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16\. Abstract

Currently, the models that TxDOT's Transportation Planning and Programming Division (TPP) developed are traditional three-step models (i.e., trip generation, trip distribution, and traffic assignment) that are sequentially applied. A limitation of this sequential approach is an inconsistency between the travel time data used in the different stages of the process that may result in: (1) TDMs, which do not accurately reflect system-wide or corridor-level travel patterns, (2) travel times in alternative analyses that may not reflect accurate results, and (3) inaccurate results being used for the air quality determination process.

To resolve these differences in the model sequence, researchers proposed an iterative feedback mechanism as an approach. This project researched current trends, practices, and tools in implementing a feedback approach for potential implementation in the TxDOT TDMs. In general, past research and practice underscores the importance of incorporating feedback loops in the travel demand process, especially in regions with moderate to high levels of traffic congestion during certain times of the day. Since the current TxDOT TDM model does not include any impedance or accessibility measures in the trip generation step, the best current approach is to feed back the output from the traffic assignment step to the trip distribution step. Overall, critical consideration should be given to the relative impact that implementing feedback might have on existing TxDOT-TPP practices. A feedback mechanism necessarily includes additional training and increases the calibration time associated with delivering base year travel models; and possibly could include additional data processing (and collection) related to time-of-day implementation.

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INTRODUCTION

BACKGROUND

Metropolitan area travel demand models (TDMs) are a critical quantitative analysis tool used to support the development of long-range transportation plans and air quality analysis. TxDOT's Transportation Planning and Programming Division (TxDOT-TPP) provides TDM development support to 23 Metropolitan Planning Organizations in the state. Currently, the models that TxDOT-TPP developed are traditional three-step models (i.e., trip generation, trip distribution, and traffic assignment) that are sequentially applied with minimal adjustments between each step. A recognized limitation of this sequential approach is an inconsistency between the speed/time data used in trip distribution (i.e., the decision people make on where to go), which is based on a preliminary set of estimated network link speeds and travel times, versus the resulting speeds and travel times from the final traffic assignment step, which reflect some level of congestion. This inconsistency between the speed/time data used in different stages of the traditional sequential process may result in travel models that do not accurately reflect current system or corridor-level travel patterns. As a result, the speeds and travel times resulting from alternative analyses used to support long-range transportation planning decisions may not entirely reflect accurate results.

Since the 1970s, this limitation of sequentially structured TDMs has been discussed in the TDM professional community. As a result of Clean Air legislation in 1990, momentum increased to address this issue and improve model representation of actual travel behavior. Two primary approaches have been proposed: direct optimization through a combined model and various iterative methods. In a combined model, the model steps are solved as a single unit instead of sequentially. More common, an iterative feedback mechanism runs a traditional sequential model as a loop, 'feeding back' output from traffic assignment (for example, the congested link travel times) for use in the trip distribution step of the next loop, or iteration, of the model. These model iterations are continued until specific criteria are met, typically some measure indicating that the speed/time values used in the trip distribution step and those output from traffic assignment have converged.

This project intends to research a fundamental advancement to the traditional TDM development approach that TxDOT-TPP currently uses. By implementing a feedback approach, TxDOT-TPP could better represent current and forecasted travel patterns, and thus substantially improve the quality of this critical decision-making tool for TxDOT and local decision makers statewide. This project researches current trends, practices, and tools in implementing a feedback approach for potential implementation in the TxDOT travel models for study areas where this may be considered a viable option (e.g., larger, congested study areas).

Overview of Current Feedback Techniques and Approaches

Of particular interest for TxDOT is the question of whether the effort to implement and maintain a feedback mechanism as part of the standard TDM model stream is merited, and if the answer to this question differs for different urban areas. The issue that feedback intends to address is best demonstrated with a walk-through of the current sequential model approach.

Current Standard TxDOT Travel Demand Model Process

Figure 1 summarizes the three-step sequential model process that TxDOT-TPP currently uses. Following the typical state of practice for a three-step sequential TDM, under the first step, Trip Generation, the number of productions and attractions by trip purpose are estimated for each Traffic Analysis Zone (TAZ). Productions and attractions represent 'trip ends,' the two ends of a single trip. For example, a zone's home-based work productions are estimated based on the number of households, population, and other characteristics. Home-based work attractions, on the other hand, are estimated based on the number and type of employment positions per zone.

For the TxDOT TDM process, the software application TRIPCAL5 is used, and highway network characteristics such as travel time are not considered. The human behavior that the model is attempting to represent under Trip Generation is to translate TAZ demographic characteristics on the population and employment sides into numbers of trips produced or attracted. For example, a TAZ with a dense subdivision will produce many more trips than a rural TAZ with undeveloped or agricultural uses. Likewise, a TAZ having a large mall that employs many people will attract many more trips than the rural TAZ.

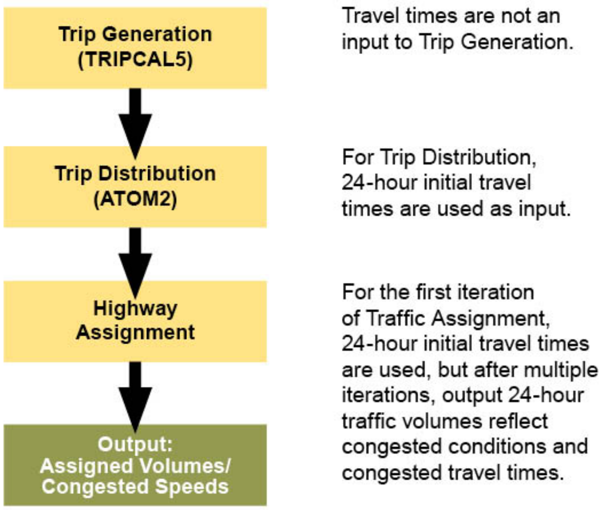


Figure 1. Current TxDOT Three-Step Sequential Travel Demand Model.

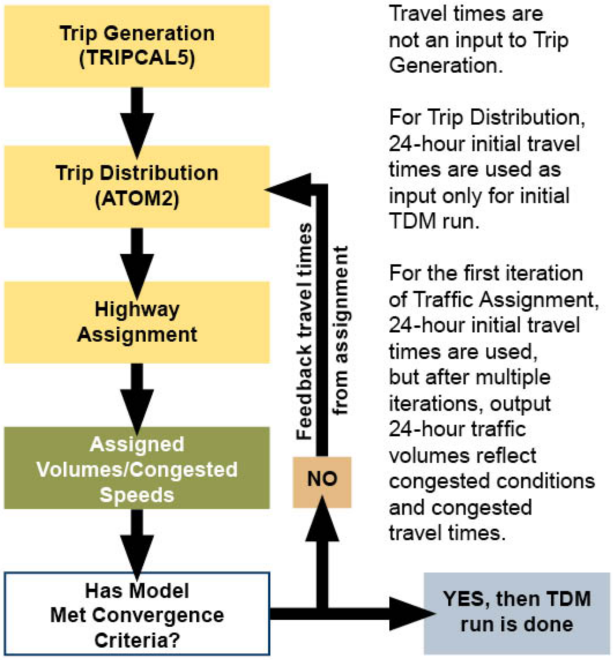
Under the second step, Trip Distribution, the production ends and the attraction ends are linked to comprise single trips (a trip in one direction, not a round trip). These linkages are determined using the ATOM2 application, which considers as a primary input the travel time between each TAZ to match up productions and attractions. The travel times currently input into this Trip Distribution step are based on input speeds that reflect representative 24-hour uncongested characteristics along the different types of facilities. Thus, for freeways, initial speeds are generally higher and network link travel times shorter, than those for collector facilities of comparable length. The human decision that the model is attempting to represent is, if someone needs to leave their house (the production end) to go buy groceries, all other things being equal, they will try to minimize their travel time when they decide where to buy the groceries (the attraction end). At this step, the best information the model has is the input initial travel time, because assignment has not been performed to locate where congestion exists on the roadway system. Thus, the Trip Distribution pattern is less representative of the actual destination choice process, where a traveler often considers route-specific congestion and related travel times in deciding where to go to satisfy their trip purpose. After Trip Distribution, the production-attraction trip table is manipulated to balance it to represent trip origins and destinations (ODs).

Under the third step, Traffic Assignment, the route taken for each trip is determined using the standard TransCAD equilibrium assignment algorithm. The same 24-hour initial travel times are input into the first assignment iteration, but then the model continues to iterate, adjusting the resulting travel times along every roadway link based on the level of congestion (i.e., assigned volume on the link with respect to link capacity). Thus, by the final iteration of assignment, the choice of which route a particular traveler will take between origin at TAZ A and destination at TAZ B is based on travel times under congested conditions. For the example of the shopping trip, the model assumes that the traveler will choose the route that provides the lowest travel time under congested conditions.

This is the current TxDOT TDM process for estimating travel patterns for a study area. In the context of this project, the question is (for the traveler making a shopping trip), would they have made a different decision about where to go to shop under Trip Distribution, if the model had been able to consider congested travel times? Logically, travelers do consider traffic congestion when deciding where to go or choice of route for all types of trips. It is this issue that feedback attempts to resolve—the consistency between travel times considered for Trip Distribution versus for route choice under Traffic Assignment.

Current Standard TxDOT Travel Demand Model Process with Feedback?

Figure 2 summarizes the three-step sequential model process that TxDOT-TPP currently uses, with a potential simplified feedback loop inserted.



Travel times are not an input to Trip Generation.

For Trip Distribution, 24-hour initial travel times are used as input only for initial TDM run.

For the first iteration of Traffic Assignment, 24-hour initial travel times are used, but after multiple iterations, output 24-hour traffic volumes reflect congested conditions and congested travel times.

Figure 2. Current TxDOT TDM with Potential Feedback Loop.

Although Figure 2 is an over-simplification of a feedback loop, it demonstrates the basic premise. After running the TDM through the first time under the current TxDOT process, at the end of Traffic Assignment, the resulting link travel times from Traffic Assignment are then used as the input link travel times to determine TAZ-to-TAZ travel times for Trip Distribution. This starts a second loop through the model. Using the previous example, this time however, travelers are able to consider congestion with respect to travel time when they decide where to go shopping.

Congested travel times are often substantially different than initial travel times; hence, the resulting Trip Distribution results will differ, as well. This new pattern of distributed trips gets assigned under Traffic Assignment in the second loop, resulting in updated congestion levels and travel times across the roadway network. After the second loop, travel times (as one possible measure) are examined to see how close these are between the two Assignments. If the changes are within acceptable parameters or meet specified criteria, then the model is considered to have 'converged' and the process is complete. Otherwise, additional loops are performed until convergence is reached. Under this type of iterative process, the feedback process arrives at a solution where the travel times used for Trip Distribution are substantially similar to those arrived at under Traffic Assignment, and Trip Distribution has considered the effect of traffic congestion.

Variations on Feedback Approach

The concept of feedback is simple; the details, less so. As demonstrated in a 2009 Technical Synthesis of Travel Model Improvement Program email discussion on this topic (Hall, 2009), there is still much debate in the travel demand modeling community regarding approaches, which model input should be fed back (time is just one choice), and what the convergence criteria should be. Some options for approach depend on choices made regarding what to feed back and vice versa. Some convergence criteria are related to the type of approach. This is the area of feedback that the current research effort intends to explore and explain, and, based on findings, make recommendations for the TxDOT-TPP TDM model process.

Summarized in numerous resources, the more common examples of iterative feedback approaches include the:

- Direct approach.
- Fictive Costs approach.
- Method of Successive Averages (MSA) with either fixed or variable weighting.
- Constant Weights applied to trip tables.
- Evans Algorithm.

Under the Direct approach, sometimes called the 'Naïve' approach, speeds or other variable output from Assignment are fed directly into Trip Distribution with no manipulation. A common observation under the Direct approach is that it leads to significant oscillation of output results between feedback loops and may not reach convergence at all.

Under the most common Fictive Costs approach, the variables output from the first Assignment are fed directly back into Trip Distribution for the second model loop. Then the output variables from both first and second loops are averaged and used as input to the third and final loop through the model. As the name suggests, one critique against this method is that model convergence is indeed fictive; that is, the model is not necessarily reaching convergence with respect to travel time.

Under the MSA approach, one of the variables (such as link travel times) output from the first Assignment is fed directly back into Trip Distribution for the second model loop. For the second loop, output is averaged with output from the first loop. Then, for each subsequent loop, output from the most recent loop is averaged with the MSA-averaged value calculated from the prior loop. The weight of the current loop versus the prior MSA-averaged value (sometimes also referred to as the step size) is a further area of flexibility. For example, some approaches use half of the current loop and half of the prior MSA-averaged value, others weight them unevenly, and still others adaptively change the weighting scheme as the number of feedback loops increase. The intent behind the MSA approach is to address the oscillation issue observed under the Direct Approach; it also has been shown mathematically to converge.

An alternative to the MSA approach, the Constant Weights approach (as it is commonly referred to) has a primary goal of reducing the time necessary to achieve convergence. The common method for implementing a Constant Weights approach is to average the trip matrix of the current iteration with the trip matrix from the prior iteration. Case studies (Boyce et al., 2007) and professional discussions (Hall, 2009) indicate that the Constant Weights approach can effectively and efficiently arrive at a stable solution while avoiding a lengthy convergence process.

An additional approach based on the Evans Algorithm has been presented as the ‘other’ mathematically proven method besides MSA. As noted recently (Hall, 2009, Walker, 2008), Evans is less commonly discussed than other approaches and only rarely implemented. Using an Evans approach, weights between each feedback iteration are optimized based on what is called the Frank-Wolfe objective function instead of pre-determined weights. According to Walker (2008), who documents findings from implementing Evans feedback for the Delaware Valley Regional Planning Commission, Evans offers the benefit of being more computationally efficient than MSA.

One of the considerations in choosing an approach for feedback is the number of feedback iterations necessary for convergence. As discussed above, an increased number of iterations can translate into a significant length of time. Some case studies have suggested that the number of feedback loops necessary to converge using an MSA approach can be high or even unrealistic for regular model application, which has been a motivation for using other approaches. Even using MSA, the settings can be a differentiator: Lin et al. (2008) have shown in a simulated study that the step size can be an important determinant of how fast convergence is achieved.

As mentioned previously, the direct optimization (also called Combined Model) approach has previously been proposed as an alternative to an iterative feedback mechanism. It is much less commonly implemented than the iterative approach.

Variations on What Gets Fed Back

In the simple feedback example presented in Figure 2, link travel times were the variable fed back into the next model loop. However, other variables are commonly used instead of travel time. Caliper Corporation, the developer of TransCAD®, which is the chosen TDM software platform in Texas, advocates an MSA approach applied to link flows (TransCAD 5.0). For each successive feedback loop, link flows from the current loop are factored and weighted together with those from the previous loops to arrive at a new value called MSA Flow. Travel time is then derived from this flow value by applying the BPR formula. It is this derived MSA Time value which is fed back into the next feedback loop. This procedure is iterated until there is convergence in travel time. As mentioned above, David Boyce, one advocate of the Constant Weight method, argues in favor of applying feedback to trip tables and not travel times or link flows (Boyce et al., 2007 and Zhang and Boyce, 1998).

Variations on Stopping Criteria and Measures of Convergence

Stopping criteria and measures of convergence demonstrate similar variation in discussions and application of feedback. *Stopping criteria* refers to the measurement of when to stop feedback. *Convergence* refers to the model reaching some sort of stable solution, where continued feedback loops are judged to no longer offer a significant enough improvement on the current solution.

The simplest stopping criterion, of course, is a maximum number of iterations. Given the length of time necessary to run many of the more complex models, a maximum number is a good idea as a practical application. Of some concern is the use of a set number of loops when the model is known to still be oscillating widely. A reasonable maximum very much depends on the nature of the feedback approach chosen, as well as the time constraints of applying the specific model in question. Even in cases where a maximum number of loops are reached, measures of model convergence should be conducted and reported. As a specific example, because the MSA approach can take many iterations to reach convergence, with some significant oscillations between successive iterations, fixing a maximum number of iterations under the MSA approach is not a good idea (Ortuzar and Willumsen, 1994).

To measure convergence, a single global measure may be inadequate because it can describe many different solutions; instead, a measure which aggregates the variations among many observations may provide better information. One TMIP report recommends five measures based on several test cases, focusing on measures that capture the change in link volumes and origin-destination flows as well as changes in key output variables such as speed (TMIP, 1996). According to recent TMIP discussions, typical measures employed for feedback include comparison of loops using absolute or percentage difference, a Total Misplaced Flows approach, examining Root Mean Square Error, and the GEH Statistic, although there is continued debate in the modeling community concerning the best measures to use (Hall, 2009).

As this brief summary of feedback demonstrates, a critical task in this effort is to research, expand on, and further explain the state of practice with respect to feedback theory and implementation and the relevance of these different approaches to the TxDOT TDM process; see Chapter 1. As an additional issue to be explored, one assertion made fairly regularly in professional discussions on the topic is that feedback may be less applicable for smaller urban areas. In this context, the support for this assertion is often a reference to the limited role that congestion plays in these models, as well as commentary on the relative lack of modeling capability available to develop and support a feedback mechanism for these areas. Chapter 2 addresses the technical question of the relative benefit of implementing feedback for smaller urban areas versus larger areas.

Report Organization

If the information above shows anything, it is that there may be as many options for implementing a feedback mechanism as there are different TDMs using it. This should not be intimidating. In fact, one implication is that feedback is best implemented as a solution specifically tailored to the individual model system, and that preserving some flexibility in implementing feedback for the behavior of a particular model structure may be the most important lesson of all. A significant advantage TxDOT has in this question is that the majority of urban models that TxDOT implements have a consistent model structure. This means that, once a feedback structure is tested and implemented for one standard urban model, TxDOT should be able to easily implement it for the majority, if not all, of its models. Nonetheless, there remain several issues and implications that this research considers.

The remainder of this report is structured as follows. The first three chapters provide background and supporting context for a sensitivity test and field analysis of implementing feedback within the TxDOT TDM process. Chapter 1 provides a discussion of the state of the practice in feedback implementation by identifying and presenting the many dimensions that characterize the feedback loop procedure, based on earlier and ongoing research. It describes the state of the practice of feedback implementation, documents dimensions of feedback implementation, and summarizes the findings from the synthesis of practice, thereby providing some general directions for incorporating feedback in the context of the current TxDOT TDM model system. Chapter 2 provides a detailed examination of the TxDOT modeling process and discusses potential issues to consider in implementing feedback as part of the TxDOT TDM process. Chapter 3 then offers an overview of the state-of-the-art in future development trends in feedback implementation. Chapter 4 then follows with a summary of this research project's field test and sensitivity analysis of applying feedback within the TxDOT TDM process using a previously validated Texas Metropolitan Planning Organization (MPO) model. The concluding chapter then summarizes findings for the entire research effort and makes recommendations for TxDOT consideration.

Emphasizing what is practical based on current state of practice with feedback is crucial to the research approach described in this report, as well as logical for incorporation into the TxDOT urban models as they stand today. For this reason, a primary focus of the research effort has been existing approaches for feedback implementation in the context of the TxDOT TDM process.

The theme overarching this research effort is that TxDOT arrive at a better understanding of the need for, advantages and disadvantages of, and steps needed to implement a feedback mechanism as part of the standard TxDOT urban model. This theme applies to the TxDOT model as it exists today and as it will most likely be implemented in the near-term. Thus, the field test component of this effort (Chapter 4) demonstrates the challenges and opportunities in terms of ease in practical application, run-time considerations, and the effects on trip flows and travel times outputs from the travel demand model. It also provides perspective on the feedback process by providing a comparison output between a sequential model run and a run with feedback.

CHAPTER 1. STATE OF PRACTICE IN FEEDBACK IMPLEMENTATION

INTRODUCTION

The trip-based modeling approach to urban transportation planning is the most widely used method to generate urban region travel demand forecasts in response to changes in demographic, land use, built environment, and transportation systems. It is basically a sequential approach, with the attributes of travel (whether to travel, where to travel, what mode to use, and finally what route to take) determined in four steps. Each of these steps is very briefly described below, along with an overview of the characteristics of the corresponding component of the current TxDOT travel demand modeling system.

Trip Generation

This is the first step of the four-step model. The objective of this step is to determine the number of trips produced from, and attracted to, each TAZ in an urban region. The number of trip productions and attractions are predicted by trip-purpose, as a function of demographics, land use, and built environment factors (transportation system factors generally do not appear as predictors of trips in trip generation models, though it is becoming more common to incorporate such factors through an accessibility variable). Also, while different levels of trip-purpose resolution may be used, the most common typology used in most metropolitan planning organizations (MPOs) in the country continues to be based on three trip purposes: home-based work, home-based non-work, and non-home-based trips.

Trip production modeling is usually undertaken at the disaggregate level of households, using a cross-classification procedure, and then typically applied at the level of traffic analysis zones. A cross classification model is essentially a linear regression model with only dummy independent variables to allow non-linearity in variable effects; a linear regression model can include both dummy variables as well as continuous independent variables. Trip attraction prediction is pursued at the TAZ-level using attraction factors associated with different employment types or land uses. Though typically based on factors obtained from the Institute of Transportation Engineers (ITE) Manual, TxDOT attraction rates are derived from workplace travel surveys (ITE, 1997).

In the case of the TxDOT travel demand model (labeled TEXAS Package), TRIPCAL5 is the module used to implement the trip generation step. While TRIPCAL5 has several options, the recommended procedure is to use a two-way cross-classification approach for predicting TAZ level trip productions by trip purpose (home-based work, home-based non-work, and non-home based) based on household size and household income as independent variables. Another regression type cross-classification model is used for predicting TAZ-level trip attractions for each trip purpose stratified for up to 24 generation areas with households and employment category as independent variables. In addition, models to predict the trip attractions and productions of special generators such as airports, amusement parks, and universities are built into the TRIPCAL5 module. No transportation system factors are used in TRIPCAL5.

Trip Distribution

This next step entails the prediction of TAZ-to-TAZ trip production-attraction interchanges based on the outputs of the trip generation stage and the travel impedances between each pair of TAZs. A disaggregate attraction-end choice model that operates at the level of individual decision-makers may be estimated and applied, or an aggregate distribution model that directly operates at the level of TAZ-to-TAZ interchanges may be estimated and applied. The practice at almost all small-to-medium MPOs, and also at several large MPOs, favors the latter aggregate distribution model approach, typically undertaken using a gravity model formulation with highway travel times being the impedance measure. If a mode choice model is not available as part of the model chain, then at the end of trip distribution, the trip production-attraction matrix is translated into a trip origin-destination matrix.

Within the TEXAS model, the trip distribution step is implemented within a module known as ATOM2. This is essentially an aggregate gravity-based model formulation, except that the distribution is undertaken at a finer resolution than TAZs (by spatially partitioning each TAZ into several small parcels of land or atoms). This procedure accommodates differential attractiveness pockets within a TAZ as well as enabling better modeling of intrazonal and short distance trips. The atom-based predictions of trip interchanges are subsequently aggregated up to the level of TAZs. The travel time input to the trip distribution step corresponds to 'representative' daily 24-hour travel times. However, it is important to note that these times are not the congested travel times obtained from the traffic assignment step. Also, there is no feedback of travel parameters from the traffic assignment stage to the trip distribution stage (see "The Concept of Feedback" and beyond for more details on feedback).

Modal Split

This step predicts the proportion of trips undertaken between each TAZ pair using each of several possible travel modes. As in the case of trip distribution, a disaggregate mode choice model that operates at the level of individual decision-makers may be estimated and applied, or an aggregate mode split model that directly operates at the level of TAZ-to-TAZ interchanges may be estimated and applied. While most small-to-medium MPOs continue to use an aggregate mode split model, most large MPOs use a disaggregate-level multinomial logit or nested logit model to predict the probability of an individual using a particular travel mode for each trip, and then aggregate these probabilities appropriately to obtain the mode splits between each TAZ pair. The net result at the end of the modal split step is the number of person trips by travel mode between each origin-destination TAZ pair for a 24-hour period, which can then be translated into equivalent 24-hour vehicle trips by mode.

The TEXAS model does not have an explicit mode split model. Using the Texas Mezzo-Level HOV Carpool Model, however, it has the ability to split person trips by mode if the analyst provides an estimate of the mode shares by sector for each trip purpose and the average automobile occupancy.

Traffic Assignment

In this last step, the vehicle trips by travel mode are loaded onto the roadway/transit networks. In most cases, a static user equilibrium is used for assigning trips to different routes between each origin TAZ-destination TAZ pair so that all the paths between each origin-destination pair have the same impedance (typically, travel time) at equilibrium. The outputs of this step are the traffic volumes and travel times on each link of the transportation network in the study area. While the traffic assignment step is undertaken for an entire day at small-to-medium MPOs for highway travel, it is typical at large MPOs to introduce time-of-day split factors by trip purpose at the end of mode split to obtain a time-of-day specific vehicle trip matrix by mode and then undertake traffic assignment for multiple times of day for multiple modes.

Traffic Assignment is implemented within the TEXAS Package using the standard TransCAD static equilibrium assignment algorithm. It is undertaken only for the highway mode of travel, and on an entire day (24-hour) basis.

The Concept of Feedback

An important issue in the typical four-step model presented above is that TAZ-to-TAZ travel impedances (mostly in the form of unimodal or multimodal travel times) are used as an input in the trip distribution step in determining trip interchanges, and also as inputs to the mode split step if that step exists. (Note: In some small-to-medium MPOs with little to no transit service, it is common to not have the mode split step at all). However, the travel demands resulting from these travel impedance inputs get loaded on to the network in the final traffic assignment step, an output of which is link travel times that themselves determine the TAZ-to-TAZ travel impedances.

The resulting travel impedances from the traffic assignment step should be consistent with those used as inputs in the earlier steps. Otherwise, the conditions on the network do not reflect the conditions used to generate the demand in the first place. For instance, the use of uncongested travel times for links on paths between a particular TAZ-to-TAZ pair when there is substantial congestion on these links in the real world could lead to the trip distribution step assigning much more trip activity than would be appropriate between the TAZ pairing. The consistency between demand and supply may be achieved by feeding back the travel impedances to the trip distribution model, and iterating until a certain level of consistency is reached between the travel impedance inputs (to the trip distribution and mode split models) and the travel impedance outputs. This feedback loop process is the focus of this research project.

This report does not discuss feedback processes in the context of non-sequential combined optimization-based travel demand modeling systems of the type discussed in Bar-Gera and Boyce (2003, 2006), Siegel et al. (2006), and Xu et al. (2008). Such approaches are not commonly used in practice. Also, the report does not examine feedback processes in the context of an activity-based travel demand approach to travel demand modeling that more of the large MPOs in the country are considering and adopting. Lin et al. (2008) provide an overview of feedback approaches in the context of an activity-based model.

DIMENSIONS OF THE FEEDBACK PROCESS

The travel demand modeling approach with no feedback loop may be expected to perform less well in traffic forecasting and transportation system performance prediction than the approach with feedback, when there is traffic congestion during certain times of the day (Avner, 2009). However, there is no clear consensus in the travel demand modeling community regarding how best to implement a feedback loop. In this section, we identify several dimensions that characterize the feedback process; in the succeeding section, those dimensions are used to present and discuss the feedback procedures adopted in practice.

Ongoing and previous research on feedback procedures identify several dimensions along which the procedures could differ. These dimensions include the following:

- Demand modeling step to which the data is fed back.
- Time-of-day considerations.
- What travel parameter is fed back.
- Is the travel parameter unimodal or multimodal.
- Basis for feedback of travel parameter.
- Updating procedure.
- Convergence determination.

Demand Modeling Step to Which Data Are Fed Back

In most cases, the output from the traffic assignment step is used to update the impedance measures used in the trip distribution step. However, the output from traffic assignment may be fed back to the trip generation step or even to the land-use models before the trip generation step. For instance, Beimborn (2006) argues that travel times from a certain zone A to another zone B will not only affect the trip interchange between the zones (i.e., trip distribution), but can also affect total number of trips produced from Zone A and the total number of trips attracted to Zone B (i.e., trip generation; see also Levinson and Kumar, 1993a and Feng et al., 2007).

The effect on trip productions from Zone A may be attributable to an overall increase (decrease) in accessing activity opportunities from Zone A because of a low (high) travel time between Zones A and B (everything else being equal). The impact on trip attractions to Zone B may be associated with an increase in the overall attractiveness of Zone B (relative to other zones) because of a low (high) travel time between Zones A and B (everything else being the same). Further, the increase in accessibility of zone A may lead to more households locating in Zone A, while an increase in attractiveness of Zone B may lead to more employment locating in Zone B. These residential location and employment patterns are determined in land-use models. Thus, Beimborn suggests that the travel impedance feedback from traffic assignment be taken all the way back to the land-use modeling step that precedes the trip generation step (Beimborn, 2006). Feng et al. (2009a, 2009b, 2010a, 2010b), also reinforce this notion of including trip generation and the precursors of trip generation within the feedback loop, using the output of traffic assignment to:

- Update modal impedance measures.
- Develop updated ‘logsum’ (or generalized impedance) measures from the mode choice model.
- Construct an accessibility measure for trip productions from each zone z ($z = 1, 2, \ldots., Z$) based on the sum of the number of attractions from each other zone x ($x = 1, 2, \ldots, Z$) weighted by an inverse function of the generalized impedance between zone z and zone x.

- Construct an accessibility measure for trip attractions from each zone using a procedure similar to that for trip productions.
- Use these accessibility measures as predictors to obtain new zonal trip productions and attractions.
- Move down to each of the other steps in sequence.
- Continue the interlinking of the various steps until convergence.

Time-of-Day Considerations in the Feedback Process

The feedback process is closely intertwined with the time-of-day representation in the travel demand model system. As indicated earlier, the concept of feedback arises because the travel impedance used as an input to earlier steps of the travel demand modeling process will not, in general, be consistent with the congested travel impedance from the traffic assignment stage, when congested conditions exist on the network. When congested conditions never exist on the network, however, there is no need for feedback because the inputs to the earlier steps of the demand modeling process appropriately reflect the uncongested travel impedance. For example, in some of the smaller urban areas, a few congested paths or links may exist; yet, alternative competing paths are probably not congested. Consequently, trip matrices by trip purpose would not change or the amount of change would be negligible as a result of introducing feedback. Thus, there are three issues to consider when accommodating feedback loops:

- The number of distinct time-of-day periods used in the traffic assignment step.
- The number of distinct time-of-day periods used in earlier modeling steps.
- How to reconcile any differences in the time-of-day representations between the traffic assignment step and earlier steps.

For instance, if there are two distinct time-of-day periods considered in the traffic assignment step (say, peak and off-peak), and the same two time-of-day periods are considered in earlier steps, the feedback of travel impedance is quite straightforward. However, consider again the case above, but let the earlier steps in the modeling process consider only a single period corresponding to the entire day (no time-of-day distinction within a day). That is, assume that there is a time-of-day split factor used to partition the vehicle trip origin-destination matrix by mode (obtained at the end of the mode split step) just before the traffic assignment stage, so that earlier modeling steps are all undertaken with no time-of-day representation. In this case, one possibility would be to feed back a travel impedance to the earlier steps that is the weighted (by the time-of-day split factors of trips) average of the travel impedances originating from each of the peak and off-peak traffic assignments. Alternatively, one may simply feed back the peak travel impedance to the trip distribution step and trip purpose(s) that best represent(s) the peak period, though this would be less appropriate and desirable.

What Is Fed Back?

Link travel time is the most common travel impedance parameter that is fed back. Specifically, link travel times from the traffic assignment stage are used to construct a new table of TAZ-to-TAZ travel times, and fed back to earlier steps. However, link travel time is not the only travel impedance parameter that may be fed back. For instance, one can also feed back generalized cost measures (in the form of a composite of money cost and time measures). This may be particularly important in locations with a reasonably significant number of toll roads or priced corridors. In such a case, the link travel time outputs from the traffic assignment step may be combined with the link cost of travel to develop a new table of TAZ-to-TAZ generalized cost measures that then feeds back to earlier steps of the modeling process (such as trip distribution or trip generation). However, such a procedure will be appropriate only if the earlier steps in the modeling process are sensitive to costs as well as travel times.

Is the Travel Parameter Unimodal or Multimodal?

A unimodal travel parameter corresponds to the impedance of a single mode (such as travel time by the highway mode), while a multimodal travel parameter is a vector of impedances of multiple modes (such as travel times by highway and transit modes). In practice, it is not uncommon to feed back only the highway (auto) travel parameter from the traffic assignment stage to earlier steps in the four-step process. To a large extent, this is because many trip distribution models use friction factors that are based solely on highway (auto) travel times. Such a situation may be acceptable in an environment where auto use will continue to be the substantially dominant mode of travel in the foreseeable future. However, with increasing traffic congestion, energy independence considerations, and air quality and greenhouse gas emissions concerns, several MPOs and local planning agencies are examining ways to encourage the use of non-solo auto modes of travel such as high-occupancy vehicles and public transportation.

To support such planning decisions, multi-modal trip distribution models or trip distribution models that use some composite impedance measure of multiple modes are being incorporated into TDMs, especially among the large MPOs (Levinson and Kumar, 1993b). In this context, the travel parameter that is being fed back should also be multi-modal to extract the full value from the use of a trip distribution model that directly (by stratifying trip distribution by mode) or indirectly (through the use of a composite impedance measure) accommodates multiple modes.

Basis for Feedback of Travel Parameter

A common basis for the feedback of the travel parameter is to combine the link travel impedance parameter from the traffic assignment step of one iteration with the corresponding values from earlier iterations. For instance, it is quite routine to combine the link travel time from one iteration with the link travel times from earlier iterations to construct an updated TAZ-to-TAZ travel time matrix that is fed back. However, one can also use the link flows from the traffic assignment stage as the basis attribute for feedback of travel times (rather than use link travel times from the assignment stage as the basis attribute for feedback). In this latter approach (see Slavin et al., 2006), the link flows from one iteration are combined with the link flows from earlier iterations to obtain updated link flows that are subsequently translated to updated link travel times using the BPR formula. Then, as earlier, the updated link travel times are translated to TAZ-to-TAZ travel times for feedback to earlier steps of the four-step process.

Another possibility is to use the trip matrices at the end of the trip distribution step (if the mode split step does not exist) or the mode split step (if a mode split step does exist) as the basis attribute for feedback of travel times. In this approach, the trip matrix from one iteration is combined with the trip matrices from earlier iterations to obtain an updated trip matrix (Boyce et al., 2007). This updated trip matrix is loaded on to the transportation network in the traffic assignment stage to obtain updated travel times. The updated travel times are converted to updated TAZ-to-TAZ travel times and fed back to earlier steps.

Updating Procedure

The technical synthesis compiled by Hall (2009) (based on the discussions in the Travel Model Improvement Program email list) provides a good overview of different updating procedures (that is, the procedure used to combine the basis attribute used for feedback from one iteration of feedback to the next). The most commonly used updating methods are discussed below:

Direct or Naive Feedback Method

In this approach, the basis attribute value obtained from one model iteration is directly fed back to the next iteration of the model system, without any kind of averaging or factoring (note that the basis attribute value may be in the form of a vector or a matrix; for instance, if the basis attribute is highway link travel time, its value will be a vector of highway link travel times, but if the basis attribute is the trip matrix, its value will be a matrix). Since there is no averaging across feedback iterations, the direct or naïve method is known to result in substantial oscillations in the output from the traffic assignment step from one feedback iteration to the next, leading to convergence problems.

Fictive Cost or 2.5 Cycles Method

In this method, the basis attribute value obtained from the first iteration of feedback is used directly in the second iteration. The values from the first and second iterations are then averaged, and a third, concluding, iteration is undertaken to get the “final” results. This method does not likely result in ‘true’ convergence, because of the arbitrary pre-determined number of iterations.

MSA Method

For this approach, the basis attribute value from the current iteration and the weighted average of the corresponding values from earlier iterations are combined using weights determined by the iteration number (Sheffi and Powell 1981). Specifically, the basis attribute value from the k^{th} iteration ($k = 1, 2, \ldots$) is assigned a weight of $\frac{1}{k}$, and the weighted average of the values from earlier iterations is assigned a weight of $\frac{k-1}{k}$. The resulting weighted average is used in the next iteration, and this process is continued until there is convergence in the basis attribute value.

Another variant of the MSA method is to use an optimal weight on the most recent value (rather than a pre-specified value based on iteration number). Evans (1976) proposed one approach to obtaining such an optimal weight based on a mathematical formulation that casts the trip distribution and trip assignment steps as an optimization problem. Walker et al. (1998) suggests that the Evans method is more efficient (in terms of computation time to reach convergence) than the traditional MSA method, though it is seldom used in practice because of the level of mathematical sophistication needed to implement it.

Finally, Feng et al. (2010a) consider a reverse MSA process where the k^{th} iteration ($k = 1, 2, \ldots.$) is assigned a weight of $\frac{k-1}{k}$, and the weighted average of the values from earlier iterations is assigned a weight of $\frac{1}{k}$.

Constant Weights

In the constant weights approach, the basis attribute value from the latest iteration is weighted the same as the weighted average from earlier iterations. The weight can be any value between 0 and 1. The naive feedback method may be seen to be a special case of the constant weights method, with the weight being unity.

There is some research on the performance of the updating methods, particularly by Boyce and colleagues and Feng and colleagues. The literature, in general, suggests that the direct updating method performs the worst in terms of convergence compared to the other methods (Boyce et al., 2007; Boyce and Xiong, 2007; Louden et al., 1997; Comsis Corporation, 1996). The studies suggest using an updating method which involves some kind of averaging of outputs from different iterations. Boyce et al. compared the constant weight and MSA methods for averaging, and found that not only does the constant weight method provide better convergence in general, but also a constant weight of 0.75 on the basis attribute value from the latest iteration provided reasonably good results for different levels of congestion (Boyce et al., 2007). The study concluded by recommending that the MSA approach should only be used if the constant weights approach does not work effectively. Feng et al.'s (2010a) study reported similar results where they found that the weight w on the new value in the constant weight approach should be at least 0.5 for good convergence. Feng et al.'s study also found that a reverse MSA approach provided about the same stability and rapidity in convergence as the constant weight method with $w > 0.5$.

The above research results on updating methods are quite specific to the empirical contexts in which the studies were pursued, as well as to the specific characteristics of the feedback process within which the updating methods were examined. Overall, the issue of which updating method is the best, and under what circumstances, is still a relatively open question.

Convergence Determination

Convergence refers to the feedback process reaching a stable solution, where further implementation of feedback loops does not result in any substantial change in the basis attribute value. Obviously, the number of iterations of the feedback process needed to reach convergence will be a function of the updating procedure used. Thus, arbitrarily predetermining the number of iterations, independent of the updating procedure used, is unlikely to be the best approach to determine convergence. Instead, several other convergence measures that compare the basis attribute values from successive iterations are used.

Some of the most common of these are based on absolute error and root squared error values. In the mathematical expressions below, $p(k-1)$ refers to the basis attribute value at the end of the $(k-1)^{\text{th}}$ iteration of the feedback process, while $q(k)$ refers to the basis attribute value from the k^{th} iteration. E is the convergence target value or the tolerance value at which the feedback process is considered to have converged.

1. *Total Absolute Error (TAE):* The TAE is simply the sum of the absolute values of the element-by-element differences in the basis attribute value between successive iterations (in the notation below, the indices *i* and *j* together identify an element of the basis attribute value). Boyce et al. and others use the label 'Total Misplaced Flow' for the TAE when the trip matrix or link flow vector is used as the basis attribute for feedback (Boyce et al., 2007). The feedback process is declared as having converged if the TAE is lower than a predetermined tolerance level of *E*.

   $$TAE_k = \sum_{ij} \left| p_{ij}(k-1) - q_{ij}(k) \right| \leq E \Rightarrow \text{Convergence achieved at the } k^{\text{th}} \text{ iteration.}$$

   The mean absolute error (MAE) measure is another version of the TAE measure that is also very widely used. The MAE is essentially a way of arriving at the threshold E based on the cardinality of the membership of the basis attribute value.

2. *Percentage Total Absolute Error* (*PTAE*) *or Percentage Mean Absolute Error* (*PMAE*): This is similar to the TAE or MAE, except it is computed as a percentage TAE/MAE change. When a trip matrix or link flow vector is used as the basis attribute for feedback, it is also sometimes labeled as the Relative Total or Relative Mean Misplaced Flow.

   $$PTAE_k \,/\, PMAE_k = \frac{\sum_{ij} \left| p_{ij}(k-1) - q_{ij}(k) \right|}{\sum_{ij} p_{ij}(k-1)} \times 100\,\% \leq E^* \Rightarrow \text{Convergence achieved at the } k^{\text{th}}$$

   iteration.

3. *Root Total Squared Error (RTSE):* This measure is obtained as the square root of the sum of the squared differences of the element-by-element basis attribute value vector/matrix between successive iterations:

   $$RTSE_k = \sqrt{\sum_{ij} \left(p_{ij}(k-1) - q_{ij}(k) \right)^2} \leq \tilde{E} \Rightarrow \text{Convergence achieved at the } k^{\text{th}} \text{ iteration.}$$

   Another more widely used version of the RTSE measure is the Root Mean Squared Error (RMSE), which is essentially a way of arriving at the threshold $\tilde{E}$ based on the cardinality of the membership of the basis attribute value.

4. *Percentage Root Total Squared Error* (*PRTSE*) or *Percentage Root Mean Squared Error* (*PRMSE*): This is similar to the RTSE or RMSE, except it is computed as a percentage RTSE/RMSE change.

   $$PRTSE_k \,/\, PRMSE_k = \frac{\sqrt{\sum_{ij} \left(p_{ij}(k-1) - q_{ij}(k) \right)^2}}{\sum_{ij} p_{ij}(k-1)} \times 100\,\% \leq \hat{E} \Rightarrow \text{Convergence achieved at}$$

   the k^{th} iteration.

The discussion above assumes that the attribute used to determine convergence is the same as the basis attribute used to construct travel impedances for feedback. This is not always the case, because some other attribute other than the basis attribute may also be used to measure convergence. Thus, while link flow may be the basis attribute for updating the travel time fed back, link speed may be used as the attribute to determine convergence.

THE FEEDBACK PROCESS IN PRACTICE

This section describes the state of the practice of feedback loop implementation in the travel demand modeling procedures of MPOs in the United States. The information in this section was gathered based on an online search of MPO websites and/or email contact with MPO Staff. Our efforts yielded results from 14 MPOs, representing a spectrum of medium to large MPOs from around the country.

Our synthesis of the state of the practice suggests that many MPOs are either currently implementing or planning to implement feedback in their TDMs. However, there is substantial variation in the specifics of the feedback process. Table 1 characterizes the feedback process based on the dimensions identified in the previous section. In some instances, we have not been able to obtain the relevant information, and this is indicated in the table by an entry of "unavailable" in the corresponding cell.

In 10 of the 14 MPOs listed in Table 1, the feedback loop is used to update the input to the trip distribution step. This is mainly because travel impedance measures (such as travel times and costs) are first used in the trip distribution step of the four-step modeling process. However, when the trip generation step is also sensitive to travel impedance, the feedback is taken all the way to trip generation or even into earlier auto ownership models, as in the case of the Atlanta Regional Council (ARC) model and the Southern California Association of Governments (SCAG) model. In the case of ARC, the highway and transit travel times from traffic assignment are used to determine zone-level auto importance indicator (defined as the ratio of the accessibility to employment by highway divided by the sum of the accessibility to employment by highway, transit, and walk modes), which is used to determine the automobile ownership level of each household in the study area. In addition, ARC also uses composite accessibility measures (computed from highway and transit impedances) as predictors of trip generation. The SCAG system includes a vehicle availability model that precedes the trip generation step, and the vehicle availability model is a function of auto and non-auto accessibility measures. The San Antonio Bexar County MPO is the only MPO among the ones reviewed here in which the feedback in the TDM model is taken to the modal split step.

In seven of the 10 MPOs for which the information could be obtained, the time periods used in the earlier steps are different from those used in the traffic assignment. In cases where the traffic assignment is done at a more fine (or same) time period resolution, including those used in the earlier steps, the outputs of only the relevant time periods are used directly without any weighting (Chicago Metropolitan Agency of Planning [CMAP], SCAG, and ARC). Alternatively, in cases where the number of time periods in earlier steps is less and different from those used in the traffic assignment step (mostly a single 24-hour time period), the outputs in the traffic assignment step are combined either using a simple or weighted average (Genesee County MPO and Denver Region COG).

Table 1. Review of Feedback Loop Implementation in the TDMs of Different MPOs.

MPO	Region	Data fed back to	Time-of-day Considerations			What Parameter fed back	Unimodal or Multimodal	Basis attribute for feedback	Updating Procedure	Convergence Considerations		
			Time period used in assignment	Time periods used in earlier steps	Reconciliation procedure					Measure used	Attribute used	Threshold rule
Chicago Metropolitan Agency for Planning (CMAP)	Chicago, IL	Trip distribution	Eight (8) Time periods*	Two (2) Time Periods: AM Peak and Midday periods	Only the AM peak and Midday period link flows are used in the earlier steps	Composite logsums of travel times, distance, and out-of-pocket costs	Multimodal-highway and transit	Link Flow	MSA	Not applicable	Not applicable	Always run four (4) iterations
Denver Regional Council of Governments (DRCOGS)	Denver, CO	Trip distribution	Two (2) Time Periods: AM Peak (6:30–9:00am), Off peak (9:00am–3:00pm)	Single 24-hour time period	Simple average of the output of the two time periods is used in earlier steps	Travel Time	Unimodal Trip based Multi-modal Activity-based model	Link Speed	Constant Weight	% Mean Absolute Error (PMAE)	Link Speed	No more than 1% of links can change speed by more than 10%
Southern California Association of Governments (SCAG)	Los Angeles, CA	Trip generation	Four (4) Time periods: AM Peak (6am–9am), PM Peak (3pm–7pm), Midday (9am–3pm), Night (9pm–6am)	Two (2) Time periods: AM Peak and Midday periods	Only the AM peak and midday time period outputs are used	Travel time	Multimodal	Link Speed	MSA	Not applicable	Not applicable	Always run four (4) iterations
METRO	Portland, OR	Trip distribution	Two (2) Time Periods: Peak versus Off Peak	Two (2) Time Periods: Peak versus Off Peak	No need	Travel time	Multimodal	Travel time	MSA	Mean Absolute Error (MAE)	Travel time weighted by peak SOV demand	MAE ≤ 0.03

*AM Peak (7am– 9am), two AM Peak shoulder periods (6am–7am and 9am–10am), PM Peak (4pm–6pm), two PM peak shoulder periods (2pm–4pm and 6pm–8pm), midday (10am–2 pm), and PM off-peak (8pm–6am).

Table 1. Review of Feedback Loop Implementation in the TDMs of Different MPOs (Continued).

MPO	Region	Data fed back to	Time-of-day Considerations			What Parameter fed back	Unimodal or Multimodal	Basis attribute for feedback	Updating Procedure	Convergence Considerations		
			Time period used in assignment	Time periods used in earlier steps	Reconciliation procedure					Measure used	Attribute used	Threshold rule
Atlanta Regional Commission (ARC)	Atlanta, GA	Trip generation	Four (4) time periods: morning peak (6am–10am), midday period (10am–3pm), evening peak (3pm–7pm), evening/night period (7pm–6am)	One (1) time period, Morning peak period	Only the morning peak period output is used in the earlier steps	Travel time	Multimodal	Link Flow	MSA	% Root mean square error (PRMSE)	Link flow	PRMSE ≤ 3.5%
Boston Region Metropolitan Planning Organization	Boston, MA	Trip distribution	Unavailable	Unavailable	Unavailable	Composite impedance measures	Multimodal	Travel time	Direct feedback method	% Mean Absolute Error (PMAE)	Travel time	PMAE ≤ 2%
Capital Area Metropolitan Planning Organization (CAMPO)	Austin, TX	Trip distribution	Two (2)-hour AM peak period; 24-Hour Congested Time	Two (2)-hour AM peak period; 24-Hour Congested Time	No need	Travel time	Multimodal	Link flow	MSA	PRMSE	Link flow	PRMSE ≤ 0.015%, or maximum of 12 iterations
San Antonio Bexar County Metropolitan Planning Organization (SA-BC MPO)	San Antonio, TX	Modal Split	Unavailable	Unavailable	Unavailable	Travel time	Unavailable	Link speed	Direct feedback method	Unavailable	Unavailable	Unavailable

Table 1. Review of Feedback Loop Implementation in the TDMs of Different MPOs (Continued).

MPO	Region	Data fed back to	Time-of-day Considerations			What Parameter fed back	Unimodal or Multimodal	Basis attribute for feedback	Updating Procedure	Convergence Considerations		
			Time period used in assignment	Time periods used in earlier steps	Reconciliation procedure					Measure used	Attribute used	Threshold rule
North Central Texas Council of Governments (NCTCOG)	Dallas, TX	Trip distribution	Two (2) time periods: AM Peak (6:30am–8:59am), Off-Peak (9am–2:59pm & 6:30pm–6:29am)	Two (2) time periods; AM Peak and Off-peak	No need	Travel time	Multimodal	Link flow	Constant Weight	Root mean square error (RMSE)	Link travel time	RMSE ≤ 1%
										Maximum absolute error (MAE)	Link travel time	MAE ≤ 10%
										RMSE	Link volume	RMSE ≤ 2%
Houston-Galveston Area Council (H-GAC)	Houston, TX	Not applicable	Unavailable	Unavailable	Unavailable	Developing Feedback Loop	Unavailable	Not applicable	Testing MSA	Looking for suitable criteria for trip tables	Not applicable	Not applicable
Genesee County Metropolitan Planning Organization (GCMPC)	Genesee County, MI	Trip distribution	Four (4) time periods: AM Peak (6am–9am), Midday (9am–3pm), PM Peak (3pm–6pm), Night (6pm–6am)	Single 24-hour time period	Weighted average of the output of four time periods is used in the feedback process	Travel time	Multimodal	Link flow	MSA	Unavailable	Unavailable	Maximum iteration equals 10 or stop criteria met
Baltimore Metropolitan Council, MD	Baltimore, MD	Trip distribution	Two (2) time periods: Peak (6:30am–9:30am; 3:30pm–6:30pm), Off-peak (9:30am–3:30pm; 6:30pm–6:30am)	One (1) Time period; Peak Period	Peak Period travel times are used in the feedback	Travel time	Multimodal	Link speed	Direct feedback method	% Mean Absolute Error (PMAE)	Link speed	Reasonably low
Santa Barbara County Association of Governments (SBCAG)	Santa Barbara, CA	Trip distribution	Unavailable	Unavailable	Unavailable	Travel time	Unavailable	Unavailable	Unavailable	Unavailable	Unavailable	Unavailable
Regional Transportation Commission of Southern Nevada (RTC)	Las Vegas, NV	Trip distribution	Seven (7) time periods*	Single 24-hour time period	Unavailable	Travel time	Multimodal	Link flow	MSA	Unavailable	Unavailable	Unavailable

* 12 am–7am, 7am–9am, 9am–2pm, 2pm–4pm, 4pm–6pm, 6pm–8pm, and 8pm–12am.

Of the 14 MPOs, 11 use link travel times from the assignment step as the travel impedance variable that is fed back. This is consistent with the fact that travel time is the only impedance variable considered in the trip distribution step of most MPO's TDMs. However, the Chicago MPO uses a composite 'logsum' feedback measure of travel times and costs as input to their trip distribution model, and the Boston MPO uses a composite impedance (based on a parallel conductance formula) measure of travel times and travel costs as input to their trip distribution model. The Houston MPO is currently developing a feedback approach for their TDM and is evaluating different options.

Among the MPOs, a multimodal feedback approach that uses updated travel impedances by highway (auto) and transit modes is quite popular relative to the unimodal feedback option that considers travel impedance by only the highway (auto) mode. Specifically, nine of the 11 MPOs for which the information could be collected use a multimodal approach. Denver is the only region which uses the unimodal approach, where only the highway (auto) travel times are used to update the input to the trip distribution step. However, in the activity-based travel demand model currently under development in Denver, a multimodal 'logsum' measure is being considered for the feedback process.

Of the observed MPOs, link flow is the most common basis attribute (used to construct the travel impedance measure that is fed back). That is, the link flows are first updated at the end of the traffic assignment step during each feedback loop iteration and translated to link travel times based on a volume delay function (typically the BPR formula). Next, link travel times are translated to TAZ-to-TAZ travel times and subsequently fed back. In particular, six of the 11 MPOs for which information could be obtained adopt this approach. However, other basis attributes such as link travel time and link speed are also used in practice. For example, while the Denver Region COG, SCAG, Baltimore Metropolitan Council, and the San Antonio Bexar County MPO use link speed as the basis attribute, METRO in Portland uses travel time as the basis attribute.

With respect to the updating procedure, there is clear diversity across MPOs, though the method of successive averages (MSA) is more prevalent than others. Specifically, seven of the 12 MPOs for which we have information on the updating procedure use the MSA approach. Two of the MPOs use the constant weight approach (Denver Region COG and the North Central Texas Council of Governments), and the remaining three appear to use the direct or naïve method (Boston MPO, San Antonio and Bexar County MPO and Baltimore Metropolitan Council). The relative popularity of the MSA updating approach may be attributed to the perception that it is a good smoothing procedure that also provides good convergence properties relative to other feedback methods. For instance, for the Capital Area MPO travel demand model system in Austin, Texas, both the MSA and constant weight methods were examined, and the MSA method was found to provide a more stable solution than the constant weight method (Avner, 2009). However, Boyce et al. (2007) have found that the constant updating procedure with a weight of 0.75 on the most recent iteration outperformed the MSA method. This analysis was undertaken with the travel demand model system of the Capital District Transportation Committee (CDTC), which is the MPO for the New York State counties of Albany, Rensselaer, Saratoga, and Schenectady.

Finally, in terms of convergence issues, some MPOs (for example, the Chicago Metropolitan Planning Agency and SCAG) set their stopping criterion for feedback looping to be a pre-determined fixed value of number of iterations. This may not always be desirable because the number of iterations needed for convergence depends on the various dimensions characterizing the feedback approach. The Boston MPO, the Denver Regional Council of Governments (DRCOG), and the Baltimore Metropolitan Council (BMC) TDMs use the percentage mean absolute error measure to determine convergence between successive values of travel impedances, travel times, or travel speeds.

On the other hand, the ARC and the Capital Area Metropolitan Planning Organization (CAMPO) TDMs use the percentage Root Mean Square Error (PRMSE) measure to determine convergence between successive trip table matrices. In the Portland Metro travel demand model, a mean absolute error (MAE) convergence measure is computed using travel time normalized by peak period single-occupancy vehicle (SOV) demand. The North Central Texas Council of Governments (NCTCOG) staff in the Dallas-Fort Worth area uses a combination of measures and attributes to define convergence (Paschai et al., 2010). In particular, they use the RMSE measure using link travel time and link flows, as well as a maximum absolute error measure for link travel time, as joint convergence criteria.

CHAPTER SUMMARY

This chapter identified the key dimensions that characterize the feedback process in travel demand modeling systems and briefly discussed different options available within each of these dimensions, including research studies examining one or more of these dimensions (most of the research studies focus on updating methods in the feedback process). In addition, the feedback procedures used at several MPOs in the country were then reviewed.

In general, past research and practice underscores the importance of incorporating feedback loops in the travel demand process, especially in regions with moderate to high levels of traffic congestion during certain times of the day. In the context of the TxDOT TDM modeling process, this suggests study of alternative feedback processes to examine the impact on the accuracy and robustness of traffic forecasts. Since the current TxDOT TDM model does not include any impedance or accessibility measures in the trip generation step, one possibility, as suggested by the synthesis of research and practice, is to feed back the output from the traffic assignment step to the trip distribution step.

The following chapter provides a more detailed examination of the TxDOT modeling process and discusses potential issues to consider in implementing feedback as part of the TxDOT TDM process.

CHAPTER 2. POTENTIAL ISSUES WITH IMPLEMENTING FEEDBACK AS PART OF THE TXDOT TDM PROCESS

OVERVIEW OF TXDOT SOFTWARE

TxDOT has been involved in model-related activities since the early 1960s beginning with the advent of the 1962 Surface Transportation Act. At one time, TxDOT was the lead model developer for all 25 urban areas in the state with a population greater than 50,000. Currently, the Transportation Planning and Programming Division of TxDOT is responsible for model development for 23 of the 25 study areas in the state. The North Central Texas Council of Governments (NCTCOG) is responsible for model activities in the Dallas-Fort Worth metroplex, while the Houston-Galveston Area Council of Governments (H-GAC) is responsible for the eight-county Houston region.

Throughout the intervening decades, TxDOT has been unique in the fact that, as an agency, it has readily supported research that has directly influenced model approaches and software development. This continuing support and research initially led to the development of the Texas Package Suite of Travel Demand Models, which is commonly referred to by TxDOT staff as the, 'Texas Package.' Notably, it was adopted for operational use prior to any of the federal packages being available and since then has been maintained independently of any commercially available software. Moreover, TxDOT continues to maintain the Texas Package for operational use though the suite has been partially integrated with the TransCAD® software, a commercially available software platform developed and distributed by the Caliper Corporation.

Currently, the trip generation and trip distribution steps are performed using software available in the Texas Package. TxDOT uses the TransCAD software to apply the traffic assignment step in the sequential three-step models that are prevalent in the state. The geo-spatial capabilities inherent with the TransCAD software have partially encouraged TxDOT's decision to migrate away from the mainframe platform to the microcomputer platform in the late 1990s. Because of this, all network development activities are performed using the TransCAD software.

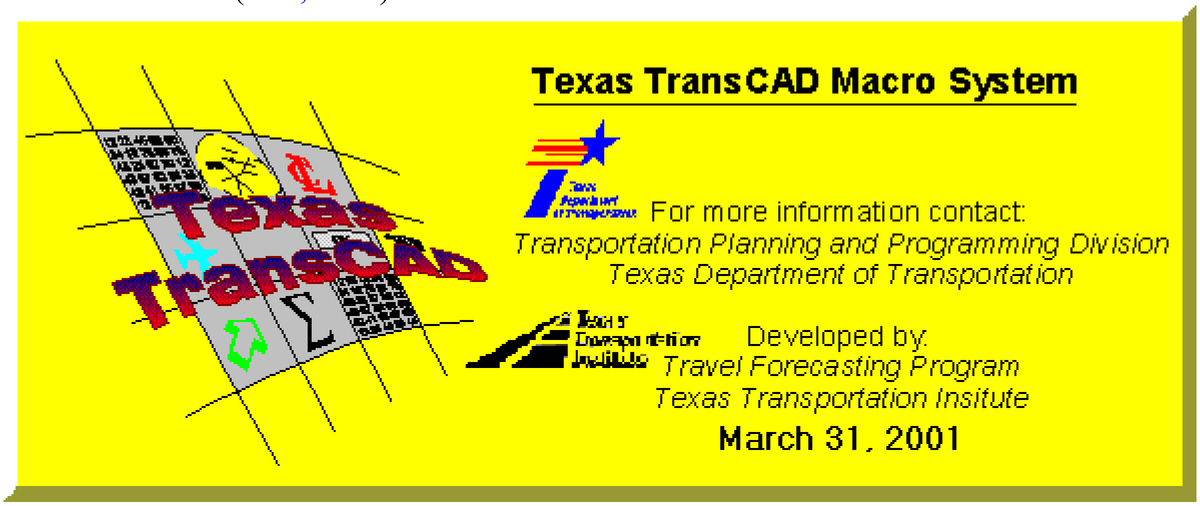
In addition to partially integrating the sequential model development and application process in the TransCAD platform, TxDOT also embarked on standardizing the approach for model development in the state. This includes specifications for file naming standards, file storage, and file distribution. As such, the Texas Package refers to the software as well as the approach and practice that TxDOT used.

For most Texas study areas, a sequential three-step model is developed involving trip generation, trip distribution, and traffic assignment. Local planning agencies rarely need or request the mode choice step. H-GAC has developed a mezzo-level mode choice model, which Beaumont has operationally used and, more recently, so did the El Paso models. The mezzo-level model uses mode shares developed by sector to account for transit trips.

The trip generation model is called TripCAL5 (Pearson et al., 1990 and 1995). With relatively few exceptions, vehicle trips are directly generated instead of person trips by trip purpose. The recently completed El Paso model generates and distributes person trips prior to applying the mezzo-level mode choice model which converts the person trip tables to vehicle trips prior to assignment. Austin and San Antonio use person trips for applying robust mode choice models. For these two study areas, TxDOT coordinates trip generation and trip distribution activities, while the MPOs (through third party consulting contracts) are responsible for the mode choice and traffic assignment steps.

The trip distribution model is ATOM2 (Benson and Hall, 1999; Bell and Benson, 1991). ATOM2 is a spatially disaggregate trip distribution model that considers zone size within the gravity analogy. Traffic assignment is performed using the user equilibrium procedure available in the TransCAD software. Except for Austin and San Antonio, which have peak period time segment considerations for transit in addition to the daily vehicle models, all of the study areas in the state under the purview of TxDOT-TPP are 24-hour daily models. Congestion is expressed as 24-hour volume-to-capacity ratios. Key to the interpretation of these results is the philosophy associated with the development of the daily capacities, which will be discussed in greater detail later in this document.

When TxDOT migrated from the mainframe platform to the microcomputer platform in the late 1990s, TxDOT successfully instituted the integration of the Texas Package Suite of Programs in the TransCAD software. Figure 3 shows the Texas Package is invoked in TransCAD through the use of an add-on menu item (Hall, 2007).



Texas TransCAD Macro System

For more information contact:
Transportation Planning and Programming Division
Texas Department of Transportation

Developed by:
Travel Forecasting Program
Texas Transportation Insitute
March 31, 2001

Figure 3. Texas TransCAD Macro System.

The use of the TransCAD software is limited to the following basic activities:

- Network and TAZ definition and specification.
- Zone-to-zone minimum travel time (expressed in minutes) calculation for trip distribution.
- External thru trip matrix creation (growth factor model).
- Production-attraction to origin-destination matrices.
- Traffic assignment.

All other model development and applications procedures are maintained in the Texas Package Suite of Programs. Figure 4 on the following page provides a detailed flow chart of the typical TxDOT travel demand model application steps. The flow chart highlights the basic Texas Package applications. It does not contain additional capabilities that are invoked during the model development process.

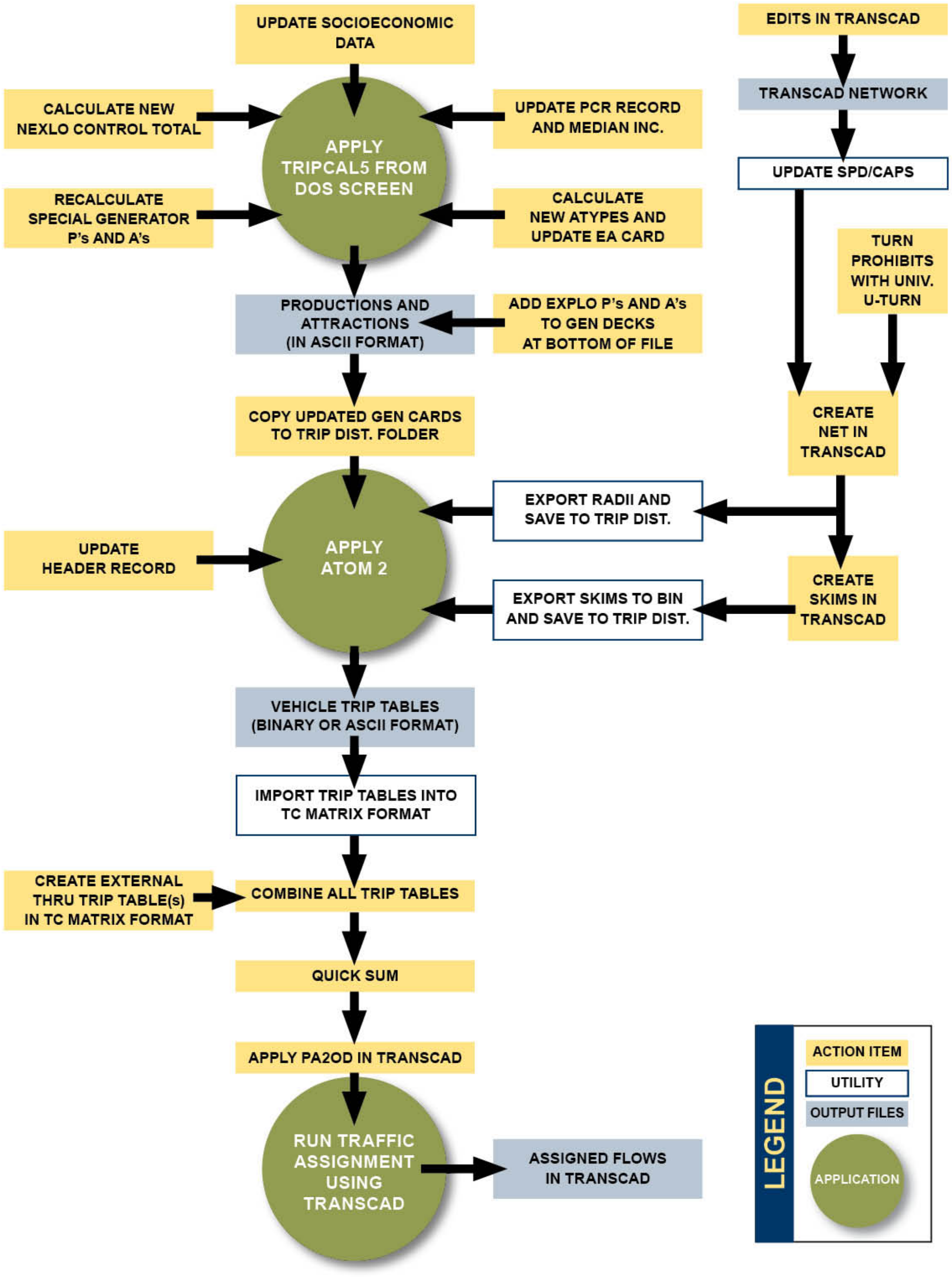


Figure 4. Texas Package Application Flow Chart.

Since the Texas Package is a sequential three-step model (except for Austin, El Paso, and San Antonio), the model application has been maintained independently of commercially available software for the most part. As such, the Texas Package was generally integrated by limiting the role of the GISDK programming language to that of an interface tool. Moreover, the use of vendor provided programming language (e.g., GISDK) has been limited for the following reasons:

- The initial lack of familiarity with the language.
- The evolving nature of the language.
- The desire to maintain flexibility when considering competing software vendors (e.g., portability).

In addition, as new versions of the TransCAD software are made available or a release of an existing version has been updated (i.e., build), TxDOT-TPP has to verify if the existing programs that have been integrated in the TransCAD software using GISDK continue to operate and produce the same results. Since TxDOT maintains and deploys a TransCAD license for each MPO and TxDOT District Planning Office in the state, software updates can be a logistical and functionality issue. Currently, TxDOT-TPP uses Version 4.5 for operational use. Since TransCAD only has limited involvement in the process, the specific version has not been an issue to date since trip generation and trip distribution are maintained independently.

This, however, could become an issue if an iterative feedback mechanism is implemented using the GISDK language in a newer version of the software. The Texas Package has never been automated; instead, each step in the process is sequentially invoked. TxDOT maintains this approach, primarily for training purposes. Since implementing an iterative feedback procedure virtually requires some level of automation, TxDOT-TPP will need to be explicit about the level of automation that should occur if a feedback mechanism is incorporated in the model approach that TxDOT-TPP employed.

The remaining portion of this chapter will concentrate on providing an overview of the Texas Package while identifying specific issues that may need to be addressed by implementing an iterative feedback procedure. At the end of each chapter section (i.e., trip generation, network specification, etc.), an interim conclusion section is included that provides a general summary of considerations and concerns associated with each step of the model development process in the context of implementing a feedback mechanism.

TRIP GENERATION (TRIPCAL5)

As noted earlier, the TripCAL5® software is used to develop the zonal trip generation estimates for each study area. Although TripCAL5 has multiple capabilities, TxDOT typically uses two-way cross-classification production and attraction models (i.e., production rates per household and expected average attractions per employee or household). The standard independent variables for the cross-classification production models are household size and income. There are a few exceptions (e.g., a third variable [employees in the household] is used for the home-based work productions in the San Antonio models), but these represent a divergence from predominant practice that are limited to two study areas (Austin and San Antonio).

The trip attraction models are stratified by area type and households or employment type. These rates are applied at the zonal level to produce unscaled attractions for each of the individual internal trip purposes. The unscaled attractions are scaled to match the production control total by trip purpose (minus trips that are independently estimated for special generators in the region). TripCAL5 software automatically performs this process, which is one of the key reports that TxDOT-TPP staff review to initially determine if there are potential issues with the population-to-employment ratio in the region or with the survey attraction rates.

With the continued use of the Texas Workforce Commission (TWC) employment data, TxDOT provides employment data to each MPO for the following four employment categories used in the state:

- Basic employment.
- Retail employment.
- Service employment.
- Education.

There are typically four to five area types in most of the study areas in Texas (i.e., Central Business District (CBD), Urban, Suburban, and Rural) with some variations due to local conditions (e.g., larger study areas with additional stratifications). The area-type classification scheme is based on the demographic density levels used to differentiate between the different area type definitions. Density is generally defined in terms of population and employment per acre.

Each MPO is required to provide for all urban area TAZs the total population, households, median household income, and employment for each of the four employment categories noted above. Because the data is aggregate zonal data, the application of the trip generation models requires the estimation of a regional matrix of households by household size and income. The distribution of zonal households by size and income is estimated by the TripCAL5 software based on the regional distribution, which is treated as a regional constraint. The individual zonal estimates are derived through an iterative process in the TripCAL5 software.

TripCAL5 can handle up to 10 internal trip purposes. The typical trip purposes used in Texas are:

- Home-base work (HBW).
- Home-based non-work (HBNW).
- Non-home based (NHB).
- Truck-taxi (TRTX).
- Non-home based non-resident (NEXLO).

Depending on whether there has been an updated travel survey that captures trips related to education employment, TxDOT staff may or may not define education as a trip purpose separate from the HBNW trip purpose.

TxDOT also models up to four external related trip purposes (depending on whether updated external station survey data is available):

- External-local auto (EXLO-A).
- External-local truck (EXLO-T).

- External-thru auto (THRU-A).
- External-thru truck (THRU-T).

The proportion of through and local external trips is determined using available external travel survey data. The external travel surveys are collected at the county line (this typically corresponds to the model area boundary). The external-local production for auto and truck-related trips are input directly into the TripCAL5 control file. The internal attractions for EXLO-A trips are scaled to the internal zonal NHB attractions. The internal attractions for the EXLO-T trips are scaled to the internal zonal TRTX attractions. A seed matrix from the external travel survey for the THRU trip purposes is used to FRATAR (a matrix growth factor methodology) the desired productions at each external station to derive the two THRU matrices.

After applying the TripCAL5 software, a minimum of two trip generation data files containing the productions and attractions by zone for each trip purpose is created. The trips are reported as integer trips. Typically, internal trip purposes are reported in one file record and a second, separate file is created for the two external-local trip purposes. A separate output report is created that provides numerous summary statistics. The generation records are key inputs to the ATOMISTIC trip distribution model.

General Trip Generation Conclusions and Recommendations

Currently, measures of accessibility and/or time are not key variables in determining zonal trip generation estimates. Consequently, the Texas Package does not have an approach to address the influence of travel time on home or business location decision making within the trip generation models. This may require long-term consideration, but for the immediate future, recycling congested times back to the trip generation step is simply not feasible.

With respect to trip generation and feedback approaches, one consideration would be to generate trips in specific time periods. For example, the HBW trip purpose could be generated for peak and off-peak time periods. The data is available in the travel surveys, but is not currently processed or published in this manner. A number of technical considerations would have to be addressed before embarking on generating trips for specific time periods, such as:

- What defines the peak period (e.g., 7am–8am or 7:15am–8:30am)?
- What defines a peak period trip?
    - Is it a trip that occurs during the specified period?
    - What about trips that have a start time that begins before the time period and ends during the peak period?
    - What about trips that begin during the peak period, but end after the peak period?

Additionally, the orientation of the trip will also have to be processed to capture trip interchanges in both the dominant and non-dominant direction. However, processing travel surveys into time segments is not the current practice for most study areas since TxDOT-TPP produces daily models. Thus, TxDOT-TPP will have to commit additional resources.

NETWORK SPECIFICATION

The network description is one of the two main databases that the local MPOs and TxDOT District Planning Offices are responsible for providing to TxDOT-TPP as a part of the model development process. Demographics by zone is the other database. MPOs and District Planning Offices are responsible for inventorying and identifying which links are to be included in the roadway network and are also responsible for updating attribute data for a limited number of the attributes in the standard network database. Using the information provided by the local study areas, TxDOT-TPP will finalize the network geographies using the TransCAD software (i.e., physical edits) and will update appropriate information on existing link attributes (i.e., changes to facility type and number of lanes).

Table 2 presents the standard network attribute data included in the travel demand model networks that TxDOT-TPP developed. This portion of the chapter will concentrate on those network variables with the greatest influence in terms of the iterative feedback process. Of the network attributes identified in Table 2, speed, capacities, Alpha/Beta, counts, and link travel time are the most relevant attributes associated with the iterative feedback process. These are discussed below.

Table 2. Network Link Data Fields and Descriptions.

Field Name	Description
ID	Unique link ID number created by TransCAD
Length	Calculated by TransCAD
Dir	0 = two-way; 1 or -1 = one-way
POSTED SPEED	Posted speed on the link
SPEED	Estimated daily speed
SPEED_U	Unique speed for a link
FUNCL	Functional classification.
FTYPE	Facility type
ATYPE	Area type
LANES	Total number of lanes
AB_CAPACITY	Link capacity in the AB direction
AB_CAPACITY_U	Unique AB directional capacity
BA_CAPACITY	Link capacity in the BA direction
BA_CAPACITY_U	Unique BA directional capacity
TOT_CAP	Total estimated 24 hour capacity
RAWCOUNT	Axles divided by two (urban saturation counts)
AXLE_FACTOR	Vehicle mix factor
COUNT_FLAG	0 = Observed count; 1 = estimate
FACTORED_COUNT	RAW_COUNT*AXLE_FACTOR
TOT_VOL	Total assigned non-directional volume (Tot_flow)
V/C_RATIO	Total Volume/Total Factored Count (Base Year)
TIME	Average 24-hour link travel time
ALPHA	BPR function value
BETA	BPR function value
TAZ	Associated zone of the link (relevant to area type definition)
CUTLINE	Number of cutline/screenline bisecting link
EDITS_YEAR	Year link edit is associated with
COUNTY	County name
ANNOTATION	MTP project number (Air Quality purposes)
DESCRIPTION	Facility type description (e.g., UPA, DPA, EXPY)
STREETNAME	Name of street
COMMENTS	Description of edit made (e.g., added two lanes)

Speed

There are three speed variables in the networks produced by TxDOT-TPP: POSTED_SPEED, SPEED, and SPEED_U. The MPO and local TxDOT District Planning Office are explicitly required to provide the posted speed limit of a link, while TxDOT-TPP is responsible for developing estimated 24-hour link speeds and annotating unique speeds by link (if necessary or appropriate). The speeds in the TxDOT-TPP networks are 24-hour speeds that are sometimes referred to as daily speeds (TxDOT will also refer to these as ‘congested-weighted’ speeds). TxDOT-TPP staff calibrates the 24-hour speeds to develop the following initial inputs to the sequential model process:

- Estimates of average trip length and trip length frequency distributions by trip purpose.
- Estimates of the average travel time for centroid connectors to develop RADII files that are input into the trip distribution models (surrogate for zone size).
- Estimates of highway zone-to-zone travel times (SKIMS) for input into the trip distribution models.
- Link impedances used in the iterative capacity restraint assignment models (i.e., user equilibrium).

Prior to the late 1990s, TxDOT developed the speed estimates by area type and functional classification for each urban area in the state (with relatively little documentation regarding the source or the process). After the successful migration to the microcomputer platform, TxDOT implemented a speed model for operational use that uses posted speeds as one of the primary inputs to estimate 24-hour speeds by facility type and area type. Since TxDOT is involved in developing 24-hour models for fairly uncongested study areas, the relative differences in 24-hour speeds by facility type and area type needed to reflect the relative differences in general operating characteristics, conditions, and, in general, the desirability of different facility types as a route choice. Having large relative differences in estimated 24-hour speeds by facility type and by area type (even within each individual facility-type segmentation) produces assignment results that do not reflect the multi-path solution set that most travelers in a regional network encounter on a daily basis.

To overcome this issue, a generalized cost scheme has been integrated into the daily speed estimation process. The following variables to implement cost considerations include:

- Typical value of time.
- Typical auto operating cost (marginal cost–gas prices).
- Regional median household income.
- Wage rate.

Key variables that are obtained from the networks include:

- Posted speed by facility type and area type.
- Average link distance by facility type and area type (surrogate for signal spacing on signalized roads).
- Average system speed.

Several other variables are also factored into the equations used to derive the daily speeds, namely:

- Typical directional splits (percent of traffic in peak direction).
- Estimated speed.
- Estimated congestion-delay-mile.
- Estimated volume-to-capacity (V/C) ratio.
- Estimated free flow time.
- Proportion of daily traffic in peak and off-peak directions.

These variables are estimated (treated as 'typical' in most instances) for both the dominant and non dominant movement for four separate time periods. These stratifications are eventually adjusted to derive daily speeds by facility type and area type.

Table 3 provides the final speed results by facility type for a recently completed base year model. In most instances, the input speed and the resulting assigned speed resolve fairly closely. The only instances where the resulting speed differs by any degree of significance with the input speeds are with facility types that have a higher volume-to-capacity ratio. The influence of delay on altering the input speeds simply is not present in most of the facility types listed below. The results presented below are probably typical of most small- to medium-sized models in the state.

Table 3. Example Speed Results (Bryan-College Station).

Facility Type	Counted VMT	User Weighted V/C Ratio	User Weighted Assign Speed	User Weighted Input Speed
Radial Other Freeway (Main lanes)	623,979	0.634	48.3	50.4
Circumferential Expressways	38,867	0.596	46.7	47.6
Principal Arterial–Divided	99,310	0.954	32.7	39.3
Principal Arterial–with CLT*	105,431	0.825	32.5	35.9
Principal Arterial–Undivided	11,037	0.933	41.9	47.4
Minor Arterial–Divided	20,707	0.696	34.9	37.7
Minor Arterial–with CLT	82,892	0.627	30.6	32.2
Minor Arterial–Undivided	69,391	0.542	33.3	34.9
Collector–Divided	28,516	0.557	25.2	25.8
Collector–with CLT	19,223	0.826	28.7	32.3
Collector–Undivided	117,941	0.557	32.0	34.4
Frontage Road	29,600	0.311	38.8	39.2
Ramp	38,118	0.370	30.5	30.7
Total Study Area	1,285,013	0.652	38.9	41.5

**CLT – continuous left turn lane.*

As noted earlier, TxDOT-TPP staff, in rare instances, will annotate unique speeds for individual links when necessary. These are found in the SPEED_U attribute field in the network database and have been developed to address a specific loading or traffic condition that cannot be properly accounted for within a speed look-up table by facility type and area type. These are used sparingly; typically to improve base year comparisons between counts and assigned volumes. All speeds by facility type and area type are updated using the APPLY SPEED/CAP LOOKUP TABLE utility available in the TxDOT add-on menu item in TransCAD. The utility explicitly identifies links with unique speeds and will annotate these speeds in lieu of the calibrated speed by facility type and area type.

Capacities

The capacities coded into the TxDOT highway network are 24-hour non-directional capacities. These are sometimes referred to as daily non-directional capacities. As is the case with speeds, a capacity look-up table is estimated by facility type and area type to specify the 24-hour capacities that will be coded on network links. There are 22 potentially available facility type definitions available in the standard facility type and functional classification table used in TxDOT-TPP practice. Capacities are developed for each of the facility type stratifications. Unique facility types are sometimes used to address specific network issues.

The 24-hour capacities used by TxDOT are developed using estimates of typical peak hour capacities per hour per lane. The typical peak hour capacity values represent level-of-service (LOS) E conditions and are expanded to represent 24-hour capacities for planning purposes. The following formula defines the relationship between the 24-hour capacity to the peak capacity.

$$C_{24} = \frac{[(C_{phpd} + C_{phnpd})/L]}{K}$$

Where:

C_{24} = 24-hour non-directional capacity per lane.

C_{phpd} = Capacity in the peak direction during the peak hour.

C_{phnpd} = Capacity in the non-peak direction during the peak hour.

L = Total number of non-directional lanes.

K = Portion of the 24-hour non-directional volume that typically occurs in the peak hour.

The peak hour capacity in the non-peak direction is estimated using the typical directional split for a given facility type within a defined area type:

$$C_{phnpd} = \frac{C_{phpd}(1 - D)}{D}$$

Where

D = percent of peak hour traffic in the peak direction.

Other variables are used to estimate the typical peak-hour capacities in the peak and off-peak directions. Analysts at TxDOT-TPP can adjust these input variables based on specific local area operating characteristics (e.g., percent trucks).

Once calculated, the 24-hour capacities are annotated to the network in the AB_CAPACITY and BA_CAPACITY fields. The total non-directional 24-hour capacity is located in the TOT_CAP field in the network data view. The directional capacities are simply the total capacity divided by two. The only exceptions are one-way links (e.g., frontage roads, freeway main lanes, and ramps). The TransCAD software uses the directional capacities during the traffic assignment procedure.

In some instances, TxDOT-TPP may apply a unique directional capacity to overcome a specific local condition (e.g., bridge crossing or for a road that exceeds the operational capacity of the facility) and/or traffic loading problem. Unique capacities are found in the AB_CAPACITY_U and BA_CAPACITY_U network attribute fields. The value in the unique directional capacity fields will take precedent when the APPLY SPEED/CAP LOOK-UP TABLE utility is applied. The impact or logic of these unique capacities may not be evident until the forecast application occurs. Localized growth in demographics in close approximation to the link will often create convergence problems in the capacity restraint procedure. This specific issue may bear more relevance in an iterative feedback process.

The relative congestion on the link as a result of applying traffic assignment is expressed as volume-to-capacity (V/C). The V/C ratio is a critical variable in the volume-delay equation. This value, along with other variables in the volume-delay expression, determines the degree of magnitude that the travel time on the link is adjusted due to the congestion level on the link during the iterative assignment procedure. Therefore, the process for deriving capacities is extremely important in the context of feedback when applying the input speeds that are produced by traffic assignment.

Alpha and Beta

Two additional parameters that are coded into the regional networks are the Alpha and Beta variables associated with the BPR volume-delay equation. TxDOT annotates these variables into the network databases because the TransCAD software allows the user to overwrite the default values for Alpha and Beta (0.15 and 4.0, respectively). The general form of the BPR delay function is as follows:

$$I_{(n+1)} = I_{(1)} * [1.0 + \alpha(\frac{v}{c})^{\beta}]$$

Where:

$I_{(n+1)}$ = adjusted impedance.

$I_{(1)}$ = beginning impedance.

1.0 = constant.

V = 24-hour assigned volume.

C = 24-hour estimated capacity.

α = Alpha (0.15).

β = Beta (4.0).

The default values for Alpha and Beta are the values that TxDOT-TPP most often used. It is also typical practice to use a single volume-delay function for all facility types. There are some examples where an alternative volume-delay function has been developed for specific facility types, but this is the exception and not the norm at TxDOT-TPP.

As noted earlier, TxDOT-TPP typically assigns a LOS E capacity (traffic operations measure where LOS E represents operations at capacity as opposed to free-flow conditions) as a part of the standardized process associated with the preparation of network link attributes. As modeled volumes approach available capacity, diversion of traffic occurs based on the corresponding delay on the link (as measured by the volume-to-capacity ratio). However, the use of LOS E capacities in uncongested small or medium-size study areas can contribute to poor traffic assignment results (in the context of count comparisons). The capacity restraint assignment procedure will not replicate traffic diversion through alternative path building because congestion does not exist at the level that would produce consideration for alternative paths. The TransCAD software permits the specification of alternative Alpha and Beta parameters for individual links, by functional classification and/or area type. Almost any permutation can be applied during the assignment process.

As such, the Alpha parameter can be modified to accommodate different levels-of-service as well as different perceived levels of congestion. TxDOT-TPP has taken advantage of this capability in limited instances to simulate different levels-of-service. Based on the standard capacity logic that TxDOT-TPP deployed, the following Alpha values can be annotated in the network link attributes to simulate alternative levels-of-service (see Table 4).

Table 4. Alternative Alpha Parameters for the BPR Function.

Simulated LOS Capacity	Alpha Parameter	Beta Parameter
B	1.639	4.00
C	0.474	4.00
D	0.229	4.00
E	0.15	4.00

The use of alternative Alpha values is considered an approach of last resort when calibrating base year travel models. TxDOT-TPP typically uses the default values presented in the user equilibrium assignment procedure in the TransCAD software. A more thorough discussion of the volume-delay formulation in the context of iterative feedback mechanism occurs in the traffic assignment portion of this chapter.

Travel Time

Travel time is given consideration because the travel times that are used in the travel models represent the typical daily travel time needed to traverse the link from beginning to end node. The link travel times are used to develop the minimum zone-to-zone travel time or SKIMS for input into trip distribution, and also serve as the initial times in the iterative capacity restraint assignment process. Travel times on centroid connectors (a subset of the network links) are also used to create RADII records (estimated travel time radius from a zone's geographic center or centroid) for input into the ATOMISTIC trip distribution models. These travel times also serve as the foundation for calibrating BIAS factors, which either encourage or discourage sector to sector interchanges by trip purpose. Travel times are also a key variable for determining the average trip length and trip length frequency distribution by trip purpose. Minimum travel time SKIMS, used along with survey expanded trip tables, are the two input variables to the GET2 utility that TxDOT staff use to derive the initial average trip length and frequency distribution by trip purpose.

The travel times are derived using the daily speeds that are calibrated for each individual network by facility type and area type. The travel times are updated as a part of the APPLY SPEED/CAP LOOKUP TABLE utility available in the TxDOT add-on menu item in TransCAD. For links with unique speeds, analysts at TxDOT-TPP manually update these links as a part of the update speed/capacity process. Alternative speeds representing non-daily time periods are not coded into the networks developed by TxDOT.

Many of the travel time modeling considerations that TxDOT-TPP should address in an iterative feedback environment are reviewed in the trip distribution portion of this chapter.

Traffic Counts

Currently, TxDOT-TPP annotates the roadway network with 24-hour counts that represent typical Monday through Thursday non-summer travel. The short-term traffic counts are performed on a 24 hour basis in either the spring or fall when schools are in session. The 24-hour counts are collected using accumulative count recorders (ACRs) or pneumatic tubes and then TxDOT-TPP staff annotate these to the network. The 24-hour counts simply represent axles divided by two and are eventually adjusted by applying an axle-factor by facility type and area type to account for vehicle mix. Until recently, only 24-hour counts were available to support travel model validation efforts; consequently, TxDOT has traditionally modeled typical 24-hour traffic conditions for planning purposes.

Beginning in the late 2000s, TxDOT began recording the 24-hour counts in 15-minute increments. Although this data is collected, TxDOT-TPP does not have the staffing available to verify and check each of the 15 minute increments. Therefore, TxDOT-TPP does not make this data available because it is highly likely that the final 24-hour count will not resolve with the 15-minute counts once these are accumulated to the 24-hour period. TxDOT-TPP has recently made these time period counts available to H-GAC and the NCTCOG at their request. CAMPO, which represents Austin, will apparently be receiving peak period data in the near future. It is unclear if TxDOT-TPP will release time period counts for any of the remaining urban areas in the state. Modeling daily traffic limits TxDOT-TPP's capability to represent and assess urban mobility issues in a number of ways and is specifically relevant to the discussion of feedback loops.

On the following pages, hourly traffic for several study areas is depicted using the 2009 automatic traffic recorders (ATR stations) and automatic vehicle classification (AVC) data (Figure 5 through Figure 14). The information is non-directional and is presented as annual average hourly volumes. Only locations that are inside existing urban model area boundaries (MAB) are presented, and not every urban area is represented.

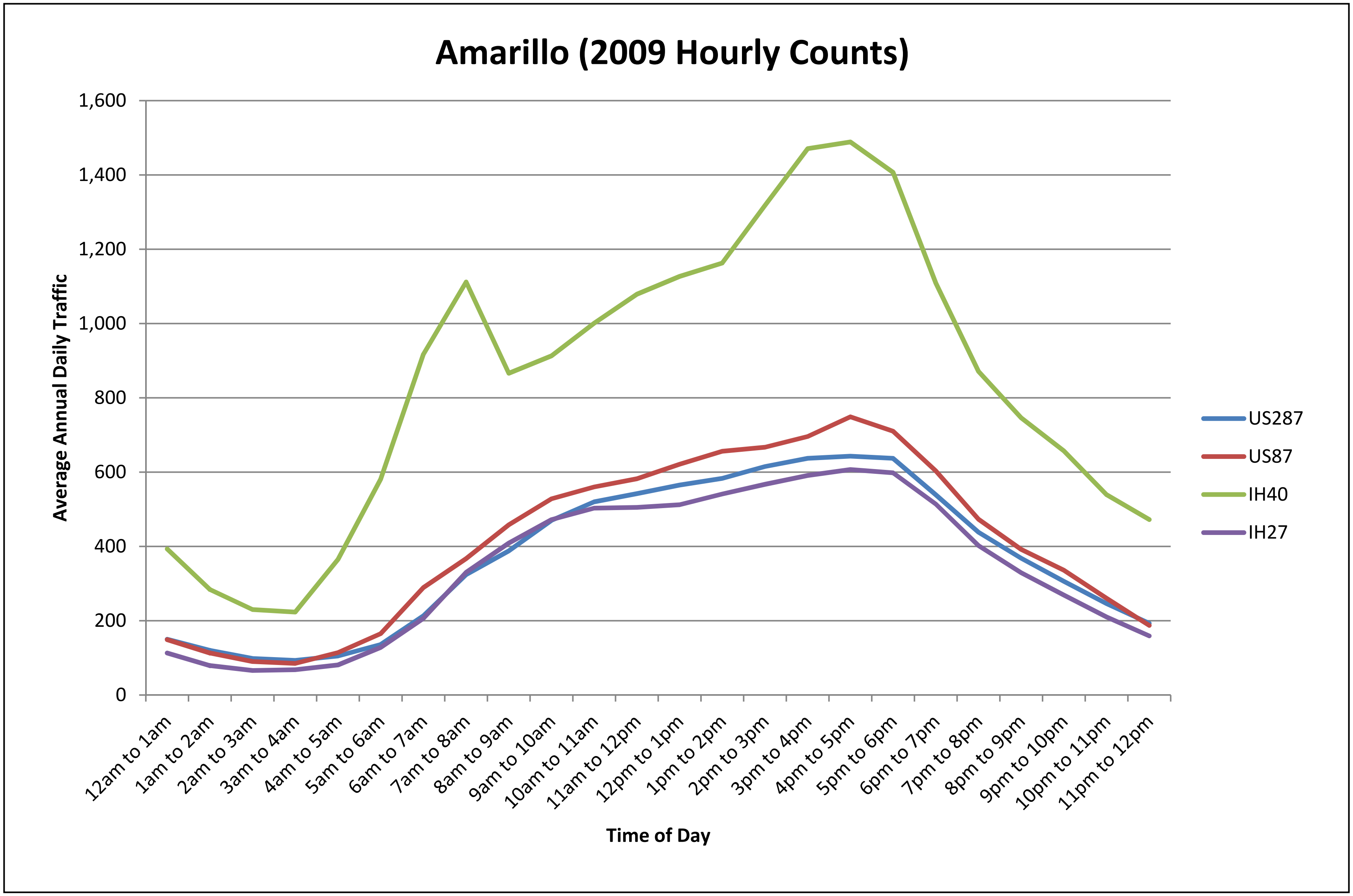


Figure 5. 2009 Hourly Counts (Amarillo).

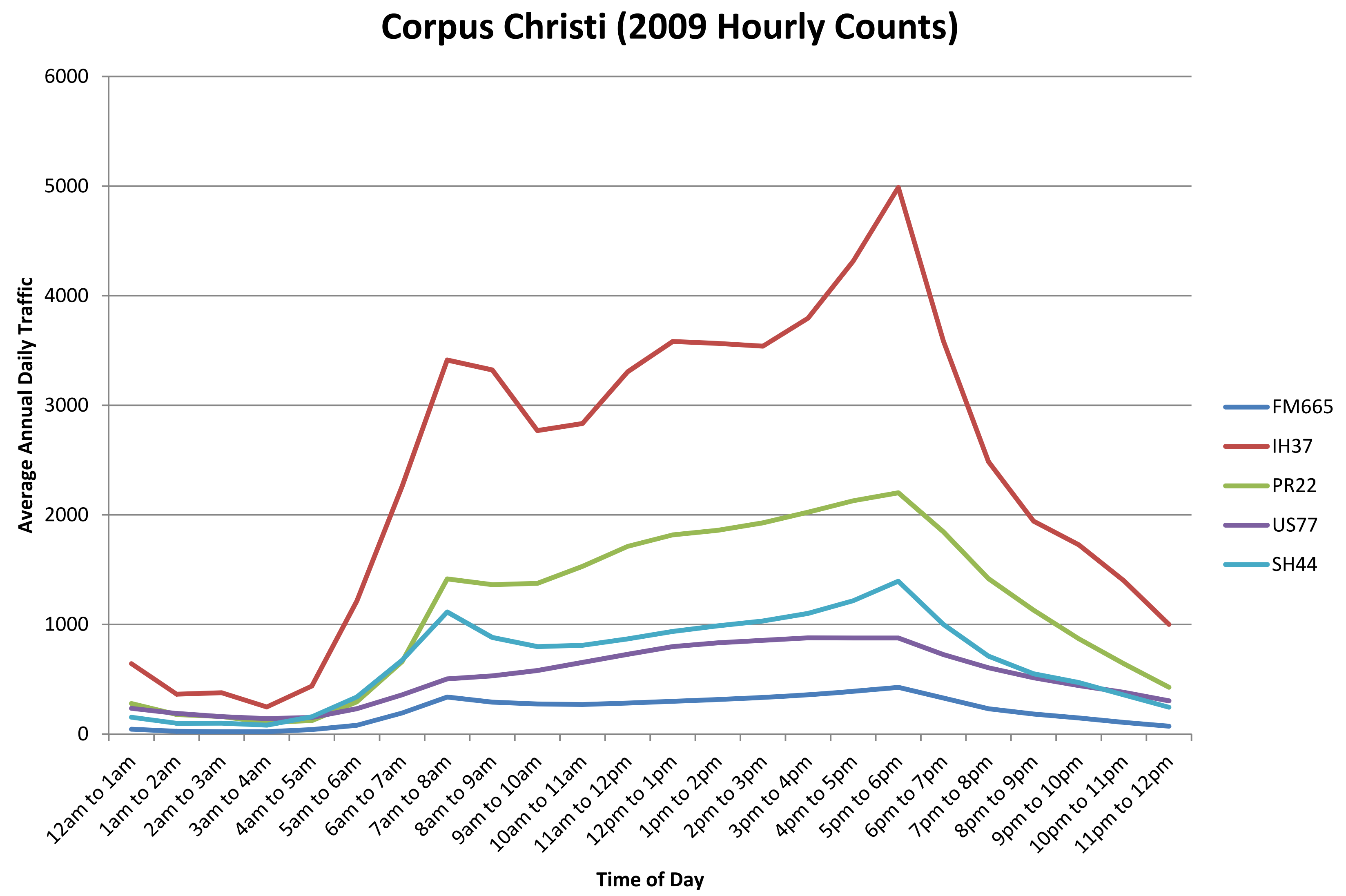


Figure 6. 2009 Hourly Counts (Corpus Christi).

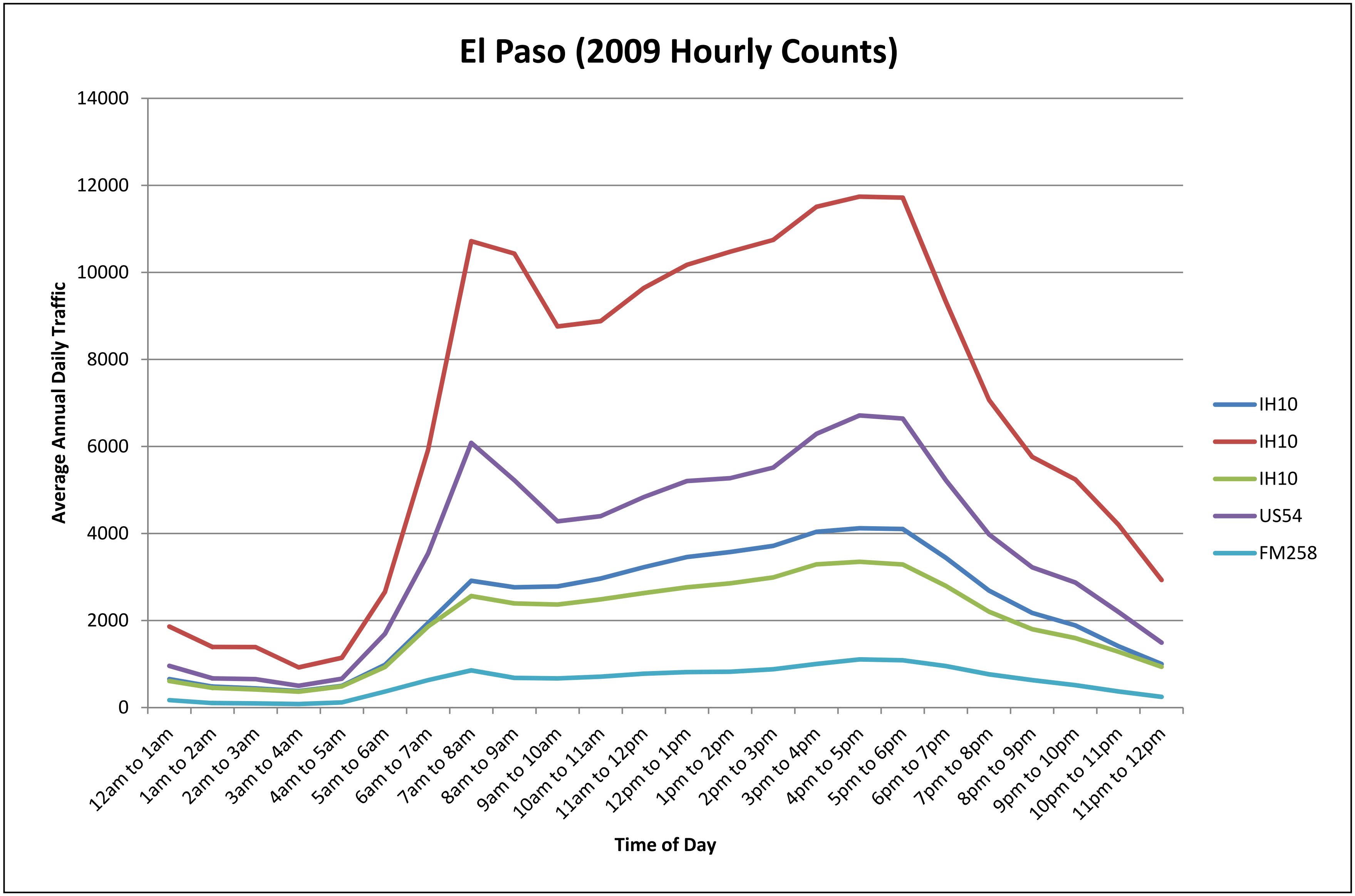


Figure 7. 2009 Hourly Counts (El Paso).

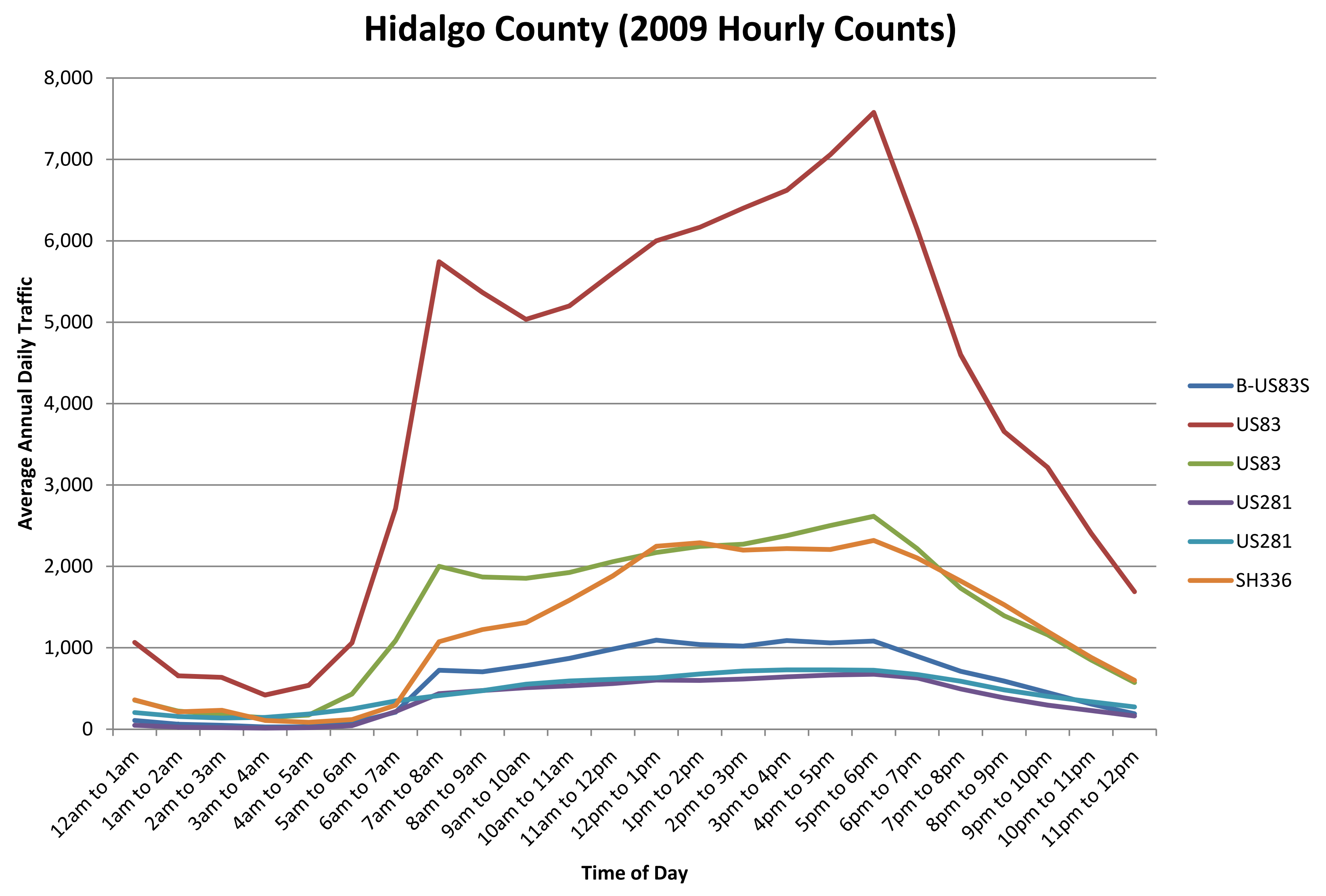


Figure 8. 2009 Hourly Counts (Hidalgo County).

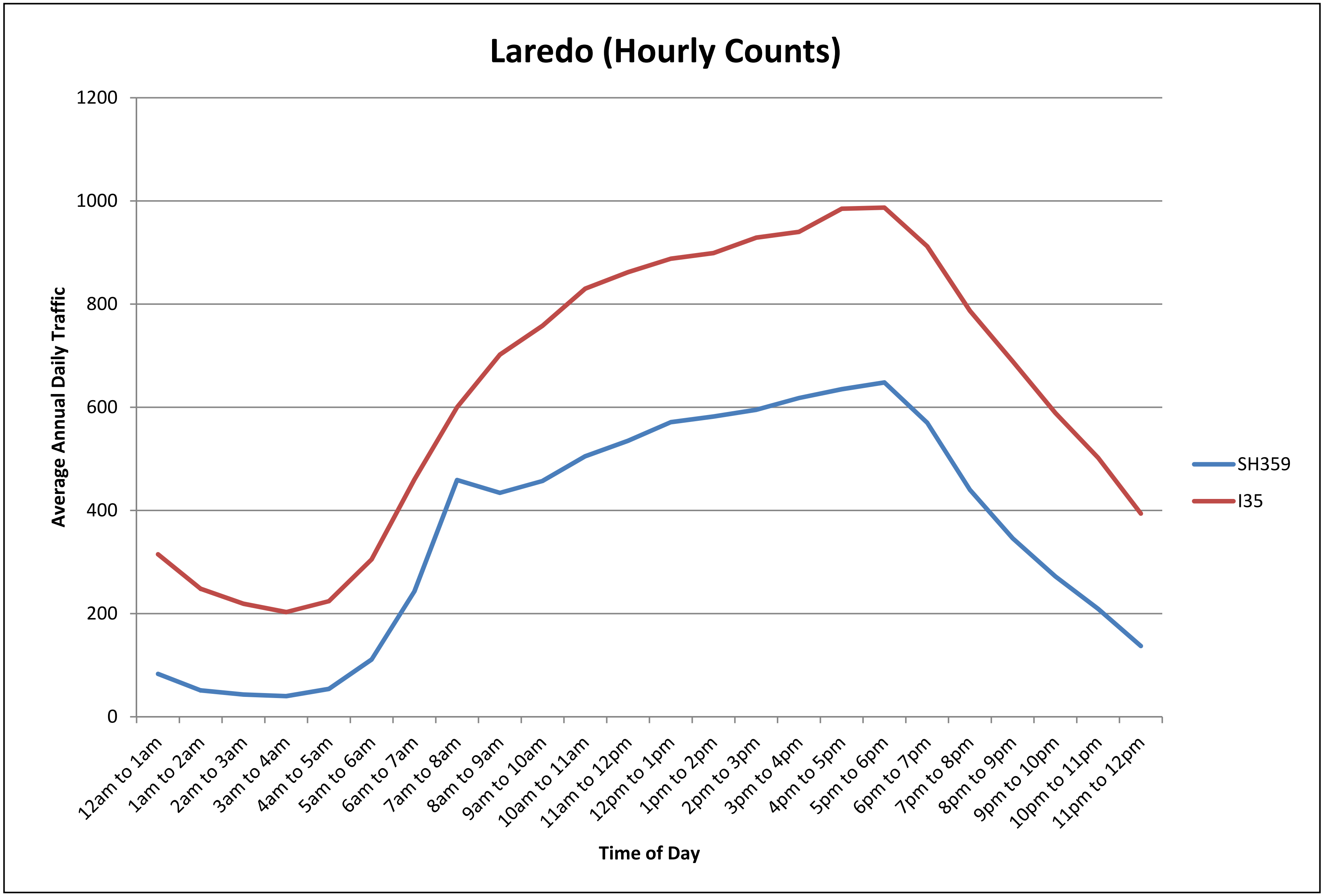


Figure 9. 2009 Hourly Counts (Laredo).

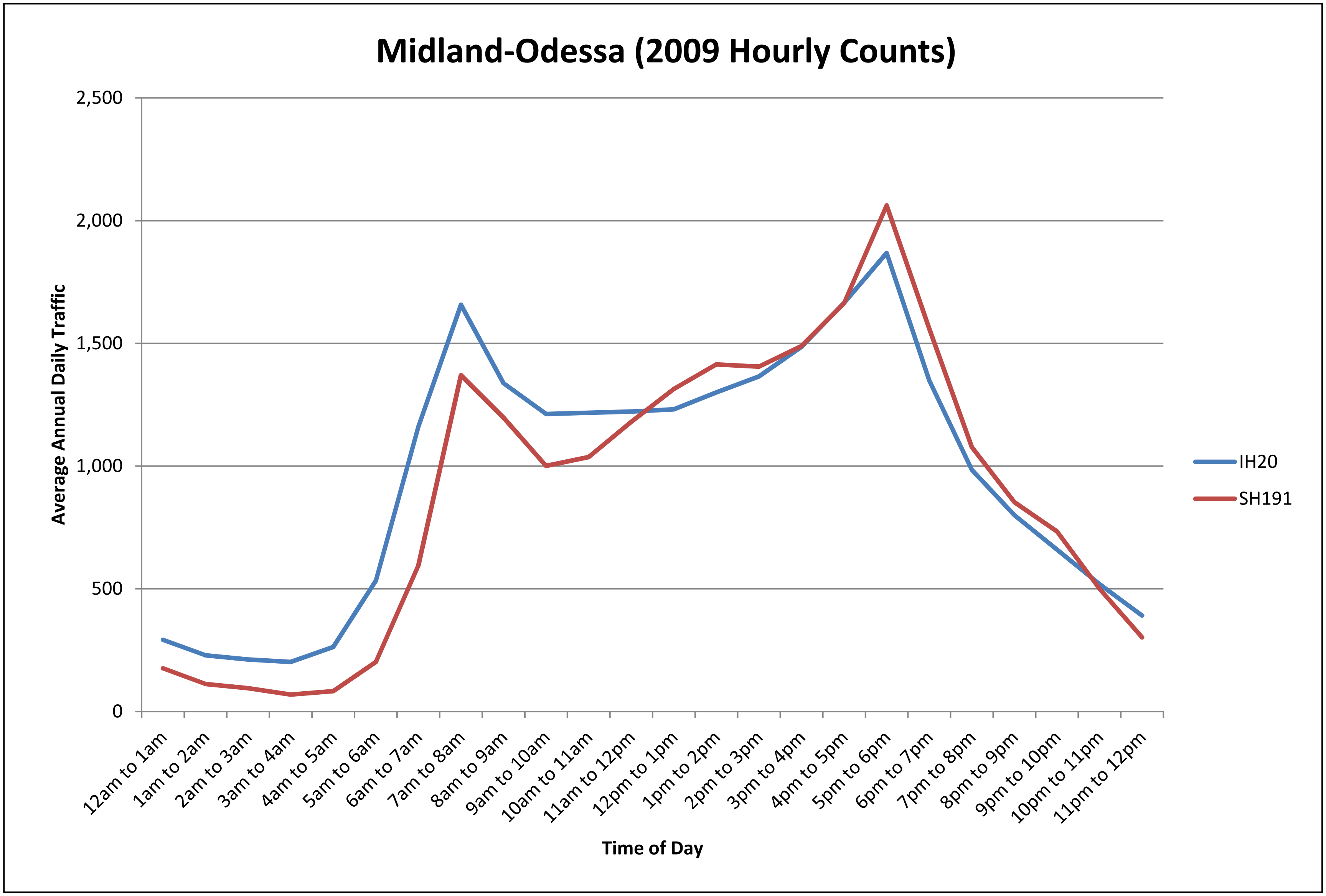


Figure 10. 2009 Hourly Counts (Midland-Odessa).

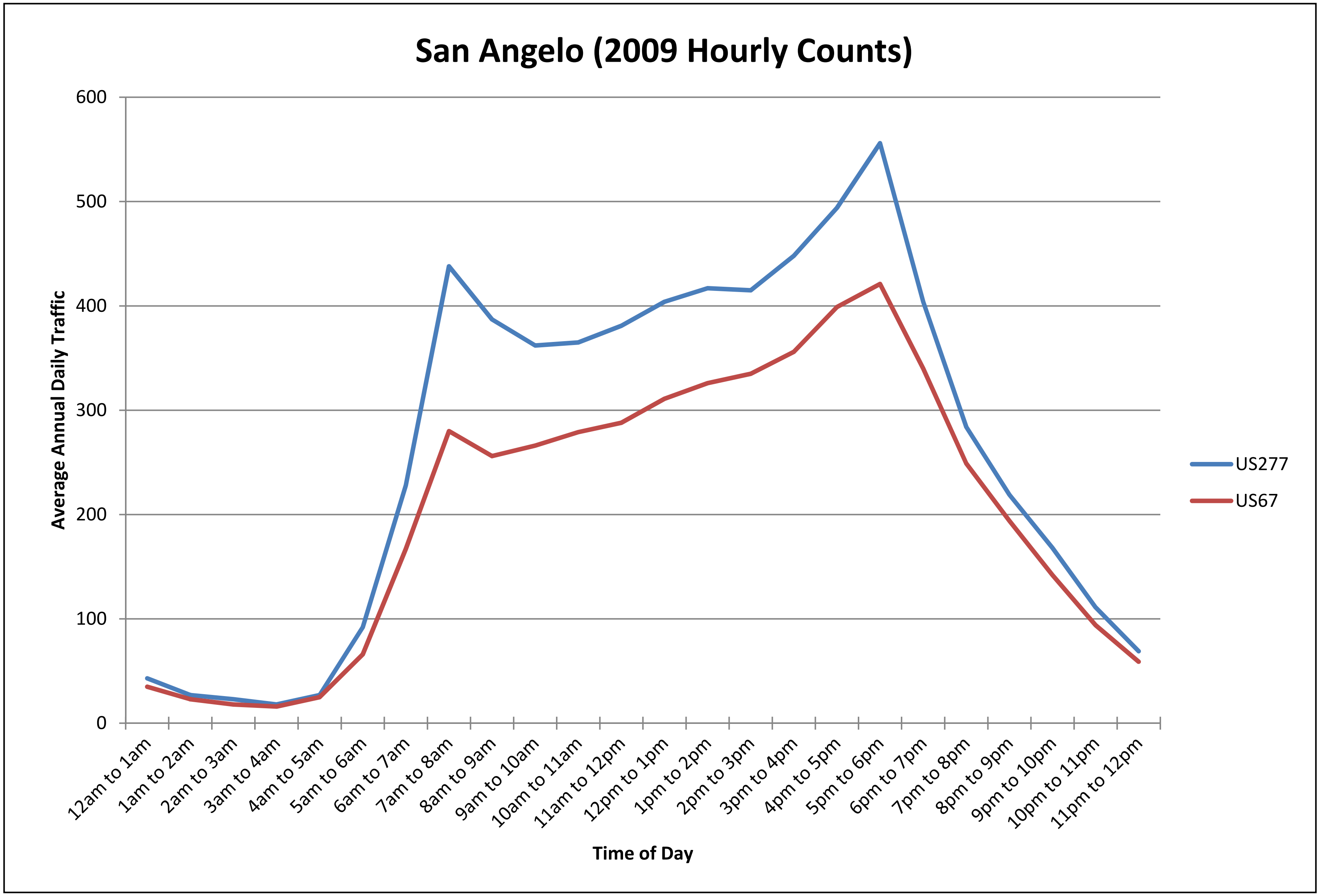


Figure 11. 2009 Hourly Counts (San Angelo).

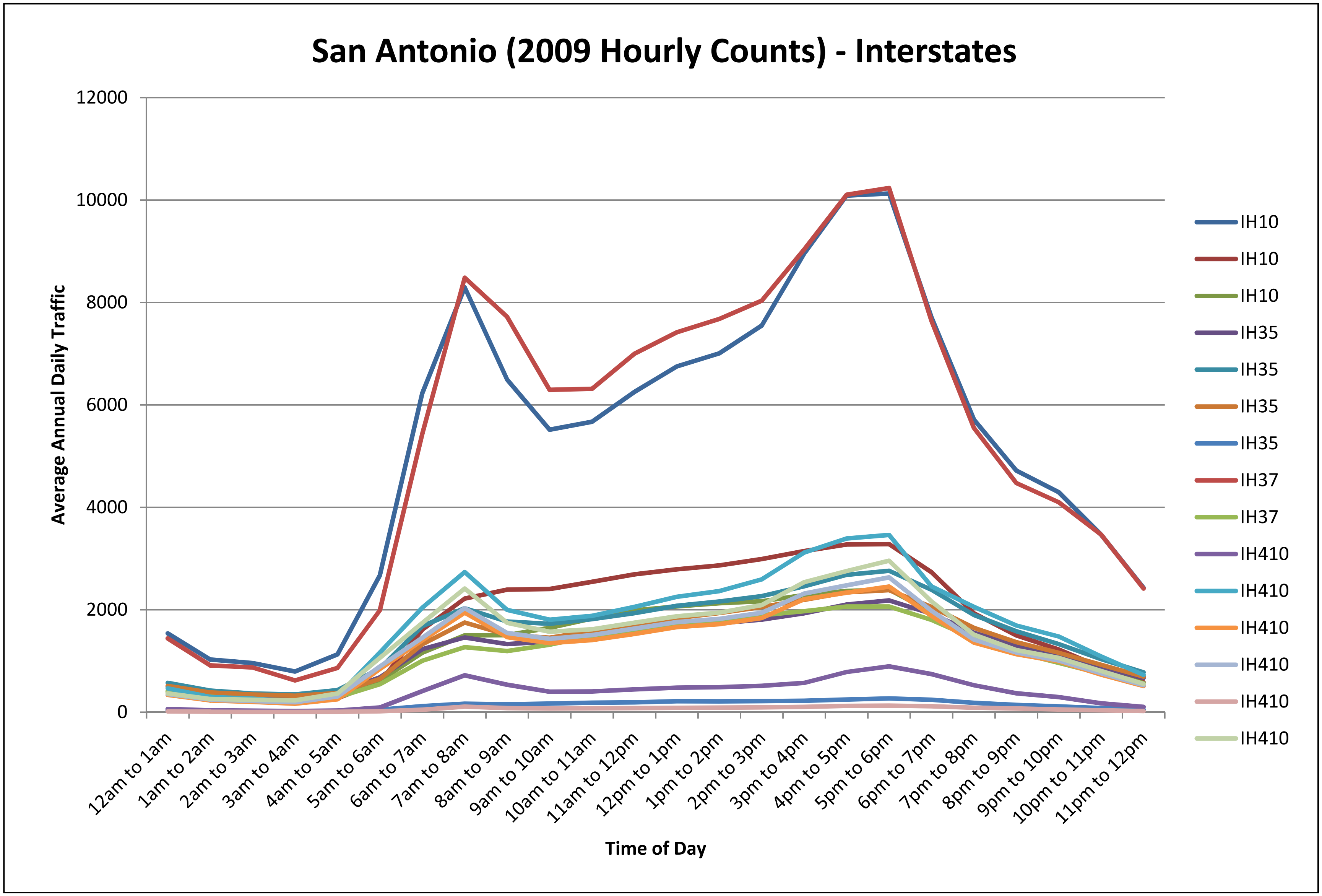


Figure 12. 2009 Hourly Counts (San Antonio)–Interstates Only.

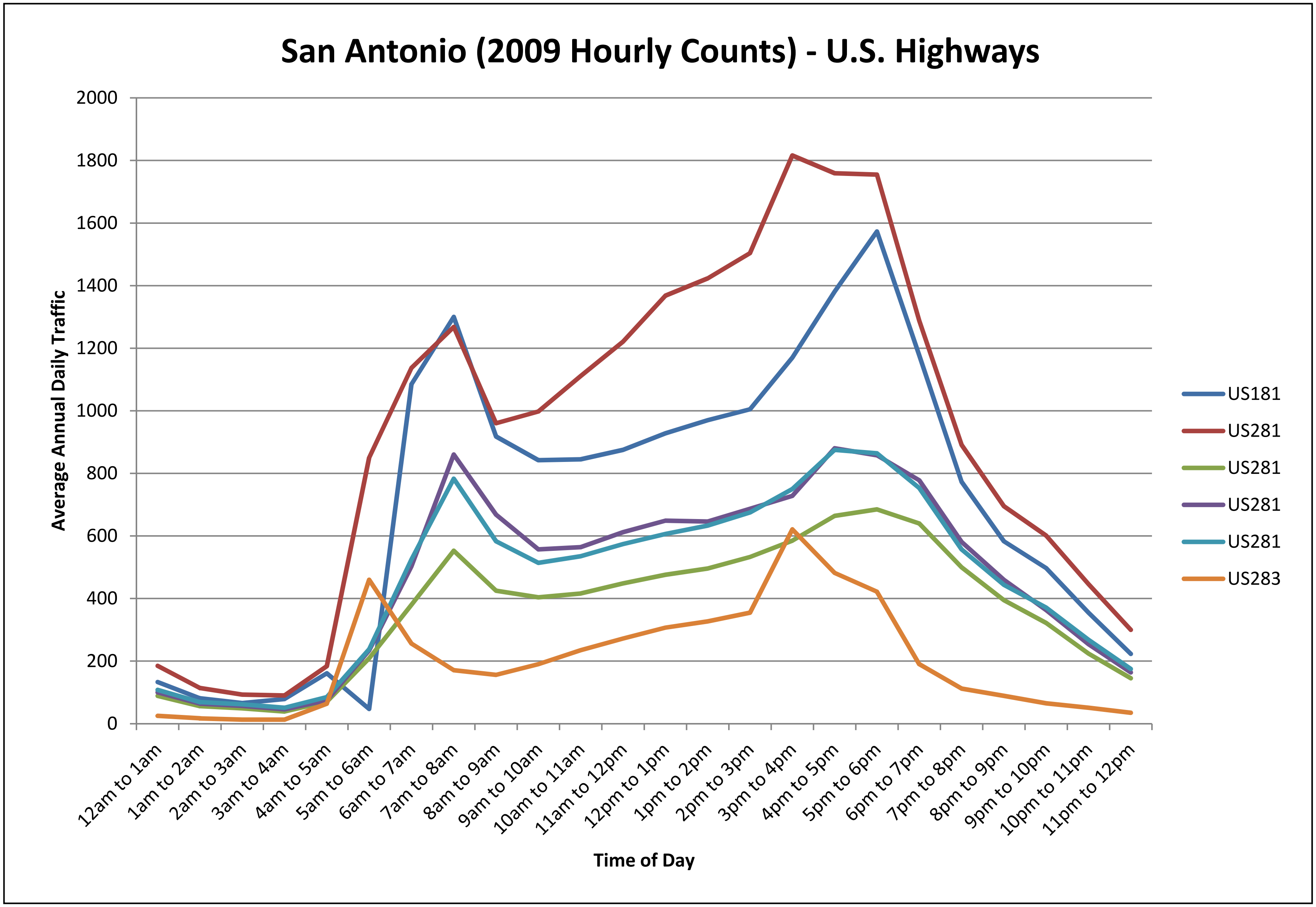


Figure 13. 2009 Hourly Counts (San Antonio)–U.S. Highways Only.

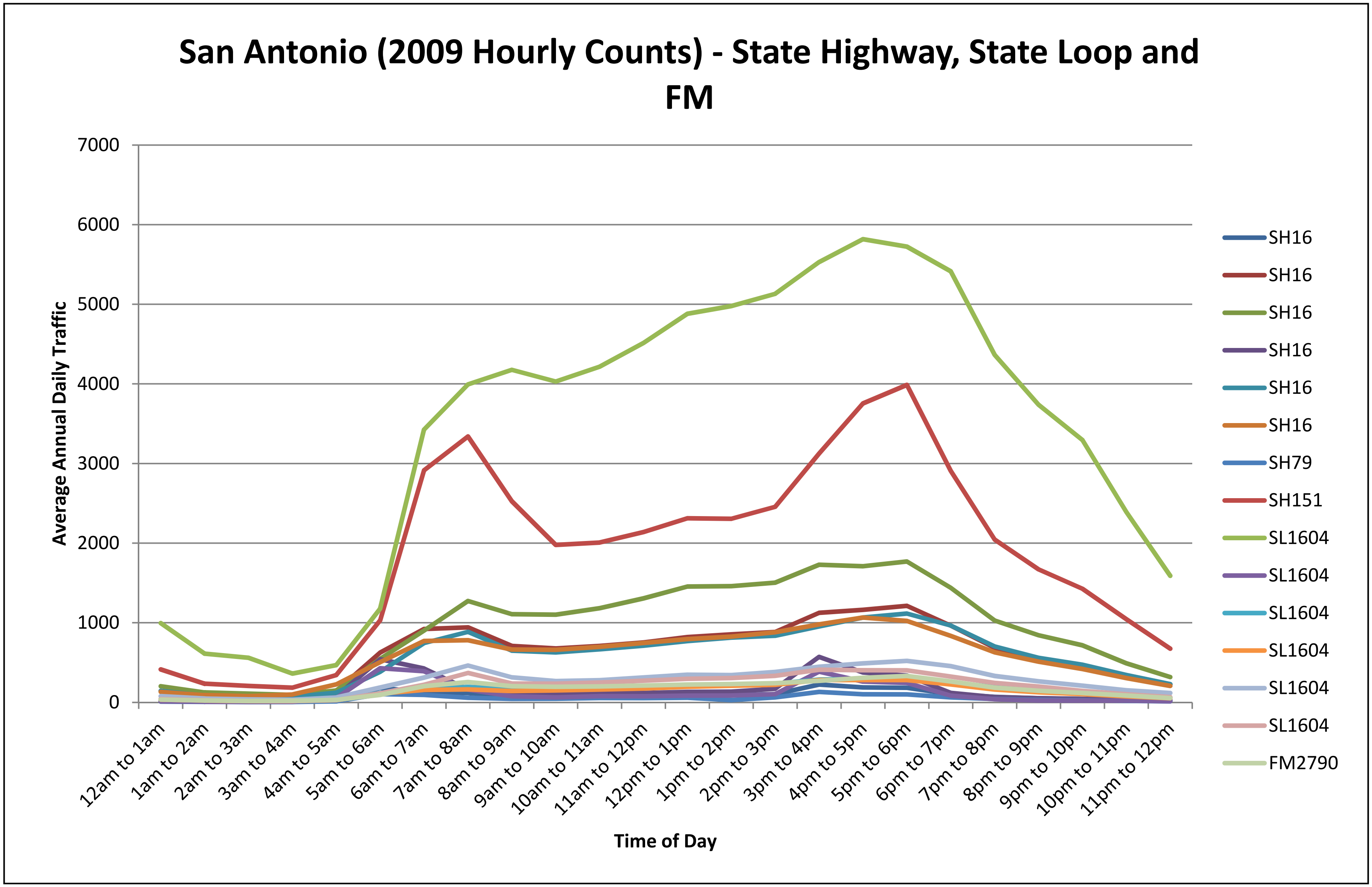


Figure 14. 2009 Hourly Counts (San Antonio)–State Highways, State Loop Roads, and Farm-to-Market.

Irrespective of directionality, the figures on the preceding pages reveal the following issues associated with potentially adopting a feedback mechanism for all study areas under the purview of TxDOT:

- There is minimal time-of-day traffic data currently available. Although TxDOT began collecting annual data in 15-minute increments, these are currently unavailable. Therefore, the only time segmented count data that TxDOT published is the annual ATR and AVC data.
- The magnitude of the traffic is very small for most of the study areas presented (*y*-axis). This is also true during typical peak periods of travel (i.e., AM and PM).
- For some of the study areas (particularly along the border), the noon peak period has equally or more traffic than the AM peak travel period.
- The PM peak period is more pronounced for all study areas.
- Only the larger study areas are exhibiting strong congestion in the peaks (e.g., El Paso, Hidalgo, and San Antonio).

General Network Conclusions and Considerations

Given that most of the study areas in the state represent relatively uncongested small to medium sized urban areas, 24-hour models have traditionally satisfied long-range planning requirements in the state. However, in instances where HOV or managed lanes are being considered (or other capital intensive strategies), there is a need for finer temporal segments beyond the daily period because 24-hour models are incapable of providing the necessary time sensitive information to analyze and forecast traffic associated with these types of facilities. Migrating to different time periods to conduct traffic modeling typically requires measurable data with which to judge the models' performance during these time periods. Currently, TPP does not publish counts beyond the 24-hour period. Automatic Traffic Records data are published as hourly data, but these sites are too few to be of any significant use.

Furthermore, TxDOT does not have a comprehensive speed-flow data collection program that could be used as the basis for developing updated volume-delay relationships. New volume delay equations could be developed for different trip purposes if TxDOT-TPP chose to model different time periods for some trip purposes (e.g., peak period home-based work trips) or if composite impedances were used. Likewise, the use of multi-class assignments might also require the application of new volume-delay functions. If this is impractical, TxDOT-TPP may want to consider implementing the generalized cost approach to traffic assignment. This could, in theory, be used as the mechanism to dampen the competing attractiveness of higher class facilities (that have higher posted and, presumably, higher free-flow speeds) and potentially address the lingering issue of accounting for toll facilities in the regional networks.

TRIP DISTRIBUTION (ATOM2)

The second step in the sequential modeling process at TxDOT, trip distribution is performed using the ATOM2 software, which accounts for zone size in the gravity analogy. There are several key input variables that are defined in individual control files by trip purpose. Many of these variables rely on the estimated 24-hour travel times found in the travel model networks. Here are the required ATOM2 inputs:

- A separation matrix of network travel times.
- Zonal radii values for each zone (surrogate for zone size).
- Productions and attractions by zone for each of the trip purposes.
- Sector equals record, which is a table-of-equals between zones and sectors.
- Trip length frequency distribution (TLFD) by minutes of separation.
- Calibrated friction factors for each trip purpose.
- Bias factors (i.e., K-factors in traditional gravity models).

The separation matrix (commonly referred to as travel time SKIMS) is the first input record that the ATOM2 software reads. Using the TransCAD software, the matrix is created by skimming the minimum path from one zone to every other zone using the estimated 24-hour network travel times. The travel times are based on estimated 24-hour, or daily, speeds developed by facility type and area type using a generalized cost speed model. Once the TransCAD matrix is created, the matrix is exported to TRANPLAN binary format. The TRANPLAN binary format was preserved to conserve file sizes. During the late 1990s, file size still deserved considerable attention, but this is becoming more irrelevant as computer storage capabilities continue to increase.

The travel times are rounded to integer hundredths of a minute (i.e., a travel time that the TransCAD software initially calculated as 14.283 minutes is exported as 1428—with an implied decimal) by the EXPORT MATRIX utility available in the TxDOT add-on menu item in TransCAD. The ATOM2 software reads these integer hundredths and translates these to whole numbers. Consequently, a travel time of 3.49 is converted to 3 minutes, while a travel time of 3.51 is converted to 4 minutes of separation. This was originally a compromise constructed for indexing the trip length frequency distributions, which are reported in 1-minute time intervals rather than fractions of minute intervals. Additionally, the ATOM2 software will reset any separation value that is either rounded to 0 (e.g., 0.41 minutes) or is reported as 0 (e.g., intra zonal travel times in the SKIM matrix) to one. Prohibits that are indexed in the RADII record are reset to a negative value (e.g., prohibiting intra-zonal travel). Also, from the perspective of TLFDs, the ATOM2 software will read these negative values as an absolute value rather than a negative number.

The RADII record is the second input record the ATOM2 software reads. This record serves as the surrogate for representing zone size. RADII records are created by the EXPORT RADII File utility available in the TxDOT add-on menu item in TransCAD. The records are exported in integer hundredths and are maintained by the ATOM2 software in this format. Unlike the separation values in the SKIM matrix, the values are not reset to integer numbers. The RADII records help establish the spatial allocation between ‘atomized’ zone pairs rather than using a single theoretical point in the zone as the center of activity (i.e., zone centroid in the network). The proportional percentage of trips is equally distributed into the atomized zones.

The third input record that the ATOM2 software reads is the generation (i.e., GEN) record that the TripCAL5 software produced and that represents the zonal production and attractions by trip purpose. For each individual trip purpose, a format statement is specified to properly read the generation file. The generation records are expressed as integer values. The practice at TxDOT-TPP is to have the ATOM2 software produce the individual trip tables in TRANPLAN binary format. As noted earlier, TRANPLAN binary format is compressed. The TRANPLAN binary trip tables do not store zero interchange values, which further compresses file size; they are also in integer format. The ATOM2 software will calculate zonal trip interchanges using a real number format, but will use residual rounding (i.e., bucket rounding) to convert the zonal trip interchanges to integer format to conserve the resulting file sizes. The resulting trip tables by trip purpose are all in integer format—that is, except for the two external-through (THRU) trip tables, which are created using the growth factor method available in the TransCAD software (i.e., FRATAR).

The residual rounding, which the ATOM2 software automatically performed, has a number of potential consequences when considering the adoption of an iterative feedback process:

- The residual rounding will make it difficult to use the trip tables as a potential measure of convergence. The residual rounding will inadvertently add statistical error to the determination of convergence. In fact, convergence may not be achieved when using integer trips. For example, a matrix may contain numerous cells with very low zonal interchange volumes (i.e., one trip) and during feedback; these values may oscillate between 0 and 1.
- The impacts of residual rounding correspondingly increases with the number of trip purposes used in the model structure which will also eventually impact convergence in the iterative capacity restraint assignment procedure.

TxDOT has been approached a number of times about using real number trip tables and minutes of separation. However, they have not supported the concept of migrating to real numbers, and so this concept has never been adopted for operational use.

The TLFD is an additional record added to each trip distribution control file. Individual TLFDs by trip purpose are created by applying the survey expanded trip tables to the latest network speed logic. This is accomplished within the Texas Package by applying the GET2 utility. An unsmoothed distribution is output as well as the average trip length. The TxDOT analyst can either manually smooth the unsmoothed distribution or apply another utility available in the Texas Package, called the Improved Trip Length Frequency Distribution Model (ITLFDM). ITLFDM can be applied for each of the internal trip purposes and will produce a smoothed trip length frequency distribution based on the input average trip length and desired maximum separation (typically from two and a half to three times the average trip length).

Using the ATOM2 software, friction factors are estimated by trip purpose and are calibrated so that the trip distribution model closely replicates the expected average trip length by trip purpose and reasonably estimates the shape of the TLFD. The friction factors are calibrated for the base year condition and are held constant for forecast applications. The translation of minutes of separation from integer hundredths to integer format is also performed in the estimation and reporting of friction factors. Again, this represents a simplifying assumption that was originally done as a compromise for file size and reporting considerations. If congested speeds are to be fed back to the trip distribution step, the application of non-integer travel times will need to be addressed (i.e., use real numbers or integer hundredths rather than integer minutes of separation) and friction factors will need to be incorporated as a continuous function rather than in 1-minute increments to be consistent with a real number travel time matrix. This is, in and by itself, a complex issue.

Once the distributions are performed for each of the individual trip purposes, the trip tables are imported into TransCAD using the IMPORT BINARY TRIP TABLES utility available in the TxDOT add-on menu item and the two THRU trip tables are appended to the imported matrix core. Since the trip tables are still in production and attraction (PA) format, the combined trip table is converted from PA format to OD format using the TransCAD PA to OD utility. The resulting matrix represents 24-hour vehicle trips, which will be assigned to the network geography using the user equilibrium procedure also available in the TransCAD software.

General Trip Distribution Conclusions and Recommendations

There are a number of technical and logistical hurdles that would have to be overcome and addressed before TxDOT-TPP could implement an iterative feedback mechanism in the existing Texas Package. As previously discussed, many of the technical challenges are software related and would require a departure from existing approaches. The issues are summarized below:

- Foremost, ATOM2 would need to be modified to produce non-integer trip tables. Currently, trip interchanges are maintained as integer trips because of a residual rounding routine that was implemented to limit individual file size. A potential measure of convergence in the iterative feedback paradigm is to determine the differences between the initial trip tables versus the updated trip tables that were created using the congested travel times. Maintaining trip tables in integer format may diminish or actually increase the perceived differences depending on individual interchange values. This may diminish or limit the capability to measure convergence. The more trip purposes that are involved in the process; the greater the impact of residual rounding on measuring changes in trip interchanges. Residual rounding will also impact convergence in the traffic assignment step as well.
- Secondly, the friction factors by trip purpose will need to be a continuous function that is no longer constrained to integer minutes of separation. Friction factors will need to be estimated as non-integer minutes.
- The determination of friction factors that reasonably match the observed trip length frequency distribution and replicate the observed average trip length will be a dynamic process that will require significant investment of resources to train existing TxDOT-TPP staff. The process will potentially involve a number of subjective technical decisions as the final feedback iteration trip matrix needs to have a resulting average trip length that reasonably matches observed values. Consequently, the calibration of friction factors will also increase the amount of time dedicated to calibrating the entire base year travel model. Indeed, other than one example in Florida, no other documented examples in the country where the calibration of friction factors has been automated could be found.
- Although limited in practice, the determination of BIAS factors will also become dynamic and, similar to the friction factors, will require additional resources in terms of time dedicated to developing reasonable BIAS factors at the sector interchange level in an iterative environment.

- Models that implement feedback procedures within a daily environment may overestimate the effects of congestion for the non-work trip purposes and underestimate the effects of congestion on the home-based work (HBW) trip purpose. Since a majority of the HBW trips occur in the two peak periods—morning and afternoon—it is logical to address the effects of congestion on this trip purpose by time of day. Since the remaining internal trips typically occur throughout all time periods, determining the effects of diversion due to congestion are only relevant for the time periods that these trips typically occur (e.g., non-home based trips typically occur during the mid-day period). These could, in theory, continue to be addressed in a 24-hour system that probably doesn't require the use of a feedback mechanism.

TRAFFIC ASSIGNMENT

The third and final step in the sequential model application process is traffic assignment. For the base year condition, the traffic assignment is intended to replicate observed conditions (i.e., ground counts). The two major inputs to the traffic assignment process are:

- A 24-hour OD matrix.
- A regional network that uses estimated 24-hour speeds, travel times, and capacities.

Once the traffic assignment models have been applied, TxDOT-TPP uses three primary benchmarks with which to judge base year model performance when comparing assigned volumes to ground counts. Within reasonable limits and acknowledging that some exceptions have been made, the general acceptable performance measures are:

- The regions overall assigned vehicle miles of travel (VMT) should be within ±3 percent.
- By facility type and area type, the acceptable difference is ±10 percent with more emphasis placed on higher classified facilities (e.g., highways, expressways, and principal arterials).
- By screenline, the general acceptable standard is ±15 percent (the term *screenline* is used interchangeably with *cutlines* at TxDOT-TPP).

The standards noted above represent the only documented standards associated with traffic assignment model performance at TxDOT-TP and generally recognize that traffic volumes on an individual link basis can vary by 15 percent on any given day. Therefore, assigned volumes rarely match observed ground counts precisely. TxDOT-TPP staff will also review other statistical measures of fit (e.g., counted volume versus percent error by counted volume ranges, percent root mean square error [RMSE]), when determining model performance relative to observed traffic patterns but will only report the criteria noted above. The statistical summaries are produced by applying the VALID9 utility available in the TransCAD add-on TxDOT menu item.

Traffic assignment is performed using the user equilibrium approach available in the TransCAD software. This is the only significant step in the sequential model process that uses software not specifically addressed in the Texas Package Suite of Programs. The U.S. Federal Highway Administration and the U.S. Environmental Protection Agency have endorsed the equilibrium assignment procedure for use in non-attainment and near non-attainment areas.

The equilibrium traffic assignment process iteratively loads trips based on the minimum paths between zone pairs (as determined by the 24-hour link travel times), calculates the delay associated with the resulting congestion and re-loads the trips to the network using the resultant updated minimum paths that have been re-calculated using updated travel times based on the previous congestion levels. Equilibrium is achieved when a traveler on the network can not improve their travel time by selecting an alternative path or route.

The assignment process is completed when either a reasonable number of iterations have been applied or the assignment results have reached predetermined convergence criteria. TxDOT-TPP staff has specified the following criteria when applying the traffic assignment procedure in TransCAD:

- Maximum number of iterations: 24.
- Convergence criteria: 0.001.

The maximum number of iterations represents a legacy value that was defined during the conversion from the mainframe platform to the microcomputer platform in the late 1990s. Twenty-four iterations were consistent with the number of iterations that were applied when conducting conformity determinations by TTI-College Station. The value is not relative to any other criteria and may warrant further considerations in the discussion of implementing an iterative feedback process as a part of this research. The convergence criterion of 0.001 was selected to improve the chances that additional iterations would be applied during the assignment procedure. Initial applications using the default 0.01 value in TransCAD yielded relatively few iterations during the equilibrium application (e.g., less than six). Based on resulting congestion levels during the initial applications using the TransCAD software, relatively little divergence was being achieved in the system networks using a capacity-restraint procedure on relatively uncongested study areas. Therefore, 24 iterations and 0.001 were selected as the convergence criteria (although there are examples of deviations for both criteria).

In the context of implementing a feedback mechanism within the current 24-hour framework, the following variables may require further consideration and study:

- Number of iterations applied during traffic assignment application.
- Convergence criteria defined during traffic assignment application.
- Volume-delay equation referenced during traffic assignment application.
- Resulting 24-hour volumes, speeds, and times.
- Input 24-hour capacities, speeds, and times.

Some of the variables noted above have been discussed in previous sections of this report (i.e., capacities, speeds, and network travel times), while others (i.e., delay function) are discussed below.

IMPEDANCE ADJUSTMENT FACTOR

A volume-delay function is used to estimate delay from congestion, which is iterated to affect path choice based on the delay derived from this function. Link volume-to-capacity ratios are used as the method to represent congestion in the network. For each assignment iteration, as the

V/C ratio increases or decreases on a link, the speed (and associated travel time) on the link is adjusted to reflect the amount of congestion on the link during the current iteration.

Prior to the late 1990s, TxDOT-TPP used a 'Texas Speed Curve' in the Texas Large Network Assignment Models on the Texas mainframe platform to arrive at resultant delay. The speed curve differed from the standard BPR formula in one major category. The constant variable in the equation in the Texas formulation is 0.92 rather than 1.0. By implementing a different constant, TxDOT could use 24-hour speeds in the models rather than free-flow speeds. The equation previously used to arrive at how much speed (and time) was adjusted based on the congestion level on the link was:

$$I_{(n+1)} = I_{(1)} * [0.92 + \alpha(\frac{v}{c})^{\beta}]$$

Where

$I_{(n+1)}$ = adjusted impedance.

$I_{(1)}$ = beginning impedance.

0.92 = constant.

V = 24-hour assigned volume.

C = 24-hour estimated capacity.

α = Alpha (0.15).

β = Beta (4.0).

Since the input speeds in previous Texas studies were for observed speeds estimated at a V/C ratio of roughly 0.85, the impedance remains unchanged at this ratio. Thus, the impedance continues to increase at ratios greater than 0.85 and, conversely, decreases at ratios of less than 0.85. Figure 15 depicts this formulation graphically.

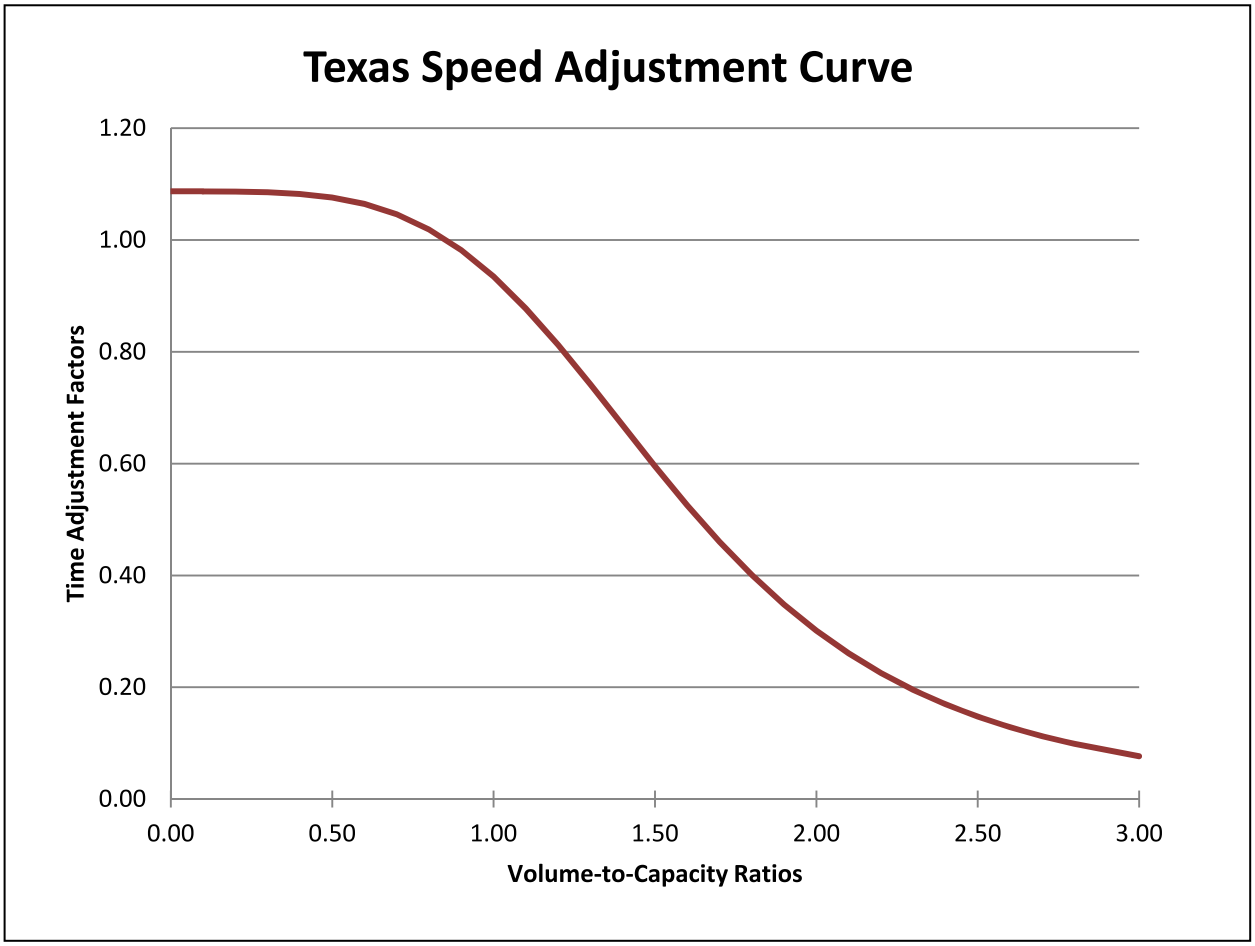


Figure 15. Texas Speed Adjustment Curve.

When TxDOT-TPP made the decision to migrate from the mainframe Texas Suite of Travel Demand Programs to the TransCAD software in the late 1990s, several existing Texas Package functions were successfully instituted within the microcomputer platform during the migration effort. One specification that could not be migrated at the time was the use of the Texas Package impedance adjustment factor because the TransCAD software did not have the capability to use outside speed adjustment curves. As a compromise during the transition to TransCAD, the Texas delay curve was jettisoned, and the use of the standard BPR formula was adopted. The significant difference between the standard BPR curve and that of the Texas curve was the use of 1.0 as the constant within the equation. The standard BPR formulation is:

$$I_{(n+1)} = I_{(1)} * [1.0 + \alpha(\frac{v}{c})^{\beta}]$$

Figure 16 presents the standard BPR volume-delay equation.

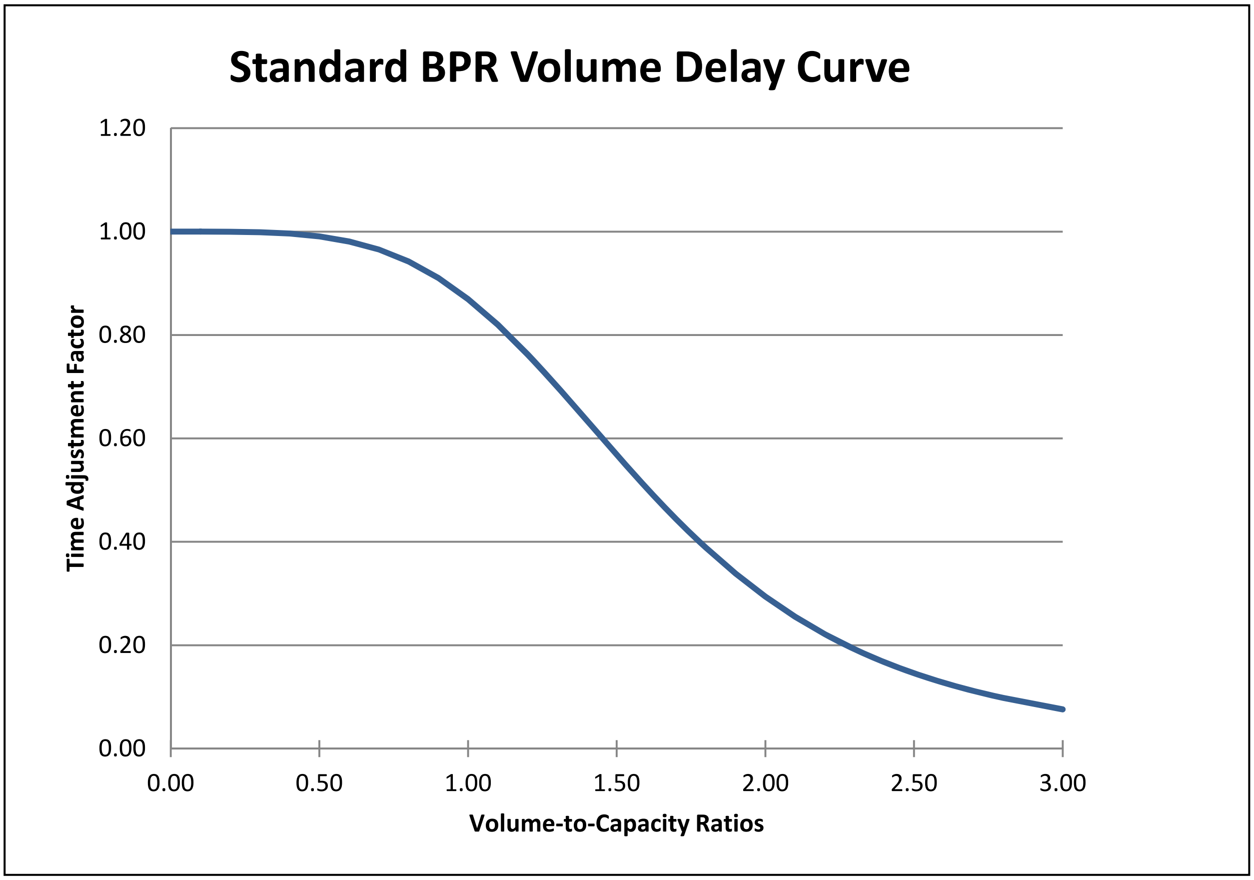


Figure 16. Standard BPR Volume Delay Formulation.

The standard BPR formula assumes that free-flow speeds are used as the initial speeds. Figure 17 illustrates a comparison of the Texas speed adjustment curve relative to the standard BPR formulation.

Since TxDOT-does not code free-flow speeds in the regional networks, an alternative approach was created. TxDOT-TPP adopted a generalized cost approach for the initial 24-hour input speeds. In this manner, the speed differences between higher class facilities (i.e., interstates) and lower class facilities (i.e., arterials) are diminished. Without first reducing the speed differences between functional classifications, calibration of 24-hour models using relatively uncongested networks is problematic. Indeed, using the calculated minimum paths, traffic tends to gravitate to the higher-class facilities because of the desirability of these facilities (i.e., uncongested links with higher speeds) and relatively little dispersion of traffic occurs. Therefore, obtaining a multi-path solution set relative to the entire network becomes challenging and approximating observed ground counts is less feasible.

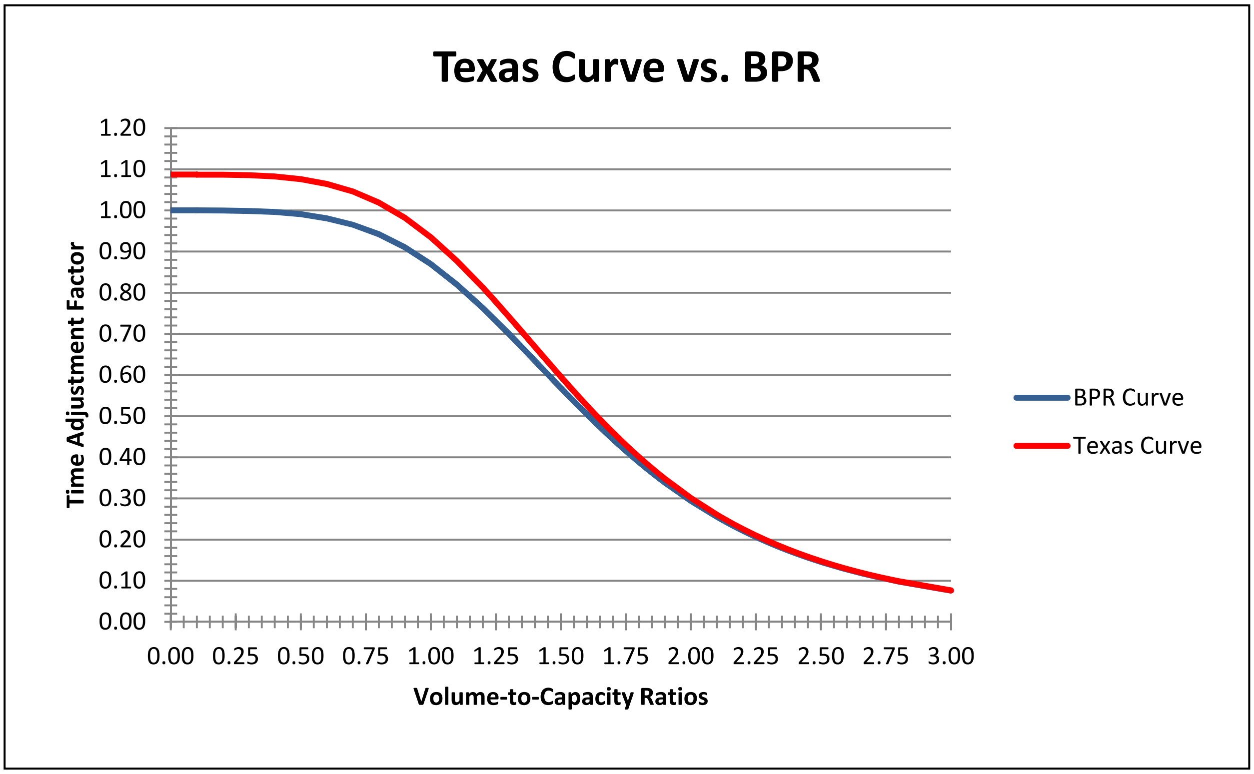


Figure 17. Comparison of Texas Volume Delay Equation to BPR.

As discussed previously, a number of simplifying assumptions are used to develop estimated 24-hour speeds (and resulting travel times) for use with the standard BPR delay function. These include some of the following variables:

- Average posted speeds by functional class and area type.
- Average intersection spacing by functional class and area type.
- Typical signal phasing on signalized facilities.
- Typical operating cost.

These variables (along with others) are used to generate estimated 24-hour (TxDOT typically refers to as ‘congested weighted’) speeds by facility type and area type stratifications. In this manner, the relative differences between operating characteristics, conditions, and, in general, the desirability from a route choice perspective of different facility types becomes less pronounced. This is especially important since a majority of the study areas are relatively uncongested (as expressed in 24-hour characteristics). TxDOT has historically expressed delay and congestion in terms of the overall system. Table 5 below presents the system congestion levels in terms of the overall volume-to-available 24-hour capacity, using the latest base year travel model networks.

Table 5. System Congestion Levels by Study Area.

Study Area	Current Base Year Model	Base Year V/C Ratio
Abilene	1998	30.87%
Amarillo	2005	26.59%
Austin-CAMPO	2005	N/A
Brownsville	2004	44.75%
Bryan-College Station	2006	44.98%
Corpus Christi	1996	38.00%
Dallas-Fort Worth*		
El Paso	2002	46.66%
Harlingen-San Benito	2004	40.98%
Hidalgo County-MPE	2004	57.39%
Houston-Galveston*		
JOHRTS	2002	47.48%
KTUTS	1997	44.54%
Laredo	2003	52.55%
Longview	2002	50.05%
Lubbock	2000	33.13%
Midland-Odessa	2002	32.14%
San Angelo	2003	30.14%
San Antonio	2008	56.04%
Sherman-Denison	2003	30.43%
Texarkana	1995	56.52%
Tyler	2002	50.52%
Victoria	1996	38.20%
Waco	1997	47.73%
Wichita Falls	2000	35.79%

**Urban areas not modeled by TxDOT-TPP*

From an overall system perspective, none of the study areas have a capacity issue that could be adequately addressed in a 24-hour iterative feedback environment. The two most congested study areas, San Antonio and Texarkana, only approach the mid-50 percent V/C ratio using the non-weighted average. San Antonio is indeed congested during peak travel periods, but in terms of 24-hour congestion, there is excess available capacity. Relatively little diversion would occur using the standard BPR formulation in a 24-hour system. Figure 18 on the following page illustrates the level of 24-hour congestion by study area. Figure 19 and Figure 20 plot the system V/C ratios by study area relative to the standard BPR decay function. Figure 20 reduces the scale of Figure 19 to assist with the definition of where each study area exists relative to the BPR formula.

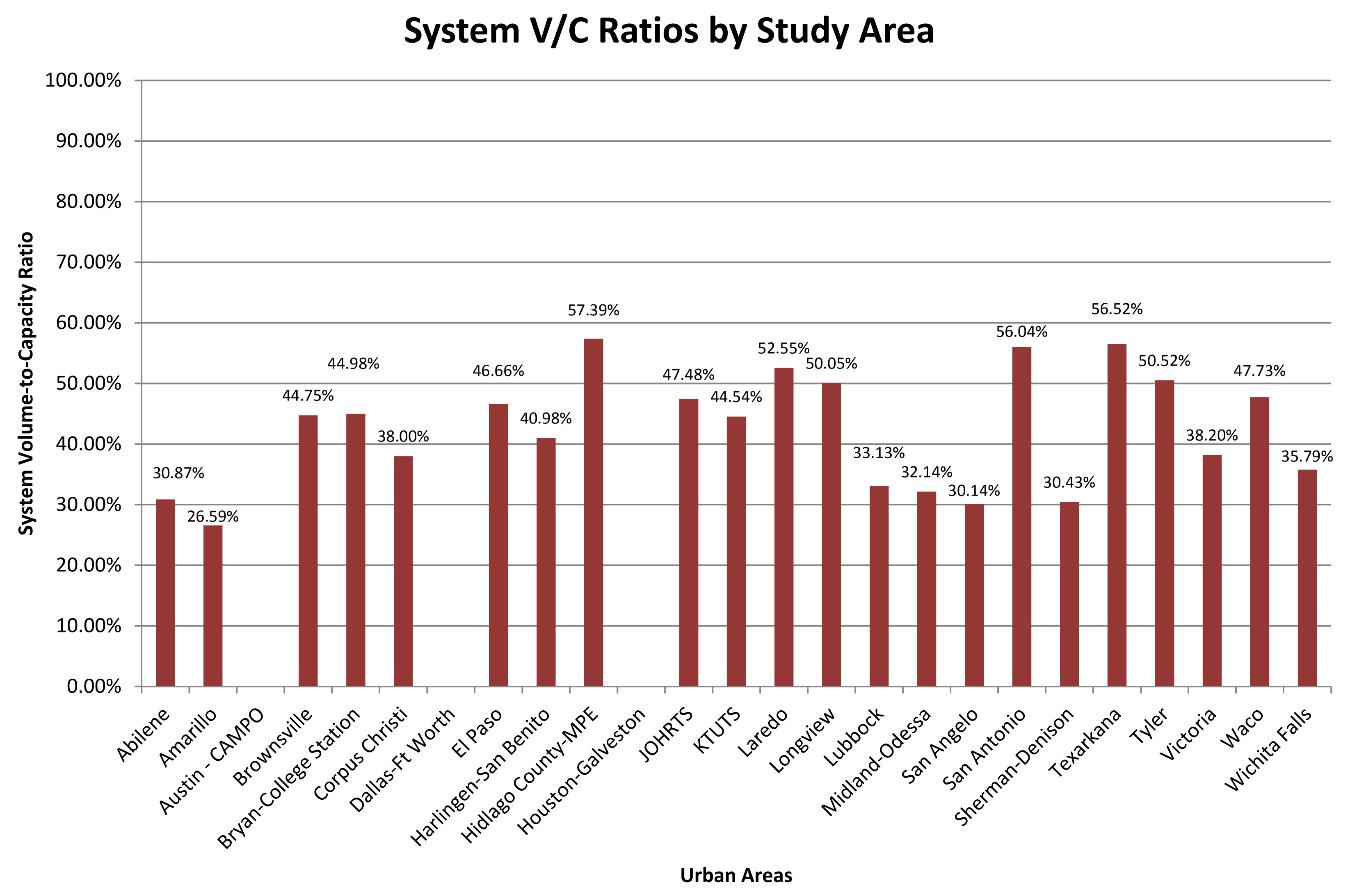


Figure 18. Volume-to-Capacity Ratios by Study Area.

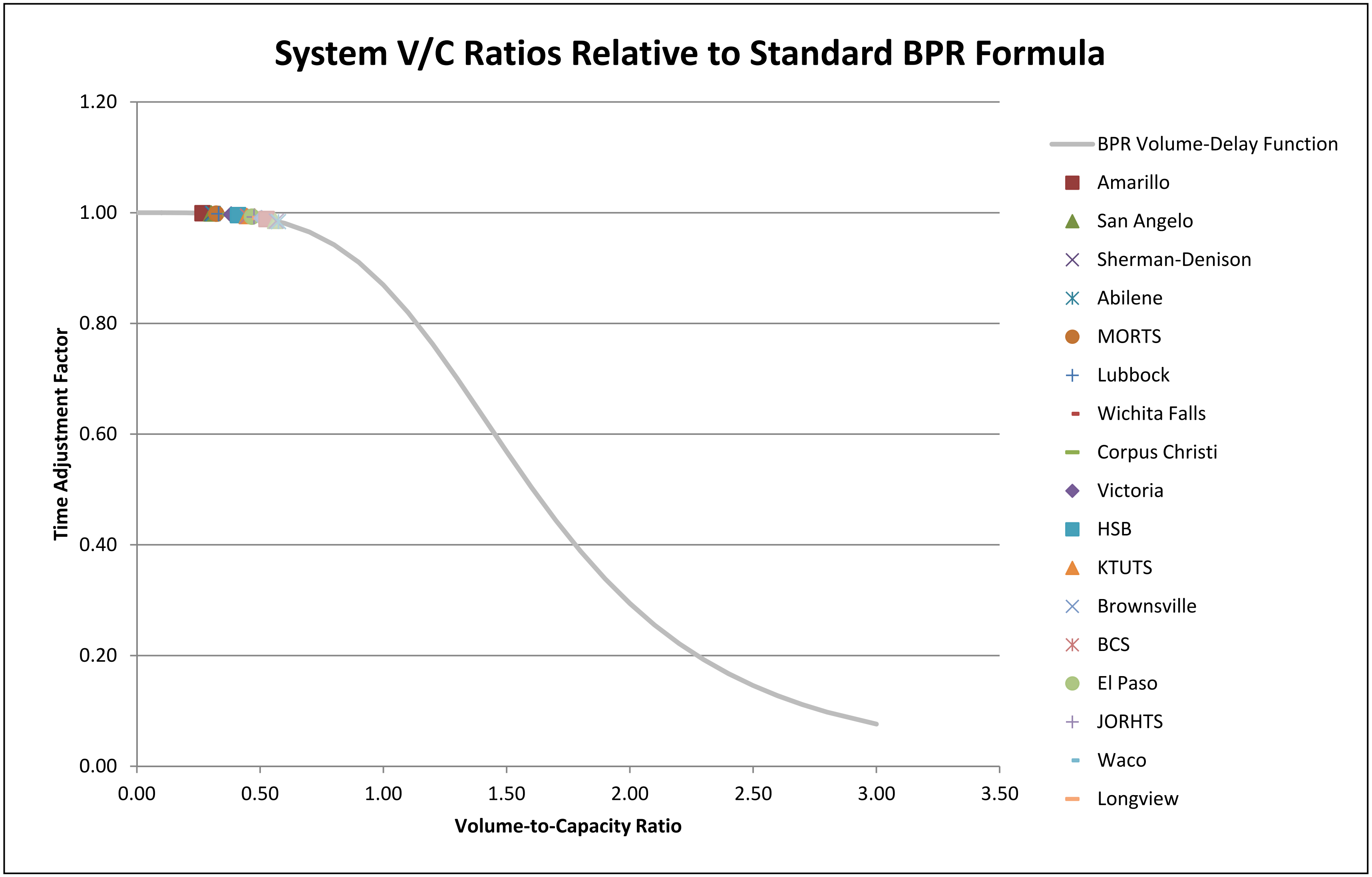


Figure 19. System Volume-to-Capacity Ratios Relative to BPR Formulation.

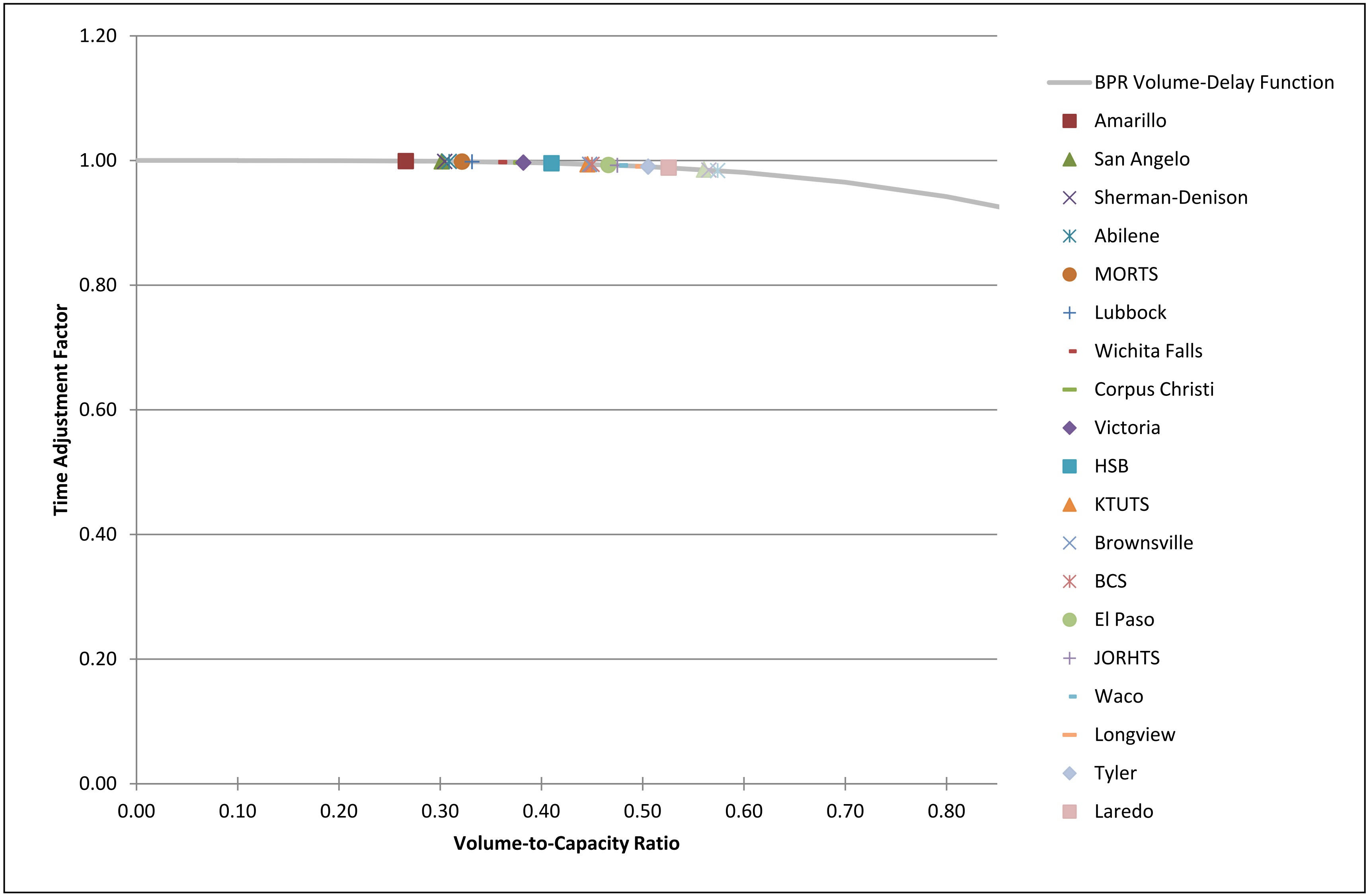


Figure 20. V/C Ratios Relative to BPR Formulation (Magnified).

Table 6 provides an additional inventory by study area of the user-weighted, volume-to-capacity ratio for each study area. The 'user-weighted' value is a V/C ratio that is weighted by VMT 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 the 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.

Table 6. User-Weighted Volume-to-Capacity Ratio by Study Area.

Study Area	Current Base Year Model	Base Year Weighted Avg. V/C Ratio
Abilene	1998	43.50%
Amarillo	2005	42.60%
Austin-CAMPO	2005	N/A
Brownsville	2004	65.20%
Bryan-College Station	2006	68.00%
Corpus Christi	1996	57.40%
Dallas-Fort Worth		
El Paso	2002	64.10%
Harlingen-San Benito	2004	60.20%
Hidalgo County (MPE)	2004	78.20%
Houston-Galveston		
JOHRTS	2002	63.90%
KTUTS	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%

Even in these terms, it is easy to dimension the magnitude of the problem, which is relatively little congestion exists in the network systems as expressed in 24-hour travel. Implementing a congestion feedback mechanism in the current 24-hour TxDOT modeling structure may yield results that are diminutive in terms of defining the unresolved differences between the input travel times and the resulting travel times from assignment. Congestion (defined as 24-hour V/C ratios) does not exist, except in larger urbanized areas, such as El Paso (on IH-10), San Antonio, and possibly Hidalgo County.

To further express this dimension, Table 7 provides an inventory by study area of the base year count to available capacity in the network system. The table lists the total number of non-centroid connector links in each urbanized area network as well as the total number of links having a count that exceeds 85 percent of the available capacity. The table also provides the percent of counted links for the region that exceed the 85 percent threshold. This is a common metric TxDOT used to determine if there is a network coding error that has occurred in the initial base year network development/coding. The errors are commonly associated with one of the variables associated with the link (e.g., number of lanes, facility type) because it is operationally rare that a link approaches 100 percent of the available capacity. Consequently, any link exceeding 85 percent of the available capacity relative to the 24-hour count is investigated further. In some instances, the count-to-capacity ratio identifies a problem with the original count. As stated earlier, the 85 percent value is also pertinent to the standard BPR decay function because at this point, travel times are degraded at a higher pace.

Based on Table 7, relatively few study areas have a capacity issue. In terms of absolute numbers, urban areas such as Midland-Odessa (MORTS), Amarillo, San Angelo, and Wichita Falls have very few links approaching capacity issues. Lubbock, which exceeds 200,000 in population and is considered a Transportation Management Area (TMA), has only 23 links in the previous base year model that exhibited potential capacity issues. This amounts to less than 1 percent of the total non-centroid connector links.

The two study areas with a relatively large number of counted links that exceed 85 percent are Laredo and Texarkana. For Laredo, the issue is probably partly due to poor network facility type definitions and incorrect count annotations, although congestion is present and observable. The Texarkana network is a legacy network and was developed prior to the standard approach for developing capacities. To be clear, Texarkana does not have a mobility problem.

The 2003 Hidalgo County base year network is a more recently completed model. This network is a subset of the larger regional Valley network. There are 401 links among the 4,607 available that exceed the 85 percent threshold. This measure is potentially deceiving since 142 of these links are collectors. Although modeled, collectors typically are not addressed in long-range planning documentation, nor do these facilities generally impact a region's accessibility. Consequently, if collectors are removed as a part of the summation of links that exceed 85 percent of count-to-capacity ratio, only 259 links would have been identified as potentially problematic or congested.

Table 7. Count-to-Capacity Ratios by Study Area.

Study Area	Current Base Year Model	Number of Congested Links*	Total Counted Links	Total Non-CC Links in Network
Abilene	1998	28	1488**	1,488
Amarillo	2005	6	879	2,362
Austin-CAMPO	2005			
Brownsville	2004	87	477	1,032
Bryan-College Station	2006	76	494	1,751
Corpus Christi	1996	93	1348**	1,356
Dallas-Fort Worth				
El Paso	2002	134	1,472	3,083
Harlingen-San Benito	2004	53	736	1,420
Hidalgo County(MPE)	2004	401	1,708	4,607
Houston-Galveston				
JOHRTS	2002	149	2,300	3,632
KTUTS	1997	58	720	1,817
Laredo	2003	146	477***	927
Longview	2002	58	597	1,252
Lubbock	2000	23	909	2,343
Midland-Odessa	2002	11	1,220	3,266
San Angelo	2003	8	1,149	1,419
San Antonio	2005	577	3,570	11,678
Sherman-Denison	2003	20	1,003	2,549
Texarkana	1995	62	380**	380
Tyler	2002	96	851	1,279
Victoria	1996	49	612	613
Waco	1997	25	462	874
Wichita Falls	2000	24	702	1,517

**As defined as Count/Capacity > 85%; **All links annotated with count (real or estimated); ***Count quality issues.*

Prior to the late 1990s, TxDOT annotated a count for every link in the system by either annotating the observed count or an estimated count (if the link was not formally counted). Therefore, for older base year networks, the percent of counted links that exceeds 85 percent of the available capacity may be overstated. For example, the 1997 Killeen-Temple base year network had 166 links where the count exceeded 85 percent of the available capacity. However, only 58 of these links represented actual counts. When the 1997 Killeen-Temple network was developed, TxDOT began using a count flag in the network databases to identify whether the count was real or estimated. TxDOT had not adopted this philosophy for operational use in study areas such as Corpus Christi, Beaumont, Victoria, and Texarkana, and, therefore, real or estimated counts were indistinguishable.

Based on observed data that are directly available from TxDOT base year travel models, the motivation to migrate a majority of the study areas to either time-of-day models or implement a congestion feedback mechanism does not exist for several of the study areas. It appears that congestion levels are not of a level that would influence route, mode, destination, or make a traveler consider an alternative time period. Large study areas (i.e., El Paso and San Antonio and possibly Hidalgo County) that have significant capital investments being considered in the long-range plans offer potential examples of legitimate feedback consideration. Beyond these study areas, it is not technically clear what a feedback mechanism will yield.

General Traffic Assignment Conclusions and Considerations

In the context of 24-hour models, there are a number of considerations that could be examined as a part of the traffic assignment step. Foremost, the volume delay equation. As noted, a number of key issues have been addressed to achieve multi-path solutions using a capacity restraint approach on relatively uncongested systems (i.e., speed models, 24-hour capacities). To implement a feedback mechanism in a 24-hour model that exhibits very little congestion, and therefore relatively little divergence due to congestion, TxDOT would potentially have to examine the following issues:

- Consider implementing time-of-day periods for certain study areas (e.g., El Paso) that exhibit relatively congested conditions on major facilities (i.e., IH-10) and are considering implementing high occupancy vehicle (HOV) lanes or managed lanes (i.e., Border Highway) or other capital-intensive projects (i.e., transit).
- Identify the appropriate speed-delay curves for the region or by facility type. TxDOT may have to implement entirely different volume-delay functions by facility type. In the absence of robust speed-flow curve relationships by study area and by facility type, this may require a significant amount of investment to arrive at a satisfying set of delay curves (e.g., where decay and, therefore, diversions would occur much earlier than the current standard BPR formulation). These may have to be 'standardized' to represent typical conditions or philosophies regarding speed-flow relationships in relatively uncongested networks.
- Update or modify the 24-hr capacity logic, which is a part of the volume-delay equation. Using LOS E capacities, as the standard, will probably be ineffective in calculating (or expressing) delay and would require artificial manipulation to achieve divergence (i.e., modify the Alpha or Beta values in the volume-delay function). Depending on the approach, time segmented capacities may have to be developed.
- Update the 24-hour speed logic to initially begin with free-flow speeds (if the BPR formulation or variation thereof is to be implemented). In the absence of free-flow speed data by study area and by facility type, this may prove problematic. Simplifying assumptions (e.g., 'typical' speed look-up tables by facility type and area type) may have to be adopted to overcome the lack of supporting data. The relative speed differential between competing routes (i.e., facility types), may produce results that are basically inconsequential in an iterative environment (the input speeds may be similar to the resulting congested weighted speeds because of the lack of system congestion). This alone may increase the level of difficulty in replicating observed traffic counts.
- Consider creating a time-of-day speed model if individual time periods are to be studied in the Texas Package.
- Consider implementing a generalized cost assignment procedure (if 24-hour models are to be continued) to dampen the relative speed differences and desirability between facility

types. In this manner, TxDOT-TPP could also account for existing or planned toll facilities in the regional networks. Currently, TxDOT-TPP does not effectively model toll facilities; these are modeled as free facilities.

- Examine the number of iterations and convergence criteria applied during the traffic assignment procedure. Currently, the 24 iterations represents a legacy determination, while the 0.001 convergence criteria was implemented to encourage the capacity-restraint traffic assignment procedure to spread traffic around the system in order to match observed ground counts. Neither variables may be adequate in the context of implementing a feedback mechanism in a 24-hour time period. Modifying these two principal considerations associated with the user equilibrium procedure may increase the processing time associated with applying an iterative feedback mechanism.

CHAPTER SUMMARY

The purpose of implementing a speed/travel time feedback loop in the sequential travel demand model process is to resolve the speed/travel time differences that exist between the trip distribution and traffic assignment steps in the sequential approach. Given that a vast majority of the study areas in the state where TxDOT-TPP is responsible for developing long-range travel models represent small- to medium-sized cities with little to no congestion, there is limited practical use or need for implementing a feedback mechanism beyond any federal requirements or expectations associated with non-attainment areas. As demonstrated in the preceding pages, the congestion levels for most of the study areas are not severe enough to warrant feedback consideration. Divergence due to congestion is not the primary motivating factor that explains traveler's alternative route selection in many of the small- to medium-sized cities. Congestion and resulting delay may be even imperceptible beyond unnecessary delays created by poor signal timing or peak demand created by university schedules in many of these cities. This probably will not change the foreseeable future for many of these urbanized areas. Furthermore, these types of operational issues are below the fidelity of a regional travel model.

Without significant long-range capital commitments toward HOV, managed lanes and transit, which require time-of-day modeling capabilities in order to appropriately analyze these system alternatives, the planning needs for many of these study areas can be satisfied with the existing 24-hour modeling approach. TxDOT should initially limit any considerations given to feedback approaches to those cities with long-range capital-intensive capacity enhancement projects and in areas that have severe congestion and mobility concerns during the peak periods.

Therefore, there are only a handful of urban areas in the state that would benefit from having such a mechanism—Austin, San Antonio, El Paso, and, to some extent, the urbanized areas that make up the Lower Rio Grande Valley (LRGV) region—primarily Hidalgo County. Laredo is also relatively congested and may possibly be given some consideration. Corpus Christi might fit into this category if the model represented summer travel when demand is the greatest. The MPOs representing Austin and San Antonio have already incorporated a feedback procedure in their existing TDMs. These were accomplished using consulting services in conjunction with the development and application of the mode choice and traffic assignment steps. As such, the opportunities are pragmatically limited to El Paso and Hidalgo County (again, with some consideration for Laredo). Beaumont is also considering HOV strategies as a means to address continuing mobile source emission issues in the region. Otherwise, the motivation to implement a feedback mechanism in the current Texas Package is to satisfy a structural change rather than addressing long-range planning capabilities and needs in the state for small- to medium-sized urban areas.

Generally, there are three approaches TxDOT-TPP may wish to examine with respect to implementing a feedback mechanism:

- Continue to use 24-hour models and feedback 24-hour congested travel times. As demonstrated in the system volume-to-capacity ratios presented in this document, there simply is not enough congestion to impact travel times in the context of daily travel. This concept may be too insensitive to peak travel conditions for specific trip purposes (e.g., HBW trips) and overly sensitive to the remaining internal trip purposes.
- Continue to use the 24-hour models but limit the feedback mechanism to one trip purpose—the HBW trip purpose. Austin, San Antonio, and Houston make a simplifying assumption regarding the HBW trip purpose—the preponderance of HBW travel occurs in the peak period because the separation of productions and attractions is dictated by the AM peak period travel conditions. This is consistent with many mode choice assumptions nationally. These study areas develop peak period travel times based on an initial 24-hour assignment by applying an initial 24-hour trip table that has been factored by time of day and orientation, and has been created using the daily model structure (the Austin model process actually assigns the HBW trips to a peak period network to derive congested peak period travel times). HBW trips are then iterated through the feedback approach to resolve congested travel times with the input travel times in trip distribution. The remaining trip purposes use the initial daily speeds. Only HBW would use or be affected by the congested times. This approach would limit the dynamic nature of friction factors and bias factors to one trip purpose as well. Figure 21 provides a basic flow chart of the concept.

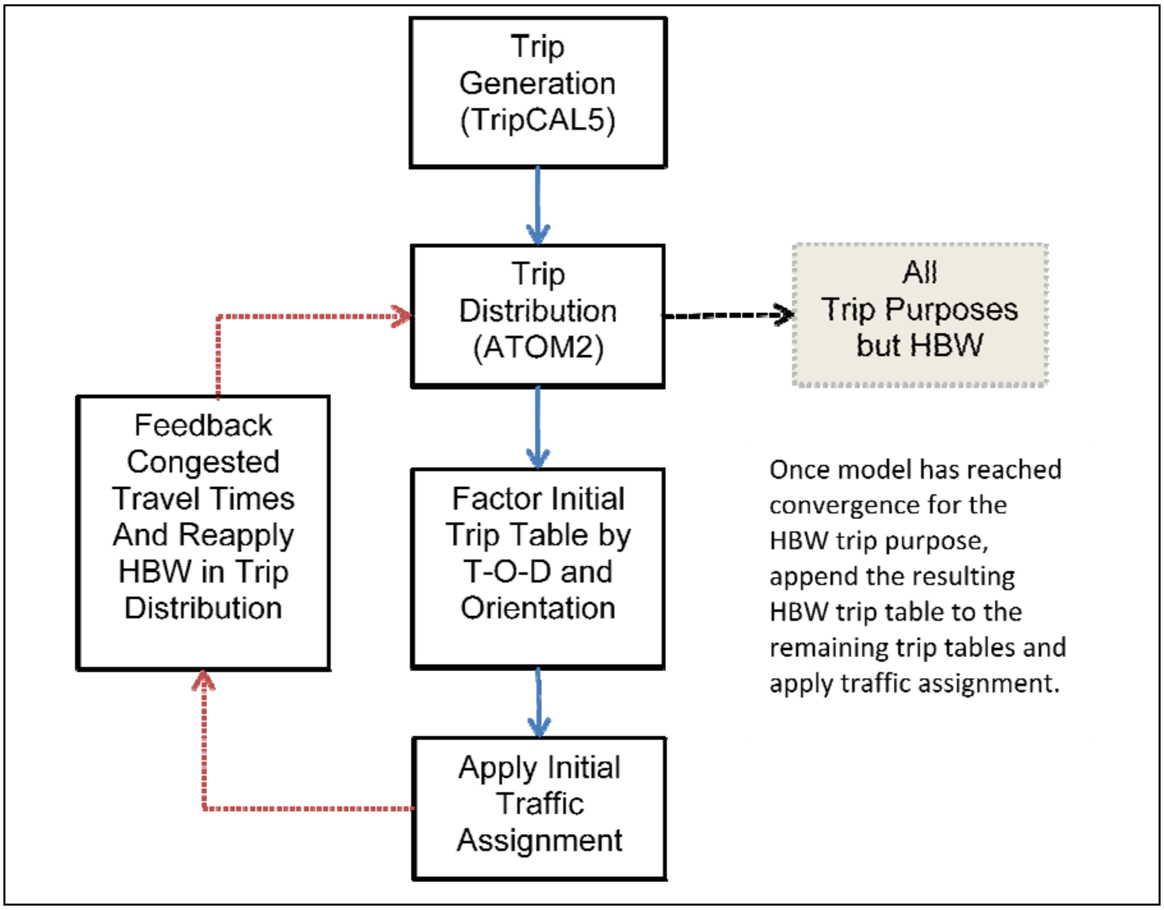


Figure 21. Example Iterative Feedback.

- Consider implementing time-of-day models for only the large urbanized areas in the state with significant transportation related projects. The consequences of implementing time-of-day models would be significant in many aspects, but it would allow TxDOT-TPP to become more involved and explore greater state-of-the-practice modeling practices that are not considered in the daily models (e.g., mode choice, toll/managed lanes, HOV). Primarily, TxDOT-TPP would have to:
    - Publish and use time-of-day counts.
    - Process the travel surveys to provide time-of-day information (in addition to trip orientation considerations).
    - Develop and annotate time-of-day capacities and corresponding speed logic.
    - Consider developing a speed-flow travel data collection program to support the calibration of volume-delay curves by time of day. There are many examples nationally of these types of programs. Historically, TxDOT, as an agency, has been reluctant to use estimated variables as a substitute for observed data. Without a robust speed-flow data collection program (e.g., space-mean-speed), volume-delay equations would have to be estimated.

Another option available to TxDOT-TPP is to implement a generalized cost approach to the existing travel model structure. A generalized cost approach would potentially address a significant philosophy that is not given consideration in existing TxDOT models–toll roads. A generalized cost approach would not only dampen the relative speed differences between competing facility types, but could be used to address tolling options in regional networks.

TxDOT could incrementally adopt the approaches noted above rather than selecting one option. The options could be classified as near-term and relatively easy to address in the existing Texas Package (i.e., Option One) to longer term approaches that would require significant redress of the Texas Package (Option Three).

Additional considerations, though, should be given to the relative impact that such a strategy might have on existing TxDOT-TPP practices. A feedback mechanism would require additional data processing (and collection), additional training, modifying existing Texas Package software (i.e., replacing integer minutes and trips with real numbers in the Texas trip distribution models), and increase the calibration time associated with delivering base year travel models.

It is also highly recommended that any feedback mechanism be constructed independently of commercially available software (i.e., TransCAD's GISDK language) to maintain the integrity and expertise associated with the Texas Package and for reasons enumerated at the beginning of this document. GISDK should only be used as the interface mechanism while the actual iterative program is maintained in an alternative language. This is consistent with historical and current TxDOT practice.

CHAPTER 3. STATE-OF-THE-ART FUTURE DEVELOPMENT TRENDS FOR FEEDBACK IMPLEMENTATION

INTRODUCTION

An important objective of the current project is to identify methods that may be suitable for the immediate implementation of the travel demand model (TDM) feedback process within the current TxDOT TDM system. To that effect, the focus of the earlier tasks was to identify the many dimensions characterizing the feedback process and compile information on the state-of-the-practice along each of these dimensions. In addition, approaches that may be particularly appealing within the context of the current TxDOT travel modeling system were highlighted. For instance, we proposed an approach where the zone-to-zone highway travel times are fed back from the output of the traffic assignment step to the trip distribution step.

Simple fixed time-of-day factors may be applied to 24-hour interchanges from the trip distribution step, followed by time-of-day-based traffic assignment procedures and a loop-back of the resulting travel times to the trip distribution step. The exact procedures for the feedback process, including the basis attribute to be used for computing updated travel times (i.e., the precise methodology to translate link travel times output from the TxDOT traffic assignment step into TAZ-to-TAZ travel times for input back to trip distribution), the updating procedure, the travel attribute(s) to be used for determining convergence, and the measures/thresholds for determining convergence are issues that need further empirical investigation within the context of the current TxDOT travel demand model.

In this chapter, we examine the state-of-the-art of the techniques and methods for the feedback process that may become important in the context of the medium (3–5 years) to longer (beyond five years) term evolution of the TxDOT TDM system. It is important to emphasize that some of these potential changes to the TxDOT TDM system may be relevant only to specific metropolitan areas and not to others. Also, the validation of the feedback processes and the TDM system as a whole in the future will need movement toward the collection, dissemination, and application of traffic counts by time of day, an issue that the research team recommends TxDOT seriously consider within the next couple of years.

FEEDBACK APPROACHES IN THE CONTEXT OF POSSIBLE MEDIUM-TERM CHANGES IN TXDOT'S TDM

In the medium term, we will assume that the trip generation step continues to be primarily driven by demographic and land-use characteristics, and not by the transportation system level of service attributes. Of course, this implies that changes to the transportation system will only result in a redistribution of trips in space or by mode or by time of day, and that there will be no changes in the overall amount of travel during the day. For the small- to medium-sized urban areas under the purview of TxDOT's Transportation Planning and Programming Division, this may not be an unreasonable assumption.

Trip Distribution Step

A current TxDOT TDM uses only the inter-zonal highway travel times in the trip distribution step. However, the use of such pure time-based impedance measures can lead to inaccurate predictions of demand in the presence of toll road and related managed lane facilities (because there is no consideration of cost elements in how trips may be spatially dispersed). Several large metropolitan areas in Texas are actively considering toll and other managed lane options, and it is possible that similar options may be considered in medium-sized urban areas under TPP's purview in the next five years. If this happens, the TDM system will have to be changed to reflect monetary as well as time costs in the trip distribution step. Then, the feedback process will also have to consider a combination of monetary and time costs.

One possible approach is to use time-of-day specific time-value of costs to convert toll costs to equivalent travel times and add these to the original inter-zonal travel time to get the effective representative inter-zonal travel times. For example, the Denver Regional Council of Governments (DRCOG) (2004) staff keeps its trip distribution model time-based, but converts the dollar cost of tolls to a time equivalent using different value-of-time factors for peak and off-peak periods. Moreover, for the peak period alone, the DRCOG uses three different value-of-time equivalents for three different income groups. The time equivalent of tolls is then added to the travel time and stored in a special matrix used only for trip distribution.

One advantage of this approach is that the traffic assignment step can still be based only on travel times, not on travel costs. Thus, when developing the combined (time and money) costs for use in the trip distribution step at each iteration, the time measures are obtained from the previous run of the traffic assignment step, while the cost measures remain fixed across iterations. The limitation of this approach is that it assumes that route choice decisions in traffic assignment are independent of cost and only dependent on travel time. But, the interaction of cost and time effects in route choice decisions can lead to inter-zonal travel times that are quite different from those based solely on time effects in route choice decisions, leading to potentially inaccurate spatial distributions of demand. Of course, this problem would be resolved if a combination of time and money costs (generalized costs) are used both in the trip distribution and traffic assignment steps.

Mode Choice Element

An important change in the near future in medium-sized urban areas may be the inclusion of a mode choice element in the modeling system. The impetus for this may come in the form of regulations that require an increase in the use of non-auto related modes (to reduce environmental pollution or to reduce investments in costly infrastructure supply enhancements to accommodate travel demand), or in the form of a need to examine the effectiveness of toll and managed-lane strategies. In such a case, a simple unimodal feedback approach would no longer be appropriate; rather, the feedback process should take into consideration the level of service offered by alternative non-auto modes between any two zones. The feedback approach may be modified in one of two ways in such a case, tied to the way in which mode choice is incorporated in the model system. If the mode choice element is included directly in the trip generation step (so that the number of trips by mode produced from each zone as well the number of trips by mode attracted to each zone are the outputs of the trip generation step), then the mode stratification can be retained in the trip distribution step. A multi-modal traffic assignment procedure may then be implemented, followed by the feedback of inter-zonal skims by mode to the mode-stratified trip distribution step. Note that, in this system, even though the trip generation system is stratified by mode, it is not a function of level-of-service of modes. Rather, the number of trips by each mode is simply determined in the trip generation step as a function of demographic and land-use characteristics.

An alternate approach, more commonly used, is to employ a composite impedance measure in the trip distribution step, which combines travel impedances by multiple modes. This may be implemented using weights obtained from the mode choice model for the modal shares between zone pairs (based on the last completed run of the mode choice model that is positioned between the trip distribution and the traffic assignment steps), or by using a composite utility-based (also commonly referred to as the log-sum) measure translated into equivalent travel time units, or by using a parallel conductance formula (Feng et al., 2009a; Feng et al., 2009b; Feng et al., 2010a; Feng et al., 2010b; Bhat et al., 1998). For example, the Chicago MPO (CMAP) currently uses a composite auto-transit impedance measure (including cost and time) in the trip distribution step based on the log-sum measure, while the Boston MPO uses a composite impedance measure based on the parallel conductance formula (please refer to Appendix B for details of the parallel conductance formula). The multimodal logsum and the parallel conductance methods are particularly appealing when there are also different components of level-of-service by each mode (such as travel time and travel cost by transit).

An important issue is in order here regarding the use of a multimodal impedance measure in trip distribution. This relates to the impedance measure used in the traffic assignment step, and how the outputs from the traffic assignment stage are ‘synched-up’ with the trip distribution step. Thus, the Chicago MPO runs a purely auto travel time-based traffic assignment procedure, and combines the resulting auto travel time zone-to-zone matrix with the cost matrix for auto/transit and the transit travel time zone-to-zone matrix. That is, the only variable that gets updated in successive iterations is the auto travel time. The implicit assumption is that route choice is not affected by transit travel times or transit/auto travel costs. On the other hand, the Atlanta Regional Council (ARC) (2008) also uses a multimodal measure combining travel times by auto and transit, but undertakes a multi-modal traffic assignment process. Thus, the variables that get updated in each iteration of the feedback include the auto travel time as well as the transit travel time.

Time-of-day and Its Relationship to Feedback

As indicated in Chapter 1, the splitting of the origin-destination trip table using time-of-day factors will need to be undertaken even in the immediate term to implement a feedback process within the TxDOT TDM model. Then, following traffic assignment for each time period, the outputs of each time-period specific impedance measure may be averaged (either using a simple average or a weighted average based on the time-of-day factors) to feed back to the 24-hour trip distribution model. In the medium term, there may be benefits to pursuing the trip distribution step itself for each time period used in the traffic assignment step, in which case the impedance outputs from the traffic assignment stage can be directly applied to the trip distribution model for the appropriate time period.

The benefit of doing so is that there is compatibility in the supply and demand of travel by time period. For example, one would expect that there will not be too many shopping trips during the peak period between two zones if there is a large number of work trips during the peak period between the two zones (because of the resulting large travel times during the peak period). However, using a 24-hour trip distribution model will not mimic this well, and can predict a higher number of shopping trips. The use of fixed time-of-day factors can then result in a higher number of shopping trips than appropriate. Of course, another change that may be considered in a TxDOT TDM is the incorporation of an explicit time-of-day model that is sensitive to time-of-day-based impedance measures. Doing so can increase the realism of predictions and provide more appropriate responsiveness to policy measures

FEEDBACK APPROACHES IN THE CONTEXT OF POSSIBLE LONG-TERM CHANGES IN TXDOT'S TDM

The discussion in the previous section provided an overview of different feedback options for possible changes to a Texas TDM in the medium term. In this section, we discuss a possible TDM system that combines a tour-based model with a traffic assignment procedure and we discuss feedback procedures within this modeling context.

A Tour-Based Model

The traditional trip-based approach to travel demand modeling uses individual trips as the unit of analysis and usually comprises three or four sequential steps in travel dimensions, as already discussed in Chapter 1. On the other hand, tour-based models use tours as the basic elements to represent and model travel patterns. A tour is a chain of trips beginning and ending at the same location, say, home or work. The tour-based representation helps maintain consistency across, and captures the interdependency (and consistency) of the modeled choice attributes among, the activity episodes (and related travel characteristics) undertaken in the same tour. This is in contrast to the trip-based approach that considers travel as a collection of 'trips,' each trip being considered independent of other trips.

The explicit consideration in the tour-based approach of the inter-relationship in the choice attributes (such as time of participation, location of participation, and mode of travel) of different activity episodes within a tour, and therefore the recognition of the temporal, spatial, and modal linkages among stops within a tour, can lead to improved evaluations of the impact of policy actions. Take, for example, an individual who drives alone to work and makes a shopping stop on the way back home from work. The home-work and work-home trips in this scenario are not independent.

Now consider an improvement in transit between the home and the work place. The activity-based approach would recognize that the individual needs to make a stop on the return home from work, and so may not predict a shift to transit for the work tour (including the home-work, work-to-shop, and shop-work trips). A trip-based model would break the tour into three separate and independent trips—a home-based work trip, a non-home based non-work trip, and a home-based non-work trip, and would be more likely (and inaccurately so) to shift the morning home-based work trip contribution of the individual to transit. In fact, the close association between stop-making during the commute periods and the mode choice for the work tour is now well-established (Portoghese et al., 2010).

Tour-based approaches also allow the analyst to employ models with a high level of temporal resolution (such as 30-minute or 1-hour time periods), with temporal modeling of tours and trips within tours. For the assessment of time-of-day specific policy measures such as peak period pricing, high occupancy vehicle lane designation during peak periods, and flexible work schedules, such fine-resolution representations of time of day in the modeling process can lead to more realistic evaluations of policy measures. Also, the tour-based model predicts travel patterns at the individual and household levels at which decisions are actually made. Thus, the impact of policies can be assessed by predicting individual-level behavioral responses instead of employing trip-based statistical averages that are aggregated over coarsely defined demographic segments. Further, even from a long-term forecasting point of view, the cross-classification techniques that are at the core of the application of trip-based methods employ statistical averages over highly aggregated socio-demographic segments. On the other hand, the tour-based model can accommodate virtually any number of decision factors related to the socio-demographic characteristics of the individuals, and the travel service characteristics of the surrounding environment. Thus, the tour-based models are better equipped to forecast the longer-term changes in travel demand in response to the changes in the socio-demographic composition and the travel environment of urban areas.

Feedback in Tour-Based Models

The travel patterns predicted by a tour-based modeling system (and that are input into traffic assignment) are based on specified travel impedance values. Thus, as in a traditional trip-based model, one needs to ensure that the impedance values obtained from the traffic assignment procedure are consistent with those used as inputs in the tour-based model. This is usually achieved through an iterative feedback process between the traffic assignment stage that outputs travel impedance (and flows) and the tour-based travel model that outputs travel patterns. It is important to consider such demand-supply interactions for accurate predictions of activity-travel behavior, and the resulting traffic flow conditions.

The precise form of feedback between a tour-based model and a traffic assignment model depends on the nature of the assignment model used. In many places where tour-based models have been implemented in practice, it is not uncommon to convert the travel patterns into trip tables by travel mode for four-to-five broad time periods of the day, and then load the time period-specific trip tables using a traditional static traffic assignment (STA) methodology. This methodology uses analytic link-volume delay functions, combined with an embedded shortest path algorithm, to determine link flows and link travel times. In such a static assignment approach, there is, in general, no simulation of individual vehicles and no consideration of temporal dynamics of traffic flow (Appendix A provides a brief overview of five different STA methodologies, ranging from the simple to the more advanced).

An important appeal of the tour-based approach, however, is that it predicts travel patterns at a fine resolution on the time scale. Thus, using a tour-based model with a static assignment process undoes, to some extent, the advantages of predicting travel patterns at a fine time resolution. This limitation, and the increase in computing capacity, has allowed the field to move toward a dynamic traffic assignment (DTA) methodology. The DTA methodology offers a number of advantages relative to the STA methodology, including the ability to address traffic congestion, buildup, spillback, and oversaturated conditions through the explicit consideration of time-dependent flows and the representation of the traffic network at a high spatial resolution. As a result, DTA is able to capture and evaluate the effects of controls (such as ramp-meters and traffic lights), roadway geometry, and intelligent transportation system (ITS) technology implementations.

There has been some literature on analytical method-based DTA models. However, the implementation of most DTA models relies on a microsimulation platform that combines (and iterates between) a traffic simulation model (to simulate the movement of traffic) with time-dependent routing algorithms and path assignment (to determine flows on the network). In particular, the traffic simulation model takes a network (nodes, links, and controls) as well as the spatial path assignment as input, and outputs the spatio-temporal trajectories of vehicles as well as travel times. The time-dependent shortest path routing algorithms and path assignment models take the spatio-temporal vehicle trajectories and travel times as input and output the spatial path assignment of vehicles. The two models are iterated until convergence between network travel times and vehicle path assignments. In this process, the traffic simulation model used may be based on macroscopic traffic simulation (vehicle streams considered as the simulation entity, and moved using link volume-delay functions), mesoscopic traffic simulation (groups of vehicles considered as cells and treated as the simulation entity), or microscopic traffic simulation (each individual vehicle considered as the simulation entity, incorporating inter-vehicle interactions). Macroscopic and mesoscopic traffic simulation models are less data-hungry and less computationally intensive than microscopic models, but are also limited in their ability to model driver behavior in response to advanced traffic information/management systems.

Most earlier DTA efforts have focused on the modeling of private car traffic, though a few recent research efforts have integrated mode choice and departure time choice within a microsimulation-based DTA model, thus moving further upstream in integrating tour-based models with dynamic traffic assignment (Reiser and Nagel 2009).

CHAPTER SUMMARY

In this chapter, we have discussed possible changes to the TxDOT travel demand model and how the feedback process can be updated under these possible future scenarios. Specifically, we have examined the state-of-the art of techniques and methods for the feedback process that may become important in the medium- to longer-term evolution of the TxDOT travel demand modeling system to address evolving travel conditions in metropolitan regions in the state. Should TxDOT proceed at some future time to implement a tour-based model, the issues discussed above will be further considerations in implementing or advancing their feedback methodology.

CHAPTER 4. SENSITIVITY ANALYSIS AND FIELD TEST

INTRODUCTION

This task seeks to undertake a first-level analysis of the practical challenges and the potential benefits of feedback procedures for a typical Texas urban area under the purview of TxDOT-TPP travel modeling. As described below, this field test demonstrated both challenges and opportunities in terms of ease in practical application, run-time considerations, and the effects on trip flows and travel times output from the travel demand model.

With TPP assistance, the Research Team selected a current TxDOT-developed urban model as a sample study area to implement a feedback approach using the Texas Package, and chose an approach to be implemented based on the efforts described in Chapters 1 and 2 and after discussion with TxDOT TPP. The study team then tested feedback considerations, practical challenges, and potential feedback benefits, as they relate specifically to a TxDOT urban model. These steps, as well as comparative findings, are presented in this Chapter. The Conclusions chapter documents recommendations resulting from this entire research effort.

ESTABLISH BASE MODEL

Identify a Study Area for Examination

An examination of candidate study area models was conducted based on several comparable statistics to help determine one to use as a demonstration model. Per direction from the Project Director, the list of candidate models was limited to Texas Transportation Management Areas (TMAs). Currently there are eight TMAs within the state of Texas; the eight TMAs are:

- Austin.
- Corpus Christi.
- Dallas-Fort Worth.
- El Paso.
- Hidalgo County.
- Houston-Galveston.
- Lubbock.
- San Antonio.

In addition another four urban areas are projected to reach TMA status (urbanized area population of over 200,000) based on the 2010 Census, namely:

- Amarillo.
- Brownsville.
- Killeen-Temple.
- Laredo.

Rationale for the Choice of One Model

Table 8 summarizes these 12 urban areas and, if applicable, provides a brief reason for excluding particular study areas from the list of candidates for the field test.

Table 8. Twelve TMAs Considered for Potential Case Study.

Urban Area	TMA Status	Considered Y/N)	Reason For Not Considering
Austin	TMA	No	TPP not solely responsible for TDM, already has feedback loop
Corpus Christi	TMA	No	Base year model did not use friction factors
Dallas-Fort Worth	TMA	No	TPP not solely responsible for TDM
El Paso	TMA	No	Questionable demographics
Hidalgo County	TMA	Yes	-
Houston-Galveston	TMA	No	TPP not solely responsible for TDM
Lubbock	TMA	No	Base year model did not use friction factors
San Antonio	TMA	No	TPP not solely responsible for TDM
Amarillo	Projected TMA	No	TDM validated to ’05 summer counts
Brownsville	Projected TMA	Yes	-
Killeen-Temple	Projected TMA	No	Base year model did not use friction factors
Laredo	Projected TMA	Yes	-

Two urban areas, Dallas-Fort Worth and Houston-Galveston, were not considered because TxDOT is not responsible for developing their travel models. Austin and San Antonio were excluded because TxDOT is only partially responsible for those models, and both urban areas have already incorporated a feedback process in the current model structure. Based on an initial review of the TxDOT model files, three other urban areas—Corpus Christi, Lubbock, and Killeen-Temple—were excluded because their base year models were not developed using friction factors. (These three models are each over 10 years old and were developed at a point in time when it was more common to use trip length frequency distributions in lieu of friction factors). Finally, Amarillo and El Paso were excluded due to specific concerns with the model: in the case of El Paso, the model’s demographics are problematic; the Amarillo model was validated against counts collected during the summer, which is atypical for TxDOT models.

Excluding nine of the 12 TMAs left only Brownsville, Hidalgo County, and Laredo. Brownsville and Hidalgo County are currently accounted for in a single regional model that also includes the Harlingen-San Benito urban area. The 2003 Laredo model indicated a useable level of congestion to test a feedback process; however, there were issues with the travel survey data that were collected to support the development of the model, resulting in a model that slightly under-represented counted VMT.

This left the regional Rio Grande Valley model (combined Hidalgo County, Harlingen-San Benito, and Brownsville) as the leading candidate for a feedback test case. After discussion with the PMC, the study team proceeded with the Rio Grande Valley (RGV) model for the field test.

Establish Base Scenarios for the Study Area

For the RGV model, then, the first step was to establish the base scenarios for examination. These scenarios will provide the base data—demographics, network, and model parameters—for all the scenarios to be examined for the field test. The base scenarios chosen were:

- Base Scenario: Original 2004 Calibrated Model.
- Base Scenario: Original No Build Model with 2035 Demographics on the 2004 Network.
- Base Scenario: Original Build Model with 2035 Demographics on the 2035 Network.

Table 9 summarized these base scenarios. It should be noted that, for the No Build scenario, network area types were appropriately updated to correspond to the 2035 demographics and corresponding densities and area types; hence, the network speeds and capacities will differ slightly from the true 2004 base year network.

Table 9. Original Sequential Model Runs: General Description.

Dimension	**Original Base Scenario: 2004**	**Original Base Scenario: 2035 No Build**	**Original Base Scenario: 2035 Build**
Run Name	Original Base Year 2004	Original No Build 2035	Original Build 2035
Network	Base Year 2004	Base Year 2004	Forecast Year 2035
Demographics	Base Year 2004	Forecast Year 2035	Forecast Year 2035
Time of Day	24-Hour	24-Hour	24-Hour

All three of these original base scenario runs were previously implemented using the standard Texas Package approach and tools, using TransCAD 4.5, as a sequential ('Single') model stream, and each examines the 24-hour period, which is standard for the urban area models implemented by TxDOT. More information on the standard TxDOT approach may be found in Chapter 2.

Of note, the Original Base Scenario 2004, as the base year for calibrating the original model, serves as the baseline for a broad-brush calibration of the feedback model. The feedback model will be calibrated to replicate the calibrated base year model results from a system-wide perspective, with examination of measures at the facility-type and area-type level. Scenarios B and C represent *model application* scenarios and therefore enable what Louden et al., (1997) call the 'true test':

> The true test of the effect of feedback on the output of a modeling system must be based on the difference in results from forecasting with a recalibrated model with feedback and a calibrated model system without feedback.

By examining both a base year and application scenarios, this field test provides a good basis for sensitivity analysis.

EXPERIMENTAL DESIGN

With the study area and base scenarios established, the next step was to define the design for experimentation. This involved revisiting the efforts described in Chapters 1 and 2 to incorporate insights derived from the research effort, as well as address issues of possible concern specific to feedback implementation in the Texas Package environment and established TxDOT urban model implementation using the Texas Package. The following core dimensions provide the structure for the experimental design.

Time Period to Be Examined

Given the findings discussed in Chapter 1, the biggest concern in defining an experimental design for this field test was the time period to be examined. As described in Chapter 2, the time period of the TxDOT models for the small- and medium-size urban areas is a 24-hour day. As discussed in Chapter 1, there is little research available on modeling feedback for a 24-hour full day period. While the fundamental premise of feedback seems to apply—that feedback solves the fundamental problem of sequential modeling by providing consistency of the time values input into the trip distribution step and that coming out of traffic assignment—nonetheless, many applications of feedback are made in the context of a peak period model. Although the research found in Chapter 1 did not turn up examples where it had been tested, the assertion has been made that feedback is not necessary except in ‘congested’ conditions, when peak periods tend to be more than a 24-hour period. It may also simply be the case that areas implementing feedback have already advanced their models to examine peak periods, and so they will naturally implement feedback for the peak.

This issue was discussed in length with the PMC, with the decision made to conduct the field test for the current 24-hour daily basis of the TxDOT urban-area models. By testing this aspect, the field test supports the original intent of this research report—to examine feedback for the TxDOT urban-area models as they currently are implemented. In addition, this field test would provide documentation of results for a 24-hour period model; these results might then be valuable for other communities considering implementing feedback. Certainly, given the research findings in Chapter 1 and the considerations in the above discussion, the possibility that feedback for a 24-hour model would be determined to be unnecessary seemed plausible and possible; yet it was agreed that this finding in and of itself would be a valuable finding for TxDOT.

Software Platform for the Feedback

Chapter 2 reminded us that the Texas Package has a long history independent of other travel demand model software packages nationwide. Currently, the Texas Package is run manually, with the user processing some data inputs manually to prepare input files, performing some functions using TransCAD version 4.5 menu items, calling certain utilities from the Texas Package either from a DOS screen or using a utilities menu set up within TransCAD. Chapter 2 describes this process in more detail.

For feedback purposes, involving many iterations of the model over potentially a period of hours, it was imperative to use some sort of program to run the model consistently and iteratively. For the purpose of this sensitivity analysis, the study team decided, with PMC concurrence, to develop the feedback mechanism using the Geographic Information System Developer's Kit (GISDK), a suite of software tools and functions implemented using a programming language called Caliper Script™. Similar to the BASIC programming language, Caliper Script is used to call GISDK functions and interact with TransCAD to perform repetitive and common tasks, improving consistency of model application and freeing the user to spend more time on data inputs and analysis of results. Potential advantages of choosing GISDK for the purpose of the current sensitivity analysis included using efficiencies that TransCAD enabled in the native file formats, team familiarity with GISDK, potential reuse of model components following this exercise, and not introducing another software language into the Texas Package, since TransCAD is already established in current use. Given additional time to implement a feedback procedure with the Texas Package framework, however, the research team still recommended limiting the use of vendor-provided programming languages for the reasons cited in Chapter 2.

It is important to note that the GISDK shell merely facilitates application of the Texas Package as described in Chapter 2, replacing the manual steps to apply TransCAD menu items and the Texas Package utilities, but maintaining strict adherence to the exact same Texas Package process. Figure 22 shows a flow chart of these steps of the Texas Package, with a blue-shaded area showing the steps that are being implemented as part of the feedback mechanism being tested here. Figure 23 shows the user interface developed for this field test.

The final decision made with regard to the software platform was to consider the use of TransCAD 4.5, the standard adopted version TxDOT currently uses for implementing the Texas Package, or TransCAD 5.0, the current industry-wide available version (version 6.0 is due to be released sometime in 2011). Additional considerations included:

- Version 5.0 is designed to work more efficiently with the most recent computer operating systems and take advantage of hardware architecture (e.g., multi-threading, memory allocations), a key issue for feedback.
- More straightforward coding functionality of a user interface in TransCAD 5.0 than in version 4.5.
- Improved online and customer support for TransCAD 5.0 from the developer, given that version 5.0 is their current release.
- More tools in version 5.0 to support implementation of a feedback mechanism.
- TxDOT is considering moving toward either TransCAD 5.0 or 6.0 in the future, making an investment in model development in version 4.5 a concern.

The study team lead considered these factors and decided the field test should proceed with TransCAD 5.0 for the purpose of this field test. There is no implied recommendation in this decision regarding TransCAD 5.0 for any other purpose.

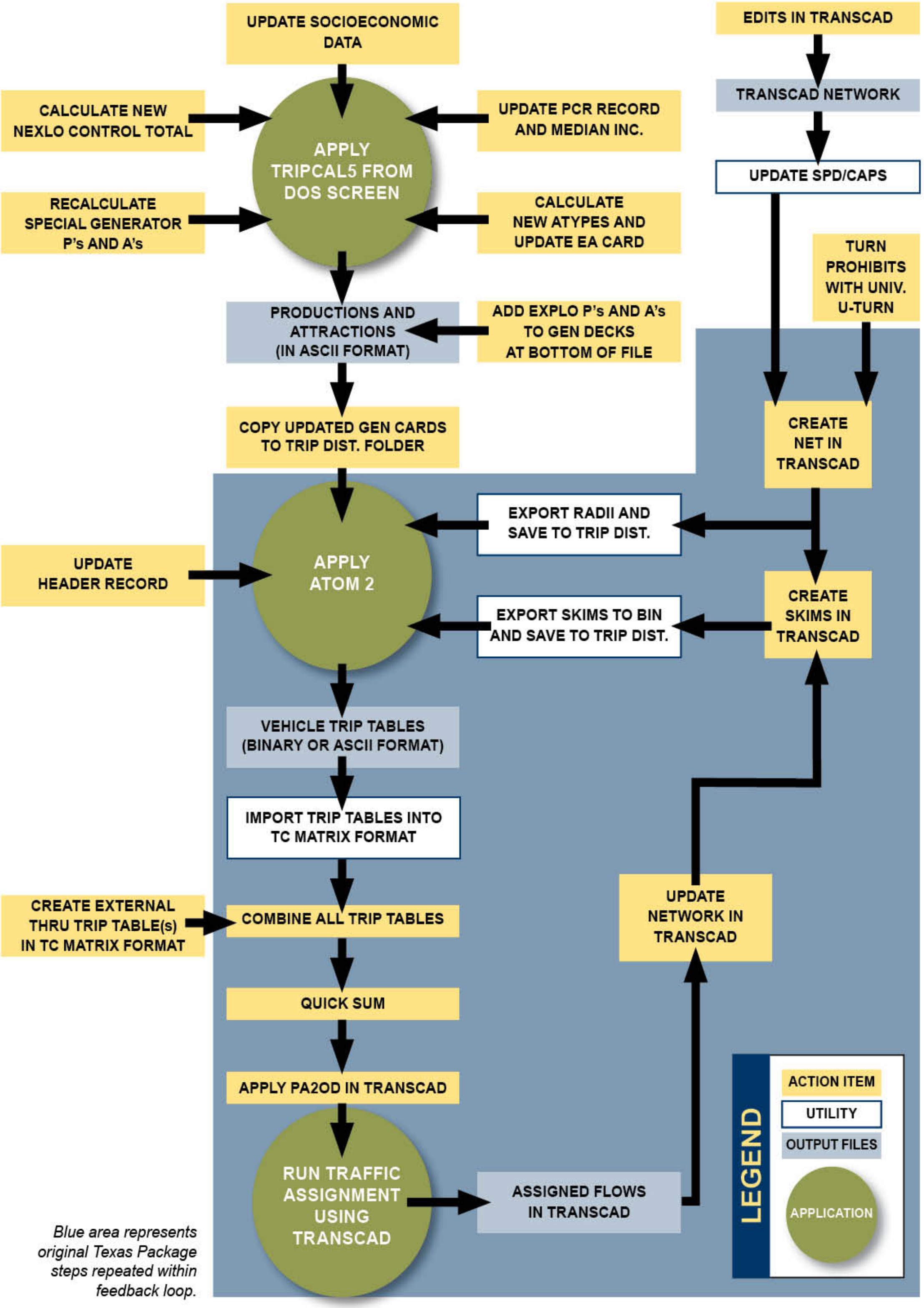
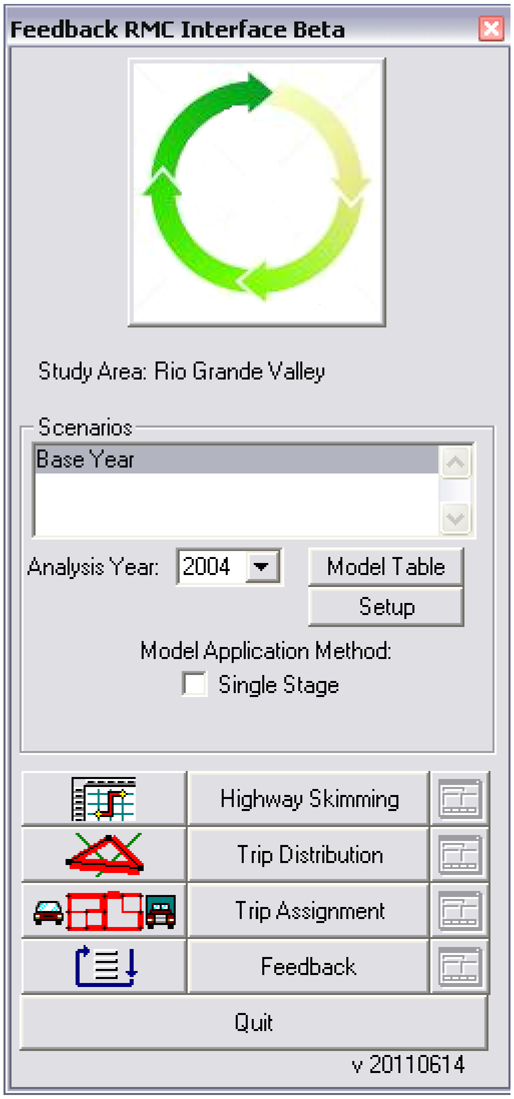


Figure 22. Implementation of the Feedback Mechanism in the Texas Package.


Feedback RMC Interface Beta

Study Area: Rio Grande Valley

Scenarios: Base Year

Analysis Year: 2004

Model Application Method:
☐ Single Stage

v 20110614

Figure 23. User Interface for Implementation of the Feedback Mechanism in the Texas Package.

Feedback Dimensions to be Tested

The feedback approaches to be tested were chosen based on the research in Chapter 1. As noted in that chapter, there is still much discussion on the various ways to approach feedback. However, certain aspects do have more background research to support a decision for use here.

Basis for Feedback Parameter

As discussed previously, a common approach, given a model which does not include accessibility inputs in the trip generation step, is to feed back travel times output from assignment into the trip distribution step. Given that the TxDOT standard urban model approach does not include accessibility measures for trip generation, the default approach chosen to test for this current examination is that shown in Figure 24, showing resulting assignment travel times being fed back to the trip distribution step.

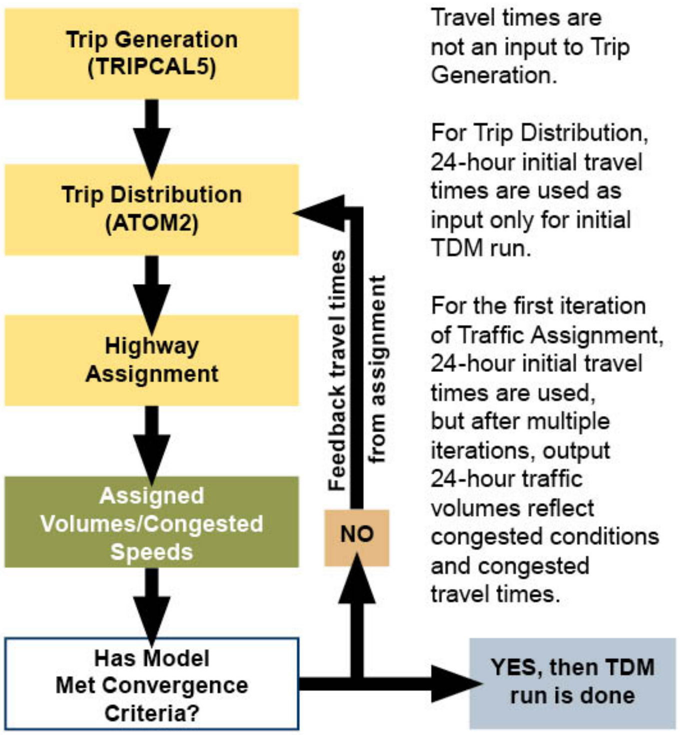


Figure 24. Approach 1: Feed Back Travel Times to Trip Distribution.

Updating Procedure

Once the decision has been made regarding which step to feed back to (in the above case, distribution), the next is choosing the method to use to adjust the times before feeding them back, and—related to this—when and how to make the adjustment. Chapter 1 discusses various options, several of which (most conspicuously, direct feedback) have been shown repeatedly to be less functional than other methods. For the purpose of the current examination, the following approach was chosen.

Under the MSA approach, link-by-link flows from the current iteration are combined with the corresponding link flows from previous iterations to produce a composite link flow value, which is then translated into a time value used for trip distribution of the next feedback loop. Deriving the composite link flow value can also be done in various ways. In this current field test, the link flows are factored using the MSA method. Using the feedback functions supported in the TransCAD software, the resulting MSA formula is:

$$MSAFlow_n = MSAFlow_{n-1} + \frac{1}{n} \cdot (Flow_n - MSAFlow_{n-1})$$

Where

n = current MSA iteration number.

$MSAFlow_n$ = calculated flow at iteration n.

$Flow_n$ = resulting flow directly from trip assignment.

The volume-delay relationship used to calculate the time resulting from the resulting MSAFlow value and the link-specific capacity value the BPR formula:

$$I_{(n+1)} = I_{(1)} * \; [1.0 + \alpha(\frac{v}{c})^{\beta}]$$

Where

$I_{(n+1)}$ = adjusted impedance.

$I_{(1)}$ = beginning impedance.

1.0 = constant.

V = 24-hour assigned volume.

C = 24-hour estimated capacity.

α = Alpha (0.15).

β = Beta (4.0).

The resulting times for each respective link are then updated to the highway network used for the trip distribution skims performed in the next loop of the model stream.

ESTABLISHING THE BASE CASE SCENARIOS

As a result of the above decisions regarding dimensions to be tested, multiple scenarios were defined as part of the experimental design process. The first are described here as the base case scenarios. The more significant model parameters as well as general summary statistics are presented and discussed, as well.

Original Sequential Model Scenarios

The Original Sequential Model Scenarios are the original base scenarios previously presented and described in the section *Establish Base Scenarios for the Study Area* on page 79. TxDOT TPP developed the Rio Grande Valley (RGV) model for planning purposes over the period 2009–2011. Table 10 defines these original model scenarios, the basis of our study here, to provide easy reference for discussion.

The RGV 2004 model was developed and applied according to standard TxDOT procedures, with one exception: the maximum number of assignment iterations—instead of being constrained to 24, the typical maximum—was set at 80. The base year 2004 model ran to 61 iterations before reaching the convergence criterion of 0.001 relative gap; the No Build and Build application models reached the maximum 80 iterations without achieving the 0.001 relative gap criterion. Test runs conducted as part of this examination demonstrated that the high number of assignment iterations resulted primarily because of constraints due to centroid connector capacities.

Table 10. Original Sequential Model Runs: Specific Parameters.

Dimension	Original Base Scenario: 2004	Original Base Scenario: 2035 No Build	Original Base Scenario: 2035 Build
Demographics	Base Year 2004	Forecast 2035	Forecast 2035
Network	Base Year 2004	Base Year 2004 with 2035 Area Types	Forecast 2035
Time of Day	24-Hour	24-Hour	24-Hour
Centroid Connector Capacities	Used	Used	Used
Assignment Convergence Criterion	0.001*	0.014*	0.011*
Maximum Assignment Iterations	80	80	80
Step Fed Back to	n/a	n/a	n/a
Data Fed Back	n/a	n/a	n/a
Basis for Feedback	n/a	n/a	n/a
Averaging Method	n/a	n/a	n/a
Feedback Convergence Criterion	n/a	n/a	n/a

**The No Build and Build model runs reached the maximum number of iterations without achieving the goal relative gap; the base year model ran 61 iterations.*

TxDOT guidance provides flexibility to the model developer to use centroid connector capacities or not, as necessary, to calibrate and validate a base year model, with a caution that using centroid connector capacities can cause problems for model application in forecast years if zonal demographics exceed the total capacity of all of the zone's centroid connectors. This issue is discussed more in the next section, regarding the development of a comparative sequential model for the purpose of this field test.

Table 11 presents demographics and the vehicle-trips by trip purpose for each of the original scenarios. Because the feedback mechanism to be tested for this field test does not affect the trip generation step, these scenario characteristics remain constant for all model scenarios, depending on whether they are a year 2004 or year 2035 demographic scenario. External trips for the 2035 Build scenario differ from those of the 2035 No Build scenario because of the addition of two international bridges as external stations; otherwise, the 2035 No Build and 2035 Build scenario demographics are the same.

Table 11. Demographics for All Model Scenarios.

Measure	Base Year 2004	No Build 2035	Build 2035
Population	1,055,394	2,136,578	2,136,578
Households	315,637	653,081	653,081
Population/ Household	3.34	3.27	3.27
Median HH Income	31,895	34,135	34,135
Total Employment	313,030	704,981	704,981
Basic	74,411	161,810	161,810
Retail	70,407	153,331	153,331
Service	136,380	331,805	331,805
Education	31,832	58,035	58,035
Employment/Population	0.30	0.33	0.33
Population/Employment	3.37	3.03	3.03
Total Vehicle Trips by Purpose	2,506,311	4,902,652	4,913,545
Home-based Work (HBW)	532,989	1,040,793	1,040,793
HB Non-Work Retail (HBNWR)	341,239	693,984	693,984
HBNW Education (HBNWE)	13,536	25,677	25,677
HBNW Other (HBNWO)	608,252	1,154,373	1,154,373
Non Home-based Work (NHBW)	146,070	304,407	304,407
Non Home-based Other (NHBO)	419,768	848,817	848,817
Truck-Taxi (TRTX)	154,017	311,797	311,797
Internal Subtotal:	2,215,871	4,379,848	4,379,848
External-Local-Auto (EXLO-A)	135,594	243,364	248,831
EXLO-Truck (EXLO-T)	20,958	37,770	37,851
NHB-External-Local (NEXLO)	132,284	238,668	244,040
External-Through-Auto (EXTH-A)	1,391	2,597	2,573
External-Through-Truck (EXTH-T)	213	405	402
External Subtotal:	290,440	522,804	533,697
Internal Trips/Person	1.95	1.90	1.90
Total Trips/Person	2.37	2.29	2.30

Testing the Sequential Model Parameters

Before considering feedback, the sequential model scenario deserves a moment of consideration by itself. For example, it is necessary to document any observed differences accountable to the change from different TransCAD versions to be able to exclude these differences from occurring because of the feedback mechanism. This also serves as an opportunity to investigate other model parameters which might need to be modified for feedback.

Four sequential runs were performed for Original Base Scenario 2004 then compared to the original model results. Table 12 shows that Alternatives 1 through 4 tested variations of the base year 2004 model results considering the TransCAD version, use of centroid connector capacities, and whether or not U-turns were prohibited. These preliminary tests were conducted to merely ensure that use of centroid connector capacities, U-turns, or different software versions were not influencing or affecting assignment results.

Table 12. Sequential Model, 2004: Base Year Tests.

Dimension	Original Base Scenario: 2004	Alternative 1	Alternative 2	Alternative 3	Alternative 4
TransCAD Version	4.5	5.0			
Centroid Connector Capacities	Yes			No	
U-Turns Prohibited	No		Yes	No	Yes

As Table 10 showed earlier regarding centroid connector capacities, the Original No Build 2035 and Build 2035 scenarios were unable to achieve the relative gap of 0.001 for assignment convergence within the specified 80 assignment iterations. Testing demonstrated that it would be necessary to run more than 200 assignment iterations to achieve the relative gap of 0.001.

It is standard TxDOT procedure to prohibit U-turns. The three Original Scenarios were performed without this prohibition; the feedback runs were performed following standard procedure. These tests demonstrate that only a minor difference overall had resulted.

For the purpose of these tests, other model parameters remained the same as they had been for the Original Base model, with the same friction factors for trip distribution and the Alpha and Beta values for traffic assignment (see Table 13).

Table 13. Alpha and Beta Values for All Model Runs.

Parameter	Alpha	Beta
Centroid Connector Links	1.00	5.30
Non-Centroid Connector Links	0.15	4.00

Table 14 (trip distribution) and Table 15 (traffic assignment) show the system-wide results for the sequential model tests. In these tables, percentages calculated for the alternative model runs 1-4 demonstrate the differences of each alternative from the Original Base Scenario 2004, run manually in TransCAD. For trip distribution, the average trip lengths barely change; intrazonal trips show some variance, but these changes are very slight compared to the regional total of 2.5 million trips. For traffic assignment, the table first presents counted VMT versus assigned VMT for all links with traffic counts. For this measure, Alternatives 1, 2, and 4 perform substantially the same as the original scenario. Alternative 3 is only 1 percentage point different, at 99 percent. For all non-centroid connector links, for the additional measures presented here, each of the scenarios performs similarly—within 99 percent of the values that the Original Base Scenario 2004 demonstrates.

Table 16 presents the results for VMT for counted links, a standard check for model validation, classified by Area Type and Facility Type. Again, these are standard system-wide checks performed for model calibration. In this table, the percentages shown are the Root Mean Square Error (RMSE) of the value as compared to the counted link values. Therefore, there are RMSE values shown for the Original Base Scenario 2004, as well. In this table, again, Alternatives 1 through 4 performed substantially well compared to the Original Base Scenario 2004 in replicating counted traffic for the RGV study area.

through 4 performed substantially well compared to the Original Base Scenario 2004 in replicating counted traffic for the RGV study area.

For the purpose of this research examination, no screenline/corridor or link level analysis was performed. This system-level examination was deemed sufficient to examine the practical impacts and feasibility of implementing a feedback mechanism for Texas urban models using the Texas Package with TransCAD 5.0. Clearly, in the case of any future model calibration, a much closer examination of link-level results is called for.

Thus, the parameters being tested here did not significantly alter the model results, but other considerations were taken into account to determine which parameters to use. For the feedback runs to follow, the decision of whether or not to use centroid connector capacities took some time as the study team weighed the goal of more closely following the original model settings versus the substantial amount of time added to each feedback iteration. The No Build scenario, exhibiting the most congestion to be resolved by the assignment algorithm, proved to be a deciding factor: for No Build, the scenario with no centroid connector capacities took 2 hours, 9 minutes (converging at 20 feedback loops). The scenario with centroid connector capacities also converged at 20 loops, but took 7 hours, 24 minutes to do so. Because the test runs of base year 2004 Alternatives 1 through 4 did not demonstrate any substantial difference at the region wide level, it was decided to proceed without centroid connector capacities for this current field test. For the decision of whether or not to prohibit U-turns, the team chose the TxDOT standard to prohibit them.

With these parameters set, the remaining runs included centroid connector capacities to a value of ‘99999’ in each direction (effectively unlimited) and prohibited U-turns. These parameter choices correspond to Alternative 4 of the alternatives tested.

Table 14. Sequential Model Results, 2004: Trip Distribution.

Trip Distribution Results	Original Base Scenario 2004	Alternative 1		Alternative 2		Alternative 3		Alternative 4	
Average Trip Length	Percentages in this table measure the difference of the alternative from the Original Base Scenario 2004.								
HBW	14.86	14.86	100%	14.89	100%	14.89	100%	14.89	100%
HBNWR	9.78	9.78	100%	9.77	100%	9.77	100%	9.77	100%
HBNWE	6.65	6.65	100%	6.65	100%	6.65	100%	6.65	100%
HBNWO	11.42	11.42	100%	11.42	100%	11.42	100%	11.42	100%
NHBW	10.99	10.99	100%	10.99	100%	10.99	100%	10.99	100%
NHBO	9.20	9.20	100%	9.20	100%	9.20	100%	9.20	100%
TRTX	18.50	18.51	100%	18.51	100%	18.51	100%	18.51	100%
NHB-EXLO	11.03	11.02	100%	11.03	100%	11.03	100%	11.03	100%
EXLO Auto	23.58	23.58	100%	23.59	100%	23.59	100%	23.59	100%
EXLO Truck	30.40	30.39	100%	30.39	100%	30.39	100%	30.39	100%
Intrazonal trips	Percentages in this table measure the difference of the alternative from the Original Base Scenario 2004.								
HBW	3,250	3,242	100%	3,345	103%	3,345	103%	3,345	103%
HBNWR	6,911	6,909	100%	7,594	110%	7,594	110%	7,594	110%
HBNWE	1,108	1,108	100%	1,114	101%	1,114	101%	1,114	101%
HBNWO	8,923	8,916	100%	9,565	107%	9,565	107%	9,565	107%
NHBW	1,610	1,609	100%	1,624	101%	1,624	101%	1,624	101%
NHBO	7,391	7,390	100%	7,747	105%	7,747	105%	7,747	105%
TRTX	1,324	1,329	100%	1,325	100%	1,325	100%	1,325	100%
NHB-EXLO	1,465	1,464	100%	1,458	100%	1,458	100%	1,458	100%
Total Intrazonal Trips	31,982	31,967	100%	33,772	106%	33,772	106%	33,772	106%

Table 15. Sequential Model Results: Traffic Assignment.

Traffic Assignment Results	**Original Base Scenario: 2004**	**Alternative 1**		**Alternative 2**		**Alternative 3**		**Alternative 4**	
Number of Iterations Run to Reach Relative Gap of 0.001	61	61		61		18		19	
Counted Links Only:	Percentages in this table measure the difference of the alternative from the Original Base Scenario 2004.								
Counted VMT	12,104,523	12,104,523	100%	12,104,523	100%	12,104,523	100%	12,104,523	100%
Assigned VMT	12,123,115	12,098,672	100%	12,106,728	100%	12,059,280	99%	12,065,559	100%
Assigned VMT/Counted VMT	100%	100%	100%	100%	100%	100%	99%	100%	100%
All Non-Centroid Connector Links:	Percentages in this table measure the difference of the alternative from the Original Base Scenario 2004.								
Assigned VMT	18,992,066	18,918,503	100%	18,945,900	100%	18,860,004	99%	18,888,424	99%
Network VMT Capacity	36,723,336	36,723,336	100%	36,723,336	100%	36,723,336	100%	36,723,336	100%
Assigned Volume/Capacity	52%	52%	100%	52%	100%	51%	99%	51%	99%
VMT/Person	18.00	17.93	100%	17.95	100%	17.87	99%	17.90	99%
VMT/Household	60.17	59.94	100%	60.02	100%	59.75	99%	59.84	99%
Vehicle-Hours Traveled (VHT)	513,429	510,252	99%	510,944	100%	509,142	99%	509,879	99%
VHT/Person	0.49	0.48	99%	0.48	100%	0.48	99%	0.48	99%
VHT/Household	1.63	1.62	99%	1.62	100%	1.61	99%	1.62	99%
Avg. Network Speed (Input)	40.98	41.01	100%	41.01	100%	41.01	100%	41.01	100%
Avg. Network Speed (Resulting)	38.03	38.10	100%	38.11	100%	38.08	100%	38.08	100%

Table 16. Sequential Model Results: Vehicle Miles Traveled for Links with Counts.

Vehicle Miles Traveled	Original Base Scenario: 2004		Alternative 1		Alternative 2		Alternative 3		Alternative 4	
By Area Type:	**VMT**	**RMSE**	**VMT**	**RMSE**	**VMT**	**RMSE**	**VMT**	**RMSE**	**VMT**	**RMSE**
CBD	145,935	31.80%	144,307	33.32%	144,336	33.23%	141,748	35.38%	141,916	35.17%
Urban	3,520,560	34.58%	3,511,749	33.86%	3,512,149	33.89%	3,508,436	34.10%	3,508,187	34.14%
Suburban	5,527,883	39.53%	5,496,898	39.00%	5,497,845	38.88%	5,473,120	39.47%	5,471,320	39.31%
Rural	2,928,737	45.93%	2,945,718	46.14%	2,952,398	49.04%	2,935,976	47.68%	2,944,137	50.48%
Total	12,123,115	40.79%	12,098,672	40.52%	12,106,728	41.48%	12,059,280	41.31%	12,065,559	42.24%
By Facility Type:	RMSEs in this table measure the difference of the alternative from the Counted Link Values.									
5–Freeways	5,033,862	20.30%	5,046,308	20.27%	5,043,731	20.31%	5,040,445	20.29%	5,033,118	20.24%
6–Freeways	61,489	9.72%	61,123	10.20%	61,570	9.69%	61,340	9.94%	61,744	9.66%
11–Div P Arts	532,942	31.91%	529,527	31.50%	530,077	31.46%	520,030	33.14%	520,077	33.22%
12–CLTL P Arts	1,885,004	31.22%	1,874,117	29.30%	1,868,614	33.28%	1,873,505	29.34%	1,868,388	33.60%
13–Undiv P Arts	2,018,514	47.51%	2,016,140	47.43%	2,029,465	48.45%	2,012,800	47.61%	2,027,336	48.62%
14–Div M Arts	17,881	74.07%	17,727	77.04%	17,744	77.34%	18,371	91.86%	18,315	92.61%
15–CLTL M Arts	740,040	43.25%	730,230	43.98%	729,129	44.06%	731,060	45.80%	729,936	45.53%
16–Undiv M Arts	672,448	62.16%	669,747	62.19%	670,234	62.30%	671,085	66.40%	671,711	66.16%
17–Div Collectors	1,766	25.36%	1,812	24.69%	1,808	24.73%	1,852	22.97%	1,848	22.95%
19–Undiv Collectors	722,989	75.91%	716,487	75.85%	718,406	75.26%	697,914	76.72%	701,701	76.33%
20–Frontage Roads	221,522	57.84%	220,980	57.68%	221,317	57.71%	214,658	61.42%	214,974	61.11%
21–Ramps	200,459	49.83%	200,122	49.67%	200,290	49.59%	201,708	49.65%	201,917	49.97%
22–Direct Connectors	14,200	46.38%	14,351	45.23%	14,343	45.31%	14,510	44.24%	14,495	44.40%
Total	12,123,115	40.85%	12,098,672	40.50%	12,106,728	41.49%	12,059,280	41.15%	12,065,559	42.11%

TransCAD Sequential Scenario: 2004

Having established the parameters to be used, Alternative 4 of the alternatives tested above is designated as the Sequential Scenario: 2004 for further reference in this examination and will be used as the comparative benchmark. Table 17 shows the parameters for this scenario. It will serve as the basis for implementing feedback for the year 2004 model.

Table 17. Sequential Scenario, 2004: Parameters.

Dimension	Sequential Scenario: 2004
Demographics	Base Year 2004
Network	Base Year 2004
Time of Day	24-Hour
Centroid Connector Capacities	Not Used
Assignment Convergence Criterion	0.001
Maximum Assignment Iterations	80

ESTABLISHING MEASURES OF FEEDBACK CONVERGENCE

Prior to testing feedback, and as part of defining an experimental design, it is necessary to formulate measures of effectiveness to assess the performance of feedback for this field test and, of course, to provide a stopping criterion. The feedback measures to be calculated for each model run are described below and are based on findings in Chapter 1. Other performance measures related to the implementation and application of the feedback looping mechanism—e.g., computational efficiency, model stability, and ease of implementation—are discussed later in this chapter.

***Percentage Root Mean Squared Error (PRMSE)*:** This is computed as a percentage Root Mean Square error (*RMSE*) change where *RMSE* is obtained as the square root of the sum of the squared differences of the element-by-element basis attribute value vector/matrix between successive iterations. The basis attribute for skim and trip are inter-zonal travel time and origin-destination trip interchanges matrix respectively. The *PRMSE* measure is shown as:

$$PRMSE_k = \frac{\sqrt{\sum_{ij}\left(p_{ij}(k-1)-q_{ij}(k)\right)^2}}{\sum_{ij} p_{ij}(k-1)} \times 100\,\% \le \hat{E} \Rightarrow \text{Convergence achieved at the } k^{\text{th}} \text{ iteration.}$$

where $p(k-1)$ refers to the basis attribute at the end of the $(k-1)^{\text{th}}$ iteration of the feedback process, while $q(k)$ refers to the basis attribute from the k^{th} iteration. E is the convergence target value or the tolerance value at which the feedback process is considered to have converged.

***Total Misplaced Flow (TMF)*:** This measure is calculated using the origin-destination trip tables of the current and previous iteration in the feedback process. The feedback process is declared as having converged if the TMF is lower than a predetermined tolerance level of *E*.

$$TMF_k = \sum_{ij} \left| p_{ij}(k-1) - q_{ij}(k) \right| \leq E \Rightarrow \text{ Convergence achieved at the } k^{\text{th}} \text{ iteration.}$$

where $p(k-1)$ refers to the OD trip table at the end of the $(k-1)^{\text{th}}$ iteration of the feedback process, while $q(k)$ refers to the OD trip table from the k^{th} iteration. *E* is the convergence target value or the tolerance value at which the feedback process is considered to have converged.

***Percentage GEH*:** This measure is based on a traffic modeling formula known as GEH which is used to compare two sets of traffic volumes. The GEH measure is shown as:

$$GEH = \sqrt{\frac{2\left(p(k-1) - q(k)\right)^2}{p(k-1) + q(k)}}$$

where $p(k-1)$ refers to the total flow for each link at the end of the $(k-1)^{\text{th}}$ iteration of the feedback process, while $q(k)$ refers to the total flow at each link from the k^{th} iteration.

The percentage GEH represents the fraction of links for which GEH value is greater than GEH threshold computed over all network links. A typical percentage GEH threshold is 5.

***Maximum GEH*:** Maximum GEH represents the maximum GEH statistic computed for all links between current and previous feedback iterations in the feedback process.

***Flow Difference for Maximum GEH*:** This represents the absolute difference in total flows for the link between current and previous feedback iterations for which the Maximum GEH has been observed in the feedback process.

***Total Link Flow for Maximum GEH*:** This represents the total link flow for the link in the current feedback loop for which Maximum GEH has been observed.

***Feedback Maximum Flow Change*:** Feedback Maximum Flow Change represents the maximum absolute difference in total link flow between current and previous feedback iterations for all the network links in the feedback process.

***Total Link Flow for Maximum Flow Change*:** This represents the total link flow computed for the link with the maximum absolute difference in total link flow between current and previous feedback iterations for all the network links in the feedback process *i.e.* total link flow for the link with ‘Feedback maximum flow change’ statistic.

***Percent of the Maximum Flow Change Over the Total Link Flow for That Link*:** This represents the percentage of the above two values, to demonstrate the order of magnitude of the link flow change.

All of these measures are calculated for each feedback loop, and the basis for examination was the current feedback loop results compared to the feedback result from the immediate prior loop. A single criterion, Percent Root Mean Square Error (PRMSE), was used to control the end of feedback (when PRMSE was equal or below 0.01). However, the results for all of the measures were recorded for examination.

MSA FEEDBACK: 2004 BASE YEAR

With the sequential 2004 model operational, and the feedback measures established, the next step is to implement the feedback loop established in the experimental design and examine the results for the base year. The goal would be to develop a feedback model that closely replicates the behavior of the original calibrated base year model for 2004. Table 18 shows the parameters for this MSA Feedback Model for Base Year 2004 with the comparable parameters for the Original Base Scenario and the TransCAD Sequential Scenario provided for comparison. As Chapter 2 anticipated, there were several issues to be resolved in implementing feedback for the Texas Package. First, some of the inputs and variables that were crucial to this field test are addressed.

Table 18. MSA Model Parameters: 2004.

Dimension	Original Base Scenario: 2004	Sequential Scenario: 2004	MSA Scenario: 2004
Demographics	Base Year 2004	Base Year 2004	Base Year 2004
Network	Base Year 2004	Base Year 2004	Base Year 2004
Time of Day	24-Hour	24-Hour	24-Hour
Friction Factors	Original	Original	New
Centroid Connector Capacities	Used	Not Used	Not Used
Assignment Convergence Criterion	0.001	0.001	0.001
Maximum Assignment Iterations	80	80	80
Step Fed Back to	n/a	Trip Distribution	Trip Distribution
Data Fed Back	n/a	Highway link travel time	Highway link travel time
Basis for Feedback	n/a	Travel time is calculated by averaging link volumes	Travel time is calculated by averaging link volumes
Averaging Method	n/a	MSA	MSA
Feedback Convergence Criterion	n/a	RMSE of Trip Distribution Skim = 0.01	RMSE of Trip Distribution Skim = 0.01

Trip Generation (TRIPCAL5)

As the experimental design was established in the Texas Package, the trip generation step does not include any sensitivity to travel time. Therefore, trip generation results are held constant and the original trip generation output results are used.

Network Specification

The relevant fields for this field test were TIME, ALPHA, BETA, and directional CAPACITY. The values used for the original model were used. The turn penalty file from the original model was also used.

Trip Distribution (ATOM2)

Chapter 2 has a detailed coverage of the model inputs for trip distribution; these are shown again for easy reference here:

- Separation matrix of network travel times.
- Zonal radii values for each zone (surrogate for zone size).
- Productions and attractions by zone for each of the trip purposes.
- Sector equals record, which is a table-of-equals between zones and sectors.
- Trip length frequency distribution (TLFD) by minutes of separation.
- Calibrated friction factors for each trip purpose.
- Bias factors (i.e., K-factors in traditional gravity models).

Trip Distribution Inputs Held Constant for Feedback

Of these input files, the following were held constant for the purpose of feedback and are the same as the original base model scenario:

- Zonal radii values for each zone (surrogate for zone size).
- Productions and attractions by zone for each of the trip purposes.
- Sector equals record, which is a table-of-equals between zones and sectors.
- Trip length frequency distribution (TLFD) by minutes of separation.
- Bias factors (i.e., K-factors in traditional gravity models).

Zonal radii values are derived by averaging the time values of all centroid connectors in a zone and used in ATOM2 to represent a proxy of zonal size. After discussion, it was decided that radii values should remain constant through feedback because the respective sizes of the zones are not changing even if times along the centroid connectors are changing. This issue became moot when the centroid connector capacities were removed.

For the remaining inputs in this group, productions and attractions by zone are output from trip generation which is unaffected by the feedback being tested here. The sector equals record and TLFD are used for informational and report generating purposes under the current model setup. Bias factors are a calibration tool which could be modified as part of a detailed calibration effort but were accepted intact as part of this field test.

Trip Distribution Inputs Modified for Feedback

During each iteration of feedback, the separation matrix of zone-to-zone travel times derived from network link travel times is updated based on revised link speeds and travel times. For the first iteration of feedback, this separation matrix is the same as the original base model scenario; in subsequent loops, this is the trip distribution input which the feedback mechanism is updating with times.

A second trip distribution model input revision that was necessary under feedback concerned friction factors. The initial feedback run using the original friction factors for the original base scenario yielded the first consequential results: total system-wide VMT dropped to 93 percent of that demonstrated for the original base scenario. After examination, researchers determined that the model system was indeed reacting to the congested travel times being fed back from traffic assignment to trip distribution. While the original friction factors were yielding the same average trip lengths in minutes, because of congestion (i.e., links revised with lower speeds and longer travel times based on assigned link volume to capacity ratios), average trip length in miles had decreased yielding a decline in VMT.

Based on the revised zone-to-zone travel times contained in the final feedback iteration separation matrix, it was thus necessary to recalibrate friction factors so that a resulting average trip length in miles by trip purpose could be achieved comparable to the original validated model average trip lengths by trip purpose. As a result, these new friction factors yielded higher average trip lengths in minutes, but comparable average trip lengths in miles. Thus, by achieving comparable average trip lengths in miles by the final iteration of feedback, total system VMT comparable to the original base year scenario was also attained. The revised friction factors were subsequently used for all feedback runs, base year, and future year.

It should be noted that though friction factors need to be recalibrated as a step towards implementing feedback, the integrity of the original trip distribution model is still maintained. The recalibration of friction factors is undertaken only to employ a set of friction factors for each trip purpose that is compatible with the revised zone-to-zone travel times (i.e., separation matrix). Note that this still yields modeled resulting average trip lengths in miles comparable to the resulting average trip length in miles for each trip purpose prior to the introduction of feedback.

Traffic Assignment

The same input TIME, ALPHA, BETA, and directional CAPACITY fields were used from the original base year model, except for the centroid connector capacities as previously discussed. To be clear, the input TIME value is always the original TIME value at the beginning of the highway assignment step for each iteration of feedback; no warm start values were tested in this field test. The same traffic assignment algorithm User Equilibrium was applied as for the base year, with the same maximum of 80 assignment iterations.

MSA Feedback Model Results: 2004

Table 19 shows feedback convergence measures. As established for the experimental design, Percentage Root Mean Square Error (PRMSE) was set as the control for feedback convergence. Table 21 indicates that all of the measures are converging; however, some are converging more quickly than others. For example, percent GEH nearly achieves the acceptable threshold of 5 percent by the fourth iteration and surpasses the 5 percent acceptable threshold by the fifth iteration. Three of the columns (i.e., maximum GEH link flow, total link flow, and percent difference) in Table 21 appear to show oscillating values; however, this is merely a function of the worst differences residing with different links for a specific iteration. For example, the worst absolute difference for iteration two was a value of 9,937 on a link with a total flow of 64,651. By the 14th iteration, the worst absolute difference is only 54 on a link with a total flow of

16,477. In this regard, the columns worth noting are maximum GEH difference and absolute difference since the differences by the last iteration declined significantly compared to the second iteration values.

Model results for the 2004 MSA Scenario model are provided in Table 20, Table 21, and Table 22. Comparative results are included for the Sequential Scenario and the MSA Scenario. As the various measures demonstrate, the MSA feedback scenario performs well to replicate the model behavior of the base year. Table 20, which summarizes trip distribution results, indicates that resulting modeled trip lengths and intrazonal trips by trip purpose are comparable. Table 21 also indicates that assignment results are also comparable, and does show that the assigned VMT versus counted VMT for counted links, a standard model check for model validation, is 101 percent for the MSA Scenario. It should be noted that this value could have been 100 percent with an additional round of friction factor calibration, a level of precision that was not sought for the purpose of the current field test.

For the base year, an initial thought might be that the development of a feedback mechanism is additional work if it merely results in the same output as the sequential model. However, it is important to note that, even in the base year model, the MSA feedback model is ensuring consistency between the times used for trip distribution and those output from traffic assignment. Table 22 provides additional data to show that assignment results are both comparable and yielding similar results in relation to counted VMT by area type and facility type.

Table 19. MSA Feedback Model Results, 2004: Feedback Measures of Convergence.

Iteration#	PRMSE-Skim	PRMSE-Trip Table	TMF-Trip Table	% GEH	Max GEH	Max GEH Difference	Max GEH Link Flow	Abs. Difference	Tot Link Flow	% Difference
1	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
2	15.1125	88.2838	22.4758	1248%	37.659	9,937	64,651	9,937	64,651	15.3694
3	4.301	41.1837	16.699	86%	12.6979	592	1,877	1,168	63,483	1.8407
4	0.3827	32.711	13.2913	6%	7.0272	292	1,585	499	11,344	4.3962
5	0.1352	28.7584	11.4867	0%	3.6908	144	1,441	306	32,322	0.9467
6	0.0857	26.7252	10.3675	0%	3.249	121	1,320	272	32,365	0.8406
7	0.051	26.0763	10.0057	0%	1.9779	301	22,996	301	22,996	1.3086
8	0.0347	25.0428	9.3383	0%	1.9848	145	5,301	165	8,439	1.9574
9	0.0231	24.1158	8.879	0%	1.2649	14	109	166	32,003	0.5194
10	0.0224	23.6387	8.6315	0%	1.4607	144	9,604	144	10,677	1.3527
11	0.0142	23.6124	8.606	0%	1.7487	120	4,619	120	4,619	2.5895
12	0.0137	23.489	8.5885	0%	1.2457	43	1,187	110	33,036	0.3323
13	0.0103	23.0651	8.3414	0%	1.0801	67	3,861	89	38,976	0.2286
14	0.0098	22.7742	8.1429	0%	0.7883	52	4,426	54	16,477	0.3257

Table 20. MSA Feedback Model Results, 2004: Trip Distribution.

Trip Distribution Results	Sequential Scenario	MSA Scenario
Average Trip Length (in minutes)		
HBW	14.89	16.39
HBNWR	9.77	10.63
HBNWE	6.65	7.23
HBNWO	11.42	12.49
NHBW	10.99	11.93
NHBO	9.20	9.89
TRTX	18.51	20.15
NHB-EXLO	11.03	12.04
EXLO Auto	23.59	26.03
EXLO Truck	30.39	33.90
Intrazonal Trips		
HBW	3,345	2,854
HBNWR	7,594	6,752
HBNWE	1,114	1,001
HBNWO	9,565	7,978
NHBW	1,624	1,474
NHBO	7,747	7,189
TRTX	1,325	1,146
NHB-EXLO	1,458	1,240
EXLO Auto	0	0
EXLO Truck	0	0
Total Intrazonal Trips	33,772	29,634

Table 21. MSA Feedback Model Results, 2004: Traffic Assignment.

Traffic Assignment Results	Sequential Scenario	MSA Scenario
Iterations Run to Reach Convergence	19	25
Counted Links Only:		
Counted VMT	12,104,523	12,104,523
Assigned VMT	12,065,559	12,242,525
Assigned VMT/Counted VMT	100%	101%
All Non-Centroid Connector Links:		
Assigned VMT	18,888,424	19,130,459
Network VMT Capacity	36,723,336	36,723,336
Assigned Volume/Capacity	51%	52%
VMT/Person	17.90	18.13
VMT/Household	59.84	60.61
Vehicle-Hours Traveled (VHT)	509,879	515,264
VHT/Person	0.48	0.49
VHT/Household	1.62	1.63
Average Network Speed (Input)	41.01	41.04
Average Network Speed (Resulting)	38.08	38.15

Table 22. MSA Feedback Model Results, 2004: VMT for Links with Counts.

Vehicle Miles Traveled	Counted	Sequential Scenario	Percent of Counted	MSA Scenario	Percent of Counted
VMT by Area Type:					
CBD	160,512	141,916	90.92%	142,364	88.69
Urban	3,512,596	3,508,187	100.23%	3,533,427	100.59
Suburban	5,521,349	5,471,320	100.12%	5,516,302	99.91
Rural	2,910,066	2,944,137	100.64%	3,050,431	104.82
Total	12,104,523	12,065,559	100.15%	12,242,525	101.14
VMT by Facility Type (number is TxDOT standard facility type number):					
5–Freeways	5,033,118	5,033,118	104.75%	5,124,195	106.63
6–Freeways	61,744	61,744	96.07%	62,131	97.07
11–Divided Principal Arterials	520,077	520,077	110.55%	520,381	107.94
12–Prin. Arterials with Center Lane	1,868,388	1,868,388	108.57%	1,900,889	109.48
13–Undivided Principal Arterials	2,027,336	2,027,336	102.33%	2,042,468	103.54
14–Divided Minor Arterials	18,315	18,315	90.49%	18,531	93.78
15–Minor Arterials with Center Lane	729,936	729,936	91.63%	740,230	91.65
16–Undivided Minor Arterials	671,711	671,711	86.81%	681,579	87.98
17–Divided Collectors	1,848	1,848	92.28%	1,901	99.32
18–Collectors with Center Lane	N/A	N/A	N/A	N/A	N/A
19–Undivided Collectors	701,701	701,701	75.47%	711,693	74.29%
20–Frontage Roads	214,974	214,974	81.45%	222,044	81.65%
21–Ramps	201,917	201,917	106.92%	202,001	107.74%
22–Direct Connectors	14,495	14,495	63.41%	14,482	64.67%
Total	12,065,559	12,065,559	100.15%	12,242,525	101.14%

MSA FEEDBACK: 2035 NO BUILD

The first application test of the feedback model was for the 2035 No Build. As explained previously, this scenario was chosen as part of the experimental design for the field test because it would represent the highest level of congestion: the network is held the same as for the base year 2004 model, but the demographics represent the forecast year 2035 demographics. As explained in Chapter 1, congested scenarios are generally thought to be the most applicable for feedback to be implemented. As asserted in Chapter 2, the Texas urban models that TxDOT developed and maintained are not thought to demonstrate much congestion. The RGV model is one of the few that demonstrates slightly higher congestion. Therefore, if the 2035 No Build scenario did not demonstrate any change in results for the field test, this might be a valid argument that feedback is not applicable for most Texas urban models.

Model Setup

For this application of the MSA feedback model, all model settings established for the MSA Base Feedback model are used (see Table 23). Because the model is a No Build, the same 2004 network database is used. The primary exception is that No Build demographic output from the No Build trip generation step is used; these demographics were summarized previously in Table 11.

Table 23. MSA Model Parameters: 2035 No Build.

Dimension	Sequential Scenario	MSA Scenario
Demographics	Base Year 2004	Base Year 2004
Network	Base Year 2004 with 2035 Area Types	Base Year 2004 with 2035 Area Types
Time of Day	24-Hour	24-Hour
Friction Factors	Original	New
Centroid Connector Capacities	Not Used	Not Used
Assignment Convergence Criterion	0.001	0.001
Maximum Assignment Iterations	1000	1000
Number of Assignment Iterations to Reach Convergence	209	68
Step Fed Back to	n/a	Trip Distribution
Data Fed Back	n/a	Highway link travel time
Basis for Feedback	n/a	Travel time is calculated by averaging link volumes
Averaging Method	n/a	MSA
Feedback Convergence Criterion	n/a	RMSE of Trip Distribution Skim = 0.01
Feedback Loops to Reach Convergence	n/a	20

** For the original No Build model, maximum assignment iterations were set to 80, but the relative gap attained was only 0.014. For the field test runs, both sequential and feedback, assignment iterations were not limited to allow the algorithm to achieve the convergence criterion.*

A second exception in the settings was made for the maximum number of assignment iterations. For the original no build model run, the assignment had not reached the TxDOT standard convergence criterion of 0.001 relative gap. For the TransCAD 5.0 sequential no build and the MSA feedback no build scenarios, the maximum number of assignment iterations was set to 1,000, effectively allowing the User Equilibrium assignment algorithm to achieve the relative gap of 0.001.

MSA Feedback Model Results: 2035 No Build

Table 24 shows the feedback convergence measures. As established for the experimental design, Percentage Root Mean Square Error was set as the control for feedback convergence. As shown in the table, however, all of the measures are converging.

Table 25 and Table 26 provide the comparative model results for the MSA 2035 No Build. MSA results are compared to the Sequential No Build Scenario. As Table 25 demonstrates, both respond to the increased congestion of the No Build scenario with increased average trip lengths (in minutes) by purpose, which is an expected result. The difference between the MSA scenario and sequential scenario reflects the different starting average trip lengths, as previously discussed.

Table 26 shows that the differences arising from the increased levels of congestion are readily apparent for the MSA model application. Also, this Table includes an additional column providing the original no build model results merely to show the iteration differences required to reach convergence. For the MSA run, assigned VMT at 33.2 million is significantly lower than the sequential values, with the original No Build scenario demonstrating almost 40 million VMT. As a result, the assigned volume-to-capacity ratio ranges between 102 and 105 percent for the two sequential scenarios but is only 87 percent for the MSA feedback scenario. Vehicle-hours-traveled (VHT) is similarly less with feedback than without it: 1.2 million versus 1.8 to 2.0 million. As the assigned volume to capacity statistic indicates, all of the VMT values are unreasonably high values, though the feedback scenario appears to respond to the constraint of system capacity by reducing the distance that people have traveled.

These results follow an intuitive storyline that the literature on feedback suggested (see Chapter 1). That is, for the sequential models, trips are distributed based on times that are unreflective of traffic congestion. Feedback corrects this inconsistency and the result is that, for a congested scenario, average trip length in time increases, but the distance traveled in that time decreases.

Table 24. MSA Feedback Model Results, 2035 No Build: Feedback Measures of Convergence.

Iteration#	PRMSE-Skim	PRMSE-Trip Table	TMF-Trip Table	% GEH	Max GEH	Max GEH Difference	Max GEH Link Flow	Max Flow Difference	Tot Link Flow	% Difference
1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2	99.4300	479.423	66.6755	47.1707	119.962	27,824	39,883	29,860	98,499	30.315
3	39.3757	344.524	45.2335	11.4678	36.1486	897	1,065	3,539	94,961	3.7264
4	2.1757	37.7997	10.7135	2.2032	12.1684	267	617	1,620	93,341	1.7355
5	0.6786	23.8495	8.6487	0.4990	8.9757	400	2,188	909	92,432	0.9832
6	0.2956	20.9472	7.7531	0.0942	6.0087	254	1,656	570	91,862	0.6210
7	0.1630	18.3287	7.1060	0	4.6203	183	1,473	390	91,472	0.4261
8	0.1039	16.8696	6.5919	0	3.8003	142	1,331	274	91,198	0.3008
9	0.0706	16.5931	6.2787	0	2.8909	81	740	223	12,790	1.7448
10	0.0505	16.6930	6.0045	0	2.4986	86	1,142	184	12,606	1.4616
11	0.0394	16.1133	5.6342	0	2.1793	72	1,069	136	19,902	0.6820
12	0.0322	14.3233	5.4372	0	1.8655	60	1,009	121	12,373	0.9789
13	0.0270	13.9891	5.3053	0	1.6355	39	552	91	29,914	0.3043
14	0.0204	13.6408	5.0324	0	1.3983	43	917	86	12,202	0.7049
15	0.0179	13.3123	4.8905	0	1.2226	37	880	75	12,127	0.6198
16	0.0156	13.2276	4.8628	0	1.1516	34	846	60	43,494	0.1381
17	0.0141	13.0647	4.7254	0	1.0688	23	449	62	12,016	0.5176
18	0.0121	12.7597	4.5991	0	0.9582	20	429	57	11,959	0.4760
19	0.0106	12.8610	4.7027	0	0.8409	14	257	48	19,382	0.2489
20	0.0093	12.9247	4.6910	0	0.8253	17	398	48	48,554	0.0996

Table 25. MSA Feedback Model Results, 2035 No Build: Trip Distribution.

Trip Distribution Results	Sequential Scenario	MSA Scenario
Average Trip Length (in minutes)		
HBW	16.52	20.11
HBNWR	10.55	12.48
HBNWE	6.43	6.94
HBNWO	12.68	14.46
NHBW	12.16	14.01
NHBO	10.06	11.36
TRTX	19.30	23.28
NHB-EXLO	12.11	13.62
EXLO Auto	24.48	31.48
EXLO Truck	32.04	42.12
Intrazonal Trips		
HBW	5,738	6,661
HBNWR	10,997	12,070
HBNWE	1,919	2,041
HBNWO	17,054	18,965
NHBW	3,481	4,467
NHBO	15,999	20,799
TRTX	2,549	2,260
NHB-EXLO	2,558	2,779
EXLO Auto	0	0
EXLO Truck	0	0
EXTHRU	n/a	n/a
Total	60,295	70,042

Table 26. MSA Feedback Model Results, 2035 No Build: Traffic Assignment.

Traffic Assignment Results, Including Vehicle-Miles-Traveled (VMT)	**Original Base Scenario**	**Sequential Scenario**	**MSA Scenario**
Iterations Run to Reach Convergence	80	209	68
Assigned VMT	39,959,244	38,953,468	33,163,703
Network VMT Capacity	38,188,275	38,188,275	38,188,275
Assigned Volume/Capacity	105%	102%	87%
VMT/Person	18.70	18.23	15.52
VMT/Household	61.19	59.65	50.78
Vehicle-Hours Traveled (VHT)	1,992,591	1,825,807	1,188,149
VHT/Person	0.93	0.85	0.56
VHT/Household	3.05	2.80	1.82
Average Network Speed (Input)	38.87	38.96	39.12
Average Network Speed (Resulting)	25.39	26.11	30.63
VMT by Area and Facility Types (number is TxDOT standard facility type number)**:**			
CBD	524,050	500,359	403,171
Urban	19,320,811	18,673,473	15,753,297
Suburban	13,903,492	13,611,323	11,399,559
Rural	6,210,891	6,168,314	5,607,675
5–Freeways	8,957,563	8,837,409	7,456,977
6–Freeways	563,482	567,297	503,371
11–Divided Principal Arterials	2,168,215	2,113,887	1,793,240
12–Princ. Arterials with Center Lane	6,206,670	6,087,007	5,458,845
13–Undivided Principal Arterials	6,087,743	6,002,882	5,422,643
14–Divided Minor Arterials	161,859	153,612	141,049
15–Minor Arterials with Center Lane	3,570,024	3,457,013	2,926,707
16–Undivided Minor Arterials	2,919,808	2,797,244	2,439,407
17–Divided Collectors	26,665	23,486	22,394
18–Collectors with Center Lane	0	0	0
19–Undivided Collectors	6,873,028	6,585,450	5,231,935
20–Frontage Roads	1,993,668	1,935,764	1,396,976
21–Ramps	398,441	361,045	343,611
22–Direct Connectors	32,077	31,371	26,548

As a minor, but interesting observation, the sequential 2035 No Build scenario took 209 assignment iterations to reach the assignment convergence criterion of 0.001 relative gap. The decision had been made to allow the assignment algorithm to reach the relative gap instead of capping the maximum number of assignment iterations, as had been done for the original 2035 No Build model application. Table 27 shows that the MSA 2035 No Build also demonstrates a high number of assignment iterations for the first model run, in response to the high level of congestion of the No Build scenario. For loop 2, in which trips were distributed based on the highly congested times from loop 1, congestion has been greatly reduced (because trip distribution is responding to the extremely high level of congestion), so that the number of assignment iterations to reach convergence is also much reduced, to 25. Loop 3 again represents higher congestion, and then the remainder of the loops demonstrates relatively less change as the system stabilizes.

Table 27. MSA Model Assignment Iterations by Feedback Loop: 2035 No Build.

Feedback Loop	Number of Assignment Iterations	Feedback Loop	Number of Assignment Iterations
1	230	11	67
2	25	12	68
3	81	13	70
4	68	14	69
5	68	15	67
6	69	16	69
7	67	17	69
8	67	18	69
9	70	19	64
10	66	20	68

Reflections on the MSA Feedback Model Results for the 2035 No Build

Because the results for the feedback application for the No Build scenario were both intriguing and surprising, the study team performed additional research to find examples of similar findings, particularly with reference to the system-wide decrease in VMT and VHT under feedback.

Florida DOT performed a similar exploration into using feedback in a 2003 report (Lan et al., 2003). Unfortunately, it is unclear from the report whether the model is a daily or peak period model. Nevertheless, the Florida researchers compared the results of two feedback approaches, direct and an MSA method, to a model without feedback. Without trip length calibration, they found that feedback resulted in shorter travel times and lower volume-to-capacity ratios. They then performed on-line trip length calibration to control the model VHT with the result that their feedback model could produce comparable results to their non-feedback model. These findings appear to be similar to what was found for the Texas Package field test, in re-calibrating friction factors for the base year model.

The Florida study pointed out that the feedback process does redistribute trips in response to congestion and that travel distance and time are generally reduced, resulting in lower VMT and VHT. They noted that the system-wide volume-to-capacity ratio decreased under feedback. Interestingly, the Florida researchers observed differences as a result of feedback even in their medium-congestion scenario, not just their high-congestion scenario. Moreover, they concluded by deciding that their results did not provide sufficient evidence for a benefit from incorporating feedback into the model. Although they do attribute this finding partially to the fact that their feedback model was not as fully calibrated as the base model it was being compared to.

The most helpful resource in providing perspective on the results for the feedback model 2035 No Build is the 1997 report on *Incorporating Feedback in Travel Forecasting*, previously referenced. Loudon et al., (1997) after justifying the use of feedback to address air quality conformity requirements in certain situations, posit and test two alternative methods of feedback (MSA versus method of optimal weighting), each with two different assignment approaches (equilibrium versus all or nothing). Two areas were used for the case studies:

Memphis, Tennessee, and Salt Lake City, Utah; and three different scenarios were tested apiece: two growth scenarios and one added capacity scenario.

Loudon et al. documented similar findings to those observed for the Texas Package field test:

- Introducing feedback necessitated a recalibration of the baseline model.
- In both test cases, feedback resulted in a reduction of system-wide VMT, reflecting reduced average trip lengths (in distance). The effect was more significant for congested conditions versus uncongested conditions.

Hence, given their results, Loudon et al. asserted a need to use feedback in order to accurately reflect the effect of congestion on trip distribution and travel time.

Given the finding from the No Build scenario, the next natural step was to apply the feedback model for a different scenario to provide an additional data point for examination and to verify that the feedback model behaves consistently.

MSA FEEDBACK: 2035 BUILD

The second application test of the feedback model was the 2035 Build scenario, again based on original model inputs for the Rio Grande Valley model that TxDOT developed and maintained. The demographics are the forecast year 2035, and the network includes additional added capacity anticipated to be built by 2035. Thus, this scenario should exhibit characteristics that are more congested than those of the base year 2004 and less congested than those of the 2035 No Build scenario.

Table 28 shows the model settings. The primary changes from the No Build scenario are the network with added capacity as described above, as well as minor changes in demographics related to the addition of two new international bridges and described previously (see Table 11).

Table 29 reports on feedback measures of convergence. Table 30 presents the model results for trip distribution, and Table 31, for traffic assignment.

Table 28. MSA Model Parameters: 2035 Build.

Dimension	Original Base Scenario	Sequential Scenario	MSA Scenario
Demographics	Forecast 2035	Forecast 2035	Forecast 2035
Network	Forecast 2035	Forecast 2035	Forecast 2035
Time of Day	24-Hour	24-Hour	24-Hour
Friction Factors	Original	Original	New
Centroid Connector Capacities	Used	Not Used	Not Used
Assignment Convergence Criterion	0.001*	0.001	0.001
Maximum Assignment Iterations	80*	1000	1000
Number of Assignment Iterations to Reach Convergence	No*	76	48
Step Fed Back to	n/a	n/a	Trip Distribution
Data Fed Back	n/a	n/a	Highway link travel time
Basis for Feedback	n/a	n/a	Travel time is calculated by averaging link volumes
Averaging Method	n/a	n/a	MSA
Feedback Convergence Criterion	n/a	n/a	RMSE of Trip Distribution Skim = .01
Feedback Loops to Reach Convergence	n/a	n/a	16

** For the original Build model, maximum assignment iterations were set to 80; the relative gap attained is unknown, but was likely close to 0.001, given that the TransCAD 5.0 implementation converged in 76 iterations.*

Table 29. MSA Feedback Model Results, 2035 Build: Feedback Measures of Convergence.

Iteration#	PRMSE-Skim	PRMSE-Trip Table	TMF-Trip Table	% GEH	Max GEH	Max GEH Difference	Max GEH Link Flow	Max Flow Difference	Tot Link Flow	% Difference
1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2	37.9594	217.459	36.6819	35.1627	75.0288	3,543	4,001	20,327	95,838	21.2095
3	13.3179	82.0833	18.3697	5.426	21.1501	1,135	2,313	2,580	93,258	2.7668
4	0.8661	25.6756	9.7047	1.0817	12.5963	559	1,690	919	92,339	0.9952
5	0.2855	20.097	8.3481	0.1862	8.5916	335	1,354	442	91,896	0.4812
6	0.1405	18.9271	7.5309	0.0532	6.3397	223	1,131	289	91,608	0.3153
7	0.0826	16.9603	7.0335	0	4.9275	160	971	195	4,903	3.974
8	0.0522	15.8065	6.4197	0	3.9701	120	851	148	4,755	3.1165
9	0.0365	15.4428	6.1054	0	3.2805	93	758	115	25,654	0.4499
10	0.0256	14.6101	5.7205	0	2.7776	75	684	92	2,713	3.3981
11	0.0219	14.0092	5.4286	0	2.3848	61	623	89	31,730	0.279
12	0.0161	13.7923	5.3165	0	2.0774	51	572	81	7,798	1.0392
13	0.0134	13.4332	5.124	0	1.8305	43	529	78	18,842	0.4122
14	0.0116	13.0667	4.9796	0	1.6295	37	492	47	25,998	0.1824
15	0.0105	12.9436	4.8879	0	1.4668	32	460	71	41,710	0.1696
16	0.0085	12.8448	4.8468	0	1.3206	28	432	49	11,375	0.4313

Table 30. MSA Feedback Model Results, 2035 Build: Trip Distribution.

Trip Distribution Results	**Sequential Scenario**	**MSA Scenario**
Average Trip Length (in minutes)		
HBW	16.37	19.19
HBNWR	10.46	12.00
HBNWE	6.41	6.94
HBNWO	12.57	14.17
NHBW	12.08	13.72
NHBO	9.96	11.24
TRTX	19.23	21.88
NHB-EXLO	11.96	13.50
EXLO Auto	24.40	29.04
EXLO Truck	32.02	40.03
Intrazonal Trips		
HBW	6,738	6,761
HBNWR	11,951	12,775
HBNWE	1,920	1,873
HBNWO	18,126	18,063
NHBW	3,773	4,080
NHBO	17,644	19,483
TRTX	2,593	2,250
NHB-EXLO	4,033	3,913
EXLO Auto	0	0
EXLO Truck	0	0
EXTHRU	n/a	n/a
Total	66,778	69,198

Table 31. MSA Feedback Model Results, 2035 Build: Traffic Assignment.

Traffic Assignment Results, Including Vehicle-Miles-Traveled (VMT)	Original Base Scenario	Sequential Scenario	MSA Scenario
Iterations Run to Reach Convergence	80	76	48
Assigned VMT	39,352,948	38,886,201	35,971,285
Network VMT Capacity	52,157,796	52,157,796	52,157,796
Assigned Volume/Capacity	75%	75%	69%
VMT/Person	18.42	18.20	16.84
VMT/Household	60.26	59.54	55.08
Vehicle-Hours Traveled (VHT)	1,375,811	1,342,011	1,144,617
VHT/Person	0.64	0.63	0.54
VHT/Household	2.11	2.05	1.75
Average Network Speed (Input)	39.33	39.38	39.52
Average Network Speed (Resulting)	31.58	31.78	33.60
VMT by Area and Facility Types:			
CBD	541,991	524,824	472,445
Urban	17,740,522	17,528,227	16,145,052
Suburban	15,019,113	14,768,026	13,470,462
Rural	6,051,322	6,065,124	5,883,326
5–Freeways	10,065,413	10,020,815	9,364,938
6–Freeways	535,731	543,519	465,251
11–Divided Principal Arterials	3,211,333	3,138,153	2,999,160
12–Princ. Arterials with Center Lane	5,914,138	5,923,510	5,692,894
13–Undivided Principal Arterials	5,161,436	5,132,416	4,849,287
14–Divided Minor Arterials	702,934	704,409	593,771
15–Minor Arterials with Center Lane	2,911,762	2,866,469	2,656,534
16–Undivided Minor Arterials	2,422,444	2,351,350	2,182,907
17–Divided Collectors	208,834	206,240	158,379
18–Collectors with Center Lane	27,494	27,787	24,998
19–Undivided Collectors	6,087,328	5,918,457	5,129,000
20–Frontage Roads	1,594,745	1,546,182	1,363,587
21–Ramps	440,133	436,360	426,851
22–Direct Connectors	69,222	70,534	63,729

As expected, the Build scenario demonstrates similar behavior to that exhibited under the No Build scenario, but with slightly less reactivity due to the lesser congestion.

The feedback measures of convergence reported in Table 29 demonstrate that the model was able to stabilize in 16 loops, which is between the 14 loops for the 2004 base year scenario and the 20 loops for the 2035 No Build scenario. As for the previous scenarios, all of the measures of feedback performance tend toward convergence as the feedback loops progress.

For trip distribution (see results in Table 30), the Build scenario under feedback responds as expected, given the results for the No Build scenario, the primary result being longer resulting average trip lengths in minutes. For traffic assignment, (see Table 31), the system-wide results demonstrate markedly less congestion than the No Build scenario. After all, system-wide network capacity has increased from 38.2 to 52.2 million vehicle-miles-capacity, so it would be surprising if the Build scenario did not show this improvement. Other statistics also behave as expected.

Overall, the 2035 Build application of the feedback mechanism further supports the finding from the No Build scenario that the feedback model does provide an improved sensitivity in trip distribution in response to traffic congestion for the RGV model used here.

SEQUENTIAL MODEL VERSUS FEEDBACK RESULTS

Given the resulting trip distribution and trip assignment changes that occur with the introduction of feedback, it is worth summarizing the differences between the sequential and feedback models.

Both models, the sequential and the feedback, are fundamentally grounded: each has been developed using the Texas Package, based on real-world model inputs from the Rio Grande Valley 2004 model; and each has been shown in the examination above to replicate system-level count data. The sequential model adheres to standard TxDOT practice and guidelines and was implemented using the accepted Texas Package approach, tools, and utilities. The feedback model builds on TxDOT practice and incorporates the Texas Package, merely adding the feedback mechanism to enable consistency of the value of time used between model steps.

Table 32 presents the model results that were examined previously by scenario, together with the sequential scenarios; and Table 33 shows the feedback scenarios together. The most striking thing about the sequential model results is the assigned VMT figure. Under the two 2035 scenarios, RGV citizens would travel almost 40 million VMT daily, regardless of whether or not additional capacity was added. The VHT experienced per person is over half an hour daily under the Build scenario and almost a full hour under the No Build. However, the sequential model indicates that RGV citizens would persist in traveling the same approximately 18 vehicle-miles per person per day, regardless of the level of congestion or the time it took to travel those 18 vehicle-miles.

The feedback model results provide different results reflecting a travel response to the substantial congestion represented in the No Build scenario. That is, VMT per person drops from the 18 miles per day value exhibited in 2004 to 15.5 miles under the No Build scenario and 16.8 miles under the Build scenario, with a resulting value of 33.1 million VMT daily under No Build and 35.9 million under the Build scenario (again, versus almost 40 million VMT predicted using the sequential model).

Table 32. Original Model Results, All Three Scenarios: Traffic Assignment.

Traffic Assignment Results, including Vehicle-Miles-Traveled (VMT)	**2004 Base**	**2035 No Build**	**2035 Build**
Iterations Run to Reach Convergence	61	80*	80*
Assigned VMT	18,992,066	39,959,244	39,352,948
Network VMT-Capacity	36,723,336	38,188,275	52,157,796
Assigned Volume/Capacity	52%	105%	75%
VMT/Person	18.00	18.70	18.42
VMT/Household	60.17	61.19	60.26
Vehicle-Hours Traveled (VHT)	513,429	1,992,591	1,375,811
VHT/Person	0.49	0.93	0.64
VHT/Household	1.63	3.05	2.11
Average Network Speed (Input)	40.98	38.87	39.33
Average Network Speed (Resulting)	38.03	25.39	31.58

** Maximum assignment iterations were set to 80, and the model did not reach 0 .001 relative gap.*

Table 33. MSA Feedback Model Results, All Three Scenarios: Traffic Assignment.

Traffic Assignment Results, including Vehicle-Miles-Traveled (VMT)	**2004 Base**	**2035 No Build**	**2035 Build**
Iterations Run to Reach Convergence	25	68	48
Assigned VMT	19,130,459	33,163,703	35,971,285
Network VMT Capacity	36,723,336	38,188,275	52,157,796
Assigned Volume/Capacity	52%	87%	69%
VMT/Person	18.13	15.52	16.84
VMT/Household	60.61	50.78	55.08
Vehicle-Hours Traveled (VHT)	515,264	1,188,149	1,144,617
VHT/Person	0.49	0.56	0.54
VHT/Household	1.63	1.82	1.75
Avg. Network Speed (Input)	41.04	39.12	39.52
Avg. Network Speed (Resulting)	38.15	30.63	33.60

Added Capacity Alternatives

An additional perspective for considering the value of running feedback is to consider the responsiveness of the model to a typical project that a planner might use the model for. For this field test, the study team examined congested links on US 83, the primary east-west corridor in the study area, to identify a project appropriate for a field test. The red links highlighted in Figure 25 have only two lanes in the base year 2004 and No Build 2035 networks. For the project-level sensitivity analysis, these links were increased to three lanes, with a corresponding increase in capacity. It is this project-level change being referred to when a scenario is called an ‘added capacity scenario.’

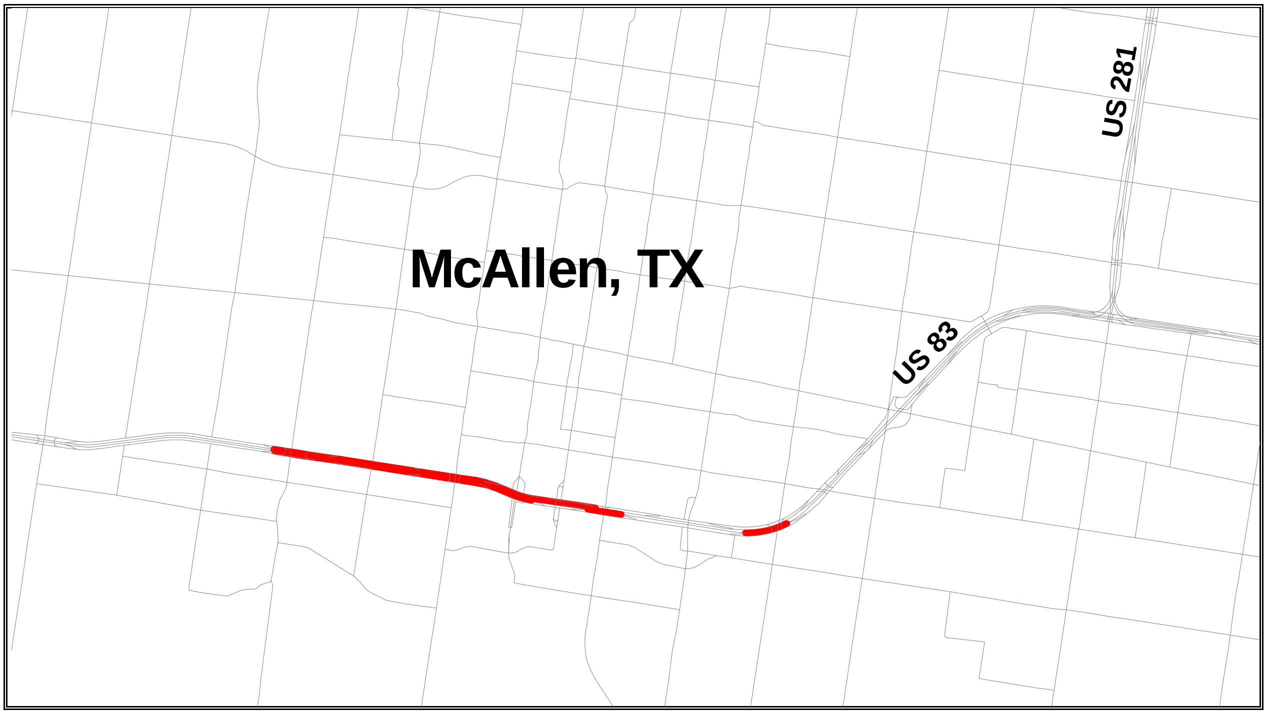


Figure 25. US 83 Project Improvement Links in McAllen.

This project-level capacity improvement was added for two scenarios: the sequential 2004 and the MSA feedback 2004 scenarios. Forty sectors were defined for the purpose of this analysis, aggregated from the 1517 original TAZs to represent general sub-areas such as downtowns, urban areas, and rural areas.

Table 34 shows that the first examination considered the resulting system-wide traffic assignment results before and after the added capacity. Both the sequential scenario and the feedback scenario demonstrated an absolute difference in response to the addition of the lane in each direction along US 83. Both demonstrated an increase in VMT—66,150 daily VMT for the sequential and 30,641 for feedback—and a decrease in VHT—1,289 daily for the sequential and 427 for feedback. Across the board for these measures, the sequential approach demonstrates a greater change in response to this project addition. One likely cause is that under the feedback base scenario, trips redistributed to other routes to avoid congestion along US 83. Therefore, the addition of added capacity on US 83 for feedback offered less of a marginal improvement.

The next examination considered the change to the trip table (i.e., how trips were distributed) as a result of the project improvement. For the sequential scenario, there was no change to how trips were distributed due to the addition of the added capacity along US 83 through McAllen. This result is logical, because trip distribution under the sequential approach considers initial time only and not time related to congestion, which the addition of lanes would relieve.

Table 34. Added Capacity Scenarios: Traffic Assignment Results.

Traffic Assignment Results	Sequential Scenario 2004			MSA Scenario 2004		
	Base	Added Capacity	Absolute Difference	Base	Added Capacity	Absolute Difference
Assigned VMT	18,888,424	18,954,574	66,150	19,130,459	19,161,100	30,641
Network VMT Capacity	36,723,336	36,800,645	77,309	36,723,336	36,800,645	77,309
Assigned Vol/Capacity	0.51	0.52	0.00	0.52	0.52	0.00
VMT/Person	17.90	17.96	0.06	18.13	18.16	0.03
VMT/Household	59.84	60.05	0.21	60.61	60.71	0.10
Vehicle-Hours Traveled	509,879	508,590	-1,289	515,264	514,837	-427
VHT/Person	0.48	0.48	0.00	0.49	0.49	0.00
VHT/Household	1.62	1.61	0.00	1.63	1.63	0.00
Avg. Network Speed (Input)	41.01	41.02	0.01	41.04	41.06	0.02
Avg. Network Speed (Resulting)	38.08	38.18	0.10	38.15	38.22	0.07

In contrast, for the feedback scenario, the model does demonstrate a redistribution of trips. Figure 26 shows a graphic demonstrating the change in flows between sectors. For the 2004 scenario experiment, the sector representing the McAllen urban area just north of US 83, for example, experienced the largest change: intrazonal trips decreased by 412, indicating that travelers who used to go on these trips now found it more attractive to visit other areas. The largest increase was related to the same sector: trips between the same McAllen urban area and the area just to the east and south of US 83 increased.

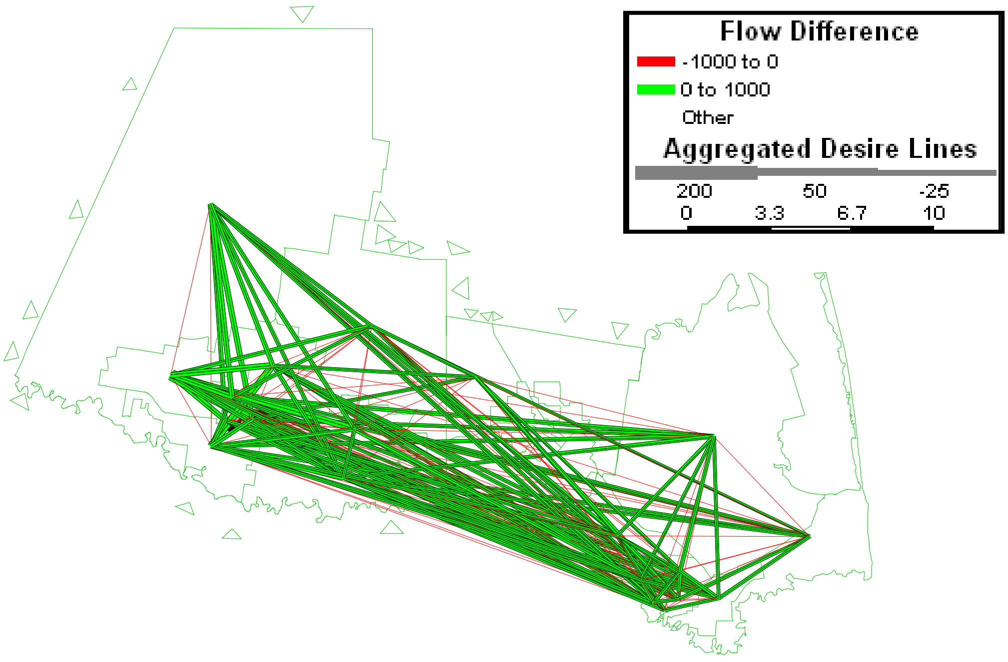


Figure 26. Flow Change between Sectors for 2004 Added Capacity Scenarios Using Feedback.

Focusing even closer, a third examination considered the change to link level flows. Figure 27 shows the positive and negative difference to link flows before and after adding capacity to US 83 for the sequential model approach and Figure 28 for the feedback approach. There are minor differences, but both appear to provide intuitive results, with greater (green) flow along US 83 links and reduced flow (red) along parallel routes as a result of the improvement.

Figure 29 and Figure 30 show the flow differences over an absolute value of 10 trips daily for the entire study area. The sequential approach yielded an absolute increase of total system-wide VMT of twice that of the feedback approach (66,150 VMT daily versus 30,641 daily). It is nonetheless interesting that the feedback approach demonstrates more widely dispersed responsiveness due to the improvement to US 83, as seen in the additional colored links in Figure 30 versus Figure 29.

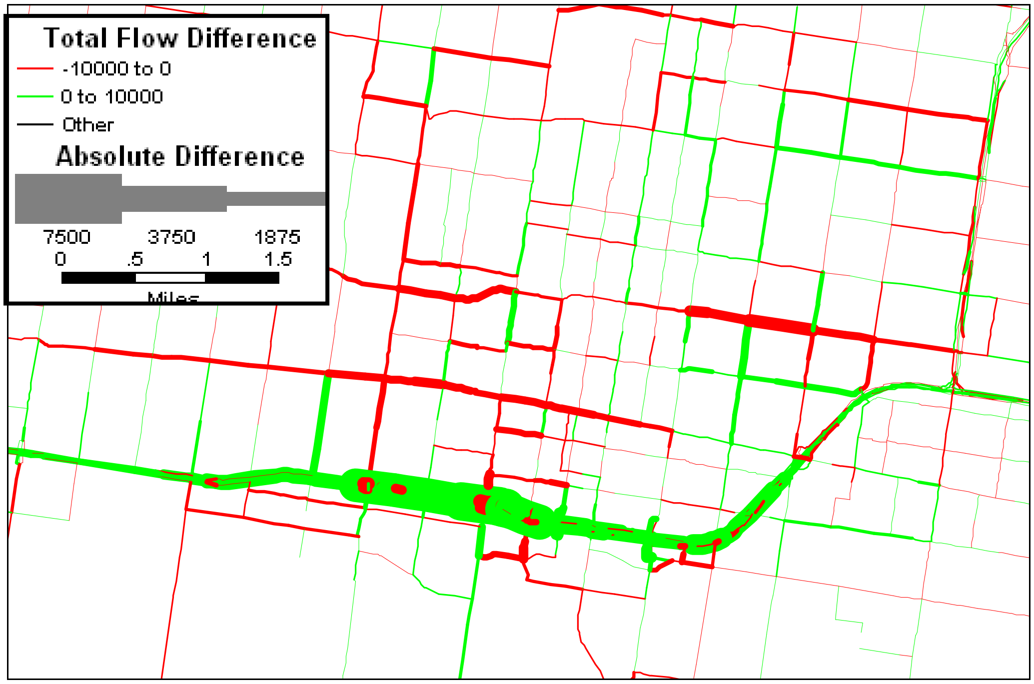


Figure 27. Sequential Model Results: Flow Difference after Capacity Added to US 83 in McAllen.

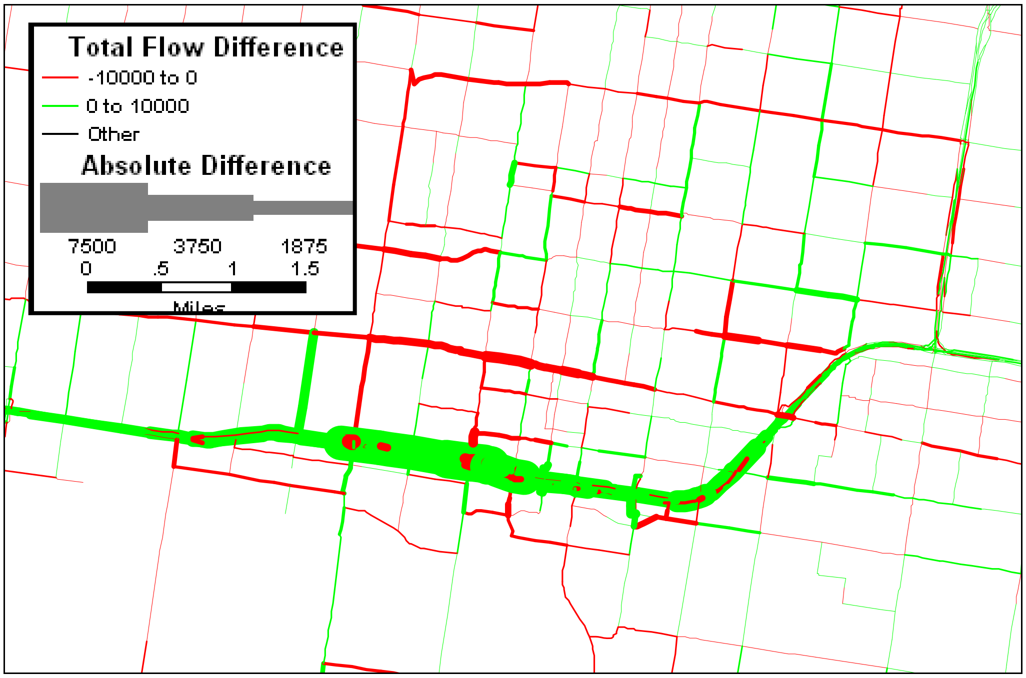


Figure 28. Feedback Model Results: Flow Difference after Capacity Added to US 83 in McAllen.

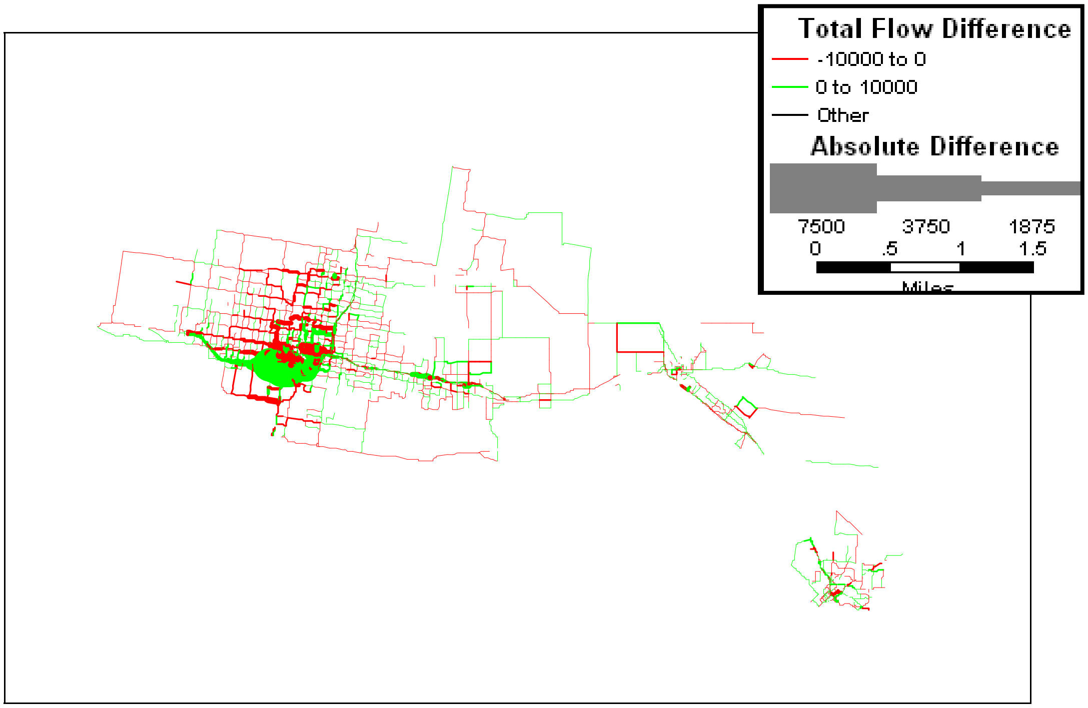


Figure 29. Sequential Model Results: Flow Difference over 10 Trips after Capacity Added to US 83 in McAllen.

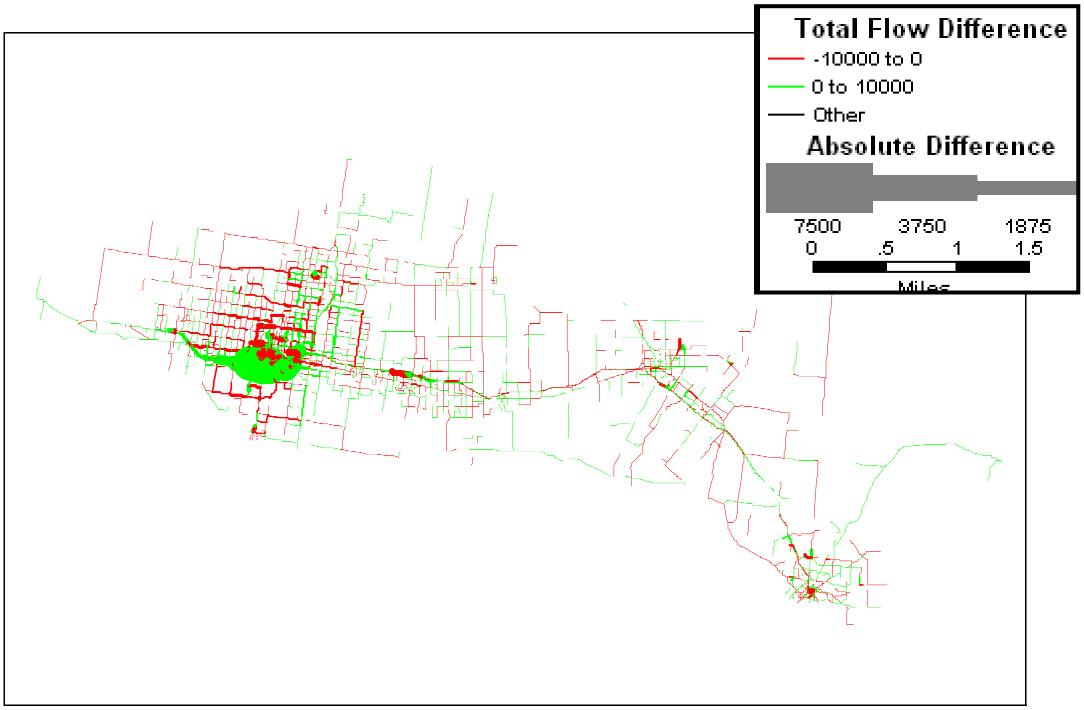


Figure 30. Feedback Model Results: Flow Difference over 10 Trips after Capacity Added to US 83 in McAllen.

Alternate Assignment Algorithm Test

A final sensitivity test was run to test an alternate assignment algorithm. In much of the literature on feedback, it is clear that assignment convergence can play a critical role in feedback convergence. Assignment noise—that is, the differences in results between each successive iteration of assignment—can negatively affect or even impede feedback convergence. It was possible that this assignment noise might even be affecting model results such as those seen in Figure 29 and Figure 30, resulting in more change further from the actual project than might be appropriate. The TransCAD developer often recommends an alternate assignment algorithm, Origin User Equilibrium (OUE), for use with feedback because it can achieve very tight relative gap in fewer iterations than the typical User Equilibrium algorithm. Figure 31 and Figure 32 show the results after the same added capacity project was tested using the feedback approach.

These added capacity scenarios demonstrate that both the sequential and feedback models appropriately demonstrate improvement as a result of adding capacity to this critical and congested area along US 83 in McAllen. The scenarios also suggest that the feedback approach may result in more conservative measures resulting from specific project improvements as a result of the base scenario already having redistributed trips in response to congestion. The cursory examination of the OUE assignment was done to examine project-level improvement, and did not demonstrate any discernible benefit.

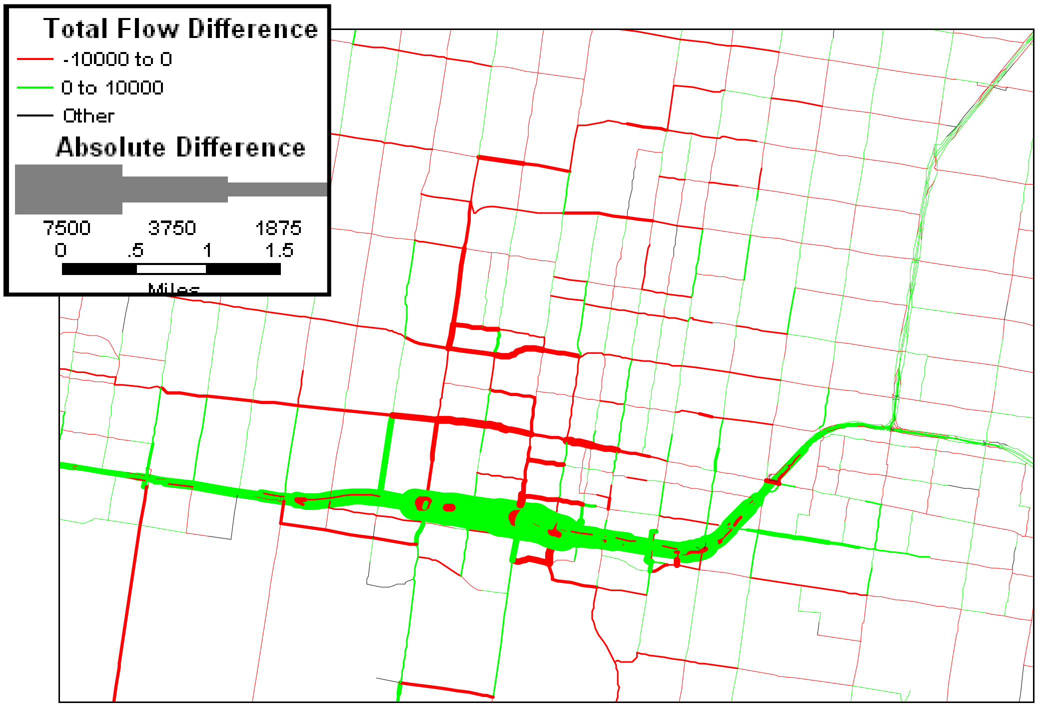


Figure 31. Feedback Model Results with OUE Assignment: Flow Difference after Capacity Added to US 83 in McAllen.

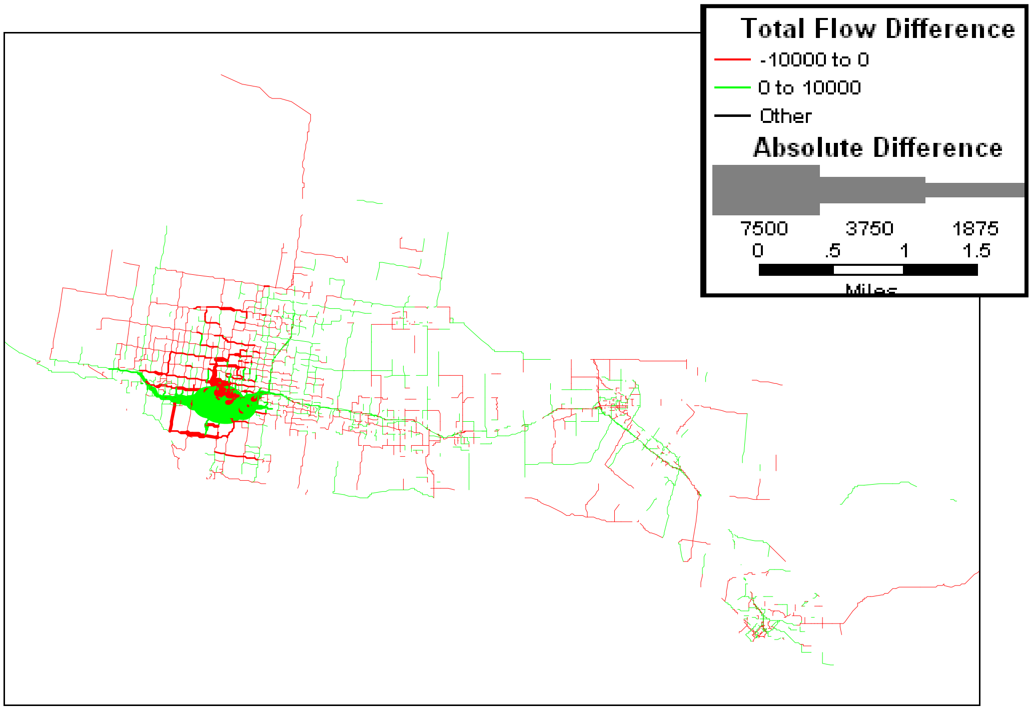


Figure 32. Feedback Model Results with OUE Assignment: Flow Difference over 10 Trips after Capacity Added to US 83 in McAllen.

PRACTICAL CHALLENGES IN APPLYING FEEDBACK FOR THE TEXAS PACKAGE

This section addresses practical challenges anticipated and observed for applying feedback in the Texas Package environment.

Model Stability

For each of the models implemented during the course of this field test—sequential and feedback—all performed solidly with regard to model stability, with no instances of TransCAD closing down due to memory or other issues. This was the case for three different laptops that the feedback runs were tested on. Model stability does not appear to be an issue.

Model Development Time

The time to develop a feedback model, including calibration and validation, will necessarily include the following steps if the steps used in this research effort are followed:

- Modification of a study area model to be run in TransCAD as a batch procedure.
- An additional step as part of model calibration to recalibrate friction factors to deliver comparable average trip lengths to a sequential model run.

Now that a basic structure for a feedback mechanism has been developed under this research effort, and if this mechanism were to be approved for use, the first step would be straightforward, but does involve some effort as each study area model does have unique characteristics that the model code must be adjusted to address. If the model has been previously calibrated in

TransCAD 4.5, then the effort should also include runs as performed here to ensure that a sequential application of the batch procedure closely mimics the results from the calibrated model before proceeding with implementing feedback.

As shown in the testing performed as part of the current research effort, it is necessary to calibrate new friction factors for feedback versus a single model run. This step is not complicated or time-consuming if there was a previously calibrated model with valid friction factors, but does involve additional time and effort. If a new model is being developed, then these two steps must still occur—friction factors must be developed first for a single-stream model to deliver appropriate average trip length values in time and length. Then the friction factors may be developed for the purpose of feedback to deliver the same average trip length in distance (as opposed to time). As for any model development process, if the speed logic of the network database is changed as part of the model calibration, then these friction factors will need to be recalibrated, as well.

Typical Application Times

Model application time is, necessarily, longer with feedback than without it. Table 35 shows that a typical sequential model application (using batch procedure) can be run in just under 4 minutes. These times do not include Trip Generation, which is assumed to have been run prior to feedback application. Several different approaches were tested for this purpose, including first the MSA approach which is the basis for most of the analysis performed on feedback for this research effort. For each of the methods shown in this table, the time shown in the last row is for performing 10 feedback loops for comparison purposes. In the final row, the number of feedback loops necessary to reach feedback system convergence is shown for additional perspective. For MSA and most of the runs performed for this research effort, the typical time for 10 loops was around 36 minutes; but typically 12–16 loops were necessary to reach convergence.

The second feedback approach tested here was a Constant Weights Approach applied to the trip tables prior to trip assignment. As the data demonstrates, there was no time advantage in implementing the Constant Weights approach when the number of feedback loops was held constant; clearly, as shown in the last row, the total number of loops to reach feedback convergence (if reachable) is a factor to be considered. For the Constant Weights runs performed for this effort, they typically did not converge by 20 loops.

Table 35. Typical Feedback Application Times.

Time in Minutes	Base Scenario: 2004	MSA Scenario: 2004	Constant Weights Applied to Trip Tables	MSA, Tight Convergence Criterion	MSA, Test Origin User Equilibrium
Assignment Method	User Equilibrium				Origin User Equilibrium
Relative Gap Criterion for Assignment	0.001	0.001	0.001	0.00005	0.00001
Single Feedback Loop or Sequential Model Run	4	4	4	8	7
Time (in Min.) for Ten (10) Loops	N/A	36	36	67	80
Number of Loops Taken to Reach PRMSE of .01 for the Skim Tables	N/A	14	Did Not Converge after 20 Loops	12	12

As explained above, in much of the literature on feedback, it is clear that assignment convergence can play a critical role in feedback convergence. Assignment noise—that is, the differences in results between each successive iteration of assignment—can negatively affect or even impede feedback convergence. Thus, a third and fourth scenario were tested with respect to application time. As noted previously, the standard TxDOT assignment approach for a typical urban area model is the User Equilibrium algorithm with an assignment convergence criteria of 0.001 relative gap, and a maximum number of assignment iterations equal to 24. The third scenario tested here is the same MSA feedback approach, but with the assignment convergence criterion tightened to a relative gap of 0.00005 (a criterion of 0.00001 gap was tested but did not reach convergence after 1000 assignment iterations). The tighter assignment convergence criteria were achievable, although with an impact to the time to perform the model run.

The fourth test is again the MSA approach, but with an alternate assignment algorithm that the TransCAD developer recommended for use with feedback because it can achieve very tight relative gap: Origin User Equilibrium. The purpose of examining the OUE approach is not to propose this method itself for future TxDOT implementation, but merely to explore the difference an alternate assignment algorithm might make for implementing feedback. User Equilibrium, as implemented in TransCAD, is based on a Frank-Wolfe (FW) method: the first iteration being an All-or-Nothing assignment, and then subsequent iterations being assigned based on computed travel times from the previous iterations. As described in TransCAD documentation, the OUE algorithm addresses two known weaknesses of the User Equilibrium (FW) method: it avoids retaining assignment paths that were unsuccessful in prior iterations, and it can compute solutions to a much tighter gap. Both characteristics make it interesting to test here. As shown in Table 35, the MSA with OUE could deliver the tightest assignment convergence criterion at 0.00001, although with an impact to the time to perform the model run.

To be clear, the figures in Table 35 have the following implied result which is a very real practical consideration: a TxDOT modeler, calibrating a base year model, decides to make a minor change in a model input for any of the model steps. If the model is not being run as feedback, the time to test the minor change could be as short as 4 minutes for a sequential model run or as long as 45–100 minutes for a feedback run comparable to those in Table 35. While not as significant a delay as other planning agencies have reported in Chapter 1, this is still a considerable jump in resource time.

Computer Memory Requirements

The computer memory requirements for running feedback are not insubstantial. Table 36 shows that the size of the folder for the Original Base Scenario 2004 was 223 megabytes (MB), or 0.223 gigabytes (GB). In contrast, the memory requirement to preserve the entire MSA feedback run for the year 2004 base year is 3.23 GB. For the feedback run, an additional 86 MB, or 0.086 GB of temporary matrices are created and deleted for each loop. Both examples include model development files and Trip Generation files.

Table 36. Size of Feedback Run Folder.

Memory in Gigabytes (GB)	Original Base Scenario: 2004	MSA Scenario: 2004
Space Needed For Entire Model Run	0.223 GB	3.23 GB*

**Files included data for 14 feedback loops to reach convergence.*

The figures shown in Table 36 are only for a single model run. It is quite typical for model developers and users performing application runs to preserve multiple copies of model runs with different model inputs and parameters. This being the case, the memory needs for running feedback are not unmanageable (the feedback folder above was compressed to a zipped folder of only 520 MG, or 0.52 GB), but they are a significant consideration.

Computer System Requirements

For the purpose of examining computer system requirements, Table 37 presents computer specifications and model run times for a single run (MSA feedback for the base year 2004) for three different laptops. This experiment presented some surprising and educational results.

Table 37. Computer System Requirements.

Characteristics of Machine	Machine-1	Machine-2	Machine-3
Operating System	Windows-XP Professional	Windows-7	Windows-XP professional
System Type	32 bit Operating System	64 bit Operating System	32 bit Operating System
RAM	3.48 GB	8.00 GB	3.00 GB
Memory	232 GB	650 GB	80 GB
Processor	Intel Core 2 Duo CPU P9600	Intel Core I7 CPU Q 740	Intel Core 2 Duo CPU T7200
No. of Cores	2	4	2
No. of Threads	2	8	2
Clock Speed	2.66 GHz	1.73 GHz	2.00 GHz
Fulfill memory requirements for TransCAD	Yes, but 2 cores (instead of 4)	Yes, but less competitive due to slower clock speed	Yes, but 2 cores (instead of 4) and slower clock speed
Feedback Run Time Comparison			
Iteration No.	**Run Time for Each Loop (Minutes)**		
	Machine-1	**Machine-2**	**Machine-3**
1	0	0	0
2	6	5	9
3	5	5	8
4	6	5	12
5	5	5	11
6	5	4	9
7	6	5	11
8	5	4	10
9	5	5	12
10	6	5	9
11	5	4	12
12	5	5	11
Total Time	59 minutes	52 minutes	114 minutes

As the bottom part of Table 37 shows, Machine 3 clearly took longer to process the MSA feedback run, at 114 minutes versus the 59- and 52-minute periods on Machine 1 and Machine 2, respectively. Looking at computer characteristics in the top half of the table, Machine 3 is either the same (number of cores, number of threads, for example, compared to Machine 1) or slower (clock speed, for example) than the other two machines. Feedback ran adequately and with no issues of stability on Machine 3, just slower.

The differences demonstrated between Machine 1 and 2 were more interesting. Machine 2 was the clear winner, despite Machine 1 generally coming closer to meeting the TransCAD developer's system requirements as published on their website (Caliper Corporation 2011). After researching this issue with the developer, the researchers determined that the number of cores was the most critical factor for this examination. That is, the predominant wait time for each of the model applications is traffic assignment, which according to the standard TxDOT specification is User Equilibrium. TransCAD's User Equilibrium algorithm is based on the Frank-Wolfe approach, which uses very little memory, but very efficiently uses multi-threading. A rule of thumb that the TransCAD developer used is that for every core, assignment time is reduced by 1/number of cores (i.e., two cores equals roughly half the run time as for one core). Thus, the four cores of Machine 2 resulted in approximately half of the assignment time than Machine 1 with two cores needed.

This example demonstrates the danger of over-simplifying the decision of system requirements. Many factors can affect the speed of model application, including the procedures being run (in this example, the choice of User Equilibrium made the number of cores important) and the batch code itself (for example, certain functions executed as matrix manipulations versus vector products). For future reference, the following considerations were also discovered:

- A 64-bit operating system will substantially affect the model application time, including offering improvements for the User Equilibrium assignment.
- The Origin User Equilibrium assignment algorithm is not multi-threaded, so that memory is more important for this algorithm.

Anecdotally, it appeared that occasionally restarting a laptop could yield a difference in the speed of model application.

The simple lesson of this demonstration is that computer system requirements as they relate to model implementation, either sequential or feedback, is that testing multiple machines and checking with the TransCAD developer is time worth spending.

CHAPTER SUMMARY

The purpose of the field test here in Chapter 4 was to conduct a hands-on feedback implementation within the Texas Package and using an actual Texas urban area model. The goal was to definitively identify challenges and examine potential benefits of feedback in a comparison to a corresponding sequential model.

ANALYSIS STEPS AND RESULTS

Establishing the Experimental Design

The initial steps followed in this field test included identifying an urban area and model for examination and specifying the experimental design. The Rio Grande Valley (RGV) 2004 model was chosen for various reasons; of note, RGV was one of the areas identified in Chapter 2 as having a higher level of congestion than other Texas urban areas under the purview of TxDOT-TPP for TDM development and maintenance. The dimensions of the experimental design were defined so that the field test would address the findings from Chapter 1. Key decisions regarding the experimental design included:

- It was decided to implement feedback for the 24-hour daily period. Critical factors in this decision including: the scope of this research effort targeted the existing Texas urban area TDM process, which is 24-hours; and that the field test would answer the question if congestion in a 24-hour model was sufficient to justify a feedback loop.

- A second key decision was to adhere as closely as possible to the standard Texas Package. A primary impetus was to ensure that feedback was tested for the current TxDOT TDM approach as described in Chapter 2; a second motivation was that this enabled more direct comparison to the original model runs.
- The primary test of feedback would test an MSA approach, since this method has more support based on findings in Chapter 1.

Testing the Core Dimensions

Having established the experimental design, the base case scenarios were documented and tested. This included testing several model parameters and establishing a sequential model in TransCAD 5.0 (since the original RGV model had been developed and applied in TransCAD version 4.5). The TransCAD 5.0 sequential model served as the basis for implementing the feedback loop. As a final step preliminary to implementing the feedback loop, measures of feedback convergence were identified.

The first feedback model developed and run used MSA to average link flows coming out of assignment with the average from the previous feedback loop, and then used times derived from this averaged flow value for the subsequent loop's trip distribution step. A key finding at this stage was the need for the feedback model to recalibrate friction factors to reproduce travel time impedances reflected in the original sequential model. The effort to recalibrate the friction factors was no more complicated than is typical to calibrate friction factors for a sequential model. With these values recalibrated, the feedback model generated model results comparable to those of the original sequential model. The feedback mechanism itself converged nicely in 14 loops, in approximately 1 hour's time.

Once the feedback model had been implemented for 2004, it was applied to the 2035 No Build scenario to test, which is—for a Texas urban area—a highly congested scenario. The results from this application were compared to what the original RGV 2035 No Build application had generated. The findings were intriguing: assigned VMT were substantially lower for the feedback model than the sequential model (33.2 million versus almost 40 million daily VMT). The volume-to-capacity and VHT measures behaved similarly. The conclusion was that the feedback scenario appears to provide results that respond to the constraint of system capacity to reduce the distance that people have traveled. These findings appear to be reasonable as it was established that others have had similar results in implementing feedback, though it remained unclear whether those similar results were achieved within a daily or peak-period model environment.

A next step was to apply the feedback model to the 2035 Build scenario and compare the results to those for the original sequential model. Findings were similar and appropriately in line between those of the base year 2004 model results and those for the 2035 No Build scenario.

Additional Experimental Dimensions

With the core model runs specified by the initial experimental design completed and examined, three additional dimensions were explored:

- An added capacity scenario to further examine model results using feedback.

- An alternate assignment algorithm approach to also further examine model results using feedback.
- A constant-weights feedback approach to explore if this approach provided a practical benefit by converging any faster; discussed under the Practical Applications section.

The additional capacity scenarios provided additional support to the change in trip distribution that feedback demonstrates. For the purpose of this limited examination of the specific link differences resulting from adding capacity, the alternate assignment algorithm did not appear to provide better results than the traditional algorithm.

Practical Challenges

While model stability was not an issue, typical application time for a feedback model and necessary computer memory storage are not inconsequential. Testing of computer system requirements demonstrated that different machines can perform substantially faster, however, that understanding which computer system characteristic can make the most difference can differ based on the procedures being run and the model batch coding itself. For the purpose of the current examination, sequential model run times were as low as 4 minutes, while feedback run times were typically anywhere from 40 minutes to 3 hours, depending on the level of assignment convergence and feedback convergence.

KEY FINDINGS

- Implementing the Texas Package in TransCAD 5.0 was not an issue. However, it should be noted that the only Texas Package analysis utility tested was VALID9. Implementing the Texas Package steps (in this case, Trip Distribution through Traffic Assignment) in batch mode was also not an issue.
- It was necessary to recalibrate friction factor values to generate model results comparable to those of the original sequential model, but the model results were then comparable. The revised friction factor values were used for the entire field test, no issues related to the absolute minute separations (see Chapter 2) seemed to arise.
- BIAS factors (i.e., K-factors in traditional gravity models) and RADII cards (proxy values for zone size), both inputs into the ATOM2 trip distribution model, were held constant at the original sequential model values for the purpose of this field test: BIAS factors would be need to be re-examined as part of a corridor-level calibration; RADII cards should, according to the researchers' logic and particularly given the decision to avoid centroid connector capacities, remain consistent through the feedback loops.
- As referenced above, centroid connector capacity use on a wide scale was found to be problematic for both the sequential and the feedback models once the forecast year demographics were introduced. According to TxDOT-TPP guidelines, it remains the modeler's discretion to use these for model calibration purposes, findings in this field test support a strong advisement to avoid centroid connector capacities.
- Feedback as it was tested here using MSA converged nicely for all measures; although changes to components of the Texas Package might improve feedback convergence, it does not appear necessary to diverge from the Texas Package to implement a functional feedback mechanism. That is, many of the issues brought up in Chapter 2—the integer rounding issue in ATOM2, volume-delay functions, Alpha and Beta modifications, speed

logic, the congestion level with respect to the BPR curve, etc.—simply did not arise as issues in this current field test.

- For the same forecast network and demographic scenario application, the feedback model demonstrated a lower system VMT, VHT, and volume-to-capacity ratio than the sequential model. Feedback appears to respond to the constraint of system capacity to reduce travel.
- A lesser congestion scenario, as the 2035 Build application had exhibited, which had substantial capacity added to the network, also demonstrated responsiveness to feedback.
- Both the sequential model and the feedback model demonstrated changes in response to an added capacity project along a critical corridor in the study area; the change is less dramatic using feedback.
- The most significant practical challenges are testing the computer system to balance the time for implementing feedback against the cost of upgrading and ensuring adequate computer storage space for multiple model runs.
- Finally, feedback did, in this field test, demonstrate a measurable response to network congestion. However, it should be noted that initial network speeds are not free-flow speeds, and the volume delay function does not allow speeds to increase on uncongested links. Consequently, speeds can only be revised downward on congested links while initial speeds remain constant on uncongested links. This finding does suggest that the volume delay function may need to be re-evaluated and/or free-flow speeds may need to be applied if feedback is implemented in the Texas Package.

Overall, the findings from this practical implementation of feedback in the Texas Package environment demonstrated that the technical challenges are surmountable and that there are potential benefits with respect to theoretical consistency between model steps and model results, which are more intuitive with respect to travel behavior. The primary issue remaining to be balanced is if the improved model consistency and intuitive results for what is, still, a 24-hour daily model, outweigh the burden of implementing feedback, with the practical challenges described above.

RECOMMENDATIONS

Given the findings from this field test, two recommendations arise. First, now that the field test has shown that there is at least one case study—the RGV model—which demonstrates tangible analysis benefit from a feedback mechanism, a logical next step would be to simply test additional scenarios for the RGV model along a grade of decreasing overall demographics. The result of this test may yield perspective on what level of congestion a base year model ceases to demonstrate responsiveness to a feedback mechanism. While a forecast year demonstrating sufficient growth might still be applicable for feedback, for areas with low enough congestion and a forecast of low future growth, feedback might then be removed from consideration for that area and model year. Again, this depends on the result of the reduced demographics test.

A second recommendation for a rather simple next step is to field test for the Texas Package the approach that the Capital Area MPO had taken for their feedback model. In the CAMPO model, directional diurnal factors are applied to the 24-hour trip table by trip purpose to derive a peak-period trip table, which is then applied to a highway network with capacities appropriate for the peak time period. These congested times are fed back to trip distribution for the HBW trip purposes; daily congested times from the 24-hour assignment are fed back to trip distribution for all other trip purposes. Figure 33 shows a similarly simplified peak period approach as it could be applied for the Texas Package.

It should be noted that such a model as shown in Figure 33 would need to be cautioned since, as described in Chapter 2, TxDOT has peak period data, but has limited resources to process it at the present time to be available for use to calibrate the peak period dimension. Other inputs such as directional diurnal factors by trip purpose might have to be borrowed from another area, for example. However, a test to see the influence of this structure in a feedback context might provide TxDOT with information to decide whether the investment of time in peak period count data is merited to improve feedback at all. Of course, there are other arguments besides feedback in favor and against peak period modeling; these are beyond the scope of this field test.

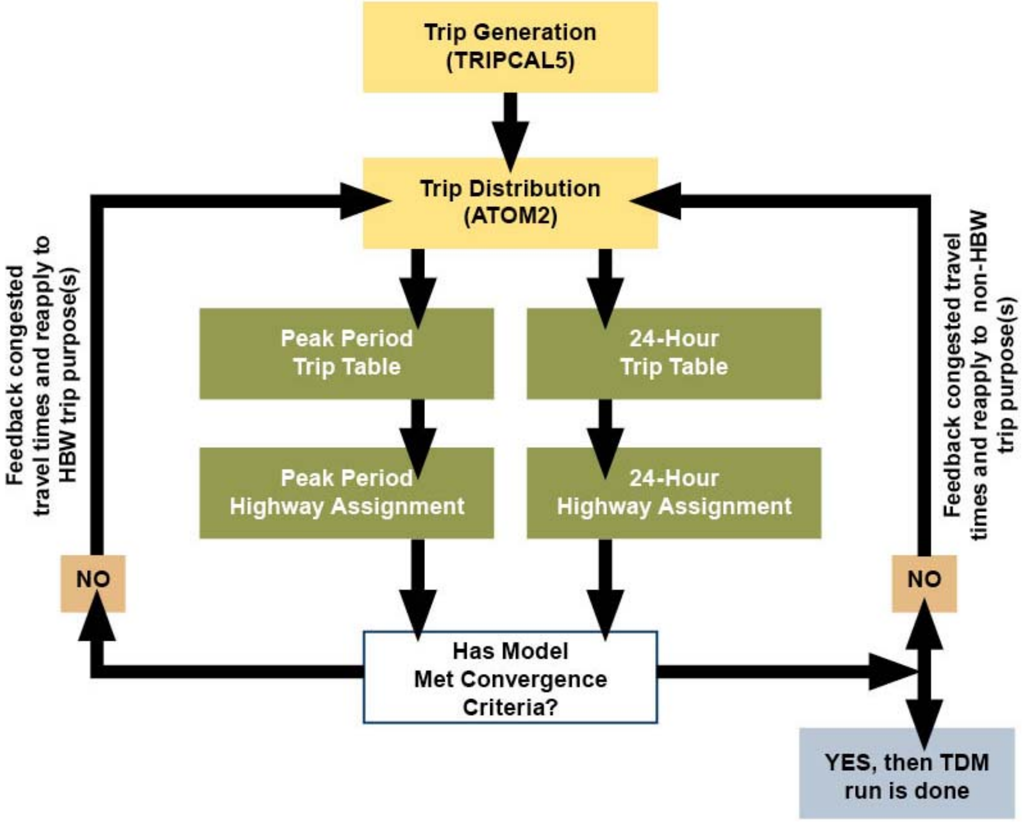


Figure 33. Example Peak-Period Feedback Model, based on CAMPO Approach.

CONCLUSION

RESEARCH SCOPE

This research project was based on the recognition that a limitation of the TxDOT sequential three-step model structure, as for many sequential travel models, is the inconsistency between the speed/time data used in trip distribution and the speed/time data resulting from traffic assignment. Trip distribution speeds and times are based on a preliminary set of estimated network link speeds and times; the resulting speeds and travel times from the final traffic assignment step will, in the presence of network congestion, reflect some level of congestion. Thus, when network congestion exists, this inconsistency of the speed/time data may result in travel models that do not accurately reflect current system or corridor-level travel patterns. Likewise, the speeds and travel times that result from alternative analyses used to support long-range transportation planning decisions may not accurately reflect travel response to those decisions.

With these known limitations in mind, the principle objective of this project was to research if incorporating a feedback approach into the traditional Texas TDM model approach could offer a fundamental advancement. Prior research indicated that through the implementation of a feedback loop, TxDOT-TPP could better represent current and forecasted travel patterns and thus substantially improve the quality of this critical decision-making tool for TxDOT and local decision-makers statewide. An additional advantage to the approach taken here would be that feedback would merely add a complementary component to an analysis tool already familiar to TxDOT users; much of the core approach fundamental to the Texas Package would remain the same.

The critical question underlying this research effort was when, if ever, implementing feedback was appropriate for one of the Texas urban models. The research in Chapter 1 emphasized the need for some level of congestion to exist for feedback to be necessary; precisely how to determine an appropriate level of congestion remained unclear, except through experimentation through specific case studies. Chapter 2 cited the system-wide volume-to-capacity ratio of each urban area under TxDOT-TPP purview as sufficient evidence that these areas lack the congestion sufficient to make feedback necessary. Both chapters took a strong stance, asserting that, because of the relative lack of congestion in daily models versus peak period models, feedback is not applicable for a daily model. The challenge, then, was that the scope of this research effort was specifically worded to examine implementing feedback in the current context of the TxDOT TDM process for urban area models. Hence, the approach of Chapter 4 was to proceed with an empirical test implementing feedback for a TxDOT daily model: the result would either substantiate the assertions of the previous chapters and release TxDOT from further considering feedback until it implements time-of-day modeling; or provide an example that feedback can add value to the current Texas Package. Either result was considered a valuable finding; indeed, the findings were valuable, as presented below.

REPORT SUMMARY

The theme overarching this research effort is that TxDOT arrives at a better understanding of the need for, advantages and disadvantages of, and steps needed to implement a feedback mechanism as part of the standard TxDOT urban model as it exists today and as it will most likely be implemented in the near-term. Therefore, key to the research approach described in this report is an emphasis on what is practical based on current state-of-the-practice with feedback, as well as *logical* for incorporation into the TxDOT urban models as they stand today. For this reason, a primary focus of the research effort has been existing approaches for feedback implementation in the context of the TxDOT TDM process.

Chapter 1 provided a discussion of the state of the practice in feedback implementation by identifying and presenting the many dimensions that characterize the feedback loop procedure, based on earlier and ongoing research. It described the state of the practice of feedback implementation, documented dimensions of feedback implementation, and summarized the findings from the synthesis of practice, thereby providing general directions for incorporating feedback in the context of the current TxDOT TDM model system. Chapter 2 provided a detailed examination of the TxDOT modeling process and discussed various potential issues to consider. Lest it be forgotten that travel modeling is a dynamic process improving over time, Chapter 3 offered an overview of the state of the art in future development trends in feedback implementation. Chapter 4 delivered a summary of this research project's field test and sensitivity analysis of applying feedback within the TxDOT TDM process using a previously validated Texas MPO model.

This conclusion chapter, then, summarizes findings for the entire research effort and makes recommendations for TxDOT consideration.

KEY FINDINGS

The following are key findings.

State of the Practice

- In general, past research and practice underscores the importance of incorporating feedback loops in the travel demand process, especially in regions with moderate to high levels of traffic congestion during certain times of the day.
- Since the TxDOT TDM model does not currently include any impedance or accessibility measures in the trip generation step, the best current approach is to feed back the output from the traffic assignment step to the trip distribution step.
- There are a variety of approaches that MPOs use nationwide with respect to feedback method and convergence criteria. MSA and constant weight approaches have demonstrated advantages over direct feedback methods and limited the number of feedback loops to a predetermined number.

Considerations Specific to the Texas Package Feedback Implementation

- The following modifications to the Texas Package components, while not necessary for the field test conducted here, could potentially improve feedback results and are worthy of additional consideration should TxDOT continue to develop the feedback approach:
    - Modification of ATOM2 to produce real number trip tables (instead of integers) and/or to use friction factors as a continuous function.
    - Dynamic calibration of friction factors during feedback.
    - Dynamic calibration of BIAS factors (K-Factors in other models).
- Should time-of-day modeling be implemented for a study area for which feedback has not already been applied, the congestion by time of day may warrant a reassessment of the applicability of feedback; other time-of-day modeling considerations include:
    - There is minimal time-of-day traffic data currently available to support full calibration of a time-of-day model. Although TxDOT collects annual data in 15-minute increments, it is currently not processed and distributed by TxDOT.
    - The magnitude of daily and peak traffic is very small for most of the study areas in Texas. For some of the study areas (particularly along the border), the noon peak period has equally or more traffic than the AM peak travel period, while the PM peak period is more pronounced than AM for all study areas.
- Various approaches could be attempted to force a Texas Package model to be more responsive to feedback than it is already. Although none of these was necessary for the field test here, they include:
    - Adjustments to the volume-delay functions by region or facility type.
    - Modifications to speed-capacity logic.
    - Implement a generalized cost assignment procedure.
- The standard maximum 24 iterations for assignment and a convergence criteria of 0.001 is a legacy determination. The field test had already deviated from this standard, so that the 0.0001 relative gap convergence criterion was used instead, with reasonable results.
- The relative impact that implementing feedback would have for TxDOT practices necessarily includes additional training and increases the calibration time associated with delivering base year travel models. It possibly could include additional data processing (and collection) related to time-of-day implementation.

State of the Art Trends

- Some areas have already transitioned their models to consider generalized cost instead of simply time as the model impedance value; this change would apply to the trip distribution step as well as trip assignment. In particular, it would improve toll analysis capabilities.
- The inclusion of a mode choice element is a logical next step for Texas urban areas with either greater transit usage, a need to test future transit scenarios, or a need to explore non-motorized effects of policy decisions. Research indicates that there are good arguments either way for including mode choice or not in each feedback loop.

- Multi-modal traffic assignment would also facilitate more detailed analysis results; feedback can incorporate multi-modal analysis, either by simply updating the auto impedance measure through trip distribution or a multi-modal measure if trip distribution supports it.
- Time-of-day is recommended for the immediate term, regardless of feedback implementation, but also generally improves the likelihood that feedback is applicable.
- Longer-term, but on the horizon, tour-based models also require a feedback step to ensure that the impedance values obtained from traffic assignment are consistent with those used as inputs.

Field Test Findings

- Implementing the Texas Package in TransCAD 5.0 was not an issue. However, it should be noted that the only Texas Package analysis utility tested was VALID9 and there are other critically necessary utilities necessary to the development and calibration of models that have not been tested in TransCAD 5.0.
- Technical implementation of the Texas Package steps (in this case, Trip Distribution through Traffic Assignment) in batch mode using GISDK scripting language was also not an issue. The use of GISDK in this instance is not, however, an endorsement of using GISDK for this type of model application. The choice of GISDK for the field test was made purely on the grounds of technical efficiency in this limited context; there remains a fundamental principle and historical precedent for the Texas Package to be maintained independently from any commercially available software.
- It was necessary to recalibrate friction factor values to generate model results comparable to those of the original sequential model. However, the model results were then comparable to the sequential model results; friction factor values were used for the entire field test, and no issues related to the absolute minute separations (see Chapter 2) seemed to arise.
- BIAS factors (i.e., K-factors in traditional gravity models) and RADII cards (proxy values for zone size), both inputs into the ATOM2 trip distribution model, were held constant at the original sequential model values for the purpose of this field test: BIAS factors would need to be reexamined as part of a corridor-level calibration. According to the researchers' logic and particularly given the decision to avoid centroid connector capacities, RADII cards should remain consistent through the feedback loops.
- As referenced above, centroid connector capacity use on a wide scale was found to be problematic for both the sequential and the feedback models once the forecast year demographics were introduced. According to TxDOT-TPP guidelines, it remains the modeler's discretion to use these connectors for model calibration purposes. However, findings in this field test support a strong advisement to avoid centroid connector capacities.
- Feedback as it was tested here using MSA converged nicely for all measures. Although changes to the components of the Texas Package might improve feedback convergence, it does not appear necessary to diverge from the Texas Package to implement a functional feedback mechanism. That is, many of the issues brought up in Chapter 2—the integer rounding issue in ATOM2, volume-delay functions, Alpha and Beta

modifications, speed logic, the congestion level with respect to the BPR curve, etc.—simply did not arise as issues in this current field test.

- For the same network and demographic scenario application, the feedback model demonstrated a lower system VMT, VHT, and volume-to-capacity ratio than the sequential model. Feedback appears to respond to the constraint of system capacity to reduce travel.
- As the 2035 Build application exhibited and which had substantial capacity added to the network, a lesser congestion scenario also demonstrated responsiveness to feedback.
- Both the sequential model and the feedback model demonstrated changes in response to an added capacity project along a critical corridor in the study area; the change was less dramatic using feedback.
- The most significant practical challenges were testing the computer system to balance the time for implementing feedback against the cost of upgrading and ensuring adequate computer storage space for multiple model runs.
- Finally, feedback did, in this field test, demonstrate measurable and intuitive results; this, despite the congestion level, as represented by the volume-to-capacity ratio from the original base year 2004 sequential model being only 52 percent. This finding does suggest that the evaluative BPR approach described in Chapter 2 may need to be supplemented with other evaluation criteria to determine feedback applicability.

Overall, the findings from the field test of feedback in the Texas Package environment demonstrated that the technical challenges are surmountable and that there are potential benefits with respect to theoretical consistency between model steps and model results that are more intuitive with respect to travel behavior. The primary issue remaining to be balanced is if the improved model consistency and intuitive results for what is, still, a 24-hour daily model, outweigh the burden of implementing feedback, with the practical challenges described above.

RECOMMENDATIONS

The following recommendations are provided as a result of the research conducted and in addition to the findings from the field test. Some of the recommendations are related to the issue of network congestion (or lack thereof in small- to medium-sized urban area daily models) and focus on additional data needs or approaches for implementing feedback within the current TxDOT model structure. Other recommendations have arisen directly from the analysis of the TxDOT model structure itself and the field test of a feedback loop using an existing TxDOT model. As a result, the recommendations emphasize the following three different areas for consideration should TxDOT decide to implement feedback loops within its travel model process:

- Data requirements.
- Software enhancements or modifications.
- Feedback applications or approaches

The recommendations also include some guidance for when one should consider implementing a feedback loop based on the perceived level of congestion.

Data Requirements Recommendations

There are no additional data requirements for implementing the feedback mechanism as it was for the field test in Chapter 4.

However, should TxDOT decide to pursue time-of-day modeling as a general improvement, independent of but complementary to implementing feedback, peak period counts will need to be made available.

An additional model enhancement TxDOT may wish to consider, again in conjunction with implementing feedback or not, is updating volume-delay relationships. New volume-delay equations could be developed for different trip purposes if TxDOT-TPP chose to model different time periods for some trip purposes (e.g., peak period home-based work trips) or if composite impedances were used. Likewise, the use of multi-class assignments might also require the application of new volume-delay functions. In this case, TxDOT may wish to consider augmenting their comprehensive travel survey program by collecting speed-flow data for some urban areas.

Finally, given that free-flow speeds are currently not input as initial network speeds TxDOT may wish to consider implementing a volume-delay function that allows speeds and travel times to be revised for uncongested links in addition to congested links so that speeds are not just revised downward and travel times lengthened.

Software Related Recommendations

In the short term, the field test provides evidence that feedback can be implemented within the current TxDOT model structure using the model code application of the Texas Package as developed for the field test. Adaption of the code for other study areas necessarily involves some effort due to fundamental differences between study areas. Strict adherence to the Texas Package steps and parameters should be maintained if following the approach implemented for the field test.

Setting aside the issue of daily models versus peak period models, our research indicates that the implementation of feedback within the TxDOT model structure may benefit from several additional software enhancements to Texas Package components. For example, the application and operation of a feedback loop would logically benefit from using non-integer trip tables, continuous friction factors, and perhaps the cessation of employing bias factors. Whether or not the software enhancement recommendations are implemented, the field test that was conducted to support this research clearly underscores the need to automate the feedback process. Otherwise, the application of feedback will be cumbersome, to say the least, given the amount of time it takes for one feedback loop and the number of feedback loops an analyst would need to run to achieve convergence.

Feedback Application Recommendations

Feedback Mechanism Recommendations

The field test conducted for this research effort tested both MSA and Constant Weights methods, the MSA applied to the link and time values coming out of assignment, and the

Constant Weight applied to the trip tables prior to assignment. In the research, MSA is shown to mathematically converge; Constant Weights is advocated for situations when MSA does not converge quickly enough. RMSE of the skim table is also commonly used as a convergence criterion. For this field test, the MSA method was found to converge reliably, whereas the Constant Weight method did not. The convergence criterion of 0.01 PRMSE of the skim table was used as the control, but all the measures used demonstrated increasing model convergence as the mechanism looped. Based on these findings, the study team recommends continuing to use the MSA approach (implemented using the TransCAD utility or not) and the PRMSE of the skim table; the exact criterion of PRMSE 0.01 appears safe to use, but it may also be the case that a less tight convergence criterion is sufficient based on other performance measures.

It is highly recommended that any future implementation of feedback continue to calculate and report these other performance measures (PRMSE of the trip table, GEH statistic, maximum link flow, etc.) for continued consideration to ensure feedback system stability.

Texas Package Recommendations in the Context of Feedback

The researchers agree that an optimal pre-requisite for feedback looping is time of day in some form in the modeling process. Nevertheless, our research suggests that there are alternate approaches TxDOT-TPP may wish to examine with respect to implementing a feedback mechanism:

- Continue to use 24-hour models and feed back 24-hour congested travel times as tested for the field test conducted here.
- Continue to use the 24-hour models, but limit the feedback mechanism to one trip purpose—the home-based work trip purpose.
- Continue to use the 24-hour models to feed back daily travel times for all trip purposes but home-based work; for home-based work, feed back peak period travel times from a proxy peak-period assignment (e.g., applying diurnal factors and peak period capacities).
- Consider implementing time-of-day models for only the large urbanized areas in the state with significant transportation-related projects.

The options above are not mutually exclusive and the advantages of one approach over another may vary over time and across study areas. If TxDOT decides to implement feedback within a daily model environment, several suggestions and recommendations are offered below, in addition to recommendations for implementing feedback with a time-of-day model structure.

Feedback Recommendations within a Daily Model Environment

Based on the field test and in the context of implementing a feedback mechanism within the current 24-hour framework, it is recommended that a number of considerations be examined as a part of the traffic assignment step prior to implementation of feedback. The following variables may require further consideration:

- Number of iterations applied during traffic assignment application.
- Convergence criteria defined during traffic assignment application.
- Volume-delay equation referenced during traffic assignment application.
- Resulting 24-hour volumes, speeds, and times.
- Input 24-hour capacities, speeds, and times.

As noted previously (Chapter 2), a number of key issues have been addressed within the TxDOT model structure to achieve multi-path solutions using a capacity restraint approach on relatively uncongested systems (i.e., speed models, 24-hour capacities). If necessary to implement a feedback mechanism in a 24-hour model that exhibits very little congestion, and therefore relatively little divergence due to congestion, it is recommended that TxDOT first test the feedback mechanism with the sequential model parameters in order to adhere to the Texas Package model structure. If there is no diversion due to congestion, only then can the modeler examine the following issues prior to the implementation of a feedback approach:

- Modify the speed-delay curves for the region or by facility type.
- Update or modify the 24-hour capacity logic.
- Consider implementing a generalized cost assignment procedure (if 24-hour models are to be continued) to dampen the relative speed differences and desirability between facility types.
- Examine the number of iterations and convergence criteria applied during the traffic assignment procedure.
- The practice of coding centroid connector capacities in some urban areas as a means of addressing network-zone incompatibilities, irregular zone size and shape, and trip loading issues will need to be discontinued as modified centroid connector travel times can impede or prevent achieving feedback convergence.

Feedback Recommendations within a Time-of-Day Model Environment

The consideration of time of day in the modeling process may be undertaken in the TxDOT TDM context by introducing a time-of-day split factoring process just before traffic assignment, running assignment for multiple time periods, and feeding back a weighted travel impedance (i.e., travel impedances from each time-of-day-specific traffic assignment weighted by the number of trips in each time-of-day period as predicted at the end of the time-of-day split model) to trip distribution for the next iteration of the feedback process.

The only traffic impedance parameter used in the trip distribution step of the current TxDOT TDM is the zone-zone travel time, and even that is confined to the highway TAZ-to-TAZ travel times. Thus, at least in the immediate future, a simple travel impedance feedback measure corresponding to highway travel times should be adequate for the TxDOT TDM. However, any future improvements to the current TDM such as inclusion of a modal split step would need a reconsideration of the use of a simple unimodal travel time feedback measure; more composite impedance measures (including costs and times) and by multiple modes may need to be examined at that time.

Other Considerations

Currently, measures of accessibility and/or time are not key variables in determining zonal trip generation estimates. Consequently, the Texas Package does not have an approach to address the influence of travel time on home or business location decision-making within the trip generation models. This may require long-term consideration, but for the immediate future, recycling congested times back to the trip generation step is simply not feasible.

TxDOT could incrementally adopt the feedback approaches noted above rather than selecting one option. The options could be classified as near-term and relatively easy to address in the existing Texas Package to longer term approaches that would require significant redress of the Texas Package.

Overall, critical consideration should be given to the relative impact that implementing feedback might have on existing TxDOT-TPP practices. A feedback mechanism necessarily includes additional training and increases the calibration time associated with delivering base year travel models; and possibly could include additional data processing (and collection) related to time-of-day implementation.

GUIDANCE FOR THE IMPLEMENTATION OF FEEDBACK

As mentioned previously, of particular interest to TxDOT is the question of when is it appropriate to consider implementing feedback within a model structure and whether the effort to implement and maintain a feedback mechanism as part of the standard TDM model stream is merited. A follow-on concern is whether the answers to these questions differ for different urban areas, given their level of congestion.

Regarding the concern that most Texas urban areas exhibit relatively low congestion, the following three criteria are offered as a means of assessing whether it might be worthwhile to consider implementing feedback:

- Regional V/C Ratio. An urban area's regional assigned volume-to-capacity ratio could be considered an initial criterion, though its use as the sole criteria is *not* recommended. Many of the Texas urban areas have extended the model boundary to include entire counties; consequently, the additional less congested, rural area network links that are included in a base year network may diminish the value of this criterion. Expanded urban areas with low overall V/C ratios may nevertheless still encompass portions of roadways that do have some level of congestion, whereby trips may take alternate paths or trip tables might change as a result of implementing a feedback procedure. One other consideration may be to examine both base and forecast year network V/C ratios in tandem as a means of making an initial determination. For example, an urban area with base *and forecast* year V/C ratios of 0.3 and 0.5, respectively, may not merit further consideration as those values clearly indicate minimal network congestion.
- V/C Ratios by Area Type and Facility Type. Though the regional V/C ratio can be used as an elementary first cut at establishing whether any meaningful level of congestion exists in a base year network, it is recommended that an additional examination of V/C ratios by area type and facility types be conducted to assess congestion levels. Particular attention should be paid to the denser area types (CBD, urban, and suburban) as this is the portion of an urban area where congestion levels will be noticeable if some level of congestion does indeed exist. V/C ratios by facility type should also be examined to determine whether adequate congestion exists such that alternative competing paths may be congested for portions of the network.
- Non-attainment Areas. Though there are currently only four non-attainment areas in Texas and only two of the four areas fall under TxDOT's purview for model development, it is possible that under the Environmental Protection Agency's 2010 proposed air quality standards up to eight additional Texas urban areas may be

designated non-attainment. Since the 1990 Clean Air Act Amendment and subsequent guidelines address the use of consistent and realistic speeds in the modeling process, TxDOT may wish to consider implementing feedback for some or all urban areas that become designated as non-attainment in the near future.

Of course, a more definitive test for the applicability of feedback to an area is to conduct a preliminary round of feedback, either manually skimming the travel times coming out of assignment and feeding them back into trip distribution to see if there is any change in the trip distribution outputs, or to conduct a simple field test as was done here for the RGV model. Because of the care that was taken to minimize changes to the Texas Package approach in the RGV field test, such an application would be feasible in many cases.

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APPENDIX A. ASSIGNMENT ALGORITHMS

Traffic Assignment is the step in which route and link flows are predicted using a given OD travel demand matrix for a specific period of the day. The five most commonly used types of traffic assignment algorithms are:

- All or Nothing assignment.
- Capacity Restraint assignment.
- User Equilibrium assignment.
- System Optimal assignment.
- Stochastic User Equilibrium assignment.

ALL OR NOTHING ASSIGNMENT

In this type of assignment, the traffic demand between each origin-destination pair is assigned to the path with the least cost. This method ignores the fact that links have a certain capacity, and also that the link travel times change with the volume of traffic. In many cases, this type of assignment is used only as a basic step in the algorithms to solve other types of equilibrium problems rather than as an assignment algorithm by itself.

INCREMENTAL CAPACITY RESTRAINT ASSIGNMENT

In the Capacity Restraint assignment, the traffic is assigned in incremental steps. There are two ways of doing this. One approach is to assign a certain fraction of the total traffic between all OD pairs using an All or Nothing (AN) assignment procedure and then updating the costs of all the links using a volume-delay function. Then, again assign another incremental fraction of traffic and iterate through the steps until all the traffic is assigned to the network. Another approach of incremental assignment is to assign the traffic demand between a subset of OD pairs on the network using the AN assignment procedure and then updating the costs of all links using a volume-delay function. In the subsequent step, traffic between another subset of OD pairs is loaded onto the network. This incremental assignment is continued until all the OD pairs are exhausted. Both the above types of incremental assignments essentially involve loading the total demand incrementally and then updating the link travel times using a volume-delay function.

CAPACITY RESTRAINT ASSIGNMENT

Capacity Restraint assignment procedure involves assigning the entire trip table for several AN iterations (e.g., five iterations) with subsequent assignment iterations after the first based on time changes due to the previous iteration's VC ratios. Then a set of weights (percentages) are applied to each iteration (e.g., for five iterations the percentages applied could be 10, 15, 20, 25, 30) to derive the final assignment volume on each link.

USER EQUILIBRIUM (UE) ASSIGNMENT

The User Equilibrium assignment is based on the idea that under equilibrium no road user can unilaterally improve his/her travel cost (typically travel time) by shifting to any other path, i.e., to say that all used paths have the same travel time at equilibrium. This condition is also referred to as the Wardrop first principle and is the most commonly used assignment in practice because it is sure to converge. This is because the underlying non-linear optimization problem for solving user equilibrium is convex in nature with a unique deterministic solution (i.e., link flows).

SYSTEM OPTIMAL (SO) ASSIGNMENT

This assignment is based on what is known as the Wardrop second principle, which states that all users adjust their travel paths such that the total system travel cost is minimal. This is not the usual behavior because most of the road users try to minimize their own travel times irrespective of other users. However, policy makers are interested in this type of assignment because this is the best the system can perform under any conditions. So, it is used most often as a benchmark, and policies such as road pricing are designed to make the system performance close to that of the system optimal.

STOCHASTIC USER EQUILIBRIUM (SUE) ASSIGNMENT

This assignment is based on the notion that all road users do not perceive the same travel times; hence, some users may end up using travel paths with higher travel costs than others. Because of this, under equilibrium the perceived path travel times (and not the actual path travel times) between each OD pair are the same. To be precise, the perceived travel time PT_i by an individual i is assumed to be equal to the actual travel time T_i plus a stochastic error component ε_i to account for the perception error. The analyst assumes a distribution for the ε_i term (usually Gumbel) and computes the probabilities for different routes.

APPENDIX B. PARALLEL CONDUCTANCE FORMULA

The parallel conductance formula is designed to explicitly account for the differential modal availabilities among zonal pairs. The underlying idea is: the total impedance between two zones connected by modes in addition to auto is always less than the total impedance between two zones with exactly the same highway/auto impedance and no connectivity through other modes. Bhat et al. developed a parallel conductance formula for three modes—auto, transit, and walk to use as an impedance measure in disaggregate attraction-end choice models. The total impedance *H* between any OD pair in Bhat's formulation is given by (*6*):

$$H = (1 - y_t)(1 - y_w)C + (1 - y_w)y_t \frac{C}{1 + \frac{C}{T^\beta}} + (1 - y_t)y_w \frac{C}{1 + \frac{C}{W^\gamma}} + (1 - y_w)(1 - y_t)\frac{C}{1 + \frac{C}{T^\beta} + \frac{C}{W^\gamma}}$$

where y_t and y_w are indicator variables for whether the OD pair is connected by transit and walk modes, respectively; *C* is the total auto impedance, T is the total transit impedance, and W is the total walk impedance between the OD pair. β and γ are positive parameters that indicate the weights of transit and auto modes relative to the auto mode, respectively. The higher the value of these parameters are, the lesser the importance of the corresponding modes relative to the auto mode. In the formula above, when both y_t and y_w are equal to zero, the total impedance is exactly equal to *C,* which is the total auto impedance; for all other combinations of y_t and y_w, the total impedance *H* is always less than *C*.