Technical Report Documentation Page

1. Report No. FHWA/TX-14/0-6759-1	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Business Process and Logical Model to Support a Tour-Based Travel Demand		5. Report Date August 2013; Published June 2014
		6. Performing Organization Code
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9. Performing Organization Name and Address Center for Transportation Research The University of Texas at Austin 1616 Guadalupe St., Suite 4.202 Austin, TX 78701		10. Work Unit No. (TRAIS)
		11. Contract or Grant No. 0-6759
12. Sponsoring Agency Name and Address Texas Department of Transportation Research and Technology Implementation Office P.O. Box 5080 Austin, TX 78763-5080		13. Type of Report and Period Covered Technical Report 9/1/2012–8/31/2013
		14. Sponsoring Agency Code

15. Supplementary Notes
Project performed in cooperation with the Texas Department of Transportation and the Federal Highway Administration.

16. Abstract
Changing modeling needs over the past few years, spurred by the evolving policy contexts of transportation planning and emerging technologies, have led the planning community to explore tour-based and activity-based modeling paradigms as an alternative to the traditional trip-based modeling paradigm. As a leading travel model practitioner, the Texas Department of Transportation (TxDOT) Transportation Planning and Programming Division sponsored an earlier study to synthesize tour-based modeling approaches in the country and identify potential benefits and costs of transitioning to this emerging modeling paradigm in Texas. Based on the results of that study, the current research effort developed a business case for a tour-based travel demand model system. The business case discusses the justification and need for a tour-based model, and includes a business process model and a logical data model that provide the step-by-step actions and procedures needed to support the design and development of a tour-based travel model. The business case not only justifies the need for tour-based models, but also proactively identifies potential challenges and constraints that may arise in implementation, and provides pathways to address them. It also addresses the need to continue to operate trip-based models in parallel with tour-based where needed or required, and assesses any impacts of tour-based modeling on the Technological Services Division of TxDOT. Although TxDOT has not yet transitioned towards a tour-based modeling approach, the current study can facilitate the model's implementation if TxDOT decides to move forward.

17. Key Words		18. Distribution Statement	
Transportation Planning, Transition to Tour-Based Modeling, Business Case, Business Process Model, Logical Data Model		No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161; www.ntis.gov.	
19. Security Classif. (of report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of pages 92	22. Price

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

Business Process and Logical Model to Support a Tour-Based Travel Demand

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CTR Technical Report:	0-6759-1
Report Date:	August 2013
Project:	0-6759
Project Title:	Developing a Business Process and Logical Model to Support a Tour-Based Travel Demand Model Design for TxDOT
Sponsoring Agency:	Texas Department of Transportation
Performing Agency:	Center for Transportation Research at The University of Texas at Austin

Project performed in cooperation with the Texas Department of Transportation and the Federal Highway Administration.

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Acknowledgments

This project was conducted in cooperation with TxDOT and the FHWA. The authors thank Darrin Jensen, John Ibarra, Greg Lancaster, Mike Schofield, and Janie Temple for their input and guidance during the course of this research project.

Products

This report represents Product 1 of Project 0-6759 (0-6759-P1). Included in this online publication are links to products 0-6759-P2, *Business Process Model*, and 0-6759-P3, *Logical Data Model*, which includes the LDM of the tour-based model as created using ERWin Data Modeler software, a data dictionary, and the ERWin file.

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EXECUTIVE SUMMARY

The Texas Department of Transportation (TxDOT), in conjunction with the metropolitan planning organizations (MPOs) under its purview, oversees the travel demand model development and implementation for most of the urban areas in Texas. For this purpose, TxDOT created a standardized trip-based modeling approach for travel demand modeling called the Texas Package Suite of Travel Demand Models (henceforth referred as the *Texas Package*). The Texas Package is used as the decision-making tool to forecast travel demand and support regional planning, project evaluation, and policy analysis efforts. However, the changing modeling needs over the past few years, spurred by the evolving policy contexts of transportation planning, have led the planning community to explore tour-based and activity-based modeling paradigms as an alternative to the traditional trip-based modeling paradigm.

TxDOT's existing trip-based modeling approach for travel demand forecasting is adequate to examine most large-scale, regionally significant, highway capacity-added projects, as well as provide output usable for the air quality analysis required for areas designated as non-attainment and maintenance areas. However, this approach requires substantial post-processing and/or is unable to provide output for decision-makers on other types of transportation improvement projects being explored in today's increasingly funding-constrained and alternative goal-oriented environment. The Texas Package suite of models does not currently include the advanced-practice behavioral analysis techniques necessary to examine some specific policy- and behavioral-response questions. In this context, tour-based modeling is considered by subject-area experts and practitioners to be an advancement of the practice over and above improvements that can be made to traditional trip-based models. Tour-based models reflect more effectively the trade-offs that an individual makes in changing their travel behavior and, therefore, are more sensitive and logical in its response to different transportation policies.

The appeal of tour-based models has led TxDOT's Transportation Planning and Programming Division (TxDOT-TPP) to document the transition from the current trip-based modeling paradigm to the tour-based modeling paradigm under a research project entitled *Tour-Based Model Development for TxDOT: Evaluation and Transition Steps*, 0-6210-2 (*1*). Research report 0-6210-2 is the basis for the current research effort. The report's main objectives were to identify the practical benefits and advantages of implementing a tour-based modeling framework and evaluate the feasibility of the steps required to implement a tour-based modeling process in Texas. Research report 0-6210-2 recommended tour-based model designs for TxDOT in the short, medium, and long term.

The current study considers a business case for a tour-based travel demand model system using formal documentation from TxDOT's Technological Services Division (TxDOT-TSD). The goals of developing a business case for the implementation of a tour-based travel demand model system in Texas are to

1) Incorporate advanced-practice technical procedures.
2) Provide stakeholders with additional performance-based metrics to make informed transportation decisions.

3) Add value to the communication of technical model procedures and results to various audiences.
4) Work within the Texas Package context and philosophy.
5) Minimize impacts to current organizational processes.

The first three goals align with TxDOT's Strategic Plan objectives, while the last two goals are designed to minimize unnecessary implementation difficulties.

To accomplish these goals from a **technical perspective**, the analysis is based on the research report 0-6210-2. This report outlines various design options for implementing behavioral-based analysis techniques considering the TxDOT modeling context, data availability, and organizational constraints. Among these options, the short-term recommendation is called "Design Option #1" and, described in simple terms, is a simple tour-based model system with no recognition of interactions among tours. The advantages of implementing this type of system as a first step are two-fold:

- TxDOT already has most of the data necessary to support it, and
- It is relatively simple to implement from a training and maintenance standpoint.

Further, to minimize changes to data collection and input development stages of the model implementation process, the tour-based approach is only applicable to the procedures to calibrate and apply the model. Thus, no changes would be necessary under the current implementation to either data collection efforts (counts and surveys) or model inputs development (demographics and networks). As a further simplifying assumption according to Design Option #1, the tour-based model analyzed here applies only to resident travel and not to other trip purposes, such as visitor and truck travel. Therefore, a tour-based model implementation can be straightforwardly incorporated into the general structure of the Texas Package.

From an **organizational perspective**, efforts that improve planning decision-making are clearly supported by the federal transportation funding reauthorization. Further, in pursuing this process improvement, TxDOT is aligning itself with other public agencies in Texas and nationwide in seeking ways to be more efficient and effective in its structure and organizational approach to serving the public needs. The tour-based module is posited to be developed independently of commercially available software, and the collaborative relationship between TxDOT and Texas MPOs would be minimally affected by a transition to a tour-based technology. The estimated cost of developing and implementing a tour-based model can reach $1 million; however, the benefits for the community in terms of more accurate policy evaluation—and, therefore, fund allocation—can surpass this figure in the long-term. The updated version of the Texas Package, with the tour-based module, would be loaded and run from TxDOT staff members' individual desktop computers, concurrent with existing practice. TxDOT can still rely on their current desktop computers, but acquiring more powerful computers is advised (minimum of a 1 GHZ processor, 4 GB RAM, and 210 GB hard drive). Likewise, the procedures to download model files and data from TxDOT servers and data systems are assumed to remain the same, as are the procedures to archive and upload model files upon completion of model tasks

Finally, from a **communications perspective**, the technical professional audience is assumed to be the same as it is currently: generally, TxDOT and MPO staff, on-call academic support staff from in-state research institutions, and consultant contractors. TxDOT should continue to develop a variety of training resources to serve the needs of the Texas transportation forecasting community: webinars on activity-based and tour-based modeling organized by the Federal Highway Administration (FHWA), the Travel Model Improvement Program (TMIP), and the National Highway Institute (NHI); Texas Package-specific modeling training sessions offered through TxDOT-TPP; and side-by-side training alongside coworkers, partner agencies, and on-call consultants (as trip-based modeling has been taught in Texas for decades).

The two main outcomes of the business case developed in this study are a business process model and a logical data model (products P2 and P3). In the current context, the **business process model** is a representation of the flow of data inputs, outputs, and models that provides a framework to ensure an efficient and correct development of a tour-based model. The business process model developed in this study graphically validates the assertion that Design Option #1 is achievable with data sources readily available to TxDOT and the MPOs. The land-use, transportation network, and system performance data require no or very little additional processing beyond that already occurring under the trip-based approach. The travel survey data does require additional processing to form tours from trips recorded in the travel diary. Most relevant for goals 4 and 5 described above, the business process model demonstrates how main components of the tour-based model can be directly interfaced as an additional module option within the Texas Package suite of programs.

The **logical data model** provides a visual representation of the tour-based travel demand model's pertinent data and relationships among data items. The model includes all data sources required for input into the tour-based and trip-based model components and provides the foundation for further system development. The logical data model can be exported to a physical data model based on TxDOT's requirements for further database development. In compliance with TxDOT data architecture standards, the logical data model includes a data dictionary, which describes the entities and attributes that are contained within the logical data model.

An evaluation of the business case concluded that tour-based modeling meets state-level contextual considerations. The impact to non-technology process and resources is considered the area of highest impact, which is unsurprising given that TxDOT-TPP is the exclusive host of the current trip-based modeling process for TxDOT. The greatest impacts are anticipated on the human side and not on the technical side, as staff adjusts to a new modeling approach. A mitigating factor is the proposed approach to integrate the tour-based model into the current, familiar Texas Package. The impact to technology resources, specifically to TxDOT-TSD, is considered minimal, assuming a continuation of the current implementation of travel demand models completely inside TxDOT-TPP and on individuals' desktop computers. The business case evaluation suggests implementing a pilot for study areas that are in attainment for air quality conformity because of concerns that the tour-based model might result in output substantially different from output from the trip-based model used for conformity analysis; this approach avoids that potential issue for the pilot. Finally, business outcomes are realistic and achievable, presented with goals for outcome evaluation. The highest risks are likely to be funding availability and perceived value by decision-makers and stakeholders.

The value of the business process exploration prior to embarking upon the tour-based model implementation is in ensuring that TxDOT has a full understanding of the issues outlined above. This business case also documents the existing process flow, the proposed flow, the business process model, and the logical data model, providing an opportunity to assess technical issues and data input considerations. This report supports TxDOT decision-making process regarding the transition towards a tour-based model and facilitates future model implementation.

1. INTRODUCTION

The Texas Department of Transportation (TxDOT) is a large public agency with established procedural and technological protocols and a history since the 1970s of travel demand model (TDM) development. TxDOT, in conjunction with the metropolitan planning organizations (MPOs) under its purview, oversees the TDM development and implementation for most of the urban areas in Texas. For this purpose, TxDOT created a standardized approach for travel demand modeling called the "Texas Package Suite of Travel Demand Models" (henceforth referred as the *Texas Package*). The Texas Package, in conjunction with TransCAD, is a daily vehicle trip-based model. The Texas Package is used as the decision-making tool to forecast travel demand and support regional planning, project evaluation, and policy analysis efforts. However, the changing modeling needs over the past few years, spurred by the evolving policy contexts of transportation planning, have led the planning community to explore tour-based and activity-based modeling paradigms as an alternative to the traditional trip-based modeling paradigm.

1.1 TRAVEL DEMAND MODELING IN TEXAS

1.1.1 Texas MPOs

TDMs predominate in Texas as a best-practice tool for planning transportation projects in the regional context. Texas has 25 MPOs (*2*) and 11 transportation management areas (TMAs) (*3*), identified in Table 1. Some MPOs operate in conjunction with the local councils of government (COGs), hence the variation in naming of MPOs in the table.

In the 1960s the state of Texas began providing traffic analysis and planning level forecasting centralized in TxDOT, including data collection, travel demand modeling, and corridor analysis to support analysis needs across the state (*14*). TxDOT's support of Texas MPOs in travel demand modeling remains centralized for the majority of the state's MPOs to this day. The formal relationships for model development between TxDOT and the individual MPOs are described in Table 2. Broadly speaking, TxDOT's Transportation Planning and Programming Division (TxDOT-TPP) handles TDM estimation and validation for 20 of the MPOs, while the MPOs handle the collection and preparation of demographic and network data for the model development and make travel forecasts using the TDM developed by TxDOT-TPP. These MPOs, small- and medium-sized in terms of population and staffing resources, are under TxDOT purview for TDM development.

Table 1. Texas MPOs and TMA Status

MPO	Major City	Area (sq. mi.)	2010 Population	Designation Year	TMA Status
Abilene MPO	Abilene	266	125,229	1969	
Amarillo MPO	Amarillo	348	216,490	1975	
Brownsville MPO	Brownsville	279	226,282	1973	TMA
Bryan-College Station MPO (BCSMPO)	Bryan	591	194,851	1970	
Capital Area MPO (CAMPO)	Austin	2,840	1,603,952	1973	TMA
Corpus Christi MPO	Corpus Christi	538	328,116	1973	TMA
El Paso MPO	El Paso	1,240	853,190	1973	TMA
Harlingen-San Benito MPO	Harlingen	343	153,819	1993	
Hidalgo County MPO (HCMPO)	Weslaco	993	772,000	1993	TMA
Houston-Galveston Area Council (H-GAC)	Houston	8,466	5,892,002	1974	TMA
Killeen-Temple Metropolitan Planning Organization (KTMPO)	Belton	555	348,556	1975	TMA
Laredo Urban Transportation Study (LUTS)	Laredo	421	243,978	1973	TMA
Longview MPO	Longview	178	103,406	1975	
Lubbock MPO (LMPO)	Lubbock	193	245,161	1976	TMA
Midland-Odessa Transportation Organization (MOTOR)	Midland	528	267,927	2005	
North Central Texas COG (NCTCOG)	Arlington	4,969	6,417,630	1974	TMA
San Angelo MPO (SAMPO)	San Angelo	96	96,283	1964	
San Antonio-Bexar County MPO (SABCMPO)	San Antonio	1,287	1,763,463	1977	TMA
Sherman-Denison MPO	Sherman	320	86,830	1980	
South East Texas Regional Planning Commission (SETRPC)	Beaumont	2,229	388,746	1970	
Texarkana MPO	Texarkana	196	94,278	1975	
Tyler Area MPO					
Victoria MPO	Tyler	343	165,017	1974	
Waco MPO	Victoria	890	86,793	1982	
Wichita Falls MPO	Waco	1,061	234,906		

Sources: (*2*, *3*)

Table 2. TxDOT and Texas MPOs: A Flexible Modeling Partnership

Formal relationship with TxDOT for model development	MPOs in Category
Independent, with TxDOT oversight	Houston-Galveston Area Council of Governments North Central Texas Council of Governments El Paso MPO
Substantially independent, with TxDOT oversight & assistance as needed	San Antonio MPO Capital Area MPO
Under TxDOT purview for model development	All remaining (20) MPOs

Source: (*18*)

The other five MPOs are in varying stages of relative independence with respect to model tasks. The largest MPOs—the North Central Texas Council of Governments (NCTCOG) and Houston-Galveston Area Council (H-GAC)—have a formal agreement with TxDOT to develop, maintain, and apply their own TDMs, with TxDOT oversight concurrent with its federally mandated responsibilities. The El Paso MPO has a similar agreement, but has worked more closely with TxDOT in recent years on TDM activities. The Capital Area MPO (CAMPO) and San Antonio-Bexar County MPO (SABCMPO) have informal flexibility in this regard.

In practice, for the larger MPOs, TxDOT's oversight on the TDM process translates into model reviews at milestones in the model development and application process. MPOs in transition to greater independence may at times seek additional technical input and guidance from TxDOT, and TxDOT staff will typically be present at key meetings during the process to ensure that communication channels remain open. For the 20 MPOs under TxDOT purview, the model development and application process is structured and highly collaborative.

1.1.2 The Texas Package

The Texas Package includes a variety of utilities and check tools; however, the models of most interest here are those directly supporting the steps of the trip-based model (shown in Figure 1). The Texas Package is maintained and applied primarily as a sequential, trip-based model, including the traditional three steps of trip generation, trip distribution, and traffic assignment. Trip generation is performed using auto-vehicle trip generation; therefore, a mode choice step is not necessary in the traditional and typical application of the Texas Package. As shown in Figure 1, the Texas Package includes two software packages proprietary to TxDOT, TripCAL5 and ATOM2, which are used for the trip generation and trip distribution steps, respectively. A commercially available software package specifically developed for travel demand modeling, TransCAD, is used for the highway assignment step.

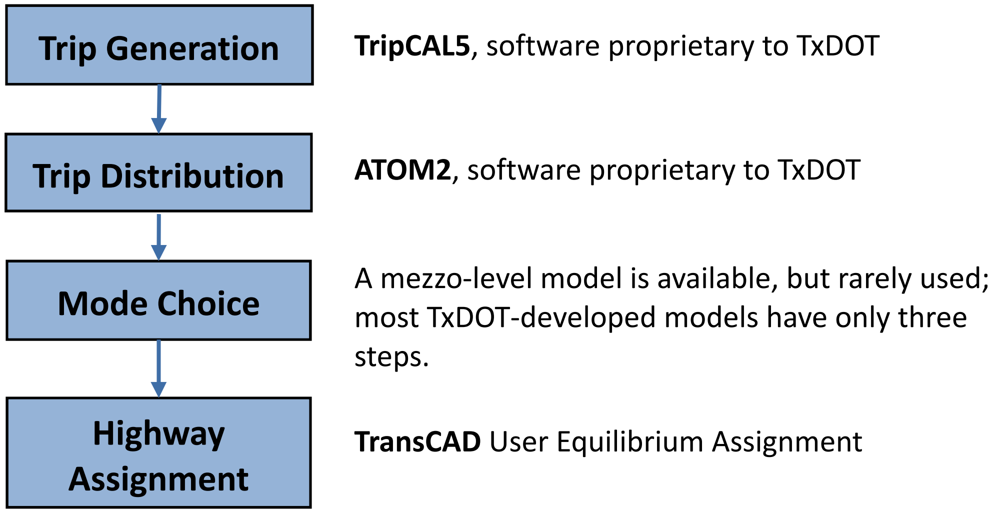

Figure 1. Texas Package Modeling Technology

In addition, TransCAD is used for maintaining the demographics and network data, as well as running the other utilities mentioned previously, such as those that facilitate the derivation of inputs for use by TripCAL5 and ATOM2. An additional utility runs the ATOM2 model from TransCAD (not the TripCAL5 model at this time). Therefore, TransCAD may be considered the modeling environment for the Texas Package, although TripCAL5, ATOM2, and many of the utilities have been coded and are maintained using FORTRAN. As noted in a recent publication, TxDOT has a philosophy of maintaining portions of the Texas Package independent of commercially available software such as TransCAD. The reasons provided are “to promote in-house capability and knowledge as well as preserve portability” (*14*).

1.1.3 Tour-Based Modeling Approach and Research Report 0-6210-2

The tour-based approach uses “tours” and not trips as the basic element to represent travel. Tours are chains of trips beginning and ending at a same location, such as home or work. The tour-based representation helps maintain consistency across, and capture the interdependency (and consistency) of the modeled choice attributes among, the trips within a tour. This is in contrast to the trip-based approach that considers travel a collection of “trips,” each trip being considered independent of other trips. The tour-based approach explicitly considers the interrelationship of choice attributes (such as time of day, origin and destination, and mode) of different trips within a tour, and therefore recognizes the temporal, spatial, and modal linkages among trips within a tour. Thus, the tour-based approach can lead to improved evaluations of the impact of policy actions.

Many in the transportation analysis community use the terms “tour-based” and “activity-based” interchangeably; an argument in favor of this use of the nomenclature is that both terms differentiate these approaches from trip-based models. The research team involved in this current effort agrees with others in the field in drawing a further distinction between tour- and activity-based models. Compared to simple tour-based models, activity-based models are more disaggregate, focus on activities as the basis of travel decisions over an entire day, and consider interactions between tours of individuals, among other differences. Activity-based models include a tour-based model (to aggregate activities into trip chains, or “tours”), but tour-based models can operate without consideration of the underlying activities driving the travel decision. Hence, tour-based models can be considered a simpler and intermediate approach short of a full activity-based model.

The appeal of tour-based models has led TxDOT-TPP to consider transitioning from the current trip-based modeling paradigm to the tour-based modeling paradigm. In fact, TxDOT has already invested in a feasibility examination of tour-based models under a research project entitled *Tour-Based Model Development for TxDOT: Evaluation and Transition Steps*, 0-6210 (*4*), funded by TxDOT RTI and completed in October 2009. Research report 0-6210-2 is the basis for the current research effort. The report's main objectives were to identify the practical benefits and advantages of implementing a tour-based modeling framework and evaluate the feasibility of the steps required to implement a tour-based modeling process in Texas.

The research report 0-6210-2 reviews the state of practice for tour-based model in the U.S. and future modeling needs to arrive at a recommended tour-based model design for TxDOT in the short, medium, and long term. The short-term recommendation is called "Design Option #1" and, described in simple terms, is a tour-based model system with no recognition of interactions among tours (simple tour-based system). The advantages of implementing this type of system as a first step are two-fold:

- TxDOT already has most of the data necessary to support it, and
- It is relatively simple to implement from a training and maintenance standpoint.

Design Option #1 starts with a population synthesizer, taking as input the U.S. Census Public Use Microdata Sample (PUMS), the population and employment data and other socioeconomic data that may be developed/available for the region. The population synthesizer will be used to create a synthetic population of households drawn from the PUMS and allocated to the traffic analysis zones (TAZs). After the generation of the synthetic population and other socio-demographics, long-term choices such as work location zone and household auto ownership are simulated for all synthetic individuals and households in the population. Next, the synthetic households and individuals are taken through three sets of subsequent models: pattern-level choice models, tour-level choice models, and trip-level choice models. Each set of models consists of a series of econometric choice models. Then, the predicted trips can be aggregated into origin-destination (OD) trip tables, and combined with other OD trip tables such as external trips and commercial traffic. Finally, the network traffic assignment models (such as using TransCAD) can be used to load the trips onto the network. Design Option #1 is reviewed in more detail in Section 3.

1.2 TRANSITIONING TO A TOUR-BASED MODELING APPROACH

TxDOT's current trip-based modeling approach is adequate to examine most large-scale, regionally significant, highway capacity-added projects, as well as to provide outputs usable for the air quality analysis required for areas designated as non-attainment and maintenance areas. However, this approach requires substantial post-processing or is simply unable to provide outputs for decision-makers on other types of transportation improvement projects being explored in today's increasingly funding-constrained and alternative goal-oriented environment.

To address the above problem, implementation of tour-based modeling should recognize Texas' unique context. However, transitioning towards a tour-based modeling approach requires a **business case analysis** to ensure that the proposed tour-based model system provides process, service, and technological benefits in exchange for the state's investment. A business case is a detailed investment proposal that considers quantitative and qualitative evaluation factors that underlie selection of business alternatives. A business case analysis is used to compare various business alternatives and provide a basis for selecting the one that delivers the greatest value to the state, the agency, and constituents (*5*). In this research, the business alternatives are the trip-based modeling approach as currently implemented by TxDOT and the tour-based modeling approach as proposed in report 0-6210-2. Then, expected outcomes of the business case are the following:

- **Statutory fulfillment:** fulfills business mandates and strategies from federal, state, or other statutes or rules
- **Strategic alignment:** aligns with the State Strategic Plan for Information Resources Management and the agency's strategic plan
- **Agency impact analysis:** impacts use of information technology resources at the enterprise level
- **Financial analysis:** delivers cost analysis, benefits, and metrics, including financial impact to the state
- **Initial risk consideration:** considers project risks and provides a preliminary review that may impact business outcomes
- **Alternatives analysis:** emerges above other project alternatives as a result of applying a consistent method for analysis and selection

1.3 RESEARCH OBJECTIVES AND OUTLINE OF THE REPORT

Based on the results of 0-6210-2, TxDOT-TPP is now moving forward to develop a business case and logical data model, including step-by-step actions and procedures to support the design and development of a tour-based travel model. This plan not only justifies the need for tour-based models, but also proactively identifies potential challenges and constraints that may arise in implementation, and provides pathways to address them. It also will address the need to continue to operate trip-based models in parallel with tour-based where needed or required, and assess any impacts of tour-based modeling on TxDOT's Technological Services Division (TxDOT-TSD). Some of these issues have been explored previously (*1*), but need to be positioned as a business case for consideration by the department before implementation on a statewide scale.

The purpose of this research project is to comprehensively explore the steps involved in the implementation of a tour-based modeling system for TxDOT and Texas MPOs that are under the purview of TxDOT-TPP. The results of this research will benefit TxDOT and Texas MPOs under the purview of TxDOT-TPP by thoroughly researching the need for and potential benefits and challenges of implementing tour-based modeling prior to TxDOT taking any steps toward implementation.

This business case begins with the problem definition in Section 2. This approach follows the delivery framework prescribed by the Texas Department of Information Resources (DIR) for enterprise-system level technology projects. Section 3 presents the assumptions and constraints for solutions to address the problem defined in Section 2. Section 4 provides the business process model and the logical data model. Finally, Section 5 presents the evaluation of the tour-based modeling approach and provides the outcomes of the business case.

2. DEFINITION OF BUSINESS ALTERNATIVES

From a general perspective, prior to implementing any effort that entails a shift of staff and technology resources, public agencies are obligated to ensure that there has been a full accounting of the need for such a transition and effort. The focus of this section is the definition of the business alternatives considered in this business case:

- Trip-based modeling approach (current technology environment)
- Tour-based modeling approach

This section concludes with an elaboration of the issue at hand into a *Problem Statement*, with associated risks considered relevant to the discussion.

2.1 BUSINESS ALTERNATIVE 1: TRIP-BASED MODELING APPROACH

The technology impacts of moving from trip-based to tour-based modeling are an important issue to be carefully assessed during the project. This section documents the technology system in which the tour-based approach would be incorporated, including the workflow context for the current trip-based modeling system. Much of the detail of the current system, including data inputs and software package requirements, has already been provided in minute detail in 0-6210-2. The traditional four-step, sequential, trip-based models have served the transportation community literally for decades. Figure 2 depicts the traditional four-step, sequential TDM approach and describes each step.

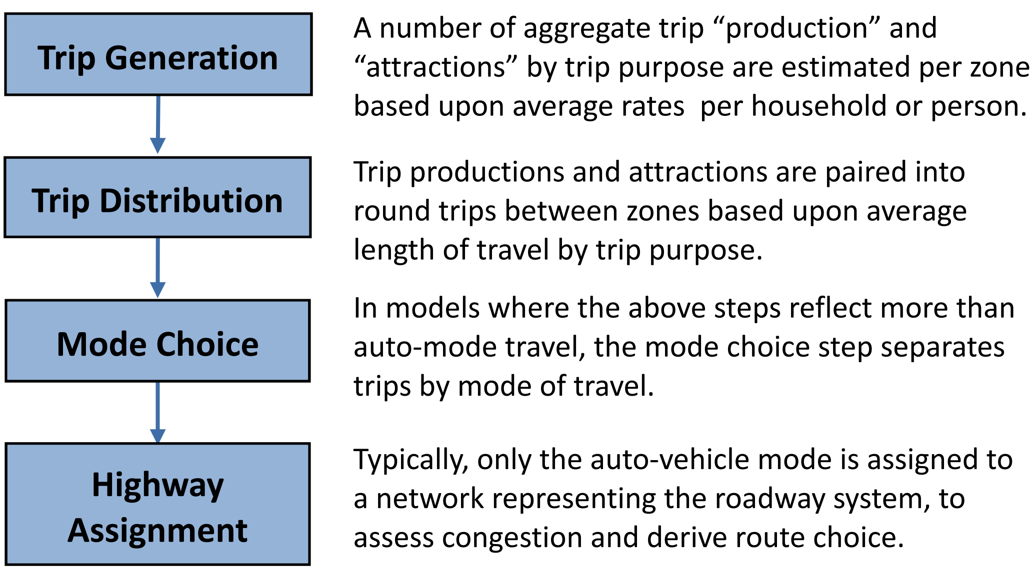

Figure 2. Traditional Four-Step, Sequential TDM Approach

2.1.1 Trip-Based Technology Summary

This sub-section summarizes the trip-based system, then outlines the business model context—how the trip-based technology is applied by the agencies and people involved as part of the transportation planning process described above. Later in this section, the research team describes the current trip-based modeling technology environment within the current TxDOT framework.

As described in Section 1, Texas substantially supports most of the Texas MPOs in travel model development and application. This decades-old relationship has resulted in the development of what is termed the "Texas Package Suite of Travel Demand Models," or *Texas Package* (*14*).

Texas Package implementation procedures

Up until mid-2012, TxDOT used TransCAD version 4.5 as the standard for travel model implementation. As models are updated, the department will update models to use TransCAD version 6.0 and the most recent versions of TripCAL5 and ATOM2. The Texas Package, including TransCAD, is loaded and run from TxDOT staff members' individual desktop computers.

Typically, TxDOT staff members assigned to perform a model update or analysis using a TDM follow this procedure:[1]

- Verify that the latest Texas Package software and components are loaded onto the individual desktop computer.
- Download the most recent model files for the specific MPO from the TxDOT-TPP internal "K" drive.
- Perform modeling tasks as directed.
- When the modeling task is complete, upload the updated model files to the TxDOT-TPP internal "T" drive, and notify appropriate personnel that the files are ready for review.
- An assigned TxDOT-TPP staff member performs the review.
- An assigned TxDOT-TPP staff member uploads files to the "K" drive.
- As appropriate, TxDOT-TPP staff forwards model files to the MPO, typically using digital media or the TxDOT-specific cloud service.

The procedures outlined above are tightly controlled for file-management and quality-control purposes.

Note that all modeling tasks occur on an individual TxDOT employee's desktop computer, due to the size of the files created for TDMs, as well as the many iterations necessary to calibrate a model. This file-management approach has been observed as common practice for TxDOT, as well as other public agencies, research institutions, and consultants performing travel demand modeling. The interaction that occurs with the TxDOT enterprise system is derivative only—data are extracted from the enterprise system for use in the model development process. Model output is archived to the TxDOT system, but no data are fed back into the enterprise system. This independence of travel demand modeling procedures from other TxDOT processes is depicted in Figure 3.

[1]Guidance provided to TTI staff assisting TxDOT-TPP personnel in model development and application tasks during the period 2009–2012.

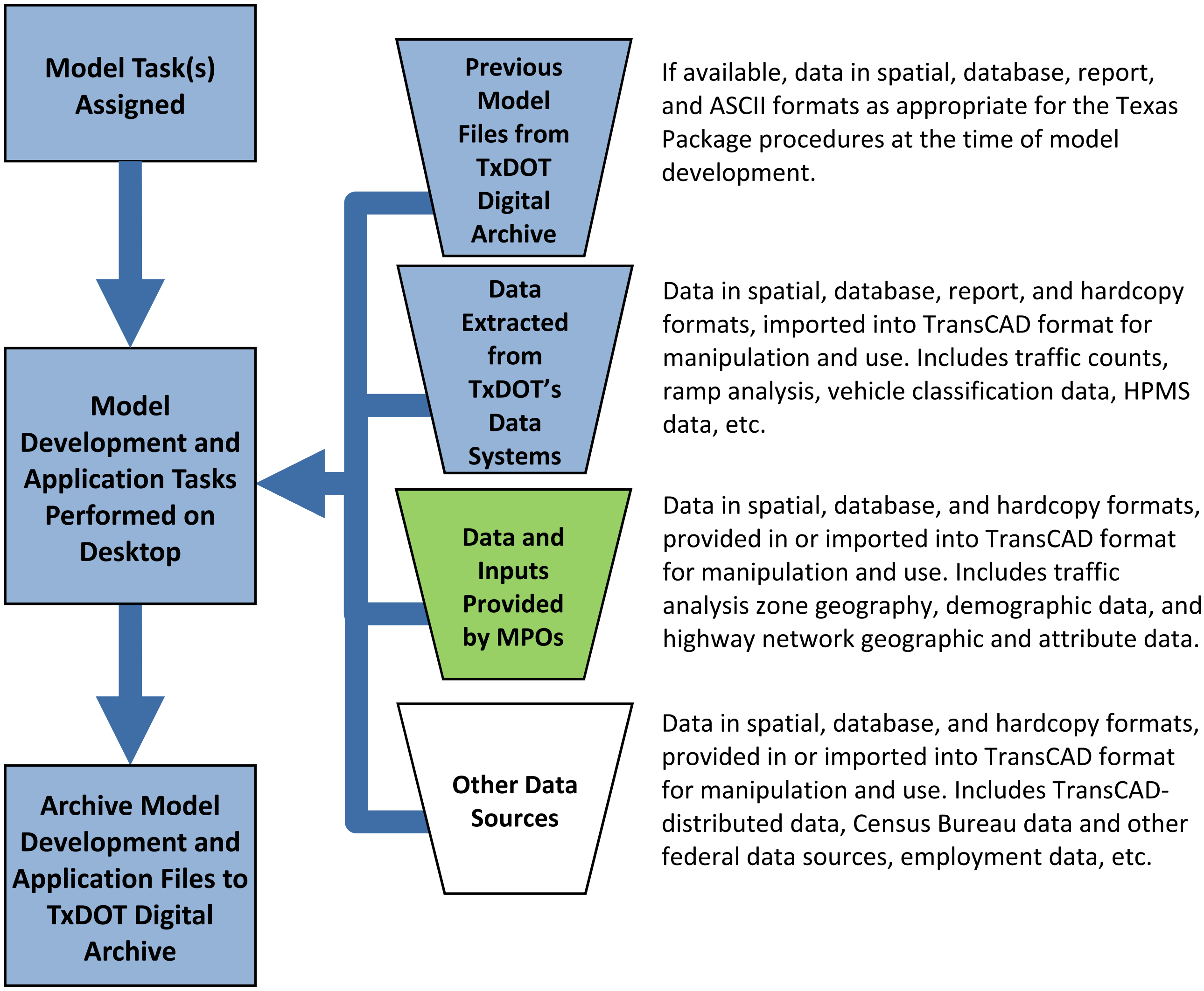

Figure 3. TxDOT Travel Demand Models' Relationship to Other Data Systems

Model outputs: Texas trip-based approach

Typical outputs from the Texas Package are shown in the following tables. Table 3 describes typical performance measures reported out of the Texas Package for standard applications, such as the development of a metropolitan transportation plan (MTP, a document requiring updating at least every 5 years[2]). Table 4 describes other performance measures the Texas Package can yield with minimal effort for specific analysis purposes.

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[2] 23 CFR 450.322 (b)

Table 3. Typical Performance Measures from the Texas Package

Level of Analysis	Measure
System-wide*	• **Vehicle-miles traveled (VMT)** Measure of regional travel – link volume (vehicles) multiplied by link length (miles) and summed for all links • **Vehicle-hours traveled (VHT)** Measure of regional hours spent traveling – link volume (vehicle) multiplied by link travel time (converted to hours) and summed for all links • **Average trip length (miles)** Average distance traveled per trip –VMT divided by total trips' average trip length (minutes) Average time traveled per trip –VHT converted to minutes and divided by total trips • **Trips per person/per household** Average of number of trips made each day or by members of a household – total trips divided by population or total trips divided by number of households
Link-level*	• **Volumes (vehicle traffic)** Daily vehicles (autos and trucks) traveling the link • **Volume-to-capacity ratio (v/c)** Measure of the amount of capacity in use – volume divided by capacity • **Congested "speed" (mph)** Link travel time from assignment based on v/c ratio and converted to a speed – link distance (miles) divided by link time (minutes) times 60
Other*	• **Point-to-point congested travel "time" (minutes)** Measure of travel time from one location in the network to another based on link travel time from assignment – the travel time of links connecting two nodes in the network summed • **Number of trips exiting and entering a TAZ** Measure of travel activity produced by and attracted to a TAZ – the volume on centroid connectors of a TAZ summed

*All are 24-hour (daily) values.
Source: (18)

Table 4. Other Performance Measures the Texas Package Can Yield with Minimal Effort

Level of Analysis	Measure
System-wide*	• **Auto-versus-truck travel measures (VMT, VHT)** Regional measures of travel miles and hours by autos and trucks reported separately and obtained from separate assignment of auto and truck trips – auto/truck link volume multiplied by link length and summed for all links • **External-versus-internal travel (VMT)** Regional measure of travel demand by residents of region and visitors reported separately and obtained from separate assignment of internal and external trip demand – external/internal link volume multiplied by link length and summed for all links • **Total system delay** Regional measure of additional time spent traveling due to recurring congestion – regional VHT minus regional VHT from a single iteration assignment
Link-level*	• **Select-link (also called *critical-link*) analysis** Identification of the TAZ trip demand passing through a specified set of links and component of flows on all links that pass through a specified set of links • **Auto-versus-truck volumes** Comparison of auto and truck demand link volumes – produced from separate assignment of auto and truck demand • **Volumes by trip purpose** Link volumes separated by the purpose of the trip travelling on the link – produced from separate assignment of purpose demand • **External-versus-internal volumes** Comparison of external and internal demand volumes – produced from separate assignment of external and internal demand
Other*	• **Turning movements at specific intersections** Turns from regional traffic assignment at pre-defined reporting network nodes. Provides macroscopic overview of direction of flows at intersections.

*All are 24-hour (daily) values.
Source: (18)

Table 3 and Table 4 describe typical performance measures the Texas Package can yield with minimal effort for specific analysis purposes. TxDOT has also developed other approaches for specific analytical needs. Table 5 lists these other Texas Package approaches that have been tested and are available as needed and upon TxDOT approval for analysis application.

Table 5. Other Texas Package Approaches for Specific Analysis Needs

Analysis Need	Texas Package Approach/Notes
Mode Choice	• Junior Mode Choice Model
Toll	• Methodology available to be implemented as necessary
Freight	• Utilize SAM for truck flows • Methodology available to be implemented as necessary
Peak Hour/Period	• Using diurnal factors by trip purpose, either specific to local area from survey data or general values
Feedback	• Has been tested as a case study only

Source: (18)

2.1.2 Planning Process and Model Application Steps for Small and Medium Texas MPOs

Within the collaborative relationship between TxDOT-TPP and the small and medium MPOs is a process to develop the regional TDMs. This process includes all the steps to collect data, develop the models, and support the MPOs in applying the travel forecasting model as part of their transportation planning process. This process also supports individual project planning activities, including those necessary for TxDOT-led projects. This model development process is summarized in Figure 4.

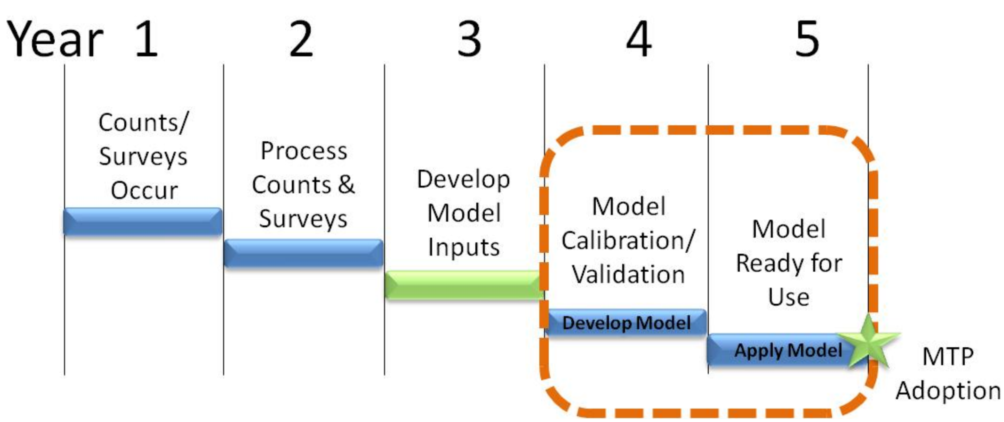


Figure 4. Travel Forecasting Model Implementation Context (*18*)

Drilling down further into TxDOT-TPP's current trip-based process for developing a model for small and medium MPOs, Figure 5 depicts the model steps of the typical Texas Package model application. This flow chart serves as the foundation to identify exact model steps that will be affected by the transition to a tour-based technology solution. For the purpose of the current goal-definition stage, the project team will include, in the goals and objectives section to follow, a goal that a tour-based model implementation be incorporated into the general structure of the Texas Package as shown in Figure 5. In this respect, a tour-based model will be merely another model component of the Texas Package, similar to the way that TripCAL5 and ATOM2 are model components of the trip-based approach.

2.1.3 Limitations of the Trip-Based Approach

Although trip-based models have provided quantitative analysis measures used by the public and decision-makers to make thousands, if not millions, of decisions regarding transportation improvements, tour-based modeling is considered to be an improvement over current practice. In order to understand why tour-based modeling is a step forward technically for transportation forecasting, it helps to have a conceptual understanding of the known limitations of the traditional trip-based approach.

Limitation 1: Aggregate analysis approach

In trip-based models, the travel model is generally applied at an aggregate level. Overall, these aggregate approaches include consideration of demographic data by zone (typically larger than census blocks, smaller than census block groups) using average trip rates by trip purpose applied across relatively generalized strata of demographic characteristics (for example population per household by income). Aggregate approaches typically apply these rates to households, instead of considering individuals and the interaction between individuals within a household (for example, parent and child). What this approach lacks in precision, it makes up for in other respects: advantages include simplified data needs and computational processing. Indeed, consideration of average travel behavior may be sufficient for many analysis needs, particularly when forecasting in the long term (at least 20 years).

Limitation 2: Sequential decision path

Underlying the traditional trip-based approach is the linear, sequential aspect. The four steps represent travel behavior as four separate and unrelated decisions: whether to travel (trip generation), where to travel (trip distribution), how to travel (mode choice), and what route to take (highway assignment for vehicle trips). In reality, a person’s travel decisions are not made through such a sequential, linear process, but via much more complex decision-making. Following are some of the elements factoring into travel decisions:

- The decision whether or not to travel and how to travel clearly depends upon ease of access to transportation options, e.g., a person who does not have a vehicle or transit option is less likely to travel.
- Where to travel is related to the modal options available, especially for populations with limited model choices (transit-dependent travelers, for example).
- Whether, where, and how to travel clearly are influenced by congestions levels that are considered under the highway assignment step.

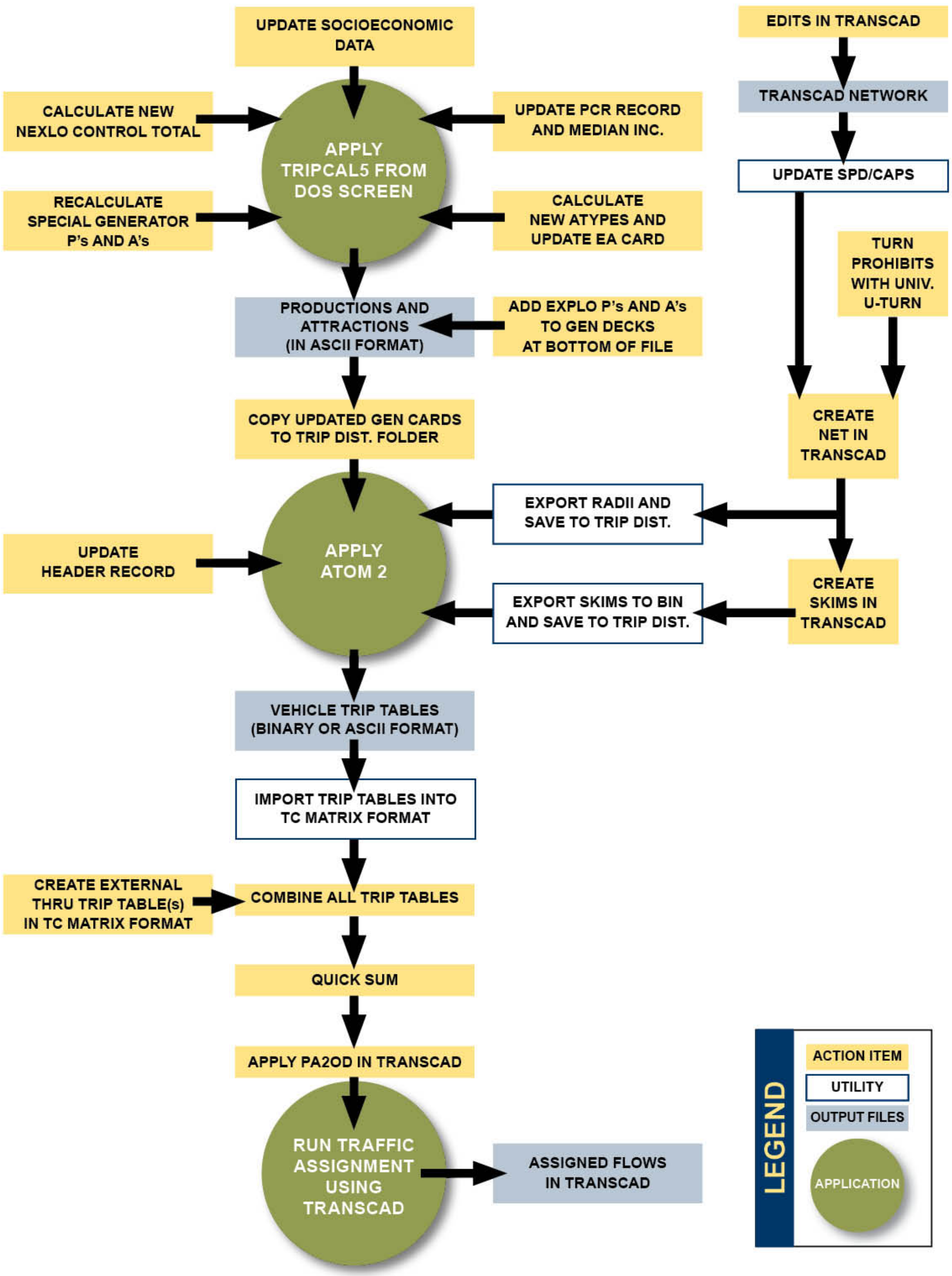


Figure 5. Texas Package Detailed Trip-Based Model Steps (*6*)

Limitation 3: Disjointed travel

The decisions of whether, where, and how to travel, as well as which route to select, are all part of a complex decision-making process. The traditional four steps conspicuously fail to address the question of *when* to travel. This drawback is related to a third limitation intrinsic to the traditional trip-based approach: trips between origin and destination pairs are independent from other trips. As shown in Figure 6, travel trips in a traditional trip-based system are modeled as independent interactions between origins and destinations.

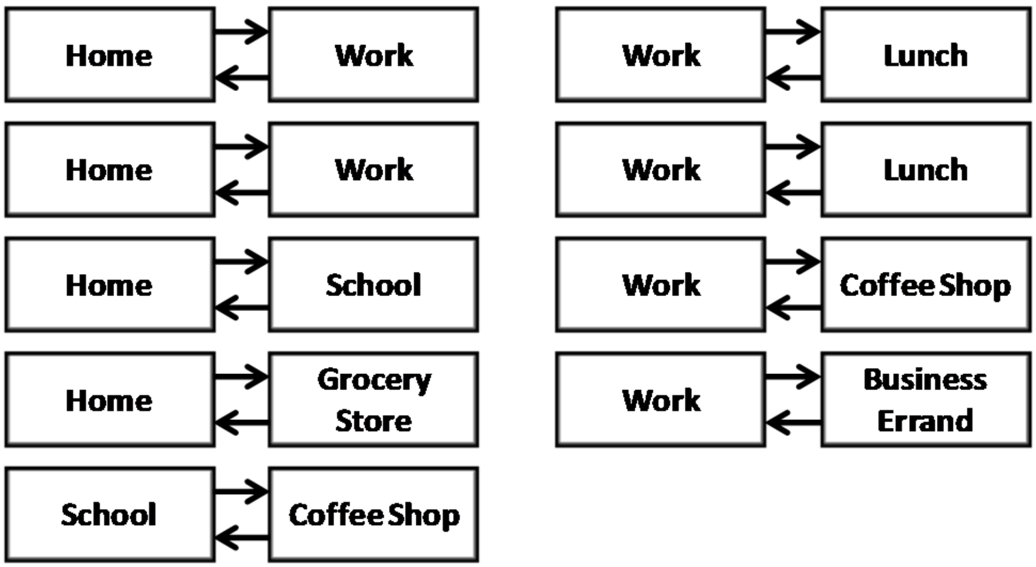


Figure 6. Trips in a Trip-Based System Are Organized by Origin and Destination

Although the representation shown in Figure 6 is a combination of the trip generation and trip distribution steps, no interaction is reflected between these individual trips, except for the "to" and "from" between each origin and destination pair reflected by each arrow pair. This approach aptly represents the type of simple trip shown in Figure 7 (a basic trip between home and work—that is, origin and destination) but not more complicated trips. In Figure 8, we juxtapose Person 1 from Figure 7 with other individuals with more complicated daily travel patterns.

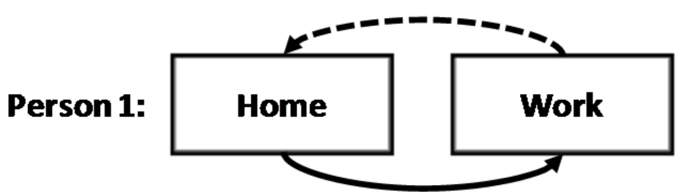


Figure 7. Simple Home-to-Work and Return Trip Diagram

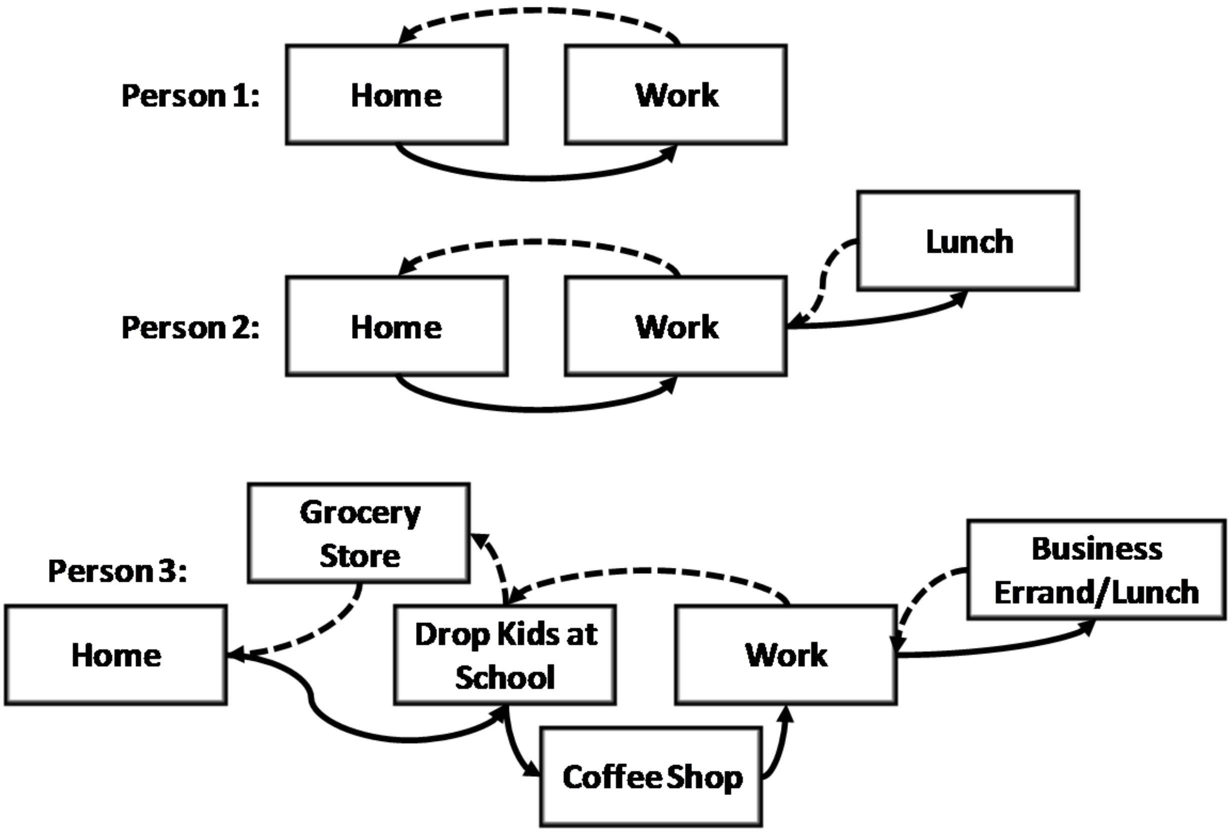


Figure 8. Trips in a Tour-Based Model Are Chained by Personal Daily Activities

Limitation 4: Limited time of day applicability

The question of *when* in the day the different trips occur naturally arises from this lack of linkages between the trips. We know that in reality people's daily travels are more often a series of interconnected trips and that travel is not an end in itself (except for tourism). For Person 2 in Figure 8, the *when* of the travel is evident, as the trip to lunch takes place *after* the trip to work; likewise, the trip home takes place *after* the trip to lunch. Person 3's travel pattern likewise implies information pertaining to when the travel occurs. Within the trip-based approach, methods to represent period travel windows, particularly peak periods, vary. None of the standard methods, however, result in linkages between the trips; even the more advanced approaches merely result in the individual trips being distributed throughout the day.

Limitation 5: Potential for irrational trip choices

A limitation resulting from the lack of linkage between the trips is a loss of rationality with regard to individuals' trip choices along a trip chain—that is, a series of stops along a tour. For example, under the trip-based approach, the same employee that was determined to have taken bus transit to work (leaving their car at home) can be determined to drive their car to lunch. In another example, it can be determined that a person drives their car to the school to drop off their child, rides their bicycle to the coffee shop, and takes the bus to work (see Person 3 in Figure 8). We know that modal shifts within a trip chain need to be consistent.

Despite these and other known limitations, the trip-based modeling approach has been a fundamental tool for regional travel forecasting for decades, including in Texas, and it remains the standard for the majority of MPOs across the country. It will remain the state of practice for many communities, where the benefits of transitioning to the newer tour-based approach do not outweigh the challenges in doing so. One demonstration of the continuing resilience and relevance of the trip-based approach is the 2012 publication of the report "Travel Demand Forecasting: Parameters and Techniques." In recognition of this continuing practice, the majority of the report is oriented toward supporting practitioners in implementing the traditional trip-based modeling approach, including best practice approaches within the trip-based context. The report also dedicates a chapter to emerging modeling practices, including activity-based modeling as one section (*7*).

2.2 BUSINESS ALTERNATIVE 2: TOUR-BASED MODELING APPROACH

2.2.1 Overview

Tour-based modeling has established support in academic and research applications for many reasons. The most pertinent considerations address the limitations discussed previously for the traditional trip-based approach:

- In contrast to the aggregate approach of traditional trip-based modeling, tour-based models focus in on individual travel at a much finer geographic level, typically parcel-based. Even if a decision is made to work with geography at a zonal level, a disaggregation technique is applied to disaggregate the zonal households and populations into individual units for analysis.
- Tour-based models estimate and forecast daily travel activities as tours by individuals. As shown in Figure 9, route choice still occurs under the assignment step. However, the remaining steps are addressed by the tour-based model, which considers all of the questions of whether, where, and how to travel as part of the travel pattern the individual creates through their day. Route choice informs these questions as well, through incorporation of a feedback loop mechanism. This aspect of tour-based modeling addresses the other limitations of the trip-based approach: the issues regarding the sequential decision path, disjointed travel, time-of-day applicability, and rational trip choices.
- Because of the more realistic representation of travel behavior, tour-based models reflect more effectively the trade-offs that an individual makes in changing their travel behavior.

The technical justification for implementing a tour-based modeling approach is already implied by the earlier discussion of limitations with the traditional trip-based approach (Section 2.1.3). The premise of tour-based modeling is implied by its name: travel results from each individual person's activities and these activities can be modeled to represent tours or chains of trips, as shown in Figure 8. Tour-based modeling re-integrates the representation of an individual's travel decision, essentially combining the first three steps of the trip-based approach with a tour-based approach, as shown in Figure 9.

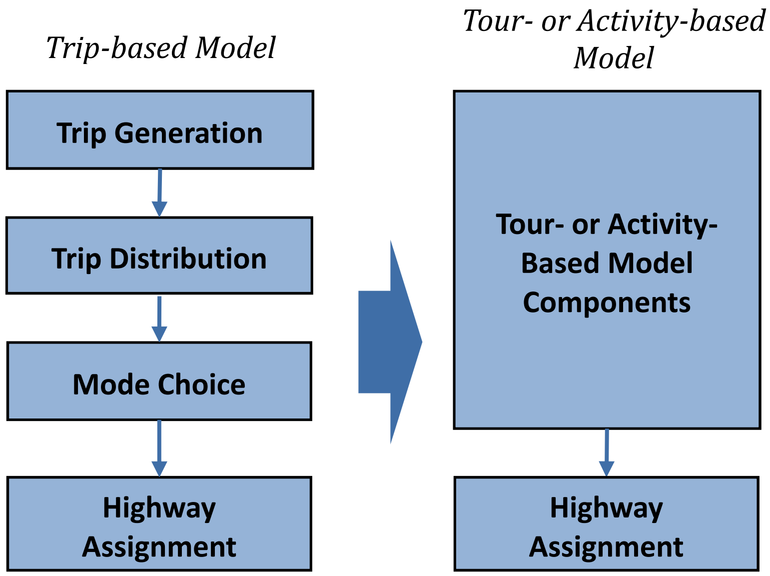


Figure 9. Integration of Travel Decision-making Representation by Individuals under the Tour-Based Modeling Approach

For these reasons, tour-based modeling, along with activity-based modeling, is considered by subject-area experts and practitioners to be an advancement of the practice over and above improvements that can be made to traditional four-step trip-based models. This assertion is supported by a wealth of documentation, such as the following:

- Special Report 288, *Metropolitan Travel Forecasting: Current Practice and Future Direction*. Transportation Research Board, 2007, Chapter 6 (*8*).
- Transportation Research Record, No. 2021, *Advances in Travel Behavior Analysis*, Transportation Research Board, 2007; 10 out of 14 of the papers address activity-based analysis (*9*).
- NCHRP Synthesis 406, *Advanced Practices in Travel Forecasting*, Transportation Research Board, 2010 (*10*).
- NCHRP Report 716, 2012. *Travel Demand Forecasting: Parameters and Techniques*, Transportation Research Board, Chapter 6 (*7*).

Given these advantages, several U.S. transportation agencies have adopted either activity-based or tour-based models, including the following:

- San Francisco County Transportation Authority, San Francisco (SFCTA)
- New York Metropolitan Transportation Commission, New York (NYTMC)
- Mid-Ohio Regional Planning Commission, Ohio (MORPC)
- Tahoe Regional Planning Agency, Lake Tahoe Region, Nevada (TRPA)
- Sacramento Area Council of Governments, Sacramento, California (SACOG)
- Denver Regional Council of Governments, Denver, Colorado (DRCOG)

- Atlanta Regional Commission, Atlanta, Georgia (ARC)
- Metropolitan Transportation Commission, San Francisco (MTC)
- Southern California Association of Governments (SCAG)
- Oregon Department of Transportation, Oregon (ODOT)
- Puget Sound Regional Council, Seattle, Washington (PSRC)

2.2.2 Technical Justification for Tour-Based Modeling

Greater realism for travel forecasting is important—by including the diversity of different activity patterns and time-of-day choices, the tour-based approach is more sensitive and logical in its response to different transportation scenarios. Examples include the following:

- Individuals who drop off or pick up a child at school on their way to work are likely to be less responsive to incentives to walk, bicycle, use transit, or change their trip time to avoid peak period travel.
- Individuals above retirement age are more flexible in the timing of their trip activities and therefore more responsive to off-peak policy decisions.
- Households with vehicle ownership equal to or greater than the number of driving-age adults have greater flexibility to use their single-occupancy vehicles (SOV) at different times of the day in response to policy decisions that incentivize off-peak travel.
- Activity-based demographics analysis enables "aging" of demographic profiles so that individual travel behavior changes in response to an individual's age. For instance, workers in their 40s exhibit a different daily travel pattern in general than after they retire, 25 years later. Similarly, individuals with children in primary school exhibit different daily travel patterns than 10 years later when their teenagers make their own way to school.

There are many other examples of how the specificity of the tour-based approach vis-à-vis the individual's daily travel activities enables a tour-based model to be much more responsive (and logical in its response) to policy decisions that affect individuals' travel behavior. In particular, transportation agencies can evaluate the application of policies such as ridesharing incentives, mixed land use development, congestion pricing, alternate work schedules, and incentives to telecommuting.

Changing planning context

Understanding the current transportation planning context is key to understanding why tour-based modeling is increasingly needed in the state of practice: the move toward tour-based modeling is being driven by changing constraints as well as evolving transportation solutions. Following are some of the constraints:

- Declining funding availability for large-scale capacity additions that were typical of and expected through the era of the Interstate Highway System.
- Environmental concerns about community impacts and air quality.
- Increasing professional and public skepticism about the sustainability of transportation solutions oriented exclusively toward SOV travel.

On the side of addressing congestion and mobility, there has been an understanding that some effort should include capacity improvements and incentives for non-SOV travel, such as incentives for high-occupancy vehicles (HOVs) including vanpools, bus transit, light and heavy rail options, and even bicycle and pedestrian models. There have also been calls for policies to address and reduce demand, particularly in response to periods of high fuel costs and air quality management programs. In more recent years, the phrase "we can't build our way out of congestion" has gained prevalence. As the above constraints increase, the public, decision-makers, and travel modelers themselves are increasingly seeking alternative approaches to address congestion, mobility, and travel accessibility, even or especially in the context of small metropolitan areas (*11*). For example, the Brownsville MPO set the goal of enhancing the integration and connectivity of the transportation system across and between modes, which relies on identify strategies and policies that serve to foster improved intermodal connections (*12*). Similarly, the Hidalgo County MPO (HCMPO) acknowledges the need of diverse transportation alternatives and has designed a bicycle network in their area. Besides providing increased mobility, this network can lead to a reduction in the number of vehicles, which at the same time can "reduce the amount of maintenance and construction funds necessary to maintain the street system" (*13*).

Recent model advancements

Even as these different approaches are being analyzed, the field is exploding with advances. Tour-based modeling represents just one area of advanced practice. Advances in assignment techniques, particularly dynamic network modeling down to mesoscopic and microscopic detail, are changing the landscape. These techniques not only replicate traveler route choice and assignment behavior more accurately, but also perform better with more detailed input data. An additional factor is that travel models, even trip-based models, have always included an underlying assumption that transportation users have full information about their choices for travel. With evolving technology including real-time data collection and communication advances, transportation users increasingly do have real-time information to inform their transportation decisions. Finally, advances in computational power enable application of more complex theoretical approaches to the state of practice. Support of these and other technical advances through research grants provided at the federal level have been key to supporting the transfer of these theories into practice.

Realism and ease of explanation

Finally, with regard to the context of this shift, an understanding of the role that public transparency is playing in the push toward tour-based modeling would be helpful. Despite the familiarity of practice for those who were originally trained in trip-based modeling, tour-based modeling is inherently more explicable to the general public and decision-makers. Referring back to Figure 6, which represents the trip-based miscellany of trips unlinked across a daily period versus the concept of individuals' activities as chains of trips shown in Figure 8, we see that a tour-based model clearly represents travel more credibly. Further, since tour-based models use a finer temporal resolution and develop activity and travel itineraries through scheduling models, they are more appropriate for the analysis of policies that involve coordination between individuals and time-sensitive scheduling constraints. Not only does the public find tour-based models more intuitive, anecdotal evidence suggests that newer planning and engineering graduates who have been trained in tour-based modeling find the transition to trip-based modeling in the field to be counterintuitive.[3]

Benefits of implementing a tour-based model in Texas

The previous discussion emphasizes the main benefits of transitioning towards a tour-based model. Agencies that adopt this approach are able to represent individual travel more closely to reality. Considering again Figure 6, the disjointed trips represented in a trip-based system, versus Figure 8, examples of trip-chains representing individual travel under a tour-based model, clearly the tour-based approach more closely approximates realism in the travel model process. This more realistic representation in itself is a technical achievement for the practice of travel forecasting, leading to a more accurate evaluation of policy. Then, overall, tour-based models are more sensitive than trip-based models to changes in the transportation system and, therefore, are more suited to policy scenario analysis.

In Texas, these benefits are particularly relevant. First, TxDOT has been recognized as one of the leaders in transportation planning and, therefore, shifting towards a tour-based modeling approach would confirm TxDOT's commitment to innovation. Second, in many urban areas in Texas the trip-based approach is not well suited to analyzing the complex range of policy alternatives that are of interest today. For example, a modification in either school or work schedules cannot be captured with the Texas Package. Similarly, trip-chaining and household interactions (for example, dropping the children to school and then going to work) are not part of the Texas Package modeling framework. The current Texas TDM is, overall, not well-suited to address pricing and tolling analysis, policies sensitive to time of day, effects of urban centers and transit-oriented development, and induced travel. Further, the Texas trip-based approach is not sufficiently sensitive to changes in demographics and car ownership. Adopting a tour-based approach could help TxDOT and Texas MPOs to improve their understanding of travel and to obtain more precise policy evaluations.

2.2.3 Challenges to Implement a Tour-Based Model

Despite the advantages presented here and other known advantages, the slow adoption of tour-based modeling in practice is a well-documented phenomenon (*14*). The following factors most strongly influence the decision by public agencies to forgo adopting the tour-based approach:

- Constrained agency resources in general disincentivize expenditures necessary to convert models, even in pursuit of long-term benefits. Further, staff and consultant training intrinsic to implementing a new approach may be cost-prohibitive.
- Tour-based modeling may require more extensive data collection efforts or more extensive data analysis than the traditional trip-based approach, at least for the typical or desirable tour-based application.
- Model results used for air quality conformity analysis could be worse than they would be under the trip-based approach (several agencies have maintained their trip-based models alongside their tour-based model development activities while they assess this issue).

[3] Texas A&M Transportation Institute, observations and discussions with recent graduates, 2011–2012.

- Tour-based model results might be inconsistent with findings from the trip-based approach upon which previous transportation decisions were based, and agency leaders may have concerns about explaining these differences.
- Agency staff may have concerns that they will be unable to adjust to the new approach.
- Time and resource investment in tour-based modeling may be difficult to justify to the parties responsible for funding modeling activities, given the lack of a specific federal requirement for the tour-based approach.

Not all of these challenges pertain to the Texas travel demand modeling framework. Section 5 discusses these issues in detail, targeted to the TxDOT context.

2.2.4 Tour-Based Modeling and TxDOT Agency Imperatives

A primary question, before taking the bold step of implementing a new technology and approach and expending the associated effort, time, and resources, is whether a step toward tour-based modeling represents a step closer to meeting TxDOT's strategic goals. This section explores how tour-based modeling addresses TxDOT's strategic goals and statutory requirements.

Tour-based modeling and TxDOT goals

TxDOT's 2013–2017 Strategic Plan, adopted on June 28, 2012, states the agency's mission as "Work with others to provide safe and reliable transportation solutions for Texas" (*15*). Following are the goals and objectives listed together with this mission:

Goal: Maintain a Safe System

- *Objective: Reduce crashes and fatalities on the system through innovations, technology, and public awareness*
- *Objective: Maintain and preserve the transportation assets of Texas*

Goal: Address Congestion

- *Objective: Partner with local officials to develop and implement congestion mitigation plans in Texas*

Goal: Connect Texas Communities

- *Objective: Prioritize new projects that will increase the state GDP and enhance access to goods and services throughout the state*

Goal: Become a Best-in-Class State Agency

- *Objective: Ensure the agency deploys its resources responsibility and has a customer service mindset*
- *Objective: Focus on work environment, safety, succession planning, and training to develop a great workforce*

After these goals and objectives are listed seven agency priorities with examples of steps to meet those priorities:

Be the Safest DOT in the United States.

Develop and Implement Authorized Comprehensive Development Agreements (CDAs) and Discuss the Need for Additional CDAs

Develop Innovative Maintenance Approaches That Reduce Costs and Improve/Preserve Transportation System Conditions
Develop Effective Information Systems
Act as Resource for Transportation Funding
Implement Congestion Mitigation Projects
Further Strengthen and Enhance Our Relationship with MPOs, Counties, and Other Key Stakeholders

Of the specific priority actions described, none directly references expanding planning and policy tools to improve transportation decision-making. And yet, the priorities themselves imply a fundamental directive: that the department as a whole should be more strategic with the resources and tools it has. Without specifying every aspect of the agency's overall operations, the TxDOT core value of trust (including credibility, responsibility, and excellence) clearly translates to process improvement at every feasible juncture, including the advanced planning process whereby future project commitments are made.

In pursuing this process improvement, TxDOT is aligning itself with other public agencies in Texas and nationwide in seeking ways to be more efficient and effective in its structure and organizational approach to serving the public and public needs. Texas effectively mandates strategic planning and budgeting through its Statewide Planning and Budgeting System, an approach whereby each agency's budget is linked to the state's Strategic Plan and specific performance measures. Therefore, agency strategic plans reflect this goal-oriented approach. In their strategic plan, the Texas DIR, for example, cites a priority of innovation and service improvement (*16*). Likewise, the Texas Comptroller of Public Accounts cites as goals efficiency and expeditious management (*17*). An initiative that supports greater efficiency and effectiveness of budgeted dollars clearly forwards a statewide value.

Federal statutory requirements

Transportation planning process and procedures are subject to federal and state regulation, in large part because of funding controls on the use of federal dollars in transportation projects. Metropolitan regions have particular requirements. Metropolitan areas with populations over 50,000 and formally designated as metropolitan planning areas (MPAs) each have an associated MPO to conduct regional transportation planning activities. MPOs have specific transportation planning responsibilities under federal transportation legislation. Transportation management areas (TMAs)—MPAs with populations over 200,000—have more stringent planning process requirements. The planning process requirements do not explicitly mandate the use of a TDM to support the development of a region's long-range transportation plan, and yet:

- The plan "shall, at a minimum, include: (1) The projected transportation demand of persons and goods in the metropolitan planning area over the period of the transportation plan" [23 CFR 450.322 (f)(1)].
- The requirements for a "simplified transportation plan" approach have been interpreted to apply only to MPOs that are not TMAs, are in air quality attainment status, and have no plans for highway or transit new-capacity projects (*7*).

The above requirements are generally interpreted to leave the determination of transportation demand forecast up to the MPO. And yet, this is not the end of the story for model requirements.

From a statutory standpoint, TxDOT, like other state DOTs, is invested with a primary responsibility for ensuring the soundness of the planning process for projects of regional significance or projects that are all or partially funded by federal dollars (*18*). This responsibility includes a new requirement of performance-based planning, as mandated under the Moving Ahead for Progress in the 21st Century Act (MAP-21), signed into law on July 6, 2012. Details of performance-based planning implementation are currently working their way through federal and state policy bodies (*19*); meanwhile, state DOTs continue to be accountable for defensible planning processes to support transportation decision-making. In summary, efforts that improve planning decision-making are clearly supported by the federal transportation funding reauthorization.

The requirement to use a TDM is more explicit under federal air quality controls. MPOs designated as being in non-attainment or maintenance status with respect to air quality under the federal Clean Air Act of 1970 and its amendments (CAAA) are required to adhere to stringent planning requirements. Other non-metropolitan areas in the state also are subject to certain planning requirements, and yet the focus of this effort are the state's 25 metropolitan areas, specifically the 20 models developed and maintained by TxDOT for small- and medium-sized MPOs. The remaining discussion, therefore, addresses MPOs.

Under the above described federal controls, the use of a TDM for regional transportation planning is *required by law* under only two scenarios:

(1) When the MPO has been designated as being non-attainment or maintenance (previously non-attainment) status for certain air pollutants as proscribed under the CAAA; or, in other cases.

(2) If, as a TMA, an MPO has a history of having used a TDM to support regional transportation decision-making in the past (this provision is frequently referred to as the "no backsliding rule").

Guidance for planning approaches that may necessitate the use of a TDM is provided by the FHWA, state DOT, and state environmental agencies (e.g., the Texas Commission on Environmental Quality [TCEQ]). Another consideration is to support transit New Starts applications, for which guidance is provided by the Federal Transit Administration (FTA) (*7*). Outside of the above instances, use of a TDM for transportation planning purposes is generally considered best practice, although sketch-planning approaches are occasionally used.

As a general description of how TDM application and output can be integrated into the transportation planning process, in the development of an MPO's required MTP, an MPO will forecast demographics and employment for the horizon year of the plan—for example, year 2040 for an MTP to be adopted in the year 2015. Concurrently, the MPO will prepare a transportation "network," which represents available transportation options in terms of speed and capacity; most often for small- and medium-sized MPOs, the network represents roadway capacity only, serving autos and commercial vehicles, because these are the predominant modes used in the area. A model is then developed and calibrated to match base-year known travel patterns and traffic conditions, and ideally validated to another given year's data. Once the model is ready to be applied, one model scenario the MPO might run to gauge transportation need is to apply the forecast year demographics for the roadway network with no improvements made above what is already committed to. This scenario is typically called "Existing plus Committed" and can be a good starting point for transportation planners in the region to identify—for themselves, decision-makers, and the public—areas in the network that exhibit need and projects that may address that need. Additional model runs may then be performed testing the benefits of various projects in comparison to each other, including scenario runs with groups of projects that are financially feasible (these scenarios are called "financially constrained scenarios"). A project-level model application follows similar steps.

Clearly, the above process demands some time to develop model inputs, perform model runs, interpret the runs, and integrate model findings into the planning process. For areas designated as being non-attainment or maintenance status for certain air pollutants under the CAAA, additional post-processing runs are necessary using model results to determine that the area's selection of planned projects meets the definition of conformity. Similarly, other post-processing steps may be necessary to evaluate model results to answer particular local questions.

Every MPO in the country has a different business process for applying their TDM in their planning process (if they use a model at all; some 15 percent of MPOs with populations under 200,000 report not using a model [*8*]). Likewise, the relationship between MPOs and state DOTs with regard to modeling varies widely across the nation, from the state DOT being highly involved in the development, maintenance, and application of models (more common the smaller the MPO is, most likely in response to resource constraints) to the state DOT having merely an oversight role ensuring that a proper planning process is being followed (*8*). In some cases, these variations of relationship between MPOs and DOT exist within a state, in response to the differing needs of the state's MPOs (*18*). Texas is one of these cases.

State statutory requirements

From the state-level perspective, Texas requires that all non-attainment area MTPs be based on TDMs, with more stringent model requirements for the areas that fall into the federal model requirement category (described above) (*21*). For TMAs not in that category, the state specifies that the MTPs be based upon "estimates of travel demand" and that "development of long-range transportation plans relies on computer travel demand forecasting" (*21*). However, the TxDOT manual quoted is in the process of being updated and some exceptions have been made.[4] In actual practice, under the auspices of the consultative partners including

[4] Interview with Janie Temple, TxDOT-TPP, conducted by Karen Lorenzini under the MPO Capacity Building RMC, September 2012.

the FHWA and TCEQ, the MPOs that are neither under air quality conformity requirements nor TMAs may not even perform travel demand modeling in support of their MTP (*18*).

As for the federal requirements, the details of the TDM processes supporting planning decisions are not statutorily specified. The use of the TxDOT approach is implied by the relationship between TxDOT and the MPO. Then, if the MPO model is being developed by TxDOT, TxDOT uses its standard approach, and other MPOs with greater resources may or may not choose to use TxDOT's model approach. However, when the FHWA asks TxDOT to provide comment upon the MPO's model (in the case of TMAs, for MPO certification, for instance), TxDOT has more confidence in providing a review of model components following standard TxDOT practice (*18*).

The conclusion under this section and the previous section is that TxDOT and Texas MPOs, except in the case of MPOs that are under air quality conformity requirements or are TMAs, have flexibility to use or not use TDMs to support their MTP development process. The type of TDM applied is not statutorily specified, but implicit in the policies and procedures controlling the relationship between TxDOT and the MPOs; that is, MPOs under the purview of TxDOT in practice use the TxDOT standard approach to maximize technical support by TxDOT and to facilitate review under oversight processes.

TxDOT and the smaller Texas MPOs

For the 20 small- and medium-sized Texas MPOs, who usually do not have the staff or technical resources necessary to develop their own travel forecasting models, the relationship with TxDOT is collaborative, as described above and illustrated in a TxDOT provided as Figure 10. TxDOT-TPP is the division in TxDOT directly responsible for this task.

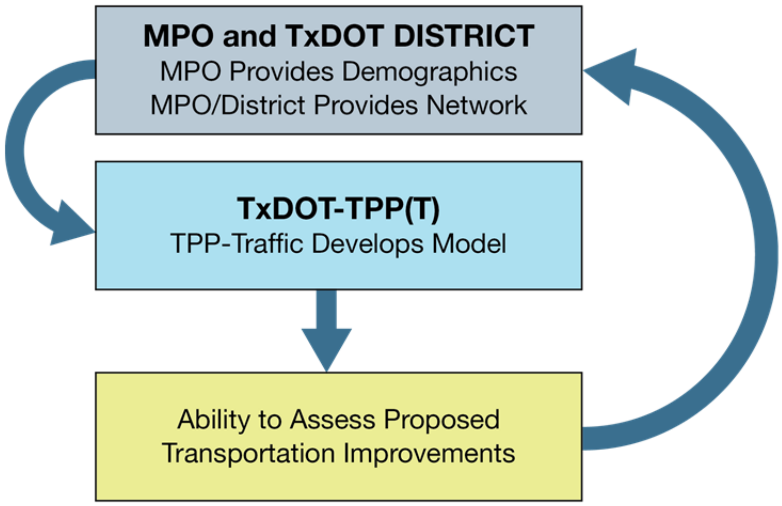


Figure 10. Model Development for Small- and Medium-Size MPOs in Texas: A Cooperative Process

Source: Graphic reformatted based upon concept in (22).

In general, Texas MPOs follow the approach described previously for use and application of modeling results in their planning processes. However, the context for Texas MPO modeling must be fully appreciated: the MPOs that have greater independence in the development, maintenance, and application of their models are also those with more resources, particularly staffing resources, to apply their models for various scenarios in support of long-range planning. The smaller MPOs, and therefore the ones with more limited resources, including staff and funding resources for consultant contracts, tend to use their models for a more limited number and scope of applications in the planning process (*18*). For example, some MPOs in Texas, in particular the smallest MPOs, may have only a single model for the MTP forecast year model with the projects listed for adoption in their plan (*18*). This practice appears to result from a variety of factors (*18*):

- Lack of time and resources during the MTP process to incorporate additional model runs (time and resource constraints on both the MPO and TxDOT sides).
- Lack of knowledge on the MPO side on how to incorporate travel demand modeling results into the planning and public involvement process.
- Lack of a federal or state requirement that this modeling occur for certain MPOs, as described above.

This examination of tour-based model implementation considers the process used for the 20 MPOs under TxDOT purview for model development. The largest MPOs—NCTCOG and H-GAC, for instance—are exploring advanced modeling options independently; their efforts inform those described here.

Other efforts related to modeling

Various additional model activities besides model development also occur within this collaborative relationship, including travel surveys, traffic count data collection, and software acquisition and maintenance. The formal relationship for those activities may differ from the one described above. Data collection efforts to support TDMs follow a similar pattern of organizational relationship, with larger MPOs exercising greater independence and smaller MPOs less, although TxDOT still conducts travel surveys for almost all of the MPOs. Traffic count efforts remain more centralized, albeit with MPOs having input into directing traffic count locations and needs. Data collection efforts specific to particular areas, such as stated preference surveys and speed studies, may be coordinated by either TxDOT or the MPO, with collaboration on details. This research effort is focusing on the model development process and the relationship between TxDOT and the MPOs, especially the MPOs under TxDOT purview for model development.

Understanding the above context—TxDOT's agency goals for addressing congestion and becoming a best-in-class agency, the state's statutory requirements with regard to transportation planning, and TxDOT's current relationship with its 25 MPOs—is critical to appreciating the complexity of the task at hand. That is, how best to implement tour-based modeling to best serve state goals and objectives, while minimizing the impact to the planning process that tour-based modeling is intended to serve.

2.3 PROBLEM STATEMENT FOR THE BUSINESS CASE

TxDOT's current trip-based modeling approach is adequate to examine most large-scale, regionally significant, highway capacity-added projects, as well as to provide outputs usable for air quality analysis required for areas designated as non-attainment and maintenance areas. However, this approach requires substantial post-processing or is simply unable to provide outputs for decision-makers on other types of transportation improvement projects being explored in today's increasingly funding-constrained and alternative goal-oriented environment. The Texas Package suite of models does not currently include the advanced-practice behavioral analysis techniques to examine the policy- and behavioral-response questions that the public and decision-makers increasingly ask.

Risks related to and resulting from the above issue include the following:

- Potential decreasing confidence in the quantitative results that TxDOT currently provides using existing trip-based technology.
- Potential impacts to decision-makers and public confidence in TxDOT's approach overall to support transportation planning decision-making.
- Potential impacts to Texas statewide project competitiveness when competing for funding against other communities that do have advanced modeling techniques, as could occur in the FHWA and the FTA funding and analysis streams.
- Potential increased training needs as current and future generations of transportation graduates have been educated exclusively or predominantly in tour-based approaches.

3. IMPLEMENTATION CONTEXT

The focus of this section is the implementation context for incorporating advanced travel behavior modeling into TxDOT's technical analysis toolbox, including

- Identification of assumptions and constraints, and
- A description of the project overall and goals and objectives, based on the assumptions and constraints identified before

The current research effort does not include actual implementation of any tour-based model, components, or code. Any and all references to implementation are intended strictly to refer to a *conceptual*, i.e., *theoretical*, framework for *potential* future implementation. Implementation is referenced merely to ensure that challenges and constraints potentially associated with implementation are explored to the extent possible under this current analysis.

Typically, when pursuing a technical model improvement for a single study area TDM (the most common case), researchers and practitioners will push forward the most advanced technical improvements possible within the limitations of their own technical abilities, time, and resource constraints. The implementation context for this research is much broader in scope: TxDOT moves very deliberately in considering even slight modifications to components in the Texas Package. This deliberation reflects the scope of Texas Package influence and use:

- Twenty-three MPOs under TxDOT purview use at least some components of the Texas Package, and all of the state's MPOs consider TxDOT's model approach a benchmark for their own modeling processes.
- Multiple study areas in the state have air quality issues and associated tightly controlled planning constraints.
- TxDOT districts and divisions statewide rely on travel models as input for a wide array of planning and engineering purposes.
- Defensibility and credibility of the Texas Package model results depend upon defensible applications and procedures, as well as consistency of application.
- Roll-out of Texas Package software or procedure changes involves a substantial advance physical effort and documentation, as well as training of TxDOT-TPP and TxDOT district staff, MPO staff, local public agency staff, and communication with in-state research institutions and consultants.

Implementation of changes in the Texas Package must consider this broad context that is, in order of magnitude and complexity, well beyond the scope of improving a model approach for a single study area.

Considering the implementation context for addressing the problem statement (see Section 2.3), the research team considered the larger business process implementation of travel forecasting models within TxDOT, and not merely the technical model tasks. Researchers began with describing the study goals and objectives, then identified assumptions and constraints, and concluded with a preliminary identification of the technology, database, knowledge, training, and staffing needs required to implement a tour-based module into the Texas Package.

3.1 ASSUMPTIONS AND CONSTRAINTS

This section examines the assumptions and constraints for developing the business case. The following assumptions and constraints are summarized by their general applicability to technical, organizational/business operations, and communication contexts.

3.1.1 Technical

Employ Design Option #1 from report 0-6210-2 as the preliminary technical framework

The extensive research effort under 0-6210-2 (*4*) outlines various options for implementing behavioral-based analysis techniques considering the TxDOT modeling context, data availability, and organizational constraints.

Minimize changes to the data collection and inputs development stages of the model implementation process

A critical assumption is that the incorporation of a tour-based approach will not affect (or only minimally affect if absolutely necessary) other established aspects of the travel forecasting approach currently implemented by TxDOT. These aspects include model data collection and processing, as well as model application within the context of transportation planning. This process was described in Section 2 and depicted in Figure 4.

Under this assumption, changes to the trip-based modeling approach are presumably applicable only to the procedures undertaken in year 4 and 5 (calibrate and apply the model). No changes would be necessary under the current implementation to either data collection efforts (counts and surveys) or model inputs development (demographics and networks). This assumption offers multiple benefits, such as the following:

- Minimizes disruption to current processes.
- Limits area of change to "bite-size" portion, which facilitates later education, awareness, and training.
- Focuses the research effort on a precise area of technology improvement within a fairly complex technical chain.
- Provides flexibility to TxDOT to adjust other processes as needed without affecting the tour-based aspect.

Minimize the transition to a targeted technical segment of the Texas Package

The research team documented the model steps of the typical Texas Package model application—TxDOT-TPP's current trip-based process for developing a model for small and medium MPOs—in Figure 5. That flow chart serves as the foundation to identify exact model steps that will be affected by the transition to a tour-based technology solution. Then, following Design Option #1 recommended in 0-6210-2, the general approach for this targeted technical improvement is presented in Figure 11.

As shown, the tour-based model applies only to resident travel and not to other trip purposes, such as visitor and truck travel. More importantly, Figure 11 demonstrates the model steps

NOT affected by the tour-based technology transition, as currently proposed. Consequently, a tour-based model implementation can be incorporated into the general structure of the Texas Package. In this respect, a tour-based model is merely another model component of the Texas Package, similar to the way that TripCAL5 and ATOM2 are model components of the trip-based approach.

Develop the tour-based module independent of commercially available software

TxDOT's historical philosophy is to maintain portions of the Texas Package independent of commercially available software such as TransCAD. This constraint benefits both TxDOT and the research team by prescribing a technical solution that will be more easily accepted by the current practitioners of the Texas Package and streamlining implementation of the technical solution. In addition, remaining independent of commercial software allows TxDOT to have more control over the travel demand modeling process and to customize it according to Texas need. On the other hand, the development of software requires allocation of resources (monetary, technical, and labor-related resources), and TxDOT should evaluate whether this investment will, in the long term, benefit the agency.

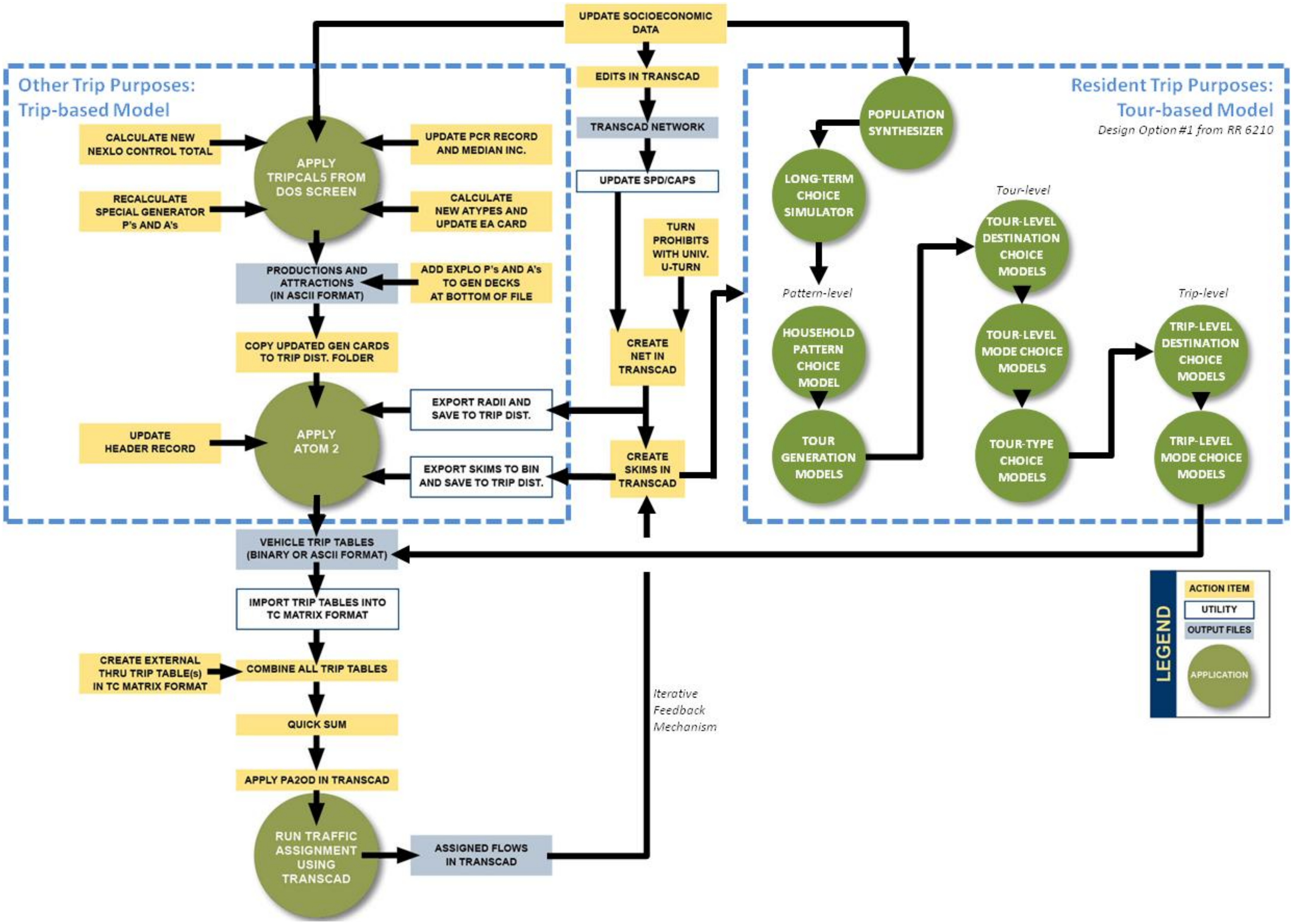


Figure 11. Texas Package Detailed Trip-Based Model Steps, with Incorporation of Tour-Based Module

3.1.2 Organizational/TxDOT Business Operations

Effect as direct and simple a transition as possible within the current model development relationship between TxDOT-TPP and Texas MPOs

One primary assumption is that the tour-based model would replace the trip-based model within its existing model implementation context. The current collaborative model development relationship between TxDOT-TPP and the small and medium Texas MPOs was depicted in Figure 10. The figure shows that the overarching collaborative relationship between TxDOT and Texas MPOs would be minimally affected by a transition to a tour-based technology. This assumption offers multiple benefits, such as these:

- Minimizes disruption to current communication protocols between TxDOT-TPP and the MPOs with regard to modeling.
- Minimizes distraction to ongoing trip-based model development efforts.

Minimize impacts to Texas Package implementation procedures

Specifically, research into the potential implementation steps for the tour-based module shall assume that the Texas Package transition to TransCAD version 6.0 and that the most recent versions of TripCAL5 and ATOM2 continue to be applicable for non-tour-based applications. The Texas Package, with the tour-based module, would be loaded and run from TxDOT staff members' individual desktop computers, concurrent with existing practice. Likewise, the procedures to download model files and data from TxDOT servers and data systems are assumed to remain the same, as are the procedures to archive and upload model files upon completion of model tasks. The current procedures are tightly controlled for file-management and quality-control purposes. This assumption offers multiple benefits, including these:

- Minimizes disruption to current model implementation protocols within TxDOT-TPP.
- Minimizes staff confusion regarding existing, well-established, and functional procedures.

Avoid changes to the current firewall between TxDOT-TPP travel models and the TxDOT enterprise and other data systems

As was depicted in Figure 3, interaction for model files and data that occurs with the TxDOT enterprise system is assumed to continue being derivative only—data are extracted from the enterprise system for use in the model development process. Model output will be archived to the TxDOT system, but no data are fed back into the enterprise system. Thus, the travel demand modeling procedures remain independent ("firewalled") from other TxDOT processes. This assumption offers the same benefits cited for the assumption above, including the following:

- Minimizes disruption to current model implementation protocols within TxDOT-TPP.
- Minimizes staff confusion regarding existing, well-established, and functional procedures.

3.1.3 Communication-Oriented

Design technical solutions that are easily communicated for understanding by technical professionals responsible for implementing it, at least to the level of existing comprehension of the Texas Package.

The technical/professional audience assumed here is understood to be limited to TxDOT and MPO staff, as well as on-call academic support staff from in-state research institutions and consultants currently implementing the Texas Package on behalf of TxDOT. This assumption affords the following benefits to the current research effort:

- It challenges the research team to appropriately document and communicate the model practice in a user-friendly manner for the staff that may potentially be responsible for implementing this technology in the future.
- At the same time, this assumption minimizes the responsibility of the research team for any existing knowledge gaps current staff has with regard to existing Texas Package modeling practice.

Design technical solutions for which the general approach and results are easily communicated for understanding by decision-makers, at least to the level of existing comprehension of the Texas Package.

The technical/professional audience assumed here is understood to be limited to TxDOT and MPO staff, as well as on-call consultant support staff from in-state research institutions currently implementing the Texas Package on behalf of TxDOT. The advantages of this assumption include

- Providing TxDOT staff an opportunity to assess the relative advantage that incorporating a tour-based model into its technical procedures will afford with respect to communicating model results to the public and decision-makers, and therefore improving the transportation planning process at its most fundamental level.

The assumptions and constraints outlined above—technical, organizational, and communication-oriented—serve as a framework for this research effort.

3.2 GOALS AND OBJECTIVES

Based on the previous assumptions and constraints, and following Design Option #1 from report 0-6210-2, the goals for this project include the following.

3.2.1 Goal 1: Incorporate Advanced-Practice Technical Procedures

Objective A. Provide an additional quantitative analysis option for regional travel demand modeling to incorporate behavioral response to travel choices, including expanding the breadth of policy and modal options available for examination.

Objective B. Provide an additional quantitative analysis option for regional travel demand modeling to incorporate temporal disaggregate data output from the demand-side of the TDMs for use in more advanced assignment mechanisms as needed for specific analysis purposes.

This goal is achieved through the adoption of a tour-based modeling approach, as in Design Option #1. Consequently, TxDOT can become one of the leading agencies in terms of advanced travel demand modeling.

3.2.2 Goal 2: Provide Stakeholders Additional Performance-based Metrics to Make Informed Transportation Decisions

Objective A. Improve and augment the travel model performance measures that TxDOT uses to evaluate and support planning project decision-making in the context of State of Texas strategic goals, including in support of

a) Agency-level strategic planning and budgeting.
b) Goal-oriented planning processes.

Objective B. Identify model performance measures that TxDOT can use to evaluate and support planning project decision-making in the context of TxDOT agency strategic goals, including

a) Maintain a safe system.
b) Address congestion.
c) Become a best-in-class state agency.

Objective C. Identify model performance measures that improve Texas MPOs implementation of performance-based planning, under the developing policies under MAP-21 and generally to support best practice planning.

After implementing this Design Option #1, stakeholders can more precisely evaluate changes in demographics (such as household size and composition, number of workers, and household income, number of vehicles, residential location), land use (population density, parking and employment mix, central business district indicators, and other build environment factors), and accessibility (out-of-vehicle travel time, in-vehicle travel time, travel cost, parking cost, and number of transfers).

3.2.3 Goal 3: Add Value to the Communication of Technical Model Procedures and Results to Various Audiences

Objective A. Provide added value in facilitating training of technical professionals in the application of the models and interpretation of results.

Objective B. Provide added value in the area of communication of the model process in support of planning decision-making; for example, the resulting solution should include identification of model explanations that are more easily translatable to lay audiences, allowing such audiences to understand the model purpose and approach and thus support the credibility of the model output.

Objective C. Provide added value in the area of communication of the model output in support of planning decision-making.

Technical staff at TxDOT and Texas MPOs will be trained in this new modeling approach and, therefore, will gain comfort with model operations and outcomes. Consequently, staff will be able to not only apply the model, but also train other practitioners and stakeholders.

3.2.4 Goal 4: Work within the Texas Package Context and Philosophy

Objective A. Apply advanced options as a technical module applicable within the Texas Package suite.

Objective B. Apply advanced options independent of commercially available software such as TransCAD, concurrent with TxDOT's philosophy for the Texas Package (as cited by the *Texas Snapshot* report).

All the design option alternatives proposed in 0-6210-2, including Design Option #1, were designed for incorporation within the Texas Package. Then, transitioning to a tour-based modeling approach will be easier for the staff of TxDOT and Texas MPOs.

3.2.5 Goal 5: Minimize Impacts to Current Organizational Processes

Objective A. Identify model performance measures that can be incorporated into existing processes and procedures to enhance TxDOT agency performance in

a) Efficiency
b) Accountability

Objective B. Minimize or mitigate impacts to TxDOT-TPP current processes and procedures; that is, introduction of new processes should be seamless and ideally result in an overall process improvement or efficiencies.

Objective C. Minimize impacts to TxDOT-TSD; that is, implementing the tour-based modeling approach should result in little to no resource expenditures by TxDOT-TSD. Minimize (ideally, avoid) affecting the current external collaborative relationship structure between TxDOT-TPP and small- and medium-sized MPOs; the solution should be confined to technical implementation aspects and not necessitate changes to coordination procedures with or data needed from the MPOs or other TxDOT operations (outside of the travel modeling group within TxDOT-TPP).

4. BUSINESS PROCESS MODEL AND LOGICAL DATA MODEL

Building upon the high-level description provided in 0-6210-2 (*4*) for the recommended tour-based model structure described as Design Option #1. This effort includes two sub-tasks:

- Define and document the Business Process Model (BPM):
  - Prepare a flow chart of the tour-based model system inputs, outputs, and processes.
  - Flow chart shall depict organizational units and the sequence of necessary activities.
- Research and define a Logical Data Model (LDM):
  - Base logical data mode upon the process presented in the BPM.
  - Describe system entities and attributes and their relation to each other.
  - Provide a visual representation of the tour-based TDM's pertinent data items and relationships.
  - Describe the entities, attributes, and relationships in a data dictionary according to the TxDOT data architecture standards.

This information will not only support a future decision with regard to tour-based modeling by TxDOT-TPP, the division charged with travel demand modeling, but also anticipates and resolves many technology issues prior to implementation.

4.1 DEFINE AND DOCUMENT THE BUSINESS PROCESS MODEL (BPM)

From a general perspective, prior to implementing any effort that will entail a broad shift of staff and technology resources, a BPM—a representation of the flow of system inputs, outputs, and processes—provides a framework to ensure an efficient and correct process. As was shown in Figure 11, the tour-based model applies only to resident travel inside the study area and not to other trip purposes, such as visitor and commercial vehicle travel. Thus, this figure shows the model steps not affected by the tour-based technology transition, as currently proposed. As shown, a tour-based model implementation can be incorporated into the general structure of the Texas Package. The BPM details this flow of activities in greater detail.

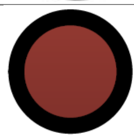
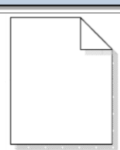
The BPM assembled for this task is provided as Attachment A (like the LDM, it is an oversize document and should be printed on a large size printer or plotter). The following sections describe the components of the BPM, focusing in particular upon the components that represent a change in process to incorporate a tour-based modeling approach for resident travel.

4.1.1 General BPM Structure and Layout Overview

A BPM is a sequential representation of all functions associated with a specific business activity and constitutes a key artifact to represent how work is performed in organizations. The primary goal of a BPM is to provide a standard notation readily understandable by all business stakeholders. The graphical representation of BPMs is based on a flowchart constructed from a limited set of graphical elements. Within these elements are the activities that represent the undertaken work, the starting point, and completion of the process, plus the decision elements known as *gateways*, which indicate alternatives along the way. These elements are connected by means of sequence flow lines that show the process flow. A large number of elements can be used for constructing a BPM. In Table 6, we have summarized the elements used in the current

BPM, along with the function of each element. The focus of the BPM developed here is the tour-based model because its development is the more complex process within the TDM.

Table 6. Business Process Model Symbology

Business Process Model Element		Function
Symbol	**Name**	
	Start event	Indicates the beginning of a process
	End event	Indicates the termination of a process
	Parallel gateway	Determines forking and merging of parallel paths, creating them without evaluating any conditions. For upstream paths, all activities must be complete before process continues downstream.
	Sequence flow line	Shows the order activities are performed
	Task	Represents a single unit of work that cannot be broken down to a further level of business process detail without diagramming the steps in a procedure
	Data object	Represents a database used in or generated by the processes

4.1.2 Tour-Based Model BPM Structure

The BPM in Attachment A has five major components with sub-components for the tour- and trip-based components (on the left side of the chart, from top to bottom).

1) **Model Inputs**: Divided by agency responsible, this is the list of the inputs required to implement (develop and use) the Texas Package with the tour-based model incorporated. The data are provided both by TxDOT and the MPO. The data sources used here are, for the most part, the same used in the trip-based modeling system.

2) **Model Inputs Preparation**: The model inputs are modified for use in the following steps. These modifications include data screening, forming the tours from travel survey data, and preparing land use and network data.

3) **Tour-based Component** (for resident travel inside study area):

   a) **Population synthesizer**: creates a list of synthetic households and individuals in each TAZ.
   b) **Long-term choice simulator**: the long-term choices modeled and estimated in this step are (1) work location and (2) household vehicle ownership.
   c) **Activity-travel generator module**: this module provides a list of all the activities, tours, and stops generated by a household in a day. It may be considered similar in function to the trip generation step in the trip-based modeling approach.
   d) **Scheduling module**: the tours and the stops generated by a household in a day are scheduled using location models and mode choice models. The outputs of this module are OD matrices for different time periods and modes.

4) **Trip-based Component** (for all other trip purposes, including truck-taxi, external-local, internal travel by visitors, external through, and special generator trips, as appropriate)

   a) **Trip Generation** following the traditional Texas Package approach.
   b) **Trip Distribution** following the traditional Texas Package approach.

5) **Traffic Assignment**: the traffic assignment component assigns the vehicle trips to the roadway network to obtain link-level vehicle volumes and travel times, and assigns the person trips to the transit network for different time periods in the day

In what follows, we describe each of these components in the context of the BPM. The following section details the components, focusing primarily on aspects that would be introduced to the Texas Package to support the tour-based approach. Existing model activities under the Texas Package will continue to be needed to support trip purposes that are not encompassed by the tour-based components, including these trip purposes: truck-taxi, external-local, internal travel by visitors, external through, as well as special generator trips, as appropriate. The existing components were elaborated extensively in 0-6210-2 and other Texas Package documentation.

4.1.3 Model Inputs

The main sources of data for the implementation of the tour-based TDM system are the household activity and/or travel survey, land use data, and transportation network. Some of this data is anticipated to be provided either by the MPO or by TxDOT following existing processes in support of the trip-based approach.

- The MPO provides these data types:
  - TAZs, as defined by each MPO (and as included in the Texas Package) and geography in TransCAD.
  - Highway network data in TransCAD for the base year. The network data includes attribute data such as the number of lanes, posted speed limit, direction (one-way or two-way facility), median access type (divided, undivided or continuous left turn), and functional classification.

- TxDOT provides these data types:
  - Household travel survey data, which are records of household and individual socio-demographic information and the activity-travel patterns of individuals on the survey day. The travel information obtained from the survey includes the time, activity type, travel mode, number of passengers, trip purpose, and start and end location of each trip.
  - Population, employment, and socio-economic data by TAZ, which includes demographic data such as total population, number of households, median household income, and total employment by different categories.
  - On-board public transit survey data. The survey collects information on trip origins and destinations, mode of travel to/from transit stop, trip purpose, transit routes taken during trip, ridership frequency, transit fare paid and method of payment, and the traveler's household characteristics (such as household vehicle availability, household size, and household income).
  - Although not commonly used for the trip-based approach, U.S. Census PUMS datasets are available free of charge, and will be used to support the tour-based model components. These datasets provide a full range of population and housing data, such as age, occupation, and place of work (*23*).

4.1.4 Model Inputs Preparation

All existing Texas Package steps for model inputs preparation are assumed to continue, to support both tour- and trip-based activities, as described above. For the tour-based model components, model inputs preparation additionally consists of assembling and reviewing survey data, generating tours and stops, and extracting land use and transportation system data as available from existing data sources.

- Land use data preparation consists of generating population demographics for TAZ and employment data by different area types by TAZ. Since the data are already generated at the TAZ level for the Texas Package, no additional data processing is required for the development of the tour-based model system.
- Level-of-service (LOS) data preparation modifies the network data and the on-board public transit survey data (if applicable to the urban area being modeled) to generate a travel time matrix and a cost matrix between each OD pair for each travel mode (SOV, transit, and walk/bike). These matrices are labeled as the LOS matrices and represent the minimum network travel time and cost path for each OD pair.
- Accessibility data preparation uses data from the transportation network and employment to create accessibility data such as roadway density, road length by functional class, parking availability, and accessibility to different types of employment within specific time intervals (for example, access to retail and service locations within 15 minutes and/or half mile from home and work). Most urban areas modeled using the Texas Package do not include transit; however, this adjustment is easily encompassed in the accessibility measures if it is present.
- The tour data screening and tour formation process uses travel survey data to ensure that the entire day of each individual is accounted for and can be plotted in time and space, and to form tours for each household. The output from this process is household travel

data in tours, such that for each household, the final tour file has one record for each tour with detailed tour-level and trip-level information.

4.1.5 Tour-Based Component

The tour-based component of the model as shown in the BPM addresses resident travel inside study area. The following modules comprise the tour-based activities.

Population synthesizer

The population synthesizer is designed to create a list of synthetic households and individuals in each TAZ. The inputs to create the synthesized data are the U.S. Census PUMS data and population, employment, and socio-economic data. The proposed method to obtain the synthetic population is iterative proportion fitting.

Long-term choice simulator

The long-term choice simulator has two components: work location and household vehicle ownership. Both components use the synthetic population (households and individuals) data as inputs, and a multinomial logit model to predict work locations and auto ownership.

Activity-travel generator module

Using data from the population synthesizer and the long-term choice simulator, the activity generator module provides a list of all the activities, tours, and stops generated at the household level. The tours are divided into six purposes and are generated in the following order (all tours are assumed to fit into one of these categories):

1. Home-based work tours.
2. Home-based school tours.
3. Home-based other tours (includes personal business, meals).
4. Home-based shopping tours.
5. Home-based social/recreational tours.
6. Home-based drop off/pickup tours.

For each tour purpose, the ***daily tour pattern choice model*** predicts whether a household makes tours in a day using a binary logit model. Then, if the household is making tours in a day, the ***tour generation model*** determines the number of tours the household will make in a day. A multinomial logit model is used to estimate the frequency of tours by purpose. The daily tour pattern choice model and the tour generation model form what is known as the ***pattern-level models***.

Among the tour-level models, the ***tour type model*** generates the number of stops on a tour for all tour purposes (maximum of five stops per tour) and whether a work tour has a sub-tour associated with it or not (the sub-tours have work location as origin and destination and can have only one stop). The tour type model needs the information from the schedule module—in particular, where (destination) and how (mode) the tours are made.

Scheduling module

Based on the results of the pattern-level models, as part of tour-level models, the scheduling module predicts the primary destination and mode for all tours and trips. For home-based work tours and home-based school tours, the destination is already known (workplace and school, respectively) and, therefore, a destination choice model is not required. For the other tour purposes (home-based other, home-based shopping, home-based social/recreational, and home-based drop off/pickup), a ***tour primary destination choice model*** is implemented. This model is applied for all tours in the order of their priority, with high priority tour-outcomes known at the low-priority tour models. Then, the ***tour-level mode choice models*** determine the primary mode by purpose for each tour. Mode choice models perform a similar task as the modal split step in the four-step TDMs.

The outputs from the tour-level mode choice models are used as an input of the tour type model, which belongs to the activity-travel generator module as previously discussed. Once the number of stops in the tour is determined, the trip-level models are implemented. Specifically, the ***secondary destination choice model*** predicts the location of intermediate stops in a tour and then the ***trip mode choice models*** predict the mode for each trip within a tour (conditional on the main tour-level mode).

4.1.6 Trip-Based Component

The trip-based component of the model as shown in the BPM addresses all remaining travel, including the following trip purposes traditional part of an urban area model under the Texas Package: truck-taxi, external-local, internal travel by visitors, external through, and special generator trips, as appropriate. The following modules comprise the trip-based activities.

Trip generation

The trip generation step of the traditional three-step Texas Package TDM is described extensively in 0-6210-2. Details of the recommended Texas Package trip-based approach for this step are documented in *TRIPCAL5 User's Manual* (*24*).

Trip distribution

The trip distribution step of the traditional three-step Texas Package TDM is described extensively in 0-6210-2. Details of the recommended Texas Package trip-based approach for this step are documented in the *ATOM2 User Manual* (*25*).

As mentioned above, most of the urban area models for which the Texas Package is currently applied do not include mode choice (which would make them four-step models). In the rare instances where they do, mode choice would be handled under the tour-based model above and not pertain to the trip-based component here.

The final and third step of the traditional three-step Texas Package TDM is traffic assignment, which is described separately below, because it is applicable to both the tour- and trip-based model component results.

4.1.7 Traffic Assignment

As shown in the BPM, prior to traffic assignment, the predicted trips made in SOV and shared rides from the tour-based module, as well as the trips from the trip-based module, would be aggregated into OD trip tables. Currently, most of the urban area models examined using the Texas Package are applied only for a daily (24-hour) assignment and analysis. When necessary or appropriate, a set of diurnal factors by trip purpose and derived from travel survey data may be used to divide the daily trip tables into trip tables for different time periods (for example, AM peak, midday, PM peak, and evening off-peak). The proposed tour-based implementation has the same flexibility. Traffic assignment is performed in the Texas Package using TransCAD.

4.1.8 Model Calibration and Validation

Similar to the approach currently being applied for a full trip-based approach, it is necessary to calibrate the model to a known base year condition and traffic before applying the model to a forecast year. The development, calibration, and validation of the base year model can be performed after each cycle of data collection. This procedure is based on the current methods used by TxDOT-TPP, who update urban area models as often as every 5 years. The data required for the calibration and validation includes zonal level socioeconomic and land-use data and transportation network level-of-service data. The calibration and validation process for the base year are undertaken in two broad steps:

- **Preliminary validation**: In this step, each model component, after estimation, is applied to the household survey data and verified for major discrepancies with the observed patterns in aggregate predictions.
- **Base year validation and calibration**: This step involves running the synthetic population of the base year through the entire model system, along with the traffic assignment procedure, and comparing the aggregate results to available external information about actual base year characteristics. The model systems are calibrated sequentially from top to bottom of the model hierarchy, similar to the current process for the Texas Package.

  The external data are obtained from census data, transit on-board surveys, and screen line and other traffic counts. TxDOT currently collects 24-hour daily traffic counts and, therefore, the validation and calibration process are also undertaken within this time framework.

4.1.9 BPM Summary

The BPM provides a simple representation of the tour-based model proposed by TxDOT in 0-6210-2. As shown in the BPM, most sources of applicable data are readily available to TxDOT and the MPOs. The land-use and the transportation network and system performance data require no or very little additional processing to be used in the development of the tour-based model. The household activity and/or travel survey data requires additional processing to form tours from trips recorded in the travel diary. Additionally, the development of the main components of the BPM (population synthesizer, the long-term choice models, activity-travel generation module, and scheduling module) can be directly interfaced with the Texas Package and TransCAD. The BPM communicates the flow of the integrated process graphically.

4.2 RESEARCH AND DEFINE A LOGICAL DATA MODEL (LDM)

The LDM provides a representation of datasets and their relationships that are pertinent for the tour-based TDM, both visually and in structured query language (SQL) format. The LDM defines datasets that are used for input generation in both the tour-based and trip-based model components, as well as a data dictionary that describes the logical model's entities, attributes, and relationships. The LDM was developed in compliance with TxDOT data architecture standards to the largest degree feasible, as discussed further below (*26*).

4.2.1 LDM Structure and Overview

As described earlier, the LDM provides a graphical representation of the tour-based TDM's pertinent data and relationships, and is presented in Attachment B. Due to its size and level of detail, the model should be printed on a large size printer or plotter.

The research team consulted with the TxDOT-TSD to determine the appropriate data modeling approach and software for development. TxDOT uses three types of data models for all database applications, which are conceptual data model, logical data model, and physical data model. While the development of a conceptual data model is a recommended activity, both logical and physical data models are mandatory for all databases, and must follow TxDOT data architecture standards (*26*).

The conceptual model should be a depiction of data elements from the business viewpoint, and should define the scope, entities (such as persons, concepts, events), and relationships among entities. As such, a conceptual model can also be described as a BPM, which the research team developed as described above (Section 4.1). The LDM defines data requirements on a more detailed level than the conceptual model, but independent of the hardware and software requirements of the database application. LDM features and functions include the following:

- Displays entities, attributes, and relationships.
- Uses Information Engineering notation.
- Identifies primary, foreign, and alternative keys.
- Is designed to third normal form.
- Includes a data dictionary.

A physical data model is a transformation of the LDM to meet requirements of a specific Database Management System (DBMS), detailing how data is actually stored in the DBMS. However, the development of a physical data model was not part of the scope for this research project.

TxDOT-TSD supports several different software tools for the development and management of data models and supporting documentation. Currently, TxDOT supports ER/Studio® in conjunction with ER/Studio Repository®, both from Embarcadero® Technologies, for the development of logical and physical data models. Before TxDOT recently made the switch to

ER/Studio, TxDOT supported Computer Associates® AllFusion ERWin Data Modeler®. Due to previous work with TxDOT-TSD, the research team had access to a license of ERWin Data Modeler, but not ER/Studio. Since the project budget did not provide for the acquisition of a license for ER/Studio, and TxDOT was unable to provide access to a temporary license, researchers evaluated the export functions of ERWin Data Modeler and the import functions of ER/Studio. A result of the testing was that ER/Studio is able to import and convert data models created in ERWin Data Modeler's native .erwin format. Then, TxDOT-TSD representatives and the research team agreed to develop the LDM of the tour-based model using ERWin Data Modeler software.

4.2.2 LDM Entities, Attributes, and Naming Approaches

Based on the results of the BPM, the research team was able to identify all required datasets for the implementation of a tour-based modeling approach. In the next step, the research team collected available information about these datasets, including samples of actual data, in an effort to analyze data content and format as detailed as possible. Applicable datasets were in a variety of formats, ranging from simple text files to Excel spreadsheets and PDF files. Table 7 is an example of sample household survey data that was analyzed in this phase of the project.

Table 7: Sample Data Contained in S5TF.dat Dataset

400012020505010000 THE GREY MOSS INN 19010 SCENIC LOOP RD HELOTES 678023 S 738- 98.68529329.619532 16 301 9351230
400012020505010000 FROST BANK 11555 BANDERA RD HELOTES 678250 S 706- 98.66496029.551537 6 803 2021 2 101 202 12451255
400012020505010000 HILL COUNTRY CLEANERS 11620 BANDERA RD HELOTES 678250 S 468- 98.66582529.552658 22 DRY CLEANERS 803 2021 2 101 202 13001310
400012020505010000 CHESTERS HAMBURGERS 16609 US HWY 281 N HELOTES 678232 S 518- 98.47361029.592844 16 203 2021 2 101 202 13451430
400012020505010000 SAN ANTONIO MUNICIPAL AIRPORT 9800 AIRPORT BLVD SAN ANTONIO 678216 S 521-98.47680629.521557 21 1103 2021 2 101 202 14451630
400012020505020000 HOME 19002 SCENIC LOOP RD HELOTES 678023 S 738-98.68527929.619318 1 1 930

In many cases, data dictionaries or descriptions of relevant datasets were not available to the research team. As a result, the research team relied on the expertise of research team members and other subject matter experts to identify the content and use of data elements in the sample data provided. In some cases, researchers were able to obtain data dictionaries of relevant datasets, which expedited the LDM development significantly. For example, Table 8 provides an excerpt of the data dictionary for commercial vehicle survey data that was available to the research team.

Table 8. Sample Data Description of Commercial Vehicle Survey Data (Record Type 21 – Vehicle Trip Information, File SANREC21.SDF)

Item	Begin	End	Type	Format	Description
Record Type	1	2	Numeric RJ	I2	Code that indicates the type of record, here it should be 21.
Vehicle ID Number	3	5	Numeric RJ	I3	Unique identification number assigned to vehicle for survey purposes. Must match the number used in data format for record type 20.
Vehicle Lic. Number	6	15	Alphanum. LJ	A10	License number of the vehicle being surveyed.
Trip Number	16	17	Numeric RJ	I2	Trip number. Beginning trip will be recorded as 0 with each subsequent trip numbered sequentially as 1, 2, 3, etc.
Address Field 1	18	47	Alphanum. LJ	A30	Name of location and address of first street name or nearest intersecting streets to the location. If name and address exceed field size, it should be continued in item 6.
Address Field 2	48	77	Alphanum. LJ	A30	Continuation of name of location and address in item 5 or second street name of intersecting streets to the location.

Following the review of data structure and content, the research team transcribed each relevant dataset into the LDM. In doing this, the research team took care to follow the entity and attribute naming standard provided by the TxDOT data architecture. For the entities in the model, the researchers applied the following entity-naming requirements:

- Entity names use only alphanumeric characters with no special characters.
- Entity names with multiple words separate words with a space.
- Entity names use all uppercase letters.
- Entity names use fewer than six words, employing singular nouns, the present tense, and the root form of words.
- Entity names are derived from the data description, are as meaningful as possible, and are easily distinguishable.

For the attributes in the model, the researchers applied the following attribute-naming requirements:

- Attribute names use only alphanumeric characters with no special characters.
- Attribute names with multiple words separate words with a space.
- Attribute names use all uppercase letters.
- Attribute names reflect the data that is actually stored.
- Attribute names use fewer than six words, employing singular nouns, the present tense, and the root form of words.
- Attribute names are derived from the data description, are as meaningful as possible, and are easily distinguishable.

- Attribute names are composed of one or more prime words, zero or more qualifier words, and one class word.

Requirements of the naming standard posed somewhat of a challenge during data transcription efforts, since many of the datasets that researchers included in the data model contained entities or attributes that did not follow the TxDOT naming standard. As a result, the research team modified or upgraded some of the original entities and data field names to make them compatible with the TxDOT standard. Table 9 and Table 10 provide examples of the name translation between the original dataset and the LDM for a sample of entities and attributes:

Table 9. Examples of Entity Name Conversion during Logical Data Model Development

Dataset	Original Entity Name	Entity Name in Logical Data Model
Household/Activity Survey	Record Type 1 – Household Information	HOUSEHOLD
Household/Activity Survey	Record Type 2 – Person Information	PERSON
Commercial Vehicle Survey	Record Type 20 – Vehicle Information	VEHICLE
Workplace Information	Workplace Employee Survey Survey Form B, Part 1 Format	WORKPLACE EMPLOYEE

Table 10. Examples of Attribute Naming Conversion during Logical Data Model Development

Entity	Original Attribute Name	Attribute Name in Logical Data Model
HOUSEHOLD	Phone	PHONE NUMBER
HOUSEHOLD	HH County	HOUSEHOLD COUNTY CODE
HOUSEHOLD	Longitude	HOUSEHOLD LONGITUDE
HOUSEHOLD	Other Residence	RESIDENCE TYPE OTHER DESCRIPTION
HOUSEHOLD	HH Vehicle Use by Non HH Number	NON MEMBER VEHICLE USE CODE

The research team did not transcribe all available data items; researchers eliminated duplicate fields and fields that did not appear to be useful for the purpose of the tour-based model.

4.2.3 LDM Normalization

Once the research team completed entity and attribute definitions, the research team started the normalization of the data model. As described earlier, TxDOT requires all data models to be designed to third normal form. However, the datasets that are relevant to tour-based modeling are so diverse in form, structure, and content that researchers evaluated a trade-off between complete normalization and data conversion efforts for each dataset included in the LDM. As a result, the LDM in its current format is in first normal form, which can be described as a model where each entity has a key to uniquely identify each row in each table, and each intersection of a row and column contains only one value (no repeating groups). Many relevant datasets transcribed into the LDM were not in first normal form. Table 11 provides an example of an entity in first normal form violation.

Table 11. Example of Entity with First Normal Form Violation

RECORD TYPE
SAMPLE NUMBER
ADDRESS 1
ADDRESS 2
ADDRESS 3

In addition to duplicative columns, the table shown in Table 11 is missing a primary key. Many of the datasets used for the LDM did not provide a clear identification of a primary key. In some cases, the research team was able to identify primary keys consisting of multiple dataset attributes. In other cases, datasets did not include a primary key at all. After some internal discussion, the research decided to add a formal primary key to all tables in the LDM, in an effort to simplify management of the data and implementation of the model.

The LDM is also normalized to second normal form, which can be described as state of a model in first normal form where every non-primary key attribute is fully dependent on the primary key, and no column value can be derived from another column. In other words, the LDM does not contain subsets of data that apply to multiple rows of a table. An example of a second normal form violation would be a table that stores an address with zip code in a field ADDRESS, but then has another field ZIP CODE that stores the zip code of the address a second time.

To achieve third normal form, each non-key attribute in a table must depend solely on the primary key of that table, and no other table. Table 12 provides an example of the entity NETWORK LINK that was in violation of third normal form. If the facility type described by the network link were changed, so would the description of the facility type, but the link ID and the length of the link would remain the same. Therefore it was necessary to decompose NETWORK LINK, create an entity FACILITY TYPE, and reference that entity in the table NETWORK LINK in order to meet the requirements of third normal form.

Table 12. Example of Entity with Third Normal Form Violation

NETWORK LINK ID
LENGTH MEASUREMENT
DIRECTION CODE
POSTED SPEED NUMBER
FACILITY TYPE DESCRIPTION

Third normal form also requires that the model does not contain any derived data, such as summations or totals. After a review of the actual data, the research team was able to remove several tables and attributes and simplify the model considerably.

The goals of data normalization are eliminating redundant data and ensuring that dependencies of datasets are logical, which should reduce the size of the database, make queries more efficient, and simplify future changes to the database. However, each decomposition within the model increases the complexity of the model and makes it more difficult to translate actual data from data sources collected in formats that are neither relational nor normalized, because an algorithm must be used to store portions of the original data in several tables. Fully normalized data designs can also be slow when implemented as a physical database. In order to make the resulting LDM as useful as possible to TxDOT, researchers only decomposed instances of attributes that were dependent on easily obtainable lookup tables, such as STUDY AREA COUNTY, NAICS, or VEHICLE MAKE. The research team also avoided too much decomposition in an effort to make the LDM easier to understand for practitioners who ultimately will have to convert survey data into a format suitable for import into the LDM.

During an implementation of the data model, TxDOT should determine whether further normalization of the LDM would provide additional benefits. One table that could be a potential candidate for further normalization would be TRANSIT SURVEY, which contains several fields that are not directly dependent on the primary key, such as HOUSEHOLD ADULT COUNT.

In a related effort, researchers created lookup tables to promote referential integrity across the data model and avoid data redundancy. For example, four entities use a HOUSEHOLD INCOME RANGE CODE with the same income ranges, which are HOUSEHOLD, TRANSIT SURVEY, WORKPLACE EMPLOYEE, and WORKPLACE VISITOR. In other cases, replacing attributes with look-up tables was not as straightforward as it initially appeared. For example, several entities have an ACTIVITY TYPE attribute, but a review of the data found that different entities use different kinds of activity types, or different kinds of activity type codes. As a result, the researchers created several tables of activity types as necessary.

Normalization of the data model also led to some entities that were not included in any of the original datasets. For example, the researchers found that household factors can be described by a lookup table called HOUSEHOLD FACTOR, but that at the same, each household can have more than one such factor. As a result, the relationship between HOUSEHOLD and HOUSEHOLD FACTOR is a many-to-many relationship. This type of relationship can be resolved by a linking table that has a primary key consisting of the primary keys of the tables that are being linked, HOUSEHOLD and HOUSEHOLD FACTOR. Linking tables that resolve many-to-many relationships are often named after the parent tables involved, which resulted in the entity name HOUSEHOLD FACTOR HOUSEHOLD (Figure 12).

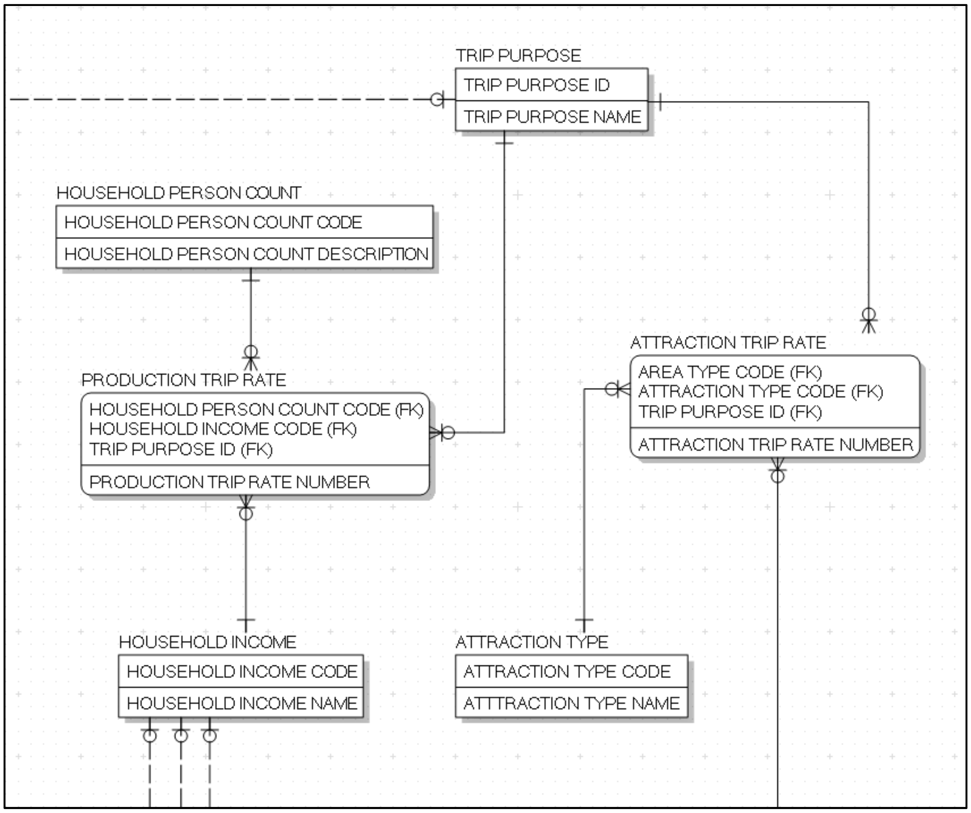


Figure 12. Relationship between HOUSEHOLD and HOUSEHOLD FACTOR in Logical Data Model

5. EVALUATE THE PROPOSED SYSTEM USING BUSINESS GOALS AND OBJECTIVES

In this section, the researchers examined how the system defined in previous sections fulfills the business goals and objectives of TxDOT. This effort included the following tasks:

- Specify how the tour-based modeling approach fulfills the state's statutory requirements and aligns with statewide and agency strategic plans.
- Address the need to continue to operate trip-based models in parallel with tour-based where needed or required.
- Assess how the use of information technology resources impacts the agency at the enterprise level.
- Perform an agency impact analysis with particular focus on information resources technology, including these sub-tasks:
    - Describe how the project will incorporate best practices and industry-proven technologies.
    - Estimate the amount of customization anticipated and how off-the-shelf solutions can be feasibly incorporated.
    - Identify specific opportunities for reuse of legacy business processes and technical components.
    - Describe how the project will conform (if necessary) to statewide information technology standards.
- Estimate when the project will deliver expected benefits and business outcomes and describe what criteria will provide the basis for evaluation of business outcomes following project closure.
- Provide a risk assessment.

The above tasks are addressed in these sections: Contextual Considerations, Impact to Non-Technology Process and Resources, Impact to Information Technology Resources, Cost Analysis, and Risk Assessment. This information not only supports a future decision with regard to tour-based modeling by TxDOT-TPP, but also anticipates and resolves many technology issues prior to implementation, if the state moves forward on this effort.[5]

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[5] Of note, while the original work plan was written to assume direct involvement by TxDOT-TSD, after project initiation, the Project Monitoring Committee (PMC) member representing TxDOT-TSD determined that TxDOT-TSD's direct involvement was unnecessary, due to these factors:

- General agreement by the PMC that there should be no significant technology impacts in this potential move to a tour-based approach.
- The size of the potential technology product likely will be under $1 million.
- The product nature will likely follow existing protocol of TDMs, being developed and applied entirely separately from the TxDOT enterprise technology system.

The remaining work on this research project has continued under this assumption, with TxDOT-TPP staff checking with TxDOT-TSD as necessary on technical issues.

5.1 CONTEXTUAL CONSIDERATIONS

This section explores state statutory requirements related to the proposed technology, how tour-based TDMs relate to agency goals, and application considerations. There are no direct state statutory requirements that TxDOT use a tour-based model approach.

5.1.1 Requirements to Use a TDM

TxDOT supports its 25 MPOs at various levels with their TDMs, the smaller MPOs receiving more direct support than the larger and more independent MPOs. For MPOs, the use of a TDM to support planning activities is required if

- The MPO study area is in non-attainment or maintenance status for air quality according the U.S. Environmental Protection Agency. Then, a TDM is required for the MTP for air quality conformity determination[6] (to occur at least every 4 years) (*21*).
- The MPO is designated as a TMA (adopted update required at least every 4 years).[7]

Certain types of project-level analysis for projects that are considered major investments also require a TDM. MPOs' consultative partners, including TxDOT-TPP, TCEQ, the FHWA, and the FTA, assist the MPOs in determining these other required instances. For the purpose of MTP adoption and updates, the current manual describing TxDOT procedures specifies that TxDOT-TPP performs TDM updates on either a 5-year or 4-year cycle to support the required MTPs; this manual includes this model cycle schedule in a table specified by the MPO and based upon air quality status and TMA designation as described above. While this manual is currently being updated and likely will loosen these requirements, TxDOT-TPP staff agrees that, while not required for all MPOs, a TDM is best practice to support an MTP.

TxDOT also performs travel demand modeling on a statewide basis, but the urban models above are the focus of this current effort.

5.1.2 Parallel Modeling Efforts

The potential need to continue to operate trip-based models in parallel with tour-based depends on the specific characteristics of the MPOs.

- If a tour-based modeling approach is applied to a study area in attainment for air quality conformity standards, where no air quality analysis is applied, it appears unnecessary to maintain an entirely trip-based parallel modeling effort. The exception would be that maintaining both does provide an opportunity to examine and compare the models side

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[6] Federal requirement pertains only to TMAs that are serious, severe, or extreme ozone, or serious CO, non-attainment areas (http://www.fhwa.dot.gov/planning/certcheck.htm). Texas requires that all non-attainment area plans be based on TDMs, with more stringent model requirements for the areas that fall into the federal model requirement category. See also TAC Title 30, Part 1, Rule 114.260.

[7] Under federal rule, all other TMAs (not in the first group) must meet minimum travel model standards under Conformity Rule IF already previous practice ("no backsliding"). Texas requires that long-range plans by TMAs be based on "estimates of travel demand" and that "development of long-range transportation plans relies on computer travel demand forecasting."

by side. In fact, some agencies prefer to simultaneously run both modeling approaches so that staff can get familiar with the tour-based approach. For example, the Atlanta Regional Commission (ARC) and the Sacramento Area Council of Governments (SACOG) maintained their trip-based models for at least 3 years after the tour-based model was operational (*27*).

- However, if a tour-based modeling approach is applied to a metropolitan area that is in non-attainment status for air quality conformity standards, the current state-of-practice recommendation is that the study area continues to operate a parallel effort of trip-based modeling at least for one iteration of base model year in order to assess impacts with regard to air quality analysis. Air quality conformity, in itself, is a moving target for many areas even if not attempting a tour-based modeling approach, because of evolving software and standards for performing air quality analysis. If a tour-based modeling approach is applied to one of these areas, it is recommended that a parallel trip-based approach be applied at least for a single pilot base year in order to assess the differences in the air quality analysis results and, if necessary, to fall back upon the trip-based analysis output while TxDOT's consultative partners, such as the FHWA, consider such differences.

As explained previously and detailed in Section 3, it will be necessary to continue to maintain the trip-based model components to examine trip purposes that are not resident travel.

5.1.3 TxDOT Goals

The TxDOT 2013–2017 Strategic Plan includes the goals provided in Figure 13 (*28*). While none of these goals directly addresses tour-based modeling, or even analysis tools, improving analysis techniques to deliver better information to decision-makers in determining where to spend constrained resources is critical.

As explained previously, trip-based models are constrained by these limitations:

- Analysis is applied at an aggregate level, not on a person- or household-level basis.
- Individuals' travel decisions are represented sequentially.
- Individuals' travel tours are represented as disjointed, single trips.

Because of the above issues,

- There is limited applicability of trip-based models to time-of-day analysis.
- Travel choices in the model may not be rationale or intuitive.

Maintain a Safe System

- **Objective**: Reduce crashes and fatalities on the system through innovations, technology, and public awareness
- Objective: Maintain and preserve the transportation assets of Texas

Address Congestion

- Objective: Partner with local officials to develop and implement congestion mitigation plans in Texas

Connect Texas Communities

- Objective: Prioritize new projects that will increase the state GDP and enhance access to goods and services throughout the state

Become a Best-in-Class State Agency

- Objective: Ensure the agency deploys its resources responsibly and has a customer service mindset
- Objective: Focus on work environment, safety, succession planning, and training to develop a great workforce

Figure 13. TxDOT Goals

The reason for investing effort and resources into tour-based modeling is to continue to advance the state of practice in travel demand modeling in Texas in order to evaluate more complex policy scenarios. In particular, in today's constrained funding era, the effects of policy decisions concerning measures such as tolling, HOV lane restrictions, and congestion pricing call for more advanced models capable of examining travel behavior response.

5.1.4 Assessment

Following are the assessments of the contextual considerations discussed above:

- The tour-based modeling approach fulfills the state's statutory requirements to the extent there are requirements for a TDM.

- Implementing the tour-based modeling approach likely does require at least an initial duplication of effort with regard to maintaining a parallel modeling product while differences are assessed. This makes a pilot implementation the most feasible option, so that TxDOT is not tasked with developing a total of 40 parallel models (one trip-based and one tour-based for each of 20 small and medium-sized MPOs).

- The tour-based modeling approach aligns with statewide and agency strategic plans and goals.

5.2 IMPACT TO NON-TECHNOLOGY PROCESS AND RESOURCES

This section assesses how the use of information technology resources impacts the agency at the enterprise and technology resources levels.

5.2.1 TxDOT-TPP Resources Impacts

The potential resource impacts to TxDOT-TPP were explored in Section 3, including impacts to the existing process TxDOT maintains to support MPOs' TDMs.

TDM approach and software impacts

The tour-based and trip-based components of the proposed integrated model were explored in Section 4. The tour-based-specific components address resident travel inside the study area. In Figure 11, these components are located inside the blue dashed box in the upper right corner. Resident trip purposes that were previously handled using a trip-based approach are now handled using a tour-based approach.

The trip-based-specific components of the model as shown in the BPM address all remaining travel, including the following trip purposes, that are a traditional part of an urban area model under the Texas Package: truck-taxi, external-local, internal travel by visitors, external through, and special generator trips, as appropriate. The modules comprising the trip-based activities are delineated in Figure 11, inside the blue dashed box in the upper left corner.

The remaining steps outside the two dashed blue boxes pertain to all trip purposes, for a complete application of the integrated model for a study area. The existing trip-based TDMs are each uniquely developed for each study area, following a standard approach, using TransCAD software and various programs and utilities written uniquely for the Texas Package (in either FORTRAN or GISDK, the scripting language used to facilitate TransCAD implementation). The tour-based implementation, as demonstrated in Figure 11, is merely incorporated into the Texas Package's existing framework.

TDM process and hardware impacts

As described, up until mid-2012, TxDOT used TransCAD version 4.5 as the standard for travel model implementation. As models are updated, the department will update models to use TransCAD version 6.0 and the most recent versions of TripCAL5 and ATOM2. The Texas Package, including TransCAD, is loaded and run from TxDOT staff members' individual desktop computers. At specific milestones, files are transmitted to other staff or MPOs, using tools such as DVDs or the TxDOT's cloud sharing service. TxDOT maintains both review and final versions of each TDM on its server.

Under a tour-based approach, the TDM process would be much the same, with the addition of the survey and U.S. Census PUMS data (see Section 4 for details). Similar to the trip-based modeling approach, a tour-based model can be maintained on an individual desktop. It has been argued that it may be difficult to achieve reasonable computer run times given the complexity of the tour-based models (*29*). However, the design option proposed in this business case is quite simple and, given the size of the majority of MPOs under TxDOT purview for model development, model run time is not anticipated to be significant. Also, similar to the trip-based approach, greater computing power results in reduced model run times. Based on past experience, the research team recommends the use of computers with Windows 2000 Professional or XP Operating System and a minimum of a 1 GHZ Processor, 4 GB RAM, and 210 GB Hard Drive.

Model input data and processing

The model inputs necessary for a tour-based TDM implementation were explored in detail in Section 4. The main sources of data for the implementation of the tour-based TDM system are the household activity and/or travel survey, land use data, and transportation network. Some of these data are anticipated to be provided either by the MPO or by TxDOT following existing processes in support of the trip-based approach. As described, the model input data comes from multiple sources inside and outside of TxDOT and in many different formats, including raster data (hardcopy or PDF formats), TransCAD file formats, and even summary reports from which data are extracted manually. These data inputs do not represent an extra burden for TxDOT or Texas MPOs, because most of the data needed to develop tour-based models is already available.

All existing Texas Package steps for model inputs preparation are assumed to continue, to support both tour- and trip-based activities. For the tour-based model components, model inputs preparation additionally consists of assembling and reviewing survey data, generating tours and stops, and extracting land use and transportation system data as available from existing data sources.

Currently, as described above, these steps to process data for use in the TDMs represent a significant amount of time in model development. These steps presently occur outside the TxDOT enterprise data system because the majority of the data used resides outside of the TxDOT enterprise data system. Of course, incorporating these datasets into the TxDOT data system would facilitate the travel demand modeling process for both types of modeling: trip-based and tour-based. And yet, that improvement is not necessary for the implementation of tour-based modeling.

5.2.2 Technology Resources Impacts

Most broadly, the impact to TxDOT-TSD of incorporating a tour-based model approach is anticipated to be minimal, given the presumed continuation of the relative independence of TDM activities from the TxDOT enterprise data system and processes, as previously described.

5.2.3 Non-Technology Resources Impacts

This section identifies the technology, data, knowledge base, staffing, and training needs for a conceptual framework to support tour-based modeling by TxDOT. These aspects are explored in two contexts:

- First, aspect by aspect, the research team compares the existing versus conceptual technology environment. This comparison is provided in Table 13.

- Second, the team identifies, as a result of this exercise, any additional potential constraints on a technology solution. Note that a constraint in this context is not necessarily a negative, merely a known constraint that restricts options. Therefore, these are identified as "controlling assumptions," also in Table 13.

5.2.4 Assessment

The assessments of the impacts to non-technology process and resources yielded the following considerations:

- Implementing the tour-based modeling approach as defined in 0-6210-2 does involve additional model components over and above existing procedures. Non-resident trip purposes must still be processed under the trip-based framework. The incorporation of the tour-based components is logical within the existing Texas Package model structure, however.

- Switching to the tour-based modeling approach does not necessitate a change to existing process or hardware.

- Minimal to no impacts to TxDOT technology services are anticipated at the agency enterprise level.

- Incorporating a tour-based modeling approach does add additional processing steps for model input data.

- Incorporating a tour-based modeling approach does impact the human capital side of TxDOT-TPP, necessitating additional training to ensure that model processes are followed. Given the current complexity of trip-based modeling, the staffing needs with regard to model application do not significantly change; however, the expertise to develop a tour-based model does demand a level of expertise that TxDOT-TPP will likely need to contract out. This last point is particularly relevant for small MPOs, which have fewer resources and staff than large and medium-sized MPOs. Special efforts should be made to ensure that staff at small MPOs is exposed to and trained in tour-based modeling techniques.

Table 13. Technology, Data, Knowledge, Staffing, and Training: Trip-Based and Tour-Based Contexts

Technology Aspect	Current Trip-based Context	Conceptual Framework for a Tour-based Model
Technology	The Texas Package, as it is called, is a suite of programs and utilities developed over a period of decades to implement three- and four-step trip-based TDMs for MPOs across Texas. The Texas Package is currently run using the following software:	The proposed TxDOT tour-based model would be conceptualized under the current research effort as an additional module available within the existing Texas Package suite of programs and applicable for implementation for any of the MPOs in the state (no coding or implementation is allowed by contract). *CONTROLLING ASSUMPTION*: The research team acknowledges that the conceptual framework must identify the approach for incorporating the tour-based model as a module option within the Texas Package, as identified in Section 4.
	• TransCAD 6.0 (transitioning from version 4.5 for older models) for geographic information system functions including maintenance and manipulation of geographic attribute data and as the user interface for the application of Texas Package generally.	• No change. The research team assumes that the conceptual framework will be (in concept) supported as would other Texas Package modules, through similar TxDOT licensing agreements.
	• TripCAL5, proprietary TxDOT software, for Trip Generation. • ATOM2, proprietary TxDOT software, for Trip Distribution.	• For resident trip-purposes, including all home-based trip purposes, additional applications proprietary to TxDOT and exclusive to the Texas Package will be necessary as the basis for detailing the traveling population of the study area: - Population Synthesizer for generating synthetic population of the study region - Long-term choice synthesizer for generating long-term choices including work location and auto-ownership of the synthetic population - Activity-travel generator for generation of tours - Activity-travel scheduler for scheduling the tours • For all other trip purposes not addressed by the tour-based module, the current versions of TripCAL and ATOM2 will be retained, for Trip Generation and Trip Distribution, respectively. *CONTROLLING ASSUMPTION*: The intersection between the trip-based approach and the proposed tour-based approach by trip purpose were identified in Section 4.
	• Mode choice: TxDOT's Junior Mode Choice Model is currently run only as part of one MPO model under direct development involvement by TxDOT-TPP, El Paso; two other MPOs, for the metropolitan areas of Austin and San Antonio, have fully developed mode choice models and model development resources and activities substantially independent from TxDOT-TPP.	• A current simplifying assumption is that the tour-based conceptual framework will not apply for the single MPO case where TxDOT's Junior Mode Choice Model is used, nor for the larger metropolitan areas of Austin or San Antonio, which have their own modeling resources. *CONTROLLING ASSUMPTION*: 3 MPOs out of 23 are excluded from consideration under the conceptual framework to be developed in later stages of this current research effort.
	• TransCAD 6.0 to run Traffic Assignment (static User Equilibrium).	• A current simplifying assumption is that there would be no change. However, in order to generate highway network level-of-service characteristics for input into the tour-based module, it may later be necessary to conceptualize utilization of the existing Texas Package approach for peak hour/peak period diurnal factoring and assignment.
	• A feedback mechanism has been tested in the Texas Package environment under a previous research effort, RMC 0-6691 and determined to be a feasible option under the current trip-based context, as needed. To date, it has not been used in a travel model implementation outside of the Austin metropolitan area, which has a model based upon the Texas Package, but is distinct in various ways.	• In order to stabilize highway network level-of-service characteristics for input into the tour-based module, which is standard for tour-based model approaches, it will be necessary to conceptualize use of the existing Texas Package approach for feedback. *CONTROLLING ASSUMPTION*: noted and previously shown in Figure 11 as part of the conceptual framework.
	• Other proprietary TxDOT utilities helpful in the process.	• No change.

<table>
<tr><th>Technology Aspect</th><th>Current Trip-based Context</th><th>Conceptual Framework for a Tour-based Model</th></tr>
<tr><td rowspan="8">Data</td><td>The Texas Package approach employs the following datasets directly:
TransCAD geographic information system shapefiles and data for TAZs and highway network (links and nodes). These files are maintained independently from TxDOT’s enterprise data system.</td><td>No change.</td></tr>
<tr><td>The Texas Package approach applies the following <u>TxDOT-maintained datasets</u> indirectly:
Urban area (saturation, average daily traffic) traffic count data imported from TxDOT’s enterprise Geographic Information System (GIS), ArcGIS, as points with data attribute data. Data is then “tagged” to fields in the highway network.</td><td>No change.</td></tr>
<tr><td>Annual (annual average daily traffic) traffic count data imported from ArcGIS as points with data attribute data. Data is then “tagged” to fields in the highway network.</td><td>No change.</td></tr>
<tr><td>Internal TxDOT work product “ramp books,” analytical tools used by TxDOT staff to derive mainlane counts from ramp counts. These are commonly used by TxDOT modeling staff to detail the count data for mainlanes, ramps, and frontage roads.</td><td>No change.</td></tr>
<tr><td>Travel survey data. Note that the datasets themselves are less often used than the summary report for manual processing of the data for use in the model.</td><td>For the tour-based model implementation, as detailed in the 0-6210-2, the development of the tour-based models requires use of the survey data already typically gathered for Texas study areas. At this early stage of this research effort, it is anticipated that travel survey data will be addressed to accommodate availability or not of existing survey data.
CONTROLLING ASSUMPTION: the conceptual framework assumes that
For study areas where <u>travel survey datasets are available</u>, they will be imported from the native format used by TxDOT into a format appropriate for analysis and use for tour-based model development.
Where a <u>travel survey dataset is not available</u> or deemed to be inapplicable for use for model development, the framework will include default parameters (likely borrowed from other areas) for small/medium-sized Texas communities.)</td></tr>
<tr><td>TxDOT Statewide Analysis Model output is occasionally used as a resource to develop external travel trip matrices.</td><td>No change.</td></tr>
<tr><td>Other spatial datasets helpful to developing and interpreting model attribute data, including county and MPO boundaries, streets, bridges, railroads, and water features.</td><td>No change.</td></tr>
<tr><td>The Texas Package approach employs the following <u>other datasets</u> indirectly, typically providing them to the MPO for consideration in development of their employment forecast; TxDOT staff uses these datasets for quality-control and data cross-checking during model calibration.
<u>Texas Workforce Commission-provided data in Excel format</u>: employer dataset including employer name, address, latitude/longitude if available, number of employees, and general type of employment (basic, retail, or service).
<u>Texas State Data Center population control totals</u> (report off Web site): various growth scenarios are available for MPO consideration in development of their demographic forecasts.</td><td>No change.</td></tr>
</table>

Technology Aspect	Current Trip-based Context	Conceptual Framework for a Tour-based Model
	The Texas Package approach applies the following MPO-provided datasets indirectly: • Demographics including population and employment data, typically provided in Excel worksheet format and appended, by TxDOT staff, to the TAZ geography for summary purposes and use by a utility to determine area types and transformed into ASCII text format data cards for use in TripCal5.	No change for trip purposes not addressed by the tour-based module. *CONTROLLING ASSUMPTION*: For resident travel to be addressed by the tour-based module, the conceptual framework will use U.S. Census PUMS data to elaborate MPO-provided demographics for the purpose of input to the tour-based model. This elaboration will be necessary for both current and future demographics scenarios and a simplifying assumption of the current tour-based approach will be that the PUMS characteristics by zone will remain constant between the current and future year.
	• Special generators data, typically provided in Excel worksheet format and used by TxDOT staff for summary purposes, and calculation of special generator productions and attractions for input into TripCal5.	No change in the procedure of how Special Generators are currently handled, i.e., the tour-based model conceptual framework will assume that Special Generators are not used unless determined to be necessary and relevant under the course of a study area's model calibration/validation.
Knowledge	TxDOT has an established repository of knowledge in support of its well-established trip-based modeling program, including • Developing Network and Demographic Inputs for Travel Demand Modeling Guidebook, TxDOT and TTI, February 2007. • Memo: Aggregating Census Data (January 2012) • Memo: Geo-coding TWC Data (January 2012) • Memo: Using Dataferret • Memo: Aggregating Census Data • ATOM2 User Manual, Texas Department of Transportation, February 2001. • Texas Travel Demand Model Applications Guidebook, Texas Department of Transportation, 2007. • TripCal5 Inputs Manual, Texas Transportation Institute, 1999. • TripCal5 User's Manual, Texas Department of Transportation, 1990. The most extensive knowledge held, of course, is within those active practitioners of modeling with the Texas Package. These include staff at TxDOT-TPP, Texas MPOs, Texas A&M Transportation Institute (through its supportive role under ongoing contract), and various consultants. Because of the prevalence of trip-based modeling across the United States, a wealth of other resources is available; care is often advised to ensure that the user understands the aspects applicable (and not) for the Texas Package and TxDOT-supported modeling practices. These resources include NCHRP Report 716, 2012. *Travel Demand Forecasting: Parameters and Techniques*, Transportation Research Board (update to NCHRP 365).	To the knowledge of the research team, TxDOT currently has no knowledge base for tour-based or activity-based modeling outside of knowledge gained through the agency's progress research program. This includes, of course, 0-6210-2, the 2009 research report that is extensively referenced here. Other knowledge resources for tour-based modeling that are easily accessible to TxDOT under various mechanisms include • In-state expertise available through at least two of Texas academic and research institutions, the University of Texas at Austin and the Texas A&M Transportation Institute. • Consultant expertise in Texas and worldwide. • Hiring of future employees as a potential strategy. There is no current controlling assumption in regarding to knowledge; the assumption made by the research team is that TxDOT will access knowledge as needed to support its technology endeavors.

Technology Aspect	Current Trip-based Context	Conceptual Framework for a Tour-based Model
Staffing	As noted in 0-6210-2, TxDOT-TPP modeling staff is finite in number and varied in experience level. Accordingly, TxDOT-TPP is in the process in 2013 of engaging on-call consultant expertise for modeling and other tasks as needed. In addition, TxDOT-TPP continues to maintain an Inter-Agency Contract (IAC) with the Texas A&M Transportation Institute to provide a continuity of technical knowledge, training, and occasional support services as necessary to TxDOT-TPP staff. TxDOT also has other research and contracting avenues (i.e., research, implementation, and other IAC contracts or partnerships) to access expertise as needed. Through these varied parties, the knowledge categories of modeling-related staff expertise available to TxDOT-TPP include • Model Program Management • Advanced Modeling (including tour-based, activity-based, and other advanced techniques) • State-of-Practice Trip-Based Modeling • Transportation Planner/Corridor Analyst • Geographic Information Systems Support It should be noted, as was identified in a currently ongoing research effort, that travel modeling tasks are quite often easily broken down into tasks easily accomplished by staff with little or no modeling expertise. Examples include network coding, demographics development and verification, and other types of data input.	The current staffing available to TxDOT as described to the left is appropriate to support the application of tour-based models, with two distinctions: • Tour-based model development for a study area requires staffing with expertise and hands-on experience with tour-based implementation. Skill sets needed include knowledge of discrete choice modeling, random utility-based economic theory, and Monte-Carlo simulation. • Tour-based model application for a study area requires staffing with at least expertise and hands-on experience with trip-based modeling, ideally with the Texas Package itself. Additional skill sets needed include an inclination and ability to assess the reasonableness of model results and effectively communicate model approach and results to other audiences. • Similar to trip-based modeling as described to the left, certain tasks do not require advanced modeling expertise. At present, the research team's assessment is that these skill sets are available only on a very limited basis internally to TxDOT; this is likely to change over time as TxDOT staff gains experience with tour-based modeling and new-hires are increasingly likely to have this experience from other job experiences. Tour-based model development expertise is widely available in research institutions and generally accessible through consultant contracts; tour-based model application experience is generally available in research institutions and is becoming more widely available through consultant contracts over time. *CONTROLLING ASSUMPTION*: the current research effort does not include reference to contracting approaches necessary to specify appropriate expertise in external staff resources; the availability of such resources has recently become more accessible to TxDOT-TPP for model development.
Training	Texas offers a broad range of training activities in support of its well-established trip-based modeling program, including • General TransCAD Training • Introduction to Travel Demand Modeling • Model Inputs Development Training • Model Application/Alternatives Analysis Training Because of the prevalence of trip-based modeling across the United States, there are a wealth of other training resources available; care is often advised to ensure that the trainee understands the aspects applicable (and not) for the Texas Package and TxDOT-supported modeling practices. These resources include • NHI Introduction to Urban Travel Demand Forecasting Course, self-paced or instructor-led options available. • Caliper Corporation (TransCAD software developer) offers "Travel Demand Modeling with TransCAD" and other on- and off-site training options.	A variety of training resources continue to be developed to serve the transportation forecasting community, including • Webinars on activity-based and tour-based modeling, organized by the FHWA/TMIP. • Tour-based modeling training sessions offered most often by academic researchers on-site at their institutions or at off-site destinations. • Side-by-side training alongside coworkers, partner agencies, and on-call consultants (as trip-based modeling has been taught for decades). *CONTROLLING ASSUMPTION*: the current research effort does not include further development of the training needs aspect of the conceptual framework for implementation; the need for training continues for both tour-based and trip-based modeling approaches.

5.3 IMPACT TO INFORMATION TECHNOLOGY RESOURCES

Section 4 described the definition of an LDM to provide the foundation of a TxDOT database system for tour-based travel demand modeling compliant with TxDOT information technology standards. The TxDOT Information Technology Services Division (ISD) provided guidance for compliance with these standards in the latest version of the TxDOT data architecture standard (*26*).

As described earlier, the research team's efforts were limited to the development of a BPM for tour-based travel demand modeling, an LDM to provide a visual representation of the tour-based TDM's pertinent data and relationships, and a data dictionary describing entities, attributes, and relationships. The data design process specified in the TxDOT data architecture standard recommends the development of a conceptual data model (or BPM) but mandates the development of an LDM.

5.3.1 Business Process and Data Management: Best Practices and Industry-Proven Technologies

The BPM identifies data from the business viewpoint, and thus helps identify persons, places, things, concepts, and events relevant to the business. The BPM also identifies important associations and prerequisites related to these objects. TxDOT-TSD does not require the use of specific software or modeling language to develop the BPM. One option that the research team considered was the Integrated Computer-Aided Manufacturing Definition Language (IDEF), specifically the Integration Definition for Function Modeling (IDEF0) for BPMs and the Integration Definition for Process Description Capture Method (IDEF3) for process flow models. Using IDEF0, systems can be modeled as a set of interrelated activities or functions for a specific purpose and from a selected viewpoint, also called a "function model" (*30*). IDEF0 diagrams have boxes that represent functions, and arrows that represent either inputs, controls, outputs, mechanisms, or calls, depending on their position relative to the function box. IDEF0 consists of a top-level context diagram, which is a function represented by a single box. The top-level context diagram is then decomposed into sub-functions on child diagrams, which may in turn have further sub-functions. Each child diagram that entails another decomposition or child diagram is also a parent diagram for its child diagram.

By comparison, IDEF3 is a technique to capture, manage, and display process-centered knowledge in a form of scenarios that are displayed as process schematics (*31*). IDEF3 can be used to describe a process as an ordered sequence of events along with objects that participate in those events. IDEF3 models can support IDEF0 models when more detailed and conditional information is available. This additional information can be expressed in junctions between activities, such as "all following processes must start/end," "one or more following processes must start/end," or if the user wants to analyze different scenarios of the same process.

A characteristic of the IDEF business process modeling notation is that the notation is highly technical and less useful to discuss BPM details with practitioners that are unfamiliar with IDEF. A part of the problem is that model reviewers see only a small portion of the model at a time, which makes it difficult to picture the entire business process, verify existing relationships, or draw new relationships. As a result, researchers evaluated other options for business process modeling. Ultimately, the researchers selected the Business Process Modeling Notation (BPMN), which depicts the end-to-end flow of a business process and has a process-oriented approach to application modeling (*32*). BPMN provides three basic types of models, which are private (internal), abstract (public), and collaboration (global) BPMs. For this project, the collaboration BMP was the most appropriate, since interactions between two or more business entities or data sources can be modeled as sequence of events, activities, and gateways that are arranged in "pools" and "swimlanes" along with data objects.

5.3.2 Potential for Legacy System Re-use and Amount of Customization Anticipated

As described previously, the opportunities for legacy system service are high due to the flexible nature of the existing Texas Package as a system of programs and utilities. As was shown in Figure 11, the tour-based approach can be reasonably integrated into the Texas Package approach. The amount of customization necessary for the tour-based components is high, because no tour-based modeling tool is commercially available at this time. Each tour-based model itself is a customized component to represent travel in a unique study area and, therefore, flexibility of approach based upon the data findings in constructing the model is of high value.

This customization impact is minimal to TxDOT-TSD because of the previously described independence of the TDM modeling operations from the enterprise system. For TxDOT-TPP staff, who are presently in the process of automating their trip-based model process, the application of a tour-based model may also be automated to some degree. The development of a tour-based model, similar to how trip-based models are currently developed by TxDOT-TPP staff, will remain an advanced modeling technique.

5.3.3 Conformity with Statewide Information Technology Standards

Model compliance focused on the elements data standards, data naming, and data normalization with a purpose to promote better understanding of the data elements, promote sharing of data across organizational boundaries, and reduce data redundancy. The research team was not tasked with the development of a related physical model or TxDOT System Interface Diagram; therefore, standard compliance was limited to the LDM and data dictionary.

The research team developed an LDM of the tour-based model using Computer Associates AllFusion ERWin Data Modeler software. The data modeling tool that TxDOT currently uses is ER/Studio from Embarcadero Technologies. At the beginning of the project, the ISD discussed with the research team how modelers could potentially get access to the software. As the project progressed, it became clear that access to the software would not be feasible. As a result, the research team chose the data modeling software that was in use at TxDOT prior to the switch to ER/Studio. The research team also ran several tests, which found that the ERWin model output was fully compatible with import algorithms provided by ER/Studio. As a result, ISD approved the use of ERWin as the modeling environment for the LDM.

The research team took care to follow the entity and attribute naming standard provided by the TxDOT Data Architecture Manual. As noted in Section 4, not all existing datasets that are used by the tour-based model follow the TxDOT naming standard. As a result, the research team modified or upgraded some of the original entities and data field names to make them compatible with the TxDOT standard.

The research team also started normalization of the data model. The requirement for TxDOT data models is the third normal form (3NF). The goal of normalization is to develop a model with non-repeating and non-redundant entities, such that modifications of the database can be made in just place and be propagated through the database using defined relationships. In first normal form (1NF), all entities have a key composed of one or more attributes that uniquely identify one occurrence of the entity, and each attribute for an occurrence of an entity must contain different information, i.e., there are no repeating groups. All entities in the model are in 1NF. In second normal form (2NF), all entities are in 1NF and, in addition, every non-key attribute of an entity is directly related to every attribute that forms the primary key. All entities in the model are in 2NF. In 3NF, all entities are in 2NF and every non-key attribute of an entity depends only on every attribute that forms the primary key. Following that definition, the research team decomposed entities as necessary to ensure that the resulting entities of the LDM are in 3NF.

5.3.4 Assessment

Based on the previous discussion, following are the potential impacts to the information technology process:

- While substantial existing data are available to feed the TDM processes, both trip-based and tour-based, the structure for managing the data for use in the TDM process appears informal with regard to TxDOT enterprise data systems. The benefit here for the current effort is that implementing a tour-based modeling approach in this unstructured data environment does not have any impact upon the TxDOT enterprise data system.

- The BPM was modeled using a simple notation that allows non-experts to understand the processes pertaining to tour-based models. The LDM, on the other hand, was developed using TxDOT standards, given by the Data Architecture Manual, which will facilitate the incorporation of the tour-based model into TxDOT-ISD.

5.4 COST ANALYSIS

5.4.1 Model Development Cost

TxDOT has made a substantial investment in the development of a standardized trip-based model for Texas. Therefore, cost is one potential barrier to the implementation of advanced modeling practices. The cost of developing and implementing a tour-based model in Texas is highly dependent on the level of complexity of the model. The Virginia Department of Transportation collected information regarding the costs of implementing an activity-based model, as presented in Table 14. The table shows significant differences in data collection costs and model development costs. On average, the agencies spent $2.5 million on collecting data. This average is, to some extent, correlated with the population of the base year. In Texas, most data required to implement the model is already available and little processing is needed. Therefore, data collection costs should be minimal. Model implementation costs across the agencies average $1 million. This figure is consistent with the one reported by Special Report 228 (*33*), which estimates that the development of a tour-based model could range from $1 million to $1.4 million. The business case developed in this report considered the simplest model design proposed in 0-6210-2, Design Option #1, which can result in a reduced development cost for Texas.

Detailed costs are provided by the Association of Metropolitan Planning Organizations (AMPO) for SACOG and ARC (*22*). ARC spent approximately $1.2 million in consulting fees from 2003 to 2011 to develop their tour-based model, plus an undetermined amount between 2000 and 2002 for model design and development of a population synthesizer. The $1.2 million was spent as follows: $360,000 to finish the population synthesizer and model estimation, $660,000 for the implementation of core model components and to calibrate and validate the model, and $150,000 to develop visualization capabilities and obtain user training. SACOG, on the other hand, has spent approximately $850,000 for model development since 2001. These expenditures correspond to an initial outlay of $514,000, which paid for the development of the model currently in use, and $335,000 to add time-of-day and pricing enhancements and to modernize their application software. During the 5-year period in which they developed their initial model, SACOG staff members contributed labor equivalent to three to four full-time employees at a value of approximately $350,000. However, since ARC and SACOG were earlier adopters, the costs for TxDOT should be less, since some of the methods and software have already been developed.

Table 14 also provides information regarding the running times and the development time. The running times can vary from 10 to 26 hours, while the model development time ranges from 1.5 years to 11 years, although most agencies estimate that the development time is 2 years. The times reported in Table 14 were obtained almost 5 years ago; therefore, running times today are probably shorter than those in the table. For example, ARC reported a running time of 20–26 hours using three 64-bit Windows machines to form a distributed/threaded modeling system, each machine running on Dual Quad Core Intel Xeon X570 2.93 GHz Processors (8 per machine), with 32 GB of RAM (22). Then, there are tradeoffs between run times and hardware cost in which more and faster processors reduce run time, but increase server costs.

TxDOT report 0-6260-1 (*34*) estimated the costs of performing a pilot case. A pilot case is important to assess the applicability of a project and helps to improve the possible weaknesses of it. The pilot case considered a representative medium-size metropolitan area with staff relatively experienced with GIS. The estimated cost of the pilot is $650,000, and the breakdown of this figure is presented in Table 15. Note, however, that this budget does not include extensive validation testing of individual components of the model system and/or validation using before/after or back-casting exercises.

5.4.2 Assessment

Based on the previous discussion, the assessment regarding cost analysis is that TxDOT should expect to pay no less than $1 million to develop a tour-based model. This budget does not include data collection and survey implementation. The model development is expected to take approximately 2 years. However, it is recommended to implement a pilot case before proceeding to develop tour-based models for Texas.

Table 14. Implementation and Cost of Tour-Based Models in the United States

Agency	Software platform		Year completed	Number of zones	Model size (sq. miles)	Base year population	Development cost		Run time (approx)	Development time
	Main application	Custom application					Data collection	Model development		
San Francisco County Transportation Authority, San Francisco (SFCTA)	Cube	C++, Java	2001	1,700	50	750,000	-	$700,000	24 hrs	18 months
New York Metropolitan Transportation Commission, New York (NYTMC)	TransCAD	C, C++, FORTRAN	2002	3,600	-	-	-	-	-	-
Mid Ohio Regional Planning Commission, Ohio (MORPC)	Cube	Java	2005	1,800	150	1.5 million	$525,000	$1,000,000	36 hours	2 years
Tahoe Regional Planning Agency, Lake Tahoe Region, Nevada (TRPA)	TransCAD	Java	2007	289	501	63,448	-	-	-	-
Sacramento Area Council of Governments, Sacramento, CA (SACOG)	Cube	Delphi, Pascal	2007	1,500	4,000	2,000,000	$4,000,000	$580,000	20-26 hrs	2 years
New Hampshire Department of Transportation (Statewide)	EMME2, TransCAD	Unknown	1998/updated 2005	-	9,350	1.2 million	-	-	-	4–5 years
Denver Regional Council of Governments, Denver, CO (DRCOG)	TransCAD	SQL, C#	2,009	2,812	5,000	2.8 million	$1,500,000	$1,500,000	-	5 years
Atlanta Regional Commission, Atlanta, GA (ARC)	Cube	Java	2,008	2,027	6,267	4.8 million	$1,000,000	$1,000,000	10–12 hours	6 years
Ohio Department of Transportation, Ohio (Statewide)	TransCAD, Cube	Java	2009	>5,000	-	12 million	$6,000,000	$2,000,000	12 hrs on 36 processors	11 years
Metropolitan Transportation Commission (MTC)	Cube	Java	2009	1,454	7,000	6,783,760	-	-	-	-
Oregon Department of Transportation, Oregon	EMME2, VISSUM	Java	2008	3,000	-	-	-	-	-	-
Portland (Metro)	EMME/2, VISSUM	Python, Java, C++	2009	2,013	-	1.6 million	-	$200,000	-	2 years
Puget Sound Regional Council, Seattle, WA (PSRC)	-	Python	2010	2006	-	1.76 million	-	-	-	-

Source: Virginia Department of Transportation, VTM Research Paper 09-01, 2009

Table 15. Cost Estimates for the Development of Tour-Based Model for a Pilot Case Study

Task	Cost
Data preparation	
Identify and compile data sources for synthetic population generation	
Assemble and review survey data (including on-board transit survey), generate tours and stops, append land-use and transportation system data	
Identify additional data sources (for example, Department of Motor Vehicles) and assemble available data	$150,000
Prepare input tour and trip data files for each model component	
Assemble validation data for basic testing of link volume predictions	
Methods and model estimation	
Design and apply synthetic population generation procedure	
Specify and estimate each model component	$200,000
Develop prediction procedures and implementation procedures	
Develop validation procedures and statistics	
Application software development, interfacing with Texas Package and TransCAD, and validation	
Identify software platform and design software architecture	
Write code and routines for seeking/writing data, call models in the appropriate sequence, make predictions, and compile predictions to generate activity-individual of each household travel patterns for each individual in the household	
Prepare a set of template files defining the input and output interfaces of each model within the model system framework	
Translate activity-travel patterns to OD trip matrices by time of day	$300,000
Augment trip matrices with external trips and freight-related trips	
Interface with a static traffic assignment model	
Test software functionality and validate model predictions with link volumes from traffic assignment	
Prepare calibration, validation, and other relevant technical documents	
Total Cost	$650,000

Source: (4)

5.5 RISK ASSESSMENT

The exercises performed as part of this study—the process summary flow chart, the BPM, and the LDM—provide the basis for this current evaluation.

Potential **technical challenges** that may hinder a successful tour-based model implementation include the following:

- The survey datasets currently gathered by TxDOT and used for travel demand modeling have not yet been applied in a tour-based model context. A quality issue with the survey data not yet identified could arise that negatively affects model quality.
  Risk: Low.
  Mitigation: Models are purposeful simulations of available data; the identification of such an issue would be noted by the model developer and then mitigated through model approach.

- As discussed previously, comparing model results from a trip-based approach to a tour-based implementation most certainly will demonstrate some inconsistencies. The level of these inconsistencies is unknown and there may be aspects for which the trip-based model performs better or comparably to the tour-based model. Even a worse performance by the trip-based model is of concern because doubts may arise about previous decisions made.
  Risk: Medium.
  Mitigation: It is recommended that the first pilot implementation of a tour-based model be conducted for a study area in attainment for air quality and not subject to the most stringent TDM observance. A parallel, entirely trip-based model should be developed as well, and a comparison conducted to assess this risk for future model implementation.

- As noted in Section 3, a tour-based modeling approach is a less sophisticated version of activity-based modeling, which is the current state of the art and best practice in travel behavior modeling. Because the tour-based approach does not demonstrate the technical rigor of a full activity-based model, it is possible that a tour-based model can yield non-intuitive results, similar to the way a trip-based model can have non-intuitive results. The risk is choosing the less complicated tour-based approach but then resulting in a model that fails to deliver upon expectations.
  Risk: Medium.
  Mitigation: Conduct the preliminary model implementation as a pilot for an area in attainment for air quality and with an existing trip-based model (or parallel-developed model), which can be utilized for planning.

- Acquisition of all of the data necessary for development of the tour-based model (including from parties external to TxDOT, such as the MPO) may take longer than anticipated, delaying the scheduled delivery of the tour-based model.
  Risk: Medium.
  Mitigation: Work with an MPO that is motivated and interested in implementing a tour-based model and with a good track record of model data delivery.

Potential **non-technical challenges** that may hinder a successful tour-based model implementation include the following:

- TxDOT may not have funding available to implement tour-based modeling at this time. In the current funding-constrained environment, this risk is high.
  Risk: High.
  Mitigation: Use the approach already recommended under 0-6210-2 (and taken in this study) to maximize the existing TDM data sources and framework. An additional mitigation possibility includes leveraging available local university resources.

- TxDOT leadership and other stakeholders may not perceive the value of the tour-based approach over the current trip-based approach. In particular, MPO staff may be reluctant to adopt a new modeling approach because of the resources needed to adapt to this new approach.
  Risk: High.
  Mitigation: Education in non-technical terminology about the types of travel questions that tour-based modeling can answer. Education, in this context, should not be only related to technical issues, but also emphasize the benefits of the tour-based approach discussed in Section 2. A pilot implementation and test may be seen as less threatening, providing a way for stakeholders to get their feet wet with the model.

- TxDOT's consultative partners, in particular the FHWA and FTA, may be concerned about a tour-based model implementation.
  Risk: Medium.
  Mitigation: Advanced travel behavior modeling is increasingly familiar to these partners, so this risk is decreasing. Advanced discussion with these partners to consider any concerns and address them early in the process is advisable.

- Non-technical users of model output for planning may reject unfamiliar TDM model output or have unreasonable expectations of model results.
  Risk: Medium.
  Mitigation: Communicate expected model benefits and limitations before, during, and after the tour-based model implementation. Presentation of the implementation as an exploratory pilot may be advantageous in this regard.

- Current TxDOT-TPP modeling resources (internal staff and others) may be slow to get involved in tour-based modeling efforts due to concerns about the difficulties.
  Risk: High.
  Mitigation: Pre-plan the tour-based roll-out (emphasizing the pilot test implementation as a first, evaluative step) and communicate how the tour-based approach fits within the existing Texas Package as an additional module (that is, a tour-based approach as presently recommended is within the familiar Texas Package).

Overall, the risks appear manageable given that TxDOT-TPP is experienced in delivering TDMs and has access to external resources to supplement internal efforts.

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