21%
Mode Choice 1	Y	1	2	Fixed share	0.0001	N	408,950	−10.76%	6.866M	−2.86%	15,978	−3.14%	620,322	−2.57%
Mode Choice 2	Y	1	2	MNL	0.0001	N	456,687	−0.34%	7.137M	0.97%	16,667	1.03%	645,199	1.33%
Feedback Loop	Y	1	2	-	0.0001	Y	446,640	−2.53%	6.905M	−2.31%	16,284	−1.29%	634,394	−0.36%
Combination 1	Y	4	2	-	0.0001	N	589,349	28.61%	6.467M	−8.51%	17,212	4.33%	651,264	2.29%
Combination 2	Y	4	4	-	0.0001	N	548,934	19.79%	6.088M	−13.87%	16,485	−0.07%	622,974	−2.16%
Combination 3	Y	4	7	-	0.0001	N	575,722	25.64%	6.192M	−12.40%	16,838	2.07%	638,324	0.25%
Combination 4	Y	4	7	Fixed share	0.0001	N	558,760	21.93%	6.195M	−12.36%	15,749	−4.53%	604,288	−5.09%
Combination 5	Y	4	7	MNL	0.0001	N	568,192	23.99%	6.090M	−13.84%	16,710	1.29%	644,111	1.16%
Combination 6	Y	4	7	MNL	0.00001	Y	541,834	18.24%	5.789M	−18.10%	15,978	−3.15%	600,330	−5.71%

Impact of Ignoring Tolls

As expected, reflecting tolls of $0.20 per mile for autos and $0.50 per mile for trucks in the network assignment step (and feeding those skimmed values back into trip distribution, mode, and time-of-day choices) decreased estimates of VHT and VMT on the tolled corridor's links and across the network.[3] A model ignoring tolls in these two demand contexts (moderate and severe congestion Tyler settings) overestimated the network-wide VMT and VHT values by approximately 1 percent and Loop 323's twin metrics by 2 percent (when comparing VHT and VMT results from the Base Alt 1 and Base Alt 2 scenarios, where the only difference is incorporation of tolling). With only one tolled route (19.7 miles in length) in the test network, the difference between results of including versus excluding tolls is small but not necessarily negligible. With more tolled routes in a network, the impact of ignoring tolls is likely to lead to even more inaccurate model estimates.

Impact of Incorporating Time-of-Day Disaggregation

Use of distinct times of day resulted in the largest VMT and VHT changes (network-wide and on Loop 323), versus the base model, as compared to the other model enhancements' impacts. Moreover, output differences between the two and four time-of-day segmentations were noticeable, with the added times of day resulting in greater changes in network and Loop 323 metrics, particularly under the most congested scenario. Incorporating such time-of-day disaggregation in the TDM also allows modelers, planners, and policymakers to reflect for more sophisticated tolling schemes—like those whose rates and HOV policies vary by time of day and/or with congestion, such as is the case with most managed lanes in Texas (and elsewhere).

Impact of Incorporating Full Feedback Loop

In both the moderately and severely congested networks, incorporating a full feedback loop provides the second most impactful improvement, as simply proxied by changes in network and Loop 323 VHT and VMT values. Under congested conditions, an outer feedback loop helps ensure that models do not prematurely stop at an intermediate solution before reaching true

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[3] VHT is simply the number of vehicles on each link times each link's estimated travel times (by time of day), summed across all links. VMT is simply the product of the link volumes and link travel times, summed over all links (across times of day).

convergence, as measured by the RMSE differences across generalized travel costs for all OD pairs for a select time period (peak auto travel time for two time-of-day specifications and AM peak auto travel time for four time-of-day specifications). Other benefits of this outer feedback loop are behavioral defensibility and no added model assumptions. However, a fully automated outer loop may not be compatible with the current Texas Package software for sequential application of ATOM2 (for distribution of trips) because the feedback loop recycles back into the trip distribution step in TransCAD. Full congestion feedback is not currently automated in TransCAD but can be achieved by creating individual model components (e.g., each of the steps outlined in Figure 34) with batch macros, and then creating GISDK loop structures to tie the steps together. For a feedback procedure, a "while" loop that feeds back updated link travel times and tests whether the convergence criterion is met is used, along with a variable that stores the current feedback iteration.

Impact of Incorporating Mode-Choice Step

The addition of a mode-choice step was next in line, in terms of percentage of impacts on model results versus the base alternative. With auto travel dominating mode choices (at approximately 95 percent of trips in the test network), the MNL mode-choice model did not provide significantly better estimates than the fixed-mode shares model. However, in a network with greater shares of transit and nonmotorized travel, the more behaviorally defensible MNL mode-choice model is generally preferred in current TDM practice.

In regions with even higher shares of such modes (as well as carpooling, for example, and HOV-related toll savings), the addition of a mode-choice step would be more meaningful for Texas TDMs. As demonstrated here on the Tyler network, in the specific context of a small to medium-sized network, where the great majority of trips are via LDVs, a fixed-shares mode-choice model may be just as effective as the MNL specification, while reducing modeling complication. For longer-term planning purposes, however, the MNL mode-choice model is more adaptable to shifts in transportation trends (such as rising gas prices and introduction of bike-sharing programs, light rail systems, and vehicle automation). As mentioned previously, for small to medium-sized Texas regions (where carpool mode share comprises 10 to 15 percent of trips), an NL model structure accounting for auto vehicle occupancy would provide additional flexibility in the mode-choice step, allowing for modeling of HOV status on managed lanes.

Impact of Incorporating Multi-class Assignment

When a region's tolls differentiate between vehicle types (e.g., cars versus trucks), simply distinguishing between these vehicles (via two user classes) can meaningfully serve a process of toll demand estimation, as observed in comparisons of the base and Base Alt 1 scenarios. However, differences in model results were not found to be significant as the specifications shifted to use of four and then seven user classes (trucks versus three income levels for LDVs, as well as work versus non-work LDV trip purposes). As congestion grew, the incorporation of such multi-class assignment (and reliance on more user classes) had a greater effect on the tolled corridor's VHT and VMT values. Thus, in settings where travelers' use of specific tolled routes is a focus of the analysis, multi-class assignment should not be overlooked.

CONCLUSIONS

As demonstrated on the Tyler network, a wide variety of model improvements may enhance the current Texas Package to better reflect toll road use and other behaviors. Under the scenarios tested here, model improvements that resulted in the greatest VHT and VMT changes on the tolled corridor and entire network are as follows:

- Recognizing multiple time periods in a day.
- Incorporating a congestion feedback loop.
- Adding a mode-choice step.
- Disaggregating traveler classes by values of time (trucks versus LDVs, and then LDVs by traveler income level and trip purpose).

With respect to the different combination scenarios, adding both multi-class assignment and time-of-day disaggregation to a TDM (Combination 2 and 3 scenarios) seems to be very effective in matching results of the most sophisticated, behaviorally disaggregate model tested here (the Combination 6 scenario, which incorporates tolling, four times of day, seven user classes, MNL mode-choice specification, a 0.0001 network convergence criterion, and a congestion feedback loop). In the test network where transit and nonmotorized shares are low, adding the combination of multiple traveler classes and multiple times of day into the TDM yields results similar to those from adding a mode-choice step to the model.

However, these test model results come with many caveats. For example, in applications focused on emissions rather than toll demand estimation, time-of-day disaggregation becomes more important, along with reflecting a minimum of two user classes (for trucks and auto travel), since emissions and route preferences can vary significantly with speeds—unless there truly is no substantial congestion (or speed variation) forecasted in these networks, within the planning horizon. Finally, the increased complexity of a region's transportation system—via introduction of various congestion pricing schemes (e.g., static and dynamic tolling scenarios) and alternative modes of transit and paratransit (e.g., bus rapid transit, car, and bike sharing)—highlights a need for transportation planners in large and small regions to be aware of the level of flexibility of each of these TDM behavioral disaggregation approaches in accommodating such potential system changes. This work highlights many of the options and their effects on the Tyler network.

CHAPTER 6: REVIEW OF TOLLING APPROACHES FOR IMPLEMENTATION WITHIN TXDOT'S TRAVEL DEMAND MODELS

INTRODUCTION

This chapter is intended to provide TxDOT with comprehensive background information by study area as a means to make informed decisions regarding potential toll approaches for the future. The previous memoranda have discussed specifics associated with study areas that have known current or planned toll roads (i.e., Brownsville, Tyler, and Longview). Given the dynamic nature of funding, one cannot be certain which study areas will require toll road projects and analysis in the future. Consequently, the list of Texas regions with tolled roads may well grow.

Indeed, there are many modeling options available that can be implemented by TxDOT to account for toll roads. These features tend to be sensitive to or dependent on the characteristics of the region and/or sub-region where the toll facility exists or is being planned. Each option has potential challenges and may not be appropriate for all study areas given the variety of contexts in the state relative to congestion levels, anticipated growth, and the nature of the toll facilities themselves. It is important to note, however, that uniformity in modeling approaches can be conducive to support technology transfer and training within the TxDOT Transportation Planning and Programming Division, TxDOT districts, and MPO staff.

For this reason, contextually related topics are discussed as background to illuminate what considerations TxDOT may wish to benchmark when selecting changes to the state's current modeling approach for toll demand estimation. This chapter seeks to determine what the general study area factors are that TxDOT may wish to include when extending travel demand modeling capabilities beyond simply implementing a generalized cost assignment technique. These factors include population trends, levels of congestion, air quality attainment status as set forth by the National Ambient Air Quality Standards (NAAQS), and ranking of MPOs relative to transportation management association (TMA) status. Each of these criteria may be used by TxDOT when examining potential toll demand estimation techniques. At the individual corridor level, the nature of the toll facility (i.e., length, toll cost/fee structure, and location), level of recurrent (existing and forecasted) congestion adjacent to the facility, demographic growth in the region and corridor, potential truck demand as a component of overall travel demand in the region and corridor, modal considerations (e.g., drive alone versus shared ride/transit), and external related travel demand growth can all factor into what approach TxDOT's choices for enhancing current modeling practices.

Beyond traditional regional travel demand analysis itself, potential additional considerations for TxDOT will be the performance and outcome-based measures associated with complying with the Moving Ahead for Progress in the 21st Century Act (MAP-21) surface transportation funding bill. Bringing toll modeling capabilities, such as enhanced assignment procedures that include vehicle and/or time-of-day segmentation, can serve both current and future planning needs for not only TxDOT but also MPOs throughout the state. Indeed, addressing toll demand estimation can be viewed as the impetus for enhancing the robustness of existing travel demand models. Toll roads may be seen as a policy approach to address congestion in a more timely fashion rather than waiting on traditional funding revenue sources. Because of this, the travel demand models will need to have the capability to assess potential outcomes of building or not building these types of facilities.

TxDOT already possesses the capability to account for toll roads in the Texas Statewide Analysis Model (Texas SAM) version 3, which was recently released. The techniques used in the Texas SAM may provide a framework for addressing tolls in the urban area models or facilities that cross multiple jurisdictions. The use of this existing capability needs to be examined in the context of practicality with respect to urbanized area implementation.

TRUCK AND TOTAL VEHICLE MILES OF TRAVELED TRENDS

Congestion, or specifically diversion due to congestion and a willingness to pay for a non-congested alternative route, plays a significant role in the demand for tolled roadways. Total and percentage changes in VMT trends across Texas between 2005 and 2010 illustrates various travel shifts over time.[4] The total daily VMT changes were also benchmarked against corresponding county-level population data to further highlight changes within study areas. The truck VMT data were accumulated to illustrate the level of truck activity in a particular region

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[4] The year 2010 was selected to be consistent with the decennial U.S. Census years. The base year, 2005, was selected to be consistent with the formatting changes implemented by TxDOT in the *Annual Mileage by County Report.* The annual VMT report was used as a means to communicate traffic levels among all MPOs in the state against all other MPOs in the state.

based on daily VMT estimates provided by county. Given that trucks are charged based on a per-axle basis, the data may be useful in determining the likelihood of truck usage on tolled facilities.

The annual county VMT summary report provides total and truck VMT data for both on-system and off-system facilities. Information regarding on-system roads includes state highways, spurs, loops, business routes, farm- or ranch-to-market roads, park, and recreational roads. The information presented in this section does not include city streets or certified county roads, more commonly referred to as off-system roads.

Thus far, only information on Tyler, Longview, Brownsville, and Laredo has been presented because there is a known element to toll demand estimation need in these regions. There are 25 MPOs in Texas. Of the 25 study areas, 12 are officially recognized as TMAs. These are typically considered to be study areas that exceed 200,000 in total population. Being officially designated as a TMA brings additional reporting responsibilities within the MTPs, to name one of the differences between a TMA and a traditional MPO. The largest study area, as measured by population, is the 12-county Dallas-Fort Worth region in north-central Texas. The smallest study area by population is Victoria in Victoria County. Table 34 shows the TMA status by study area and highlights which counties are used in the total VMT summaries that follow.

Table 34. County Summary Data by MPO.

TMA Status	MPO	Counties
	Abilene	Taylor*, Jones*, and Callahan*
	Amarillo	Potter and Randall
TMA	Austin (CAMPO)	Travis, Williamson, Hays, Caldwell, and Bastrop
TMA	Brownsville	Cameron**
	Bryan-College Station	Brazos
TMA	Corpus Christi	San Patricio, Nueces, and Aransas*
TMA	Dallas-Fort Worth	12 counties in north-central Texas
TMA	El Paso	El Paso, Texas*, and Dona Ana, New Mexico*
	Harlingen-San Benito	Cameron**
TMA	Hidalgo County	Hidalgo
TMA	Houston-Galveston	Harris, Galveston, Chambers, Liberty, Montgomery, Waller, Fort Bend, and Brazoria
	Beaumont (Jefferson-Orange-Hardin [JORHTS])	Hardin, Orange, and Jefferson
TMA	Killeen-Temple (Killeen-Temple Urban Transportation Study [K-TUTS])	Bell, Lampasas*, and Coryell*
TMA	Laredo	Webb*
	Longview	Gregg, Upshur*, Harrison*, and Rusk*
TMA	Lubbock	Lubbock*
TMA	Midland-Odessa	Midland* and Ector*
	San Angelo	Tom Green*
TMA	San Antonio	Kendall, Comal, Guadalupe, Wilson, and Bexar
	Sherman-Denison	Grayson
	Texarkana	Bowie County*, Texas, and Miller County, Arkansas*
	Tyler	Smith
	Victoria	Victoria
	Waco	McLennan*
	Wichita Falls	Wichita*

** Partial county coverage*
*** Brownsville and Harlingen-San Benito are located inside Cameron County.*

For study areas such as Wichita Falls, Abilene, San Angelo, and Texarkana, only the primary county was reported, even though portions of the study area might partially extend into neighboring counties. It was deemed unnecessary to report the adjacent county data since these portions of the study area were considered insignificant relative to the study area summary. For instance, Abilene is primarily located in Taylor County, while portions of the study area extend into Jones and Callahan Counties. The two additional counties were not included in the VMT summaries; only Taylor County was included. This approach also extends to Killeen-Temple-Belton where only Bell County was summarized. For study areas that are split by the Texas state line, such as El Paso and Texarkana, only the Texas county summary was reported. Neither Dona Ana, New Mexico, nor Miller County, Arkansas, were added to the respective summaries for El Paso and Texarkana. For these examples, the county used is highlighted in red in Table 34.

The other unique aspect of the VMT summaries concerns Cameron County. Cameron County includes both the Brownsville and Harlingen-San Benito MPOs. The VMT data are not distributed between the two MPOs. Consequently, both MPOs report the same VMT since the data are provided in county-level format.

Daily VMT Trends (2005 to 2010)

As noted previously, the annual TxDOT report on daily county VMT provides data on total daily VMT and daily truck VMT. Table 35 shows the changes in total VMT by study area between 2005 and 2010 for on-system roads only. The five-year VMT trend is mixed by study area. Some study areas experienced a total on-system decline in VMT, while others experienced only moderate growth. The five-year changes in total on-system daily VMT for each study area are depicted in Figure 40.

Table 35. 2005 to 2010 Total Daily VMT Trends by Study Area.

MPO	2005 Daily VMT	2010 Daily VMT	2005 to 2010 Total VMT Growth	2005 to 2010 Percent Growth Total VMT
Abilene	2,158,210	2,241,591	83,382	3.86%
Amarillo	3,911,533	4,210,408	298,875	7.64%
Austin (CAMPO)	28,099,444	31,342,109	3,242,665	11.54%
Brownsville	5,597,171	5,868,084	270,913	4.84%
Bryan-College Station	3,220,132	3,261,986	41,854	1.30%
Corpus Christi	8,304,594	7,256,589	−1,048,004	−12.62%
Dallas-Fort Worth	102,366,992	104,173,546	1,806,554	1.76%
El Paso	9,986,119	10,256,462	270,343	2.71%
Harlingen-San Benito	5,597,171	5,868,084	270,913	4.84%
Hidalgo County	9,616,217	10,127,589	511,372	5.32%
Houston-Galveston	87,539,165	86,221,979	−1,317,186	−1.50%
Jefferson-Orange-Hardin (JORHTS)	9,256,356	9,058,520	−197,836	−2.14%
Killeen-Temple (K-TUTS)	6,375,227	6,235,716	−139,510	−2.19%
Laredo	2,704,454	2,761,654	57,200	2.12%
Longview	2,731,191	2,659,069	−72,122	−2.64%
Lubbock	3,579,996	3,503,768	−76,228	−2.13%
Midland-Odessa	3,951,408	4,149,213	197,805	5.01%
San Angelo	1,555,841	1,651,468	95,627	6.15%
San Antonio	33,380,116	35,118,879	1,738,763	5.21%
Sherman-Denison	3,346,695	2,957,916	−388,779	−11.62%
Texarkana	2,918,246	2,607,168	−311,077	−10.66%
Tyler	5,212,255	4,883,289	−328,966	−6.31%
Victoria	2,019,611	1,933,180	−86,430	−4.28%
Waco	6,257,971	5,850,887	−407,084	−6.51%
Wichita Falls	2,279,577	2,060,504	−219,073	−9.61%
Total	**351,965,688**	**356,259,659**	**4,293,971**	**1.22%**

Source: TxDOT (2008, 2012)

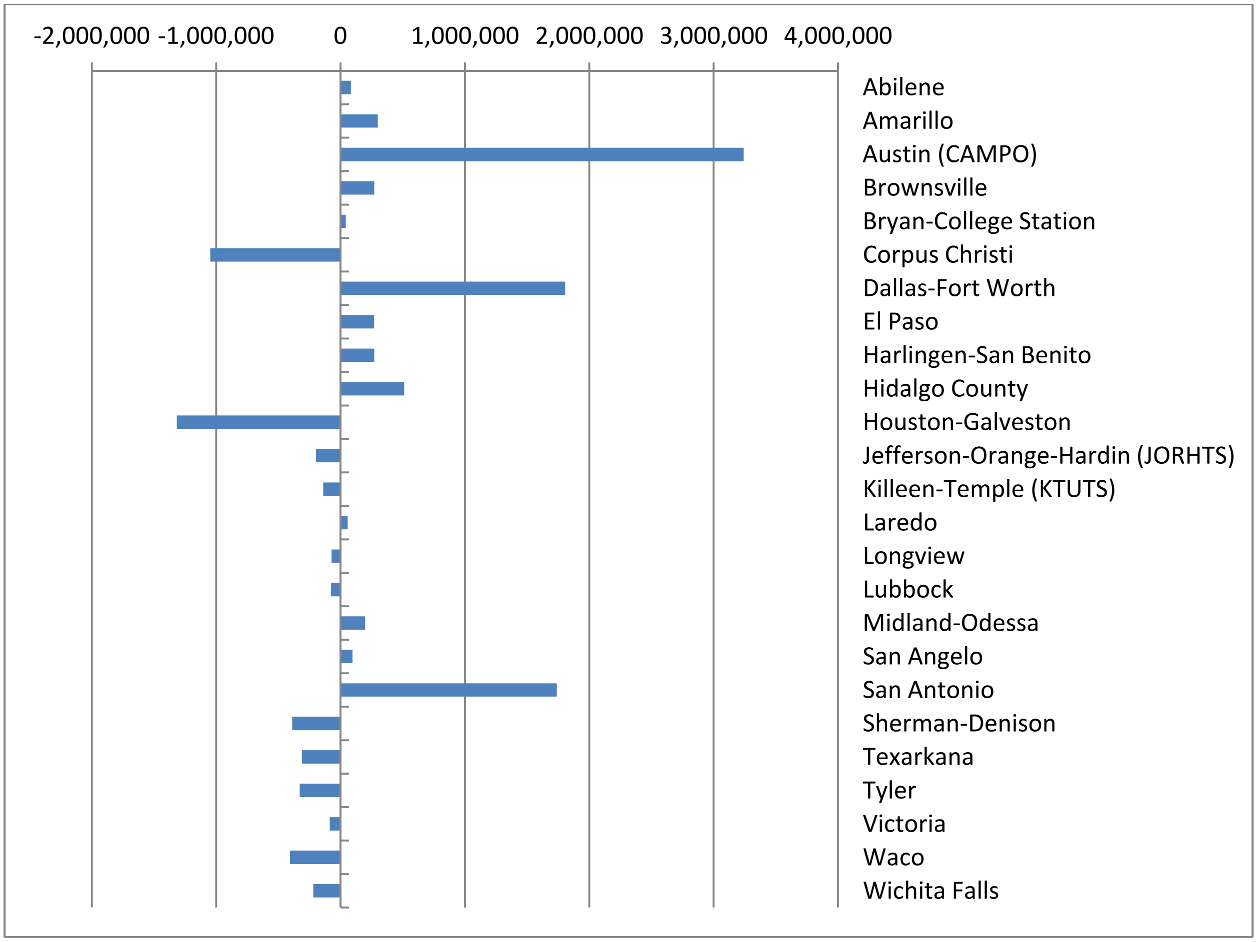

Figure 40. Daily VMT Changes between 2005 and 2010 by Study Area.

Notable findings from Table 35 and Figure 40 include the following:

- The total on-system VMT five-year trend among the five largest study areas is mixed. The five largest MPOs in the state are NCTCOG in Dallas-Fort Worth, H-GAC in Houston, CAMPO in Austin, the San Antonio-Bexar County Urban Transportation Study (SABCUTS) in San Antonio, and the El Paso Metropolitan Planning Organization (ELPMPO). Among the five largest study areas, CAMPO accounts for 75 percent of the total VMT growth. The five-county region in CAMPO grew by 3.2 million daily VMT. Conversely, the eight-county H-GAC region experienced a 1.3 million decline in total daily VMT according to the TxDOT annual report.
- The five largest study areas represent approximately 75 percent of the total VMT among the 25 MPOs.
- The five-county San Antonio region experienced the second largest aggregate increase in total daily VMT with a nearly 1.7 million increase.

- The 12 TMAs in the state represent approximately 85 percent of the total daily VMT. Consequently, the remaining 13 MPOs in the state only account for less than 15 percent of the total on-system VMT among all MPOs. This highlights the level of travel and congestion in these regions, which include study areas such as Tyler where a toll road is currently open and being expanded, and Longview where a planned toll road facility is being considered in the long-range plan. Figure 41 illustrates the distribution of total daily VMT between the 12 largest MPOs in comparison to the 13 small to medium-size MPOs not designated as TMAs.
- Two study areas experienced a total daily VMT decline greater than a million—Corpus Christi and H-GAC. Both of these study areas are TMAs.
- Two additional TMAs also experienced an aggregate decline in daily VMT—Lubbock and Killeen-Temple. The decline in daily VMT in Bell County, which represents the largest proportion of K-TUTS, may be attributable to military deployments associated with Fort Hood.

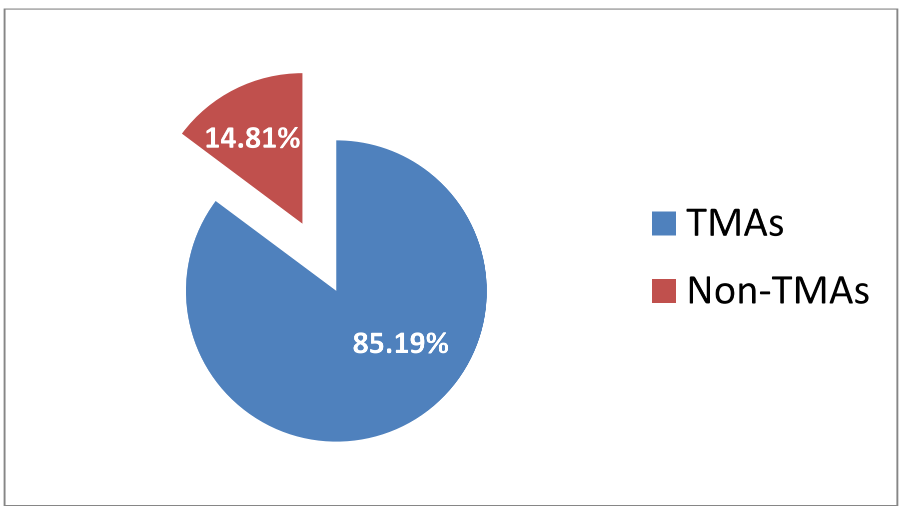

Figure 41. Distribution of Daily VMT between TMAs and Non-TMAs.

Using the data in Table 35, each of the 25 study areas can be ranked relative to total aggregate changes in daily VMT. Table 36 and Table 37 depict the aggregate changes to VMT relative to TMA and non-TMA status, respectively. The tables rank the total VMT changes from most to least.

Table 36. Five-Year Daily VMT Growth Rank for TMAs.

MPO	2005 Daily VMT	2010 Daily VMT	2005 to 2010 Total VMT Growth	MPO Rank Total VMT Growth
Austin (CAMPO)	28,099,444	31,342,109	3,242,665	1
Dallas-Fort Worth	102,366,992	104,173,546	1,806,554	2
San Antonio	33,380,116	35,118,879	1,738,763	3
Hidalgo County	9,616,217	10,127,589	511,372	4
Brownsville	5,597,171	5,868,084	270,913	6
El Paso	9,986,119	10,256,462	270,343	8
Midland-Odessa	3,951,408	4,149,213	197,805	9
Laredo	2,704,454	2,761,654	57,200	12
Lubbock	3,579,996	3,503,768	−76,228	15
Killeen-Temple (K-TUTS)	6,375,227	6,235,716	−139,510	17
Corpus Christi	8,304,594	7,256,589	−1,048,004	24
Houston-Galveston	87,539,165	86,221,979	−1,317,186	25

Source: TxDOT (2008, 2012)

Table 37. Five-Year Daily VMT Growth Rank for Non-TMAs.

MPO	2005 Daily VMT	2010 Daily VMT	2005 to 2010 Total VMT Growth	MPO Rank Total VMT Growth
Amarillo	3,911,533	4,210,408	298,875	5
Harlingen-San Benito	5,597,171	5,868,084	270,913	6
San Angelo	1,555,841	1,651,468	95,627	10
Abilene	2,158,210	2,241,591	83,382	11
Bryan-College Station	3,220,132	3,261,986	41,854	13
Longview	2,731,191	2,659,069	−72,122	14
Victoria	2,019,611	1,933,180	−86,430	16
Jefferson-Orange-Hardin (JORHTS)	9,256,356	9,058,520	−197,836	18
Wichita Falls	2,279,577	2,060,504	−219,073	19
Texarkana	2,918,246	2,607,168	−311,077	20
Tyler	5,212,255	4,883,289	−328,966	21
Sherman-Denison	3,346,695	2,957,916	−388,779	22
Waco	6,257,971	5,850,887	−407,084	23

Source: TxDOT (2008, 2012)

A few sample highlights of Table 36 and Table 37 not previously discussed include the following:

- Eight of the 13 non-TMAs experienced an aggregate decline in total daily VMT during the five-year period between 2005 and 2010.

- VMT in the 13 non-TMAs shrank with an average total daily VMT change of −93,901, while the average total daily growth in the 12 TMAs is 459,557 VMT.

The five-year trend is a relatively small sample size to make conclusive projections relative to long-term outlooks; however, the data do provide context relative to the level of traffic in a region relative to all other regions in the state.

Daily VMT per Capita Trends (2005 to 2010)

Another approach to examining daily VMT trends is to review the daily VMT values by study area relative to changes in population. Similarly to the aggregation of the daily VMT data, the county population data were used to calculate VMT per person. Fourteen MPOs in the state have MABs that extend to the county line. As noted previously, some study area MABs partially extend into a neighboring county or do not quite represent an entire county. In these instances and to be consistent with the county reporting of VMT, the primary county was used to report total population. Table 38 shows the 2005 and 2010 county population totals by study area as well as the resultant VMT per capita. The table is sorted based on the five-year growth rank in VMT per capita.

Table 38. Total Daily VMT per Person Trends from 2005 to 2010.

MPO	2005 Pop. TSDC	2010 Pop. TSDC	5-Year Pop. Growth	2005 VMT per Pop.	2010 VMT per Pop.	5-Year VMT per Pop. Trend	5-Year VMT per Pop. Growth	Rank—5-Year VMT/ Pop. Growth
Amarillo	229,405	241,798	12,393	17.05	17.41	Up	0.36	1
Abilene	127,816	131,506	3,690	16.89	17.05	Up	0.16	2
San Angelo	102,748	110,224	7,476	15.14	14.98	Down	−0.16	3
Brownsville	378,074	406,220	28,146	14.80	14.45	Down	−0.36	4
Harlingen-San Benito	378,074	406,220	28,146	14.80	14.45	Down	−0.36	4
Laredo	228,354	250,304	21,950	11.84	11.03	Down	−0.81	6
Jefferson-Orange-Hardin (JORHTS)	381,764	388,745	6,981	24.25	23.30	Down	−0.94	7
El Paso	726,006	800,647	74,641	13.75	12.81	Down	−0.94	8
Austin (CAMPO)	1,458,641	1,716,289	257,648	19.26	18.26	Down	−1.00	9
Midland-Odessa	244,185	274,002	29,817	16.18	15.14	Down	−1.04	10
Hidalgo County	677,902	774,769	96,867	14.19	13.07	Down	−1.11	11
Dallas-Fort Worth	5,854,799	6,417,724	562,925	17.48	16.23	Down	−1.25	12
Victoria	85,455	86,793	1,338	23.63	22.27	Down	−1.36	13
San Antonio	1,777,429	2,031,106	253,677	18.78	17.29	Down	−1.49	14
Lubbock	250,276	278,831	28,555	14.30	12.57	Down	−1.74	15
Longview	114,885	121,730	6,845	23.77	21.84	Down	−1.93	16
Wichita Falls	128,711	131,500	2,789	17.71	15.67	Down	−2.04	17
Houston-Galveston	5,222,861	5,891,999	669,138	16.76	14.63	Down	−2.13	18
Waco	222,313	234,906	12,593	28.15	24.91	Down	−3.24	19
Bryan-College Station	160,863	194,851	33,988	20.02	16.74	Down	−3.28	20
Texarkana	92,271	92,565	294	31.63	28.17	Down	−3.46	21
Corpus Christi	386,425	405,027	18,602	21.49	17.92	Down	−3.57	22
Sherman-Denison	117,320	120,877	3,557	28.53	24.47	Down	−4.06	23
Tyler	190,019	209,714	19,695	27.43	23.29	Down	−4.14	24
Killeen-Temple (K-TUTS)	260,526	310,235	49,709	24.47	20.10	Down	−4.37	25
Total	**19,797,122**	**22,028,582**	**2,231,460**	**17.78**	**16.17**	**Down**	**−1.61**	

Source: TSDC (2013) and TxDOT (2008, 2012)

Based on the data presented in Table 38, select findings include the following:

- Each study area had a positive trend in population growth, with some study areas experiencing more robust growth than others.
- The five largest MPOs in the state (NCTCOG, H-GAC, SABCUTS, CAMPO, and ELPMPO) had five of the six largest increases in terms of total population.
- Hidalgo County had the fifth largest aggregate increase in the state with nearly three-quarters of a million people.
- Texarkana had the smallest population increase with only 294 people added, or approximately 59 people per year.
- Tyler had a modest increase of nearly 20,000 people, or approximately 4,000 people per year, though it showed the 9th highest population percentage growth rate at 10 percent.
- Other study areas, such as Longview and Brownsville, which are constructing toll roads, experienced positive population trends. Longview, however, only added approximately 1,400 people per year (ranking 16th by population growth rate at 6 percent).
- Only two of the 25 study areas (Amarillo and Abilene) experienced a positive growth in VMT trends per capita when using county-level data. The remaining study areas experienced a decline.
- Some study areas experienced a corresponding decline in VMT or only a modest increase in VMT, which could not offset the corresponding increase in population—hence the large decline in VMT-per-capita values.
- Hidalgo County is an example of a county that had positive increases in VMT and population. However, the population increase outweighed the corresponding daily VMT increase. The county added nearly 100,000 people in the five-year period. The county also experienced an increase of nearly 0.5 million daily VMT. However, the resultant ratio of population to VMT reveals a per-capita decline.

- Corpus Christi, Sherman-Denison, Tyler, and Killeen-Temple-Belton experienced the greatest decline in per-capita VMT. Some of this may have been due to unique considerations, such base deployments at Fort Hood in Killeen. Others may be due to the sharp decline in daily VMT, such as in Corpus Christi.
- The overall trend for the state's 25 MPOs is declining VMT per capita.

It is not clear if these trends represent a temporary or more permanent change in travel behavior. The five-year period includes a near economic depression and a correspondingly slow recovery in housing and other financial markets. In addition, for those study areas that only partially represent a county, the totals may have been diluted by using the entire population and daily VMT data reported at the county level. For some study areas such as Corpus Christi, where base closures occurred and industries moved away, there are localized factors contributing to the trend analysis. The trends, though, are worth monitoring for not only the potential implications for accounting for future toll demand but also forecasting demand in general.

It could be concluded that shorter or fewer trips are being made, but it would be difficult to draw any significant conclusions regarding longer-distance trips that are high-value trips for toll roads. Overall, though, the five-year period shows a decline in VMT.

Daily Truck VMT Trends (2005 to 2010)

Given that trucks do contribute to overall toll demand (albeit slightly in terms of percent vehicle mix), a corresponding examination of daily truck VMT trends by study area was also conducted. Truck trips on existing toll roads may be relatively few when compared to auto trips, but trucks pay a larger toll based on the total number of axles. Therefore, examining truck VMT in aggregate as well as trends may provide some foundation criteria for determining when it might be appropriate to segment the trip tables into auto and truck classes. Adding additional market segmentation allows TxDOT to include different toll costs as well as vehicle operating costs by class. Decisions regarding how many classes are created are typically done at the corridor level depending on anticipated vehicle mix and to some extent commodity types/flows. Table 39 provides information regarding truck activity for 2005 and 2010.

Table 39. 2005 and 2010 Daily Truck VMT by Study Area.

MPO	2005 Truck VMT	2005 Daily VMT	2005 Percent of Daily VMT	2010 Truck VMT	2010 Daily VMT	2010 Percent of Daily VMT
Abilene	444,445	2,158,210	20.59%	441,980	2,241,591	19.72%
Amarillo	632,716	3,911,533	16.18%	679,655	4,210,408	16.14%
Austin (CAMPO)	2,573,230	28,099,444	9.16%	2,694,897	31,342,109	8.60%
Brownsville	558,035	5,597,171	9.97%	493,407	5,868,084	8.41%
Bryan-College Station	272,650	3,220,132	8.47%	320,876	3,261,986	9.84%
Corpus Christi	1,021,983	8,304,594	12.31%	876,641	7,256,589	12.08%
Dallas-Fort Worth	10,164,367	102,366,992	9.93%	10,012,651	104,173,546	9.61%
El Paso	1,142,095	9,986,119	11.44%	1,002,754	10,256,462	9.78%
Harlingen-San Benito	558,035	5,597,171	9.97%	493,407	5,868,084	8.41%
Hidalgo County	937,108	9,616,217	9.75%	822,407	10,127,589	8.12%
Houston-Galveston	6,941,623	87,539,165	7.93%	6,882,404	86,221,979	7.98%
Jefferson-Orange-Hardin (JORHTS)	1,115,289	9,256,356	12.05%	1,237,205	9,058,520	13.66%
Killeen-Temple (K-TUTS)	895,090	6,375,227	14.04%	870,557	6,235,716	13.96%
Laredo	548,440	2,704,454	20.28%	448,959	2,761,654	16.26%
Longview	350,074	2,731,191	12.82%	339,563	2,659,069	12.77%
Lubbock	451,397	3,579,996	12.61%	394,300	3,503,768	11.25%
Midland-Odessa	711,962	3,951,408	18.02%	888,919	4,149,213	21.42%
San Angelo	178,943	1,555,841	11.50%	151,569	1,651,468	9.18%
San Antonio	3,134,634	33,380,116	9.39%	2,919,845	35,118,879	8.31%
Sherman-Denison	393,000	3,346,695	11.74%	395,304	2,957,916	13.36%
Texarkana	659,491	2,918,246	22.60%	621,371	2,607,168	23.83%
Tyler	681,907	5,212,255	13.08%	709,366	4,883,289	14.53%
Victoria	338,954	2,019,611	16.78%	351,735	1,933,180	18.19%
Waco	1,033,781	6,257,971	16.52%	1,012,652	5,850,887	17.31%
Wichita Falls	331,326	2,279,577	14.53%	312,656	2,060,504	15.17%
Total	***36,070,576***	***351,965,688***	***10.25%***	***35,375,081***	***356,259,659***	***9.93%***

Source: TxDOT (2008, 2012)

Highlights of the 2005 and 2010 truck activity shown in Table 39 (as expressed in daily truck VMT) include the following:

- Ten of the 25 study areas experienced an increase in trucks, representing a larger share of total daily VMT during the five-year period.
- In 2010, only two of the 25 study areas had a truck VMT greater than 20 percent—Texarkana and Midland-Odessa. This is down from three study areas in 2005.
- Seven of the 25 study areas have greater than 16 percent of the total daily VMT attributable to truck VMT. The study areas with the largest percentages through the years are Texarkana, Midland-Odessa, Laredo, and Abilene. Texarkana consistently has the highest amount of daily VMT associated with truck activity in the region.
- In terms of total truck VMT, the 12-county Dallas-Fort Worth region has the highest total value, with more than 10 million daily truck VMT. San Angelo has the fewest, with approximately 150,000 daily truck VMT. The two areas are a study in contrast. The Dallas-Fort Worth region is the largest study area in terms of square miles, representing nearly 9,500 square miles, while Tom Green County (San Angelo) is a little over 1,500 square miles.

In terms of the proportion of daily truck VMT to daily travel, Table 39 provides the percent of truck activity relative to total VMT. The data in Table 40 are ranked according to the five-year absolute growth in truck VMT. To contrast this with total daily VMT growth, the rank for the absolute daily growth in VMT is also presented. In many instances, the truck VMT growth rank is very different from the total daily VMT growth rank. For example, Beaumont (JORHTS) and Tyler experienced fairly significant gains in daily truck VMT, while overall VMT declined. Other findings from Table 40 include the following:

- In 2010, approximately 79 percent of the total daily truck VMT is inside the 12 TMAs. As depicted in Figure 42, only 21 percent of the daily truck VMT is associated with the 13 smaller MPOs not classified as TMAs.
- The five-county CAMPO study area had the third largest truck travel increase and the highest overall daily travel increase.
- Conversely, the 12-county Dallas-Fort Worth region had the second largest overall increase in daily VMT but the second largest decline in truck VMT.

- San Antonio had the highest decline in truck VMT relative to the 25 MPOs in the state but the third largest increase in daily VMT.
- In 2010, approximately 66 percent of the total truck VMT in the 25 MPOs resided in the five largest urbanized areas.
- For the 13 smallest MPOs, the average daily truck VMT was approximately 7 million, which represents approximately 14 percent of the total daily VMT. Conversely, truck VMT represented approximately 9 percent of the daily VMT in the five largest study areas. This reinforces the potential need to segment the trips into auto and truck classes for the smaller study areas.
- For the state's 25 MPOs, there was an overall decline of nearly 700,000 daily truck VMT.
- For the state's 25 MPOs, there was an overall increase of nearly 4.3 million total daily VMT.

Table 40. 2005 to 2010 Truck and Daily VMT Trends by Study Area.

MPO	2005 to 2010 Truck VMT Growth	2005 to 2010 Total VMT Growth	2005 to 2010 Percent Growth Truck VMT	2005 to 2010 Percent Growth Total VMT	Rank Absolute Truck VMT Growth	Rank Absolute Total VMT Growth
Midland-Odessa	176,957	197,805	24.85%	5.01%	1	9
Jefferson-Orange-Hardin (JORHTS)	121,916	−197,836	10.93%	−2.14%	2	18
Austin (CAMPO)	121,667	3,242,665	4.73%	11.54%	3	1
Bryan-College Station	48,226	41,854	17.69%	1.30%	4	13
Amarillo	46,939	298,875	7.42%	7.64%	5	5
Tyler	27,459	−328,966	4.03%	−6.31%	6	21
Victoria	12,781	−86,430	3.77%	−4.28%	7	16
Sherman-Denison	2,304	−388,779	0.59%	−11.62%	8	22
Abilene	−2,465	83,382	−0.55%	3.86%	9	11
Longview	−10,511	−72,122	−3.00%	−2.64%	10	14
Wichita Falls	−18,670	−219,073	−5.63%	−9.61%	11	19
Waco	−21,129	−407,084	−2.04%	−6.51%	12	23
Killeen-Temple (K-TUTS)	−24,533	−139,510	−2.74%	−2.19%	13	17
San Angelo	−27,374	95,627	−15.30%	6.15%	14	10
Texarkana	−38,120	−311,077	−5.78%	−10.66%	15	20
Lubbock	−57,097	−76,228	−12.65%	−2.13%	16	15
Houston-Galveston	−59,219	−1,317,186	−0.85%	−1.50%	17	25
Brownsville	−64,629	270,913	−11.58%	4.84%	18	6
Harlingen-San Benito	−64,629	270,913	−11.58%	4.84%	18	6
Laredo	−99,481	57,200	−18.14%	2.12%	20	12
Hidalgo County	−114,701	511,372	−12.24%	5.32%	21	4
El Paso	−139,341	270,343	−12.20%	2.71%	22	8
Corpus Christi	−145,342	−1,048,004	−14.22%	−12.62%	23	24
Dallas-Fort Worth	−151,716	1,806,554	−1.49%	1.76%	24	2
San Antonio	−214,789	1,738,763	−6.85%	5.21%	25	3

Source: TxDOT (2008, 2012)

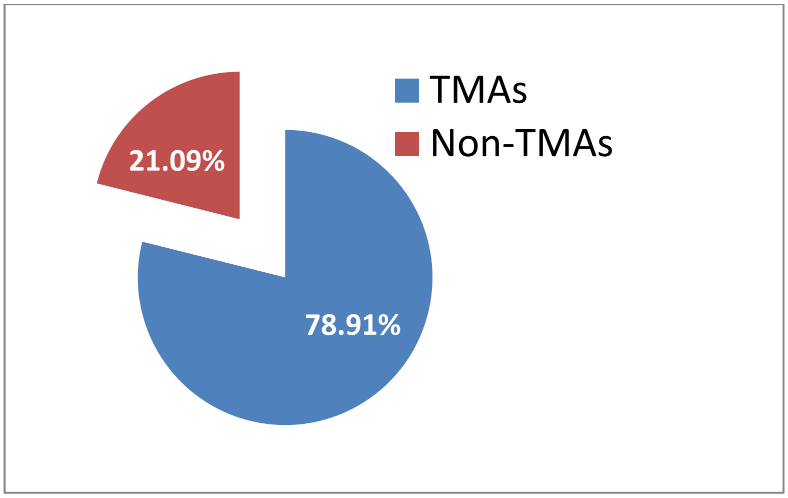

Figure 42. Percentage of Overall Daily Truck VMT for TMAs and Non-TMAs.

Clearly, vehicle mix plays a significant role in estimating toll demand or matching current counts on existing toll facilities. No matter how significant the mix of trucks, TxDOT should consider adding additional trip table segmentation to properly address toll demand using the generalized cost approach. As noted, this provides a means to distinguish costs and VOT during the assignment procedure. Depending on traffic variation by time of day, additional consideration could be given to implementing diurnal procedures to capture changes in vehicle mix by time of day.

MEASURES OF CONGESTION

As noted in the previous section regarding daily and truck VMT, congestion plays a significant role in the relative attractiveness of a toll road. A toll road allows the end user to pay for mobility on a facility that presumably has more reliable travel times and allows users to bypass congestion. For locations that do not have meaningful congestion, which has already been reviewed for study areas like Tyler, Longview, and Brownsville, the impetus is not as strong to pay for access to a facility when there are several free or lightly congested routes available. The previous section reviewed VMT values and trends by study area as one method of enumerating congestion levels by study area. More importantly, the section highlighted the differences in truck mix by study area, which may justify the need to create vehicle class segments in the trip tables, whether these are daily or time of day.

As a part of defining the context of why TxDOT may wish to consider additional travel demand modeling approaches that include considerations beyond the need to account for toll roads, three other measures of congestion were examined. The first potential measure is TTI's *Annual Urban Mobility Report* (Schrank et al. 2012), which examines current and historical congestion trends for 498 of the largest urbanized areas across the country. Historical data are available as far back as 1982. A byproduct of the *Annual Urban Mobility Report* is a list of the top 100 congested roadways in Texas. A review of these facilities is included as an additional congestion-level benchmark by study area. The third and final measure of congestion reviewed is the daily volume-to-capacity ratios derived directly from existing travel models in the state. Each of these variables is examined in the following subsections.

Texas Congestion Index

In Texas, 10 urbanized areas are summarized in the *Annual Urban Mobility Report* produced by TTI (Schrank et al. 2012). With the incorporation of INRIX travel time data, the report will be expanding to incorporate all 25 MPOs in the state. Currently, however, only 10 of the largest study areas are reported—Dallas-Fort Worth, Houston-Galveston, San Antonio, Austin, El Paso, Hidalgo County, Brownsville, Corpus Christi, Laredo, and Beaumont. The only non-TMA in the group is Beaumont. Brownsville was recently designated as a TMA with the release of the 2010 U.S. Census population figures by urbanized area. Three other TMAs are not currently covered in the report but will likely be addressed in future reports—Lubbock, Midland-Odessa, and Killeen-Temple.

The report has added new features and measures of congestion through the years, but one of the longest-tenured statistics is the Texas Congestion Index (TCI). The TCI is a value that conveys how much longer a trip would take during the peak period versus taking that same trip during an uncongested period or free-flow condition. Each study area is ranked nationally based on the TCI value. As shown in Table 41, Texas has three study areas ranked in the top 10 nationally. Houston and Dallas-Fort Worth are tied for 10th, while Austin ranks fourth. In addition to the TCI value, the report documents the following characteristics of the network system:

- Congested travel or the percent of the peak VMT that occurs in congested conditions.
- Congested system or the percent of the lane miles under congested conditions during the peak period.
- Congested time, which is the time when the system might have congestion.

Accordingly, study areas should be compared to other study areas with similar characteristics, such as population, population growth rates, and size of the network system. Typically, comparing Dallas-Fort Worth to smaller study areas, such Corpus Christi, Brownsville, Laredo, and Beaumont, would not be meaningful. However, doing so does express the order of the magnitude of the congestion problem in these regions. For example, the percent of congested travel and system in Corpus Christi is not even relatively close to that in study areas such as Austin and San Antonio. Laredo, which is similar to Corpus Christi in terms of population size, has three times as much congested travel and double the congested system during the peak period. The Brownsville region, in terms of congestion, is worse than Corpus Christi but not nearly as bad as Laredo during the peak period. Austin, meanwhile, has the same number of "rush-hour" times as Dallas-Fort Worth, which is 3.75 times greater in terms of population.

Regardless of study area size, congestion is interpreted at the individual level. Drivers in Laredo may feel just as frustrated as a driver experiencing significantly more measurable congestion in a larger study area. Consequently, individual perception of congestion should not be dismissed when anticipating toll demand by study area. Another characteristic is the number of severely congested corridors in a study area, which is examined in the next section.

Table 41. 2011 Texas Congestion Values for 10 Texas Cities.

2011 Data	**Dallas-Fort Worth**	**H-GAC**	**SABCUTS**	**CAMPO**	**El Paso**	**Hidalgo**	**Browns-ville**	**Corpus Christi**	**Laredo**	**JORHTS**
Urban Population (1,000s)	5,260	4,129	1,558	1,345	739	578	214	337	235	243
Congested Travel (Percent of Peak VMT)	70	69	63	61	31	30	17	12	39	15
Congested System (Percent of Lane Miles)	44	49	46	49	25	41	24	16	35	15
Congested Time (Number of "Rush Hours")	5.00	5.75	4.00	5.75	3.50	2.50	1.50	1.50	1.50	1.50
TCI	1.26	1.26	1.19	1.32	1.21	1.16	1.18	1.04	1.14	1.10
TCI Rank	10	10	35	4	25	51	37	101	61	87

Source: *Schrank et al. (2012)*

100 Most Congested Corridors

As noted previously, a product of the TCI effort in Texas is the list of the 100 most congested roadways in the state. The list was produced in an effort to help TxDOT identify and focus on solutions to relieve the state's worst traffic congestion problems. Only one of the 100 most congested roadways resides outside the five largest urbanized areas. In other words, congestion exists in the small to medium-size study areas, but it does not exist in an appreciable manner regionally or at the corridor level that can be measured against other corridors in the state. This has potential ramifications for implementing a generalized cost function as a part of accounting for toll roads where time and distance are weighted based on iterative congestion levels during application of the traffic assignment models. Table 42 shows the total number of facilities by county (and study area) that made the top 100 list for Texas.

Table 42. 100 Most Congested Roadway List in Texas (2013).

County	Count	Study Area
Travis	8	Austin (CAMPO)
Williamson	1	
Dallas	20	Dallas-Fort Worth
Tarrant	14	
Collin	4	
Denton	2	
Bexar	10	San Antonio—Bexar County
Harris	36	Houston-Galveston (H-GAC)
El Paso	4	El Paso
Brazos	1	Bryan-College Station
Total	***100***	

Source: TxDOT 2013

Derived 24-Hour Volume-to-Capacity Ratios by Study Area

As originally documented in the Technical Report 0-6632-1, "*Positive Feedback: Exploring Current Approaches in Iterative Travel Demand Model Implementation*," produced by TTI (Reeder et al. 2012) on iterative feedback, an analysis was performed by study area to document the level of congestion using data from the current daily models. The total 24-hour volume-to-capacity ratio was derived using a user-weighted volume-to-capacity ratio for each study area. Table 43 presents the user-weighted volume-to-capacity for each study area with the exception of Austin, Houston, and Dallas-Fort Worth where the data were not available. The user-weighted value is a volume-to-capacity ratio that is weighted by VMT that is accumulated for each non-centroid connector link in the system. In this manner, a long link with a high volume weighs more heavily in terms of overall delay than a short link with little to no traffic. TTI developed this measure to express what travelers of the system might encounter on average. The statistic is available by facility type and area type and is produced by the VALID9 summary utility available in the TxDOT add-on menu item.

Dimensioning congestion in terms of 24-hour or daily congestion is relatively inconsequential. Toll roads, however, increase in attractiveness relative to the system and corridor-level congestion (by time of day). Continuing to model in a daily environment would prevent TxDOT from adequately addressing temporal congestion in terms of estimating not only toll demand but other demand as well. Time-of-day models are typically accompanied by a feedback mechanism to resolve travel times in the sequential model application process. In terms of implementing a feedback mechanism to resolve travel times in the sequential model application process, the results would be of little consequence or meaning in a daily environment. However, congestion does exist in some of the study areas by time of day, such as in San Antonio, Austin, the Lower Rio Grande Valley, and other medium-size study areas. In terms of implementing feedback, it is not completely necessary to do so to address toll demand, but it is consistent with Federal Highway Administrative (FHWA) guidance. This is especially true for those study areas designated as in non-attainment of air quality standards.

Table 43. User-Weighted Volume-to-Capacity Ratio by Study Area.

Study Area	Current Base Year Model	Base Year Weighted Avg. Volume-to-Capacity Ratio
Abilene	1998	43.50%
Amarillo	2005	42.60%
Brownsville	2004	65.20%
Bryan-College Station	2006	68.00%
Corpus Christi	1996	57.40%
El Paso	2002	64.10%
Harlingen-San Benito	2004	60.20%
Hidalgo County	2004	78.20%
JOHRTS	2002	63.90%
K-TUTS	1997	61.50%
Laredo	2003	76.80%
Longview	2002	64.80%
Lubbock	2000	51.20%
Midland-Odessa	2002	46.10%
San Angelo	2003	46.00%
San Antonio	2008	73.60%
Sherman-Denison	2003	52.00%
Texarkana	1995	71.70%
Tyler	2002	64.50%
Victoria	1996	59.60%
Waco	1997	59.40%
Wichita Falls	2000	48.90%

Source: Reeder et al. (2012)

ATTAINMENT STATUS BY STUDY AREA

The 1990 Clean Air Act Amendment required the Environmental Protection Agency to set NAAQS. There are six criteria pollutants—carbon monoxide, lead, nitrogen dioxide, ozone, particulate matter, and sulfur dioxide. The threshold standards are subject to change, but currently Texas has only three study areas that are in violation of one or more of these standards—El Paso, Dallas-Fort Worth, and H-GAC. Areas that are not in violation are classified as attainment/unclassifiable. According to the latest information from the Texas Commission on Environmental Quality (TCEQ), six other regions/study areas are actively pursuing strategies to clean air and meet federal air quality standards within the Texas State Implementation Plan. These include the northeast Texas region, which includes the Tyler/Longview study areas, the three-county Beaumont-Port Arthur region, Victoria, the five-county Austin region, the four-county San Antonio region, and San Patricio and Nueces Counties in the Corpus Christi study area. Consequently, and with respect to small to medium-size study areas, there are no officially designated non-attainment regions in the state. Table 44 presents a summary of current and possible future toll roads as well as air quality status for the small to medium-size study areas.

Table 44. Air Quality Status for Small to Medium-Size Study Areas.

Study Area	TMA Designation	Toll Road (Existing or Planned)	Air Quality Attainment Status
Abilene			Non-classified
Amarillo			Non-classified
Beaumont			Non-classified
Brownsville	TMA	(*Under construction*)	Non-classified
Bryan-College Station			Non-classified
Corpus Christi	TMA		Non-classified
Harlingen-San Benito			Non-classified
Hidalgo County	TMA	Planned	Non-classified
Killeen-Temple	TMA		Non-classified
Laredo	TMA		Non-classified
Longview		Planned	Non-classified
Lubbock	TMA		Non-classified
Midland-Odessa	TMA		Non-classified
San Angelo			Non-classified
Sherman-Denison			Non-classified
Texarkana			Non-classified
Tyler		(*Under construction*)	Non-classified
Victoria			Non-classified
Waco			Non-classified
Wichita Falls			Non-classified

Source: TCEQ (2013)

A future designation of non-attainment would result in additional use of a region's travel model and perhaps heighten the need for model enhancements, some of which are a part of the evaluated enhancements for bringing toll model capability to a travel model. Such possibilities underscore that beyond the mere existence of planning for toll facilities, the models for these areas might become candidates for toll modeling and toll-modeling-relative enhancements. Indeed, the air quality conformity determination requires direction, vehicle mix, and time-of-day analysis. Anticipating these changes in designation and addressing modeling enhancement to capture these expectations aligns toll modeling procedures with most air quality conformity requirements.

POPULATION TRENDS BY STUDY AREA

A key component for predicting future congestion levels is the anticipated population growth in a study area. Some counties in Texas are experiencing some of the highest population growth trends nationally, while other study areas will remain relatively stable in terms of total population change. Table 45 presents the 2010 to 2040 projected population changes by study area based on current MSA data as compiled by TSDC. The table is divided into three categories—TMAs, non-TMAs, and the five largest study areas in the state. The total change, percent change, and yearly change are presented.

Table 45. State Population Projections (2010 to 2040).

MPO Region(s)	MSA	TMA Status	MSA 2010 Pop.	MSA 2040 Pop.*	2010 to 2040 Total Change	2010 to 2040 Percent Change	2010 to 2040 Growth Rate
Brownsville, Harlingen	Brownsville-Harlingen	TMA	406,220	657,452	251,232	61.8%	1.6%
Corpus Christi	Corpus Christi	TMA	428,185	517,917	89,732	21.0%	0.6%
Killeen-Temple	Killeen-Temple-Fort Hood	TMA	405,300	732,782	327,482	80.8%	2.0%
Laredo	Laredo	TMA	250,304	464,960	214,656	85.8%	2.1%
Lubbock	Lubbock	TMA	290,805	407,273	116,468	40.1%	1.1%
Hidalgo County	McAllen-Edinburg-Pharr	TMA	774,769	1,548,080	773,311	99.8%	2.3%
Midland-Odessa	Midland-Odessa	TMA	278,801	430,928	152,127	54.6%	1.5%
TMAs (not including 5 largest study areas)			*2,834,384*	*4,759,392*	*1,925,008*	*67.9%*	*1.7%*
Abilene	Abilene	Non-TMA	165,252	192,180	26,928	16.3%	0.5%
Amarillo	Amarillo	Non-TMA	251,933	395,089	143,156	56.8%	1.5%
Beaumont	Beaumont-Port Arthur	Non-TMA	403,190	511,019	107,829	26.7%	0.8%
Bryan-College Station	Bryan-College Station	Non-TMA	228,660	400,938	172,278	75.3%	1.9%
Longview	Longview	Non-TMA	214,369	344,823	130,454	60.9%	1.6%
San Angelo	San Angelo	Non-TMA	111,823	130,308	18,485	16.5%	0.5%
Sherman	Sherman-Denison	Non-TMA	120,877	163,775	42,898	35.5%	1.0%
Texarkana	Texarkana	Non-TMA	92,565	99,263	6,698	7.2%	0.2%
Tyler	Tyler	Non-TMA	209,714	339,574	129,860	61.9%	1.6%
Victoria	Victoria	Non-TMA	94,003	113,490	19,487	20.7%	0.6%
Waco	Waco	Non-TMA	252,772	322,934	70,162	27.8%	0.8%
Wichita Falls	Wichita Falls	Non-TMA	151,306	165,906	14,600	9.6%	0.3%
Non-TMAs			*2,296,464*	*3,179,299*	*882,835*	*38.4%*	*1.1%*
CAMPO	*Austin-Round Rock*	*TMA*	*1,716,289*	*4,046,649*	2,330,360	*135.8%*	*2.9%*
NCTCOG	*Dallas-Fort Worth*	*TMA*	*6,426,214*	*12,976,325*	6,550,111	*101.9%*	*2.4%*
El Paso	*El Paso*	*TMA*	*804,123*	*1,254,762*	450,639	*56.0%*	*1.5%*
H-GAC	*Houston*	*TMA*	*5,920,416*	*11,607,433*	5,687,017	*96.1%*	*2.3%*
SABCUTS	*San Antonio*	*TMA*	*2,142,508*	*3,767,306*	1,624,798	*75.8%*	*1.9%*
All Large Metro Areas			*17,009,550*	*33,652,475*	16,642,925	*97.8%*	*2.3%*
STATE OF TEXAS			**25,145,561**	**45,380,640**	**20,235,079**	**80.5%**	**2.0%**

Source: TSDC (2013)
**The higher population estimate between the 0.5 and 1.0 growth scenario is used.*

For the state, the population is expected to grow by over 80 percent in the next 30 years. As can be determined from data presented in Table 43, nearly 82 percent of the additional 20.2 million people will be concentrated in the five largest metropolitan areas in the state. Figure 43 shows a graph of the 30-year population change in the state proportionally split between the three categories noted previously.

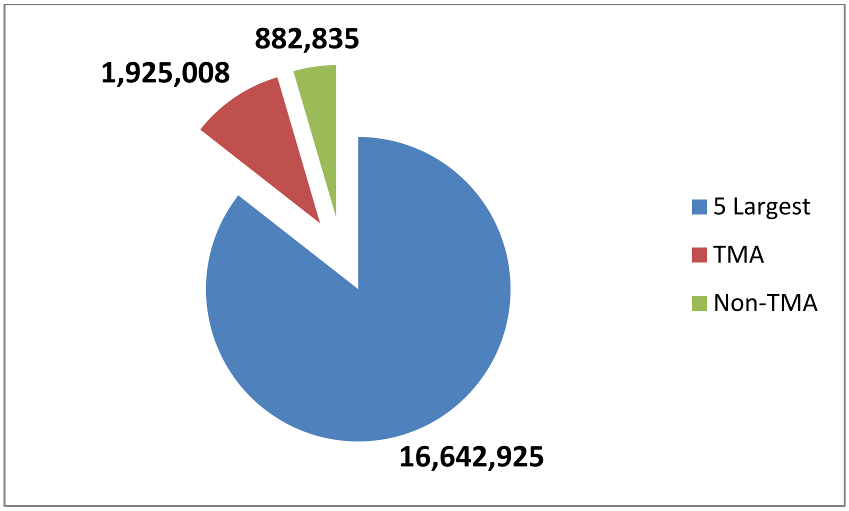

Figure 43. Proportion of Future Population Growth.

When summarizing the growth for the five largest urban areas along with the remaining TMAs, nearly 92 percent of the future population growth will be associated with the 12 TMAs in the state. Consequently, the more urbanized areas will become increasingly dense and consume more available land, while the 13 small to medium-sized study areas will only receive 9 percent of the future growth.

The data in Table 45 also show that the smaller non-TMA regions are projected to grow at a slower pace than the state as a whole. However, this should not dismiss some of the potential growth in these smaller regions. Bryan-College Station, for example, is expected to add as many people in 30 years as exist in Abilene today. That represents significant growth. While the rate of growth, in and of itself, is not a criterion for any particular toll modeling technique or travel model procedure, it can be instructive relative to the scope of changes that may be needed to study future travel demand (as well as toll demand) in a region.

Population Densities

To capture the current characteristics of each study area, the county population total relative to the available square miles in the county(ies) was determined. This provides some measure of how well future population demand could be accommodated with available land (not limited by undevelopable land such as flood plains, endangered species areas, parks, etc.). The data presented in Table 46 show the 2005 and 2010 density by study area. The data are ranked according to the 2010 calculated population density per square mile.

Table 46. Population Densities by Study Area.

TMA Status	MPO	2005 Pop.	2010 Pop.	County Size Sq. Miles	2005 Pop. per Sq. Mile	2010 Pop. per Sq. Mile	2010 Density Rank
TMA	El Paso	726,006	800,647	1,015.45	714.96	788.47	1
TMA	Houston-Galveston	5,222,861	5,891,999	7,917.09	659.69	744.21	2
TMA	Dallas-Fort Worth	5,854,799	6,417,724	9,448.22	619.67	679.25	3
TMA	San Antonio	1,777,429	2,031,106	4,022.00	441.93	505.00	4
TMA	Hidalgo County	677,902	774,769	1,585.60	427.54	488.63	5
	Longview	114,885	121,730	276.55	415.42	440.17	6
TMA	Brownsville	378,074	406,220	953.35	396.57	426.10	7
	Harlingen-San Benito	378,074	406,220	953.35	396.57	426.10	7
TMA	Austin (CAMPO)	1,458,641	1,716,289	4,284.58	340.44	400.57	9
	Bryan-College Station	160,863	194,851	590.88	272.24	329.76	10
TMA	Lubbock	250,276	278,831	901.03	277.77	309.46	11
TMA	Killeen-Temple (K-TUTS)	260,526	310,235	1,088.94	239.25	284.90	12
TMA	Corpus Christi	386,425	405,027	1,553.90	248.68	260.65	13
	Waco	222,313	234,906	1,061.09	209.51	221.38	14
	Tyler	190,019	209,714	950.06	200.01	220.74	15
	Wichita Falls	128,711	131,500	633.20	203.27	207.68	16
	Jefferson-Orange-Hardin (JORHTS)	381,764	388,745	2,225.73	171.52	174.66	17
TMA	Midland-Odessa	244,185	274,002	1,805.01	135.28	151.80	18
	Abilene	127,816	131,506	919.86	138.95	142.96	19
	Amarillo	229,405	241,798	1,844.45	124.38	131.09	20
	Sherman-Denison	117,320	120,877	979.55	119.77	123.40	21
	Texarkana	92,271	92,565	923.15	99.95	100.27	22
	Victoria	85,455	86,793	889.96	96.02	97.52	23
TMA	Laredo	228,354	250,304	3,380.89	67.54	74.03	24
	San Angelo	102,748	110,224	1,541.84	66.64	71.49	25

Population source: TSDC (2013)
County square mile source: Caliper Corporation (2002)

The study area with the greatest density is the El Paso region. Even though it occupies a portion of El Paso County, the population concentration is dense enough to produce the ranking listed in Table 46. The high ranking is consistent with other Texas border towns since four of the top eight values are along the U.S.-Mexico border. Using county level data, though, does not really capture the full extent of urbanization since some study areas really only represent a portion of the county. Laredo is a prime example of the resulting density value being impacted by the size of Webb County. Hence, it has the second lowest density relative to county square miles. Within the Laredo metropolitan area and as enumerated in the *Annual Mobility Report*, the study area has fairly appreciable congestion, which is incongruent with the county level density calculation.

San Angelo has the lowest population density per square mile due in large part to the size of the study area (small) relative to the size of the county. Houston and Dallas, both typically characterized for suburban sprawl, rank two and three, respectively, due to the sheer size of the population in these study areas. If these values were compared to other non-Texas cities, such as Washington, D.C., San Francisco, or New York City, the density values would possibly convey a different meaning relative to the interpretation of population density. However, in Texas, these two large cities rank very high in terms of population to land area.

Wage Rate

The average weekly wage rate can be an indicator of economic vitality in a region and provide some fundamental information regarding potential disposable income. The U.S. Department of Labor's Bureau of Labor Statistics (BLS) produces these data for each county in the United States. The average wage rate is often used as a means to create an estimated value of time for autos as input into the generalized cost assignment technique (i.e., One approach is to use 70 percent of the average weekly wage rate). Table 47 presents the average weekly wage rate for each of the study areas in Texas excluding the five largest metropolitan areas. The average weekly rate was derived by dividing the weekly wage by 40 hours to estimate the average wage rate for a 40-hour work week. The last column presents what a typical percentage of the average wage rate would be by study area using one of the recommended percentages for determining an initial auto value of time.

According to BLS, Texas has four of the 11 lowest-paying large counties in the United States (BLS 2013). These counties are along the U.S.-Mexico border—El Paso, Webb, Hidalgo, and Cameron. Midland-Odessa, with the dominant oil industry in the region, has the highest weekly wage rate of the small to medium-sized urban areas in the state. This information is not only useful for addressing static toll roads, such as those being built in the small to medium-sized study areas, but is potentially insightful for study areas considering managed lanes (i.e., El Paso). The TCI uses a state average of $16.79 for autos and $86.81 for commercial vehicles as estimates of values of time for these two classes respectively.

Table 47. Average Weekly Wage and Rate by Study Area.

MPO	County	Avg. Weekly Wage	Avg. Wage Rate	70% Wage Rate
Abilene	Taylor	690	17.25	12.08
Amarillo	Potter	786	19.65	13.76
	Randle	631	15.78	11.04
Brownsville	Cameron	580	14.50	10.15
Bryan-College Station	Brazos	721	18.03	12.62
Corpus Christi	San Patricio	825	20.63	14.44
	Nueces	801	20.03	14.02
Harlingen-San Benito	Cameron	580	14.50	10.15
Hidalgo County	Hidalgo	584	14.60	10.22
JORHTS	Jefferson	913	22.83	15.98
	Orange	855	21.38	14.96
	Hardin	691	17.28	12.09
Killeen-Temple	Bell	749	18.73	13.11
Laredo	Webb	637	15.93	11.15
Longview	Gregg	834	20.85	14.60
Lubbock	Lubbock	716	17.90	12.53
Midland-Odessa	Midland	1107	27.68	19.37
	Ector	975	24.38	17.06
San Angelo	Tom Green	690	17.25	12.08
Sherman-Denison	Grayson	723	18.08	12.65
Texarkana	Bowie	706	17.65	12.36
Tyler	Smith	780	19.50	13.65
Victoria	Victoria	778	19.45	13.62
Waco	McLennan	735	18.38	12.86
Wichita Falls	Wichita	675	16.88	11.81

Source: BLS (2013)

MAP-21

Although there is nothing directly tied to toll road modeling and the MAP-21 surface transportation funding bill, the bill explicitly calls for the establishment of performance- and outcome-based programs. The national policy associated with this funding bill establishes seven national performance goals for the federal-aid highway program (FHWA 2013):

- Safety.
- Infrastructure condition.
- Congestion reduction.
- System reliability.
- Freight movement and economic vitality.
- Environmental sustainability.
- Reduced project delivery delays.

The bill requires states to invest resources toward projects that collectively address or make progress toward achieving these national goals. Within 18 months of enactment of the bill, state departments of transportation are to establish seven performance measures in the following areas:

- Pavement condition on the Interstate System and on the remainder of the National Highway System (NHS).
- Performance of the Interstate System and the remainder of the NHS.
- Bridge condition on the NHS.
- Fatalities and serious injuries—both number and rate per VMT—on all public roads.
- Traffic congestion.
- On-road mobile source emissions.
- Freight movement on the Interstate System.

Each state is to establish targets for the performance-based goals as well as minimum thresholds for achieving these targets for the above criteria listed above. This effort is to be coordinated with each MPO in the state, and several existing planning documents are to enumerate these targets, such as the MTPs and Statewide Transportation Improvement Plan. The bill also continues to require that TMAs be certified every four years, and during this process, the TMA will be evaluated on whether the targets are being met. To help meet or analyze these targets, TMAs will have to use scenario analysis to show how strategies affect the system, whether statewide or metropolitan. Three typical practices that are noted in the performance-based scenario analysis include:

- Historical data.
- Forecasting tools.
- Economic analysis tools and management systems.

Travel demand models are the primary source for tracking and analyzing current and future congestion levels. Travel models are also used for a variety of metrics, including emissions analysis, access to transit, and monitoring VMT. With respect to tolling, travel models, and scenario planning, it is likely that toll roads (and congestion pricing) may be viewed as a key strategy for meeting travel time reliability and savings goals, as well as relieving congestion on existing system (and thereby potentially achieving on-road-related vehicle emission benchmarks) (Grant et al. 2013). Consequently, implementing more robust models that provide a means to address and analyze scenarios that may or may not include some aspect of tolling or congestion pricing improves the capability to address the benchmark goals of MAP-21.

STATEWIDE ANALYSIS MODEL

A context not previously discussed is a situation in which the toll facility spans multiple small and/or medium regions, and a significant market is interregional travel demand. In such a contextual setting, TxDOT may wish to consider direct use of its SAM. Version 3 of the SAM (SAM-V3), the traffic assignment portion of the model, uses the GC MMA method along with VOT segmented by vehicle mode, trip purpose, and household income.

SAM-V3 also includes several of the corollary model enhancements previously reviewed and discussed in this chapter, including time-of-day analysis and congestion feedback. Consequently, SAM could be a potential candidate for use in toll demand modeling in an individual urban region if there is a toll demand analysis need in a timeframe sooner than similar features can be brought to the regional model. However, such an approach may require update to SAM inputs for the TAZs in the region in question and perhaps even a validation of SAM for the region prior to performing any toll demand analysis. It should also be noted that the network detail for an urbanized area is not nearly as detailed in the SAM network geography as would be encountered in a stand along urban area travel model network geography.

CONCLUSION

Using available data, such as total daily VMT, truck VMT, population trends, congestion data, and wage rate data by study area, the various region-wide conditions by study area were enumerated and discussed to help frame the future direction of modeling architecture in the state designed to specifically address toll demand estimation. Many of the techniques used to support toll demand estimation, such as time of day modeling, trip table segmentation, congestion feedback, and to some extent mode choice, are implemented to not only support toll demand estimation but other modeling purposes as well, such as air quality determination. For most of the study areas in the state, the VMT trends are negative but the forecast population trends are positive. The large urbanized areas are extremely congested by time of day while the smaller study areas have fairly inconsequential total daily VMT or time of day congestion levels. Complimentary measurements from one study area to the next are difficult to capture given the variety of contexts in the state. Therefore, quantifying or recommending condition-based modeling strategies to address toll demand estimation, based on regional measurements is difficult to identify for the small to medium-sized study areas. As noted in the previous chapters documenting state and national practice, the techniques used to improve toll demand estimation were primarily determined by the characteristics of the corridor.

Modeling techniques can be implemented on a case-by-case basis or can be adopted universally to promote ease of use and technology transfer to the MPOs. While this research is not prescriptive with respect to what techniques should be considered under exact combinations of contexts, Table 48 summarizes the general contextual characteristics for each of the techniques tested and evaluated as part of this research. Ultimately, whether to use approaches that support and potentially enhance toll demand estimation, such as implementing a generalized cost assignment technique that essentially requires finer granulation of the trip table and time periods is a decision that TxDOT will have to make. Continuing with a uniform modeling architecture for all study areas and determining how well the end users—MPOs—can learn not only to apply these techniques but to understand and interpret the results will also play a key role in shaping the direction of toll demand estimation decision criteria.

Notable among the classifications presented in Table 48 is the suggestion that implementation of time-of-day modeling and feedback techniques for purposes of toll demand modeling are correlated. The research findings demonstrate that time-of-day modeling and feedback are supportive and relevant in context. Relative to enhancement of a region's model to incorporate mode choice, the research identified and evaluated both a simple fixed-share technique and a more sophisticated logit technique. While no correlation to general context is presented in Table 48, in general, widening in the variation of tolling schemes or other operational characteristics would be associated with increased modal segmentation of a mode-choice technique. It is assumed that none of these small to medium-sized urban areas have significant public transit systems beyond local bus routes or plan to have public transit systems that would warrant a need for transit sub-modes in a mode-choice model. Table 49 presents possible options for this type of model enhancement.

Table 48. Toll Modeling and Related Enhancements General Context Settings.

Technique	Context
Generalized cost assignment	All
Time-of-day assignment	Present or future congestion
Congestion feedback	Present or future congestion
Multi-class assignment	Differential auto/truck tolling
Mode choice*	Toll-induced auto occupancy/mode shifting

* *Model specificity options are presented in Table 49.*

Table 49. Potential Mode Choice Options.

Mode-Choice Options		
Fixed Shares	**Simplified**	**Expanded**
Auto	Auto	Auto
Transit	Drive alone	Drive alone
Nonmotorized	Shared ride	Shared ride 2
	Transit	Shared ride 3+
	Nonmotorized	Transit
		Nonmotorized
		Bike
		Walk

Most advanced practices, irrespective of tolling considerations, are based on addressing and studying severe congestion, whether it is daily or recurrent peak-period congestion. Moving away from daily models toward time-of-day models allows planners to examine the effects of congestion during different temporal periods. Moving toward time-of-day models is typically accompanied by iterative feedback treatments to resolve travel time inputs within the sequential travel model process. Policy motivations have also encouraged the need to have a greater understanding of the impacts of transportation alternatives on the users of the system. Consequently, the move to time-of-day applications that also include greater segmentation of the trip table has also occurred as a natural transition to study the mobility impacts of the planned system on different socio-economic classes. Each of these treatments, either individually or collectively, is consistent with the most common toll demand estimation practices nationally and within the state.

The common motivational thread among these techniques is congestion and the need to have the capability to study, analyze, and potentially address congestion within the travel models. As noted in the TxDOT TOD consultant interviews, measurable travel time differences did not exist in a meaningful way to either justify feedback or time-of-day modeling for the rural area travel models. However, capturing travel time sensitivities during different time periods is a critical element to address toll demand estimation. Hence, time-of-day periods and iterative feedback were implemented within the existing TxDOT model as a part of the feasibility study associated with the toll alternative examination. Depending on the level of observed—and, to some extent, anticipated—truck vehicle mix in the study corridor, the trip tables were segmented into truck and auto classes. This provides the capability to adequately address two critical differences between auto and truck toll demand—toll cost and value of time.

Figure 44 represents one example of how TxDOT may want to approach toll demand estimation. As noted, mode choice is included as a placeholder for any future generic modal model that TxDOT may wish to incorporate. However, for the estimation of fixed-fee toll roads, like those encountered in Tyler and Brownsville, the ability to retain trip tables by auto occupancy or to study nonmotorized trips may not be necessary. Time-of-day modeling can be performed in the absence of time-of-day calibration if counts and/or survey expanded trip tables are unavailable. The current travel surveys could yield the necessary diurnal factors to divide the 24-hour trip tables produced by trip distribution. Directional splits could be derived from count data. Depending on the level of congestion, benefit, or need, TxDOT may wish to simplify or limit any type of peak-period feedback to HBW trips and only feedback off-peak travel times for all other trip purposes when appropriate. The traffic assignment step would be performed using the generalized cost assignment feature in the TransCAD software. The trip tables should probably be segmented into at least auto and truck categories to capture toll cost and value of time sensitivities. Whether a composite cost that includes auto operating costs is included is entirely the decision of TxDOT.

Implementing a GC assignment technique in TransCAD is invoked using the MMA option. Trip table segmentation is inherent to this process because of the need to address time and distance weighting relative to cost and value of time.

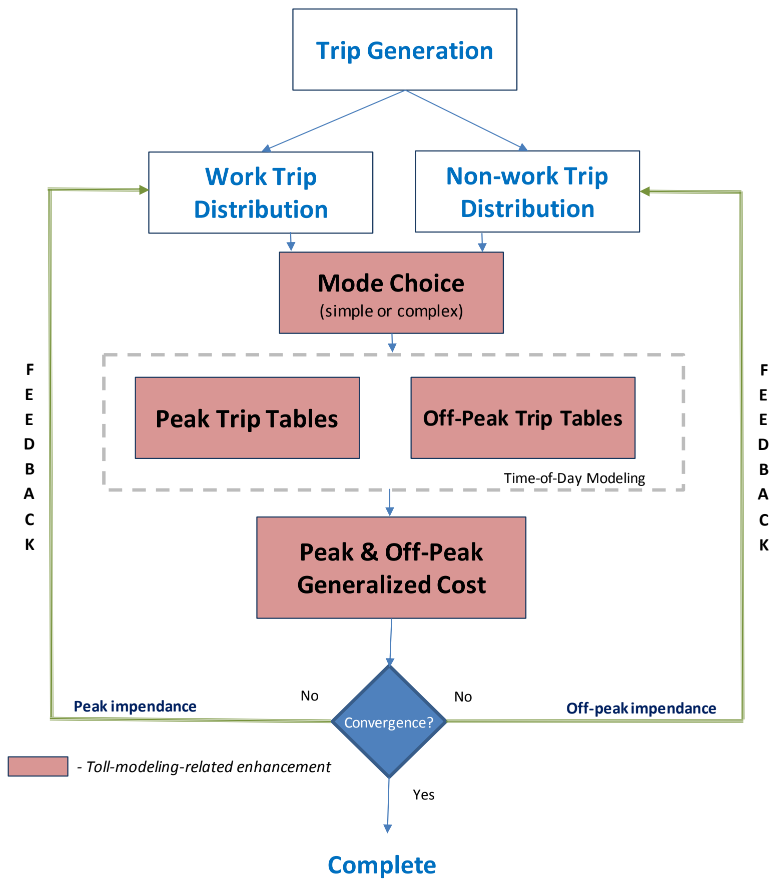

Figure 44. Example Architecture of Toll Modeling Enhanced Regional Model.

CHAPTER 7: CONCLUSIONS

RESEARCH SCOPE

The research documented in this report was intended to provide TxDOT with fundamental information regarding the challenges, limitations, and considerations that need to be addressed when considering adding toll demand estimation capabilities to the existing Texas Package. The key to this report was identifying an approach and complementary measures that TxDOT TPP could use to address tolled facilities in the small to medium-sized study areas. Traditionally, and as a part of the cooperative TDM development process in the state, TxDOT TPP has provided MPOs with daily trip tables and loaded networks (including assigned volumes) for both a base condition and forecast application (typically a 20-year horizon associated with the five-year MTP update schedule). Some study areas, such as Tyler and Longview, continue to maintain interim-year forecasts when these were initially required as a part of a historical but no longer relevant air quality designation. Once the models are delivered, TPP provides training to the MPOs in the application and uses of the travel models to support network-related alternatives analysis associated with the development of the individual MTPs. The travel models, along with the travel model inputs (e.g., socio-economic data and networks), provide the means to study different network alternatives and the corresponding impacts on mobility and travel. The models also serve as the means by which MPOs can inventory vehicle miles of travel by functional class and facility type, as well as track changes to demographics (e.g., population, households, and employment). This approach, for the most part, has satisfied a majority of the planning needs and expectations in the state.

However, the state has one of the strongest trends in population growth in the country. There are now 12 official TMAs in the state as a result of this strong growth in population (i.e., study areas greater than 200,000 in population). As discussed in Chapter 6, these 12 urban areas, which include the four largest study areas— Austin, San Antonio, Dallas-Fort Worth, and Houston—account for nearly 92 percent of the future population growth in the state. Correspondingly, these 12 areas represent 85 percent of the daily VMT and nearly 80 percent of the daily truck VMT among the 25 MPOs. Recognizing the future challenges for these 12 study areas provides a measurable benchmark by which TxDOT may wish to enhance the current TDM capabilities for these regions.

The four largest urbanized areas in the state— Austin, San Antonio, Dallas-Fort Worth, and Houston—have already implemented the capability to address fee-based systems in their urban TDMs. These study areas have appreciable and measurable daily and peak-period congestion and, as noted, will receive a significant proportion of future population growth. Therefore, the models for the four largest urban areas are significantly more robust in that these areas have the ability to perform mode-choice analysis (i.e., different transit modes and auto occupancy levels, as well as nonmotorized in some instances), time-of-day assignments, and account for toll facilities. Due to congestion levels in these areas, some toll roads are statically priced while others are dynamically priced by time-of-day and congestion level (i.e., the Katy Freeway in Houston).

The challenge of this research project was to provide TxDOT with a practical set of approaches that could be implemented in the small to medium-sized study areas that do not have the corresponding congestion and population challenges or significant planned capital improvement projects (e.g., light rail or managed lanes). Currently, there are four small to medium-sized study areas where a fixed-fee toll road is currently under construction, partially open, or planned—Tyler, Longview, Laredo, and Brownsville. Common among these four study areas is that, for the most part, the current or planned toll facilities are located in uncongested portions of the region with a number of free alternatives nearby.

To that end and without the immediate impetus to fully integrate the entire suite of changes (i.e., mode choice, time of day, market segmentation, and iterative feedback) that have already been incorporated in the four largest urban area models, the research project sought to provide the framework by which TxDOT could choose from a host of direct and complementary approaches to address toll roads in these small to medium-sized study areas.

Indeed, TPP may not require adding some of these features to satisfy the fundamental planning needs and expectations at the MPO level or even account for toll roads at the most minimum level (i.e., simply implementing a path-based approach such as generalized cost assignment). However, many of the supplementary modeling system improvements discussed in this report as a means to address tolled facilities beyond simply implementing a generalized cost traffic assignment—such as additional trip table segmentation, time-of-day, and iterative feedback—provide TPP and MPOs with additional capabilities that may be necessary to meet the performance-based approach enumerated in the MAP-21 funding bill. Incorporating these changes to support toll demand estimation, some of which have been discussed in previous research reports on time of day and iterative feedback, can potentially add value to the current Texas Package.

REPORT SUMMARY

The first two chapters examine national and state practice and try to frame the discussion of findings in the context of small to medium-sized study areas. Given the information from canvasing the state of the practice, considerations and challenges associated with implementing the national and state practices are examined. Some of the challenges are changes in how data are processed (i.e., additional travel survey data), reported (i.e., traffic counts), and accomplished in the existing Texas Package (i.e., additional market segmentation). The fourth chapter examines how these approaches affect changes in system- and corridor-level VMT and VHT using a surrogate toll road in Tyler, Texas. These findings, along with the context-sensitive information by study area presented in Chapter 6, help define the recommendations outlined in the conclusion.

KEY FINDINGS

State of the Practice

As identified in the review of the national and state practice, there are generally two approaches in current practice to address toll demand estimation—path based and choice based. The path-based approach is accomplished during traffic assignment, typically using a generalized cost assignment technique. The generalized cost assignment technique does not require a multi-class trip table, but because different user classes have different perceived VOTs and toll costs (i.e., axle based for trucks), it is typical to expect that multiple trip tables will be input into the traffic assignment step. The second approach is choice based where the number of toll-eligible users (trip tables) is determined during the application of a mode-choice model (i.e., toll nests). In the models, the decision as to whether a user is potentially eligible (and may not necessarily be assigned to a tolled route) occurs prior to traffic assignment but presumably with iterative feedback to resolve travel times between the two steps (as well as trip distribution). The following are key findings from the study:

- There are limited examples nationally of small to medium-sized study areas that are constructing toll roads to address current or future congestion/mobility concerns.
- The four largest urban in the state already have the capability to address toll roads as a part of the travel demand estimation process and systems. Three of the four areas estimate toll demand using a path-based approach, with the fourth study area moving toward this approach.
- Time-of-day and temporal considerations are consistent treatments in the larger urban areas in the state as well as nationally. These considerations can be independent of any toll road estimation needs (e.g., emissions analysis, transit, and peak-hour planning volumes). However, time-of-day analysis captures the travel time reliability of toll roads in comparison to congested or relatively congested competing corridors.
- The establishment of multiple classes within network assignments is fairly consistent practice nationally. This enables a more realistic connection between toll cost, VOT, and traveler classes. Including alternative VOTs by time of day may be an additional consideration.
- The addition of a mode-choice model is typically driven by larger urbanized areas. There are relatively few examples nationally of smaller study areas having a mode-choice model.
- None of the study areas in the state perform detailed traffic and revenue analysis. This is performed under the auspices of TxDOT TOD. Third-party contractors have performed this analysis for small to medium-sized study areas, such as Tyler, when examining the viability of Loop 49. The consultants use the existing TxDOT models as much as possible and augment the available models with additional information and structural changes (e.g., time-of-day counts and additional segmentation of the external trip tables).
- The incorporation of an iterative feedback loop to improve the consistency of travel times (and costs) throughout the model chain is typically implemented for larger urban areas where there is measurable congestion. The TxDOT TOD consultants noted adding a feedback process to the existing TxDOT models, but this was not motivated as a part of the toll analysis approach but rather a standard structural change.

Specific Considerations to the Texas Package

Although there are challenges to implementing some of the approaches outlined in the report to address toll demand estimation, it is realistically possible to include most strategies in the existing Texas Package. Some of these challenges are associated with data processing (i.e., additional travel survey processing), data availability (i.e., published time-of-day counts and travel time/speed data), and software enhancements/integration (i.e., automating the application of diurnal factors to develop time-of-day trip tables post trip distribution). The following are potential modifications to the Texas Package, processes, or inputs:

- Network geography (additional attributes):
    - Toll costs (by user class).
    - Optional composite cost field (by user class that would represent the summation of toll cost, VOT, and auto operating costs (optional).
    - Free flow speeds by facility type and area type.
    - Time-of-day capacities and speeds.
    - Time of counts (not currently published in an easily usable format).
    - Potentially different volume-delay parameters for alpha and beta by facility type.
    - Toll road facility type and corresponding capacity and speed inputs.
- Trip generation (additional trip tables):
    - HBW segmented into income categories (TPP could limit this to three categories, but this would require additional survey processing).
    - Additional segmentation may require the creation of additional TripCAL5 input files.
- Trip distribution (additional trip tables):
    - Further segmenting travel survey data would require further processing of the travel survey data and could possibly create issues associated with sampling size in the original data (e.g., survey expanded trip tables used to create the initial trip length frequency distribution).
- Time-of-day modeling (not currently developed and would require software enhancements):
    - Diurnal and directional factors from travel surveys (would require further processing of travel survey data).

    - Count data (as noted in network geography attribute data).
- Auto-occupancy factors (not currently developed and would require software enhancements):
    - Factors would be acquired from further processing of travel survey data.
- Traffic assignment:
    - Implement generalized cost multimodal assignment technique.
    - Inputs would be VOT (by user class), toll costs (auto versus truck and depending on segmentation of commercial vehicle trip tables), and estimating auto operating costs (optional) as part of using a composite cost rather than just VOT and toll costs. The derivation of VOT may initially present challenges. Two existing TxDOT systems, the SAM and TCI, use a single statewide value for autos and a single value for trucks. The analysis of pivoting off of wage rates by study area in Chapter 6 reveals differences in estimated VOT by study area using a standard approach.
    - Adjustments to the volume-delay parameters by facility type (as noted in the network geography).
    - Additional iterations and a different convergence criterion. The existing 24 iterations may not achieve a satisfactory level of convergence when comparing competing routes.
- Iterative feedback (not currently applied in existing study area models and would require software enhancements):
    - Dynamic calibration of friction factors and bias factors.

State of the Art Trends or Other Considerations

While the basic modeling approach at most MPOs and state agencies remains a sequential four-step process, the overall trend in the state-of-the-art travel demand modeling is turning toward disaggregate, activity-based modeling (at least for the largest urbanized areas). The activity-based approach is considered more behaviorally defensible as it views travel as a derived demand from the need to pursue activities and can provide link flows at finer time resolutions (e.g., 30 minute intervals) for purpose of forecasting emissions (Bhat and Koppelman 2003). Recently, the Federal Highway Administration funded a free open-source activity based travel forecasting tool called the Transportation Analysis and Simulation System (TRANSIMS) with the potential of serving as a basic platform for smaller MPOs and statewide activity-based models (FHWA 2012). Toll road demand forecast can be modeled as a part of an activity-based model by using revealed and stated preference surveys as the basis for including pricing into the decision hierarchy in the model.

Even within the traditional four-step TDM, trends in advanced models are emerging. While most MPOs accomplish trip distribution via a gravity model, destination-choice models are becoming more popular. Instead of relying on the travel impedance between two zones, destination-choice models use traveler characteristics (e.g., income and vehicle ownership) and destination characteristics (e.g., employment density, retail square footage) to determine the likelihood of each trip. MPOs concerned with accurate modeling of nonmotorized travel have reduced traditional transportation analysis zones to smaller spatial units to reflect meaningful walking distances. The use of sensitivity testing is becoming more and more common among transportation modelers, to gauge the reasonableness of model outputs based on widely varied inputs.

Toll demand can be estimated within the mode choice step of the TDM, separating automobile trips on tolled and non-tolled roads as two distinct modes (and further split by trip purpose within those modes). This type of toll model structure requires a full congestion feedback loop, where the generalized cost impedances are fed back from trip assignment to trip distribution and mode split (Kriger et al. 2006) Toll demand can also be estimated within the trip assignment component of a model, as demonstrated in Chapter 5, by incorporating the toll into the generalized travel cost and allocated through equilibrium assignment. Toll demand can also be modeled exogenously using the output of a four step TDM, where assigned volumes may be diverted from non-tolled routes to tolled routes. This procedure is simple to implement but not sensitive to changes in traveler behavior (Kriger et al. 2006).

Field Test Findings

Using the Tyler study area as a test case, an analysis was performed using Loop 323 as a surrogate toll road, which tested different implementation strategies (e.g., market segmentation, time-of-day) against a base or free scenario of the same facility. A generalized cost assignment technique was evaluated using the TransCAD software, which is the adopted modeling software platform for the state. The existing Loop 49 toll road was not used because the current and forecast volume levels were not large enough to capture statistically significant changes. Based on this analysis and using VHT and VMT system and corridor-level changes as benchmarks, the following enhancements were recognized as having the greatest impact:

- Addressing multiple time periods.
- Incorporating a congestion feedback loop.
- Adding a mode-choice component.
- Disaggregating traveler classes.

These enhancements were tested individually and in combination. With respect to combing different complementary approaches, adding both a multi-class assignment and time-of-day segmentation appeared to have the greatest impact. As noted, if the focus of adding these enhancements migrates away from toll demand estimation and toward emissions analysis, time-of-day modeling increases in orders of magnitude.

Contexts

The research evaluated a number of contextually related measures for each of the 25 MPOs in the state:

- Daily VMT trends for a five-year period (2005 to 2010).
- Daily truck VMT trends for a five-year period (2005 to 2010).
- VMT-per-capita trends for the five-year period.
- Different measures of congestion:
  - Texas top 100 congested roadways.
  - TCI.
  - Daily v/c ratios from existing travel models.
- Population trends.

Not surprisingly, the greatest changes in VMT and population are concentrated in the 12 largest urbanized areas in the state. Three of these study areas—Dallas-Fort Worth, Houston, and El Paso—are in non-attainment of one or more the criteria pollutants. The 13 remaining study areas, or non-TMAs, represent proportionally smaller overall population growth. That being said, some non-TMAs, such as Bryan-College Station, Amarillo, Tyler, Longview, Sherman, Waco, and Beaumont, are projected to have greater than 25 percent changes in population between 2010 and 2040. Tyler and Longview have partially opened or planned tolled facilities, while Brownsville, which is a newly designated TMA, is currently constructing a toll-based facility.

RECOMMENDATIONS

TxDOT TPP has developed a uniform approach to travel model development and application that has been fairly consistent throughout the decades. This approach works well with the small to medium-sized study areas for a number of reasons:

- The characteristics of the small to medium-sized study areas are similar in nature. For the most part, the challenges encountered by larger study areas—brought about by large demographic changes, corresponding traffic congestion as a byproduct of that growth, and accompanying significant capital improvement projects, both highway and transit related, to address congestion—do not exist in the smaller study areas.
- There is limited staff at the small to medium-sized MPOs.
- The financial agent for some of the smaller study areas may lie with the host city, thereby creating multiple demands for limited staffing at the smaller MPOs.
- There is limited TDM application experience among most MPOs, which is the case not only in the state but nationally. Consequently, the knowledge base and software familiarity may be limited. The uniform approach to TDM development and application tends to enhance technology transfer, software training and familiarity, and knowledge base.

Although there are subtle differences by study area, such as additional trip purposes and area type specifications, the approach is standard for all study areas in the state. The need for different modeling platforms or approaches has traditionally not been present in the smaller urbanized areas for a number of reasons. The advent of toll roads in a select few of these smaller study areas, however, has potentially created an impetus to migrate toward some level of change to address not only toll demand in the current Texas Package system but also complementary structural changes to the architecture of the models. General changes could be categorized as follows:

- Implement a *generalized cost procedure* to properly address concession-based roads.
- Consider *modifying the assignment convergence criteria* with additional iterations and tighter convergence to achieve greater resolution of the assignment algorithm.

- Consider adding *additional market segmentation* (i.e., autos versus trucks) to the trip tables to address perceived differences in VOTs and match to corresponding toll fees based on auto or commercial vehicle differences. Currently, TxDOT TPP models have an internal truck trip purpose that primarily addresses delivery vehicles. Distinguishing external travel between commercial and non-commercial is dependent on whether an external station survey was conducted in the past. TxDOT assigns a single demand matrix by summing all of the trip tables from trip distribution. Rather than summing all of the trip tables into a single matrix, some of the matrices, such as TRTX, external-local truck, and external-through truck, could be preserved during the process as individual trip tables to be assigned in a multi-class assignment technique.
- Consider *migrating to time-of-day trip tables* to capture travel time savings associated with premium routes where fees are assessed to bypass congestion. Higher volumes on toll routes are typically associated with peak-period congestion.
- Consider, when necessary and appropriate, resolving travel times in the sequential model application process by *implementing an iterative travel time feedback loop*.

The argument for implementing a robust mode-choice model in the smaller study areas is probably more to address a structural change in the models rather than to address a planning need that exists given that most of the small study areas are operating local bus systems with extremely low ridership numbers. These transit systems rarely have a long-range plan that is consistent with the MTP horizon year. A mode-choice model, though, could yield trip tables by auto-occupancy factor, which lends itself to addressing dynamically priced facilities. Although auto occupancy factors can be externally developed, this exogenous approach does not create a connection between occupancy, time of day, and travel time/congestion levels, which would be addressed in a properly defined mode-choice model.

A cogent argument could be made to implement not one but all of the suggested changes above and to do this for the entire state to continue uniform TDM treatment. Addressing toll roads may create a departure from traditional practice by having similar but different systems within the TxDOT TPP purview to address study areas with toll facilities and those without. The question is: is it really necessary to implement each of these strategies for a small study area with minimal changes in population, declining VMT (at least short term), and no plans for significant roadway expansion or toll roads? In these cases, the daily three-step models probably serve most needs for these study areas.

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APPENDIX: EXAMPLE DRAFT DISCUSSION ITEMS FOR TEXAS TURNPIKE AUTHORITY

- What urban area(s) has your firm had experience with in the state?
- What is a greater motivation when accounting for tolls?
  - Volumes?
  - Revenue?
- What input data from TPP are requested?
  - As a follow-up, does the approach change with changes to urban area size and/or level of congestion?
- Is the TPP travel demand model used and to what extent?
  - Does your firm receive the trip generation, trip distribution, and traffic assignment models?
    - If the trip generation models are received, are the outputs modified to preserve income levels for certain trip purposes?
  - Does your firm only get the daily trip table and loaded highway network?
    - Do you work with the fixed trip tables, or do you have a method to adjust these?
    - If the trip tables from distribution are provided and external data by vehicle class are not distinguished, are the trip tables estimated to obtain general vehicles versus truck (internal and external)? How?
  - Does your firm receive travel survey data (if available)?
  - Does your firm obtain count data from TxDOT?
- If the above data were not obtained from TxDOT, what complementary data were collected?
  - RP survey?
  - SP survey?
  - OD data?
  - Traffic counts?
  - Travel time/speed data for routes?
- What data in the loaded network are used (if obtained)?
  - Are the daily volumes considered the "ceiling" for demand, for example?
  - Are the 24-hour "daily" speeds used, or are free-flow speeds input?
  - Are the existing daily capacities used, or are these modified to include time-of-day considerations?
  - Are the BPR curves provided by TPP used, or are these updated to accommodate toll considerations during traffic assignment?
- At a minimum, what must be done to account for tolling in the existing TxDOT models?
  - Are time-of-day models developed?
  - Is a feedback mechanism incorporated?
    - To what step?
    - What is measured for closure?

        - All trips or only select trips?
        - Are composite times feedback (time + cost)?
        - What are the initial speeds—free-flow?
            - How are these derived?
    - Are toll diversion curves and/or generalized cost approaches used in the small to medium-sized study areas? Questions for toll diversion curve:
        - Are toll diversion curves used by trip purpose?
        - Are toll diversion curves used by vehicle class (auto versus truck)?
        - Are toll diversion curves developed by trip purpose and income category (are incomes preserved from trip generation and trip distribution)?
        - If income groups are used, how are these derived (travel survey)?
        - Does the travel survey ask if people used a toll road or not (potential data for toll diversion curve)?
    - What is the toll estimation procedure, and when is it addressed—mode choice, traffic assignment?
    - If the TxDOT model has been augmented by an external developed transit model, are the transit trip re-estimated and assigned as a part of this process?
        - Is a generalized cost formula specified? If so, what inputs are used (e.g., in vehicle time [IVT], wait time, transfer time, access time, egress time, fare [fare factor])?
        - Are the dollars used for fares, parking, and VOT all expressed in consistent constant dollars?
- What are the variables used in traffic assignment (if a generalized cost approach is used)?
    - Travel time
        - How is travel time derived (estimated peak times versus off-peak times)?
    - Distance
        - How is distance derived (off-peak travel time path or peak travel time)?
    - Are the tolls in the network:
        - Point based?
        - Distance based?
        - Variable by time of day?
        - Dynamic?
        - Cordon or other pricing scheme?
        - Is there an ETC bias in the models?
    - Operating cost (how is this derived?)
    - Value of time (how is this derived and how is this distinguished by class?)
        - Are these derived from a SP survey?
        - Are these borrowed from another study area?
        - Are these applied by trip purpose?
        - Are these applied by vehicle classes?

        - Are these derived by pivoting off of the average wage rage for the area (e.g., 50 percent to 70 percent of wage rate)?
        - Is the VOT relative to the times on the networks (is there a disconnect between the times on the network, and what is considered an accurate VOT)?
        - Are these derived via a calculation (e.g., based on coefficients relative to distance and/or elasticity of income or cost)?
        - Which steps use VOT—distribution, mode choice (MC), or traffic assignment (TA)? Are VOTs varied by income group (if income groups preserved in models or segmentation of the population)?
    - How is auto operating cost derived?
        - Pivot off of AAA?
        - Distinguish vehicle type?
- What are the TxDOT standards or guidelines for conducting tolling in the state (look-up report referenced by PB)?
- Who developed these guidelines (again, look-up report referenced by PB)?
- How do you "validate" the toll demand procedure?
    - Areas with existing toll roads—are these counts and travel times?
    - Areas without existing toll roads—what procedures are considered reasonable?
    - What are the general criteria for model validation by FTYPE, ATYPE, and Screenline?
    - What additional validation criteria does your agency use for overall model performance?
        - RMSE, R-squared, GEH, etc.
    - Does your agency measure assigned travel times relative to observed travel times on toll facilities and competing free parallel routes as a measure of validation?
        - Are travel time surveys collected as a part of this effort?
    - Has a review of previous forecasts relative to current counts on toll roads ever been conducted? If so, how close were the forecasts, and can we get a copy of the findings?
    - Are competing free routes reviewed relative to toll assignment results?
- Do you conduct any sensitivity testing of the toll demand procedures?
    - Identify key input variables.
    - Provide minimum and maximum value for each input variable.
    - +/- VOT values to test for elasticity of demand.
    - Different scenarios (e.g., lower/higher pop, VOT, tolls, speeds, toll rate increases).
    - Are probabilities of exceeding forecasted volumes or revenues developed as a part of this process?
    - Are risks to the forecast quantified (e.g., changes in gas prices)?
- Do you review previous forecasts?
- Would estimates of toll demand coming from the TxDOT models be of benefit to your work?
- What potential enhancements to TPP models would most benefit your toll modeling work in the state?

- Any key lessons learned that have not already been covered or general thoughts regarding how TxDOT TPP should move forward?
  - Acceptance of results may be relative to the expectations of what a model can or cannot do.