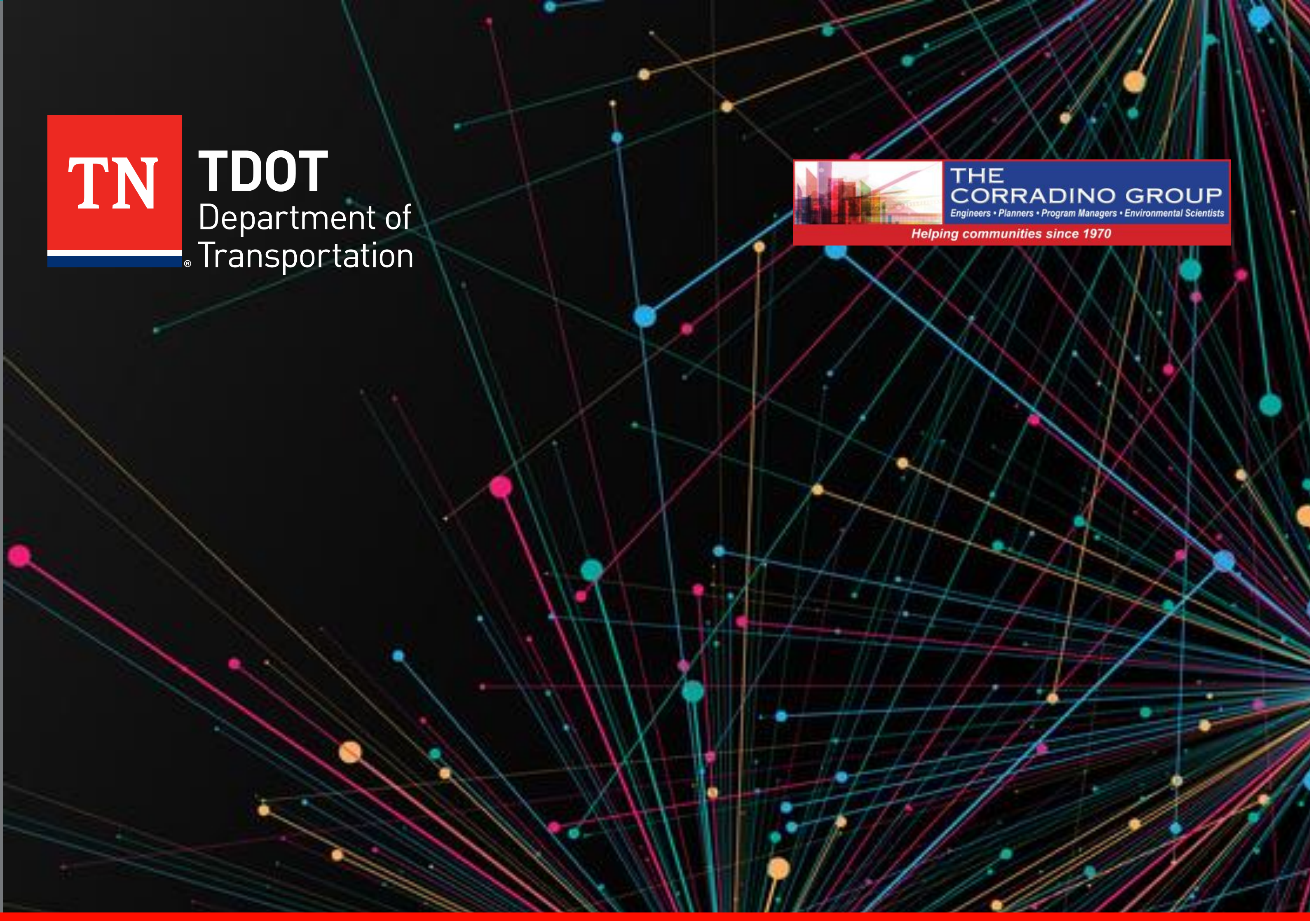


Development of Travel Demand Modeling Standards

Phase 1: State-of-the-art Literature Review

May 2022

Prepared for: TDOT/Long Range Planning Division/Forecasting Office | Mohammad Molla, Chris McPhilamy, Golnaz Sarram, Marshall Wilson

Prepared by: The Corradino Group, Inc. | Ken Kaltenbach, Senior Vice President

Acknowledgement

Thanks to the participants in this study, who helped us assemble the data and references:

- The Tennessee Department of Transportation:
  - Matt Meservy, PE– Long Range Planning Division Director
  - David Lee, PhD – Long Range Planning Assistant Director
  - Chris McPhilamy, GISP – Planning Manager
  - Mohammad Molla, PhD – Forecasting Planning Supervisor
  - Marshall Wilson – Planning Specialist Advanced
  - Golnaz Sarram, PhD – Planning Specialist
- UTK Center for Transportation Research:
  - Jerry Everett, PhD
- Tennessee MPO staff Participants:
  - Bristol – Steven Mott
  - Chattanooga – Yuen Lee, AICP, GISP
  - Clarksville – Stan Williams
  - Cleveland – Greg Thomas
  - Jackson – Stan Pilant
  - Johnson City – Glenn Berry
  - Kingsport – Bill Albright
  - Lakeway – Rich DesGroseilliers
  - Knoxville – Mike Conger, PE
  - Memphis – Pragati Srivastava
  - GNRC – Max Baker
  - GNRC – Hary Prawiranata
- MPO Framework Standardization Committee:
  - Chattanooga – Yuen Lee, AICP, GISP
  - Chattanooga – Aleeta Zeller
  - UTK – Jerry Everett, PhD
  - GNRC – Max Baker
  - GNRC – Hary Prawiranata
  - Clarksville – Stan Williams
  - Knoxville – Mike Conger, PE
  - Matt Meservy, PE
  - David Lee, PhD
  - Chris McPhilamy, GISP
  - Mohammad Molla, PhD
  - Marshall Wilson
  - Golnaz Sarram, PhD

Disclaimer

This project, Phase 1: The Development of Travel Demand Model Standards Using the TransCAD Platform (State project No: 18SPR1-F7-036 and contract No_ 65550-48), was funded by the Tennessee Department of Transportation, Long-Range Planning Division, Forecasting Office.

This document is disseminated under the sponsorship of the Tennessee Department of Transportation in the interest of information exchange. The State of Tennessee and the Department of Tennessee assume no liability of its contents or use thereof.

The contents of this report reflect the views of the author(s) who are solely responsible for the facts and accuracy of the material presented. The contents do not necessarily reflect the official views of the Tennessee Department of Transportation or the State of Tennessee.

Executive Summary

This report documents the work and findings of Phase 1, Development of Travel Demand Modeling Standards task order. It presents a roadmap of how TDOT could implement a standard travel demand model program. It also provides a summary of travel demand modeling practices in Tennessee, how several other states have approached model standards, presents a literature review, provides recommendations for a standard TDOT model with descriptions of major model elements, and suggests the next steps that TDOT should take.

The study confirms that it would be a good idea to develop standard model guidelines and procedures and recommends that TDOT follow this path. The survey conducted during the study (also summarized in this report) suggests that such a program would be accepted by the MPOs, and that it would be recognized as an improvement to their transportation planning process while reducing their workload.

A prototypical model is outlined in this report. It is a four-step model which implements best-practice procedures. It recognizes that many of the procedures would not apply to the three MPOs with advanced practice models (Chattanooga, Knoxville, and Nashville), but that even these areas might benefit from statewide programs to obtain and distribute data, and to display and summarize model results.

This report presents recommendations for Phases 2 and 3 of this three-phase study. It is recommended that Phase 2 develop and implement a prototypical model for: 1) the Tri-Cities (Kingsport, Bristol, and Johnson City) MPO TDM area; and, 2) the Jackson Area MPO. This would include the development, validation, and implementation of the models, and development of guideline documents. Phase 3 would address: 1) development of a highway-only model if there is an MPO with no transit service at the time; 2) development of standard TDOT modeling procedures that could be used by the advanced practice model areas relating to reporting, visualization, and sharing of input data sources; 3) two-way integration and sharing of data inputs and outputs in the statewide model; and, 4) development of the land use model. The land use model would be integrated into the Tennessee statewide model, which would provide land use data to the MPO models.

Table of Contents

List of Tables

List of Figures

Chapter 1 Introduction

This report documents the work and findings of Phase 1, Development of Travel Demand Modeling (TDM) Standards task order. As described in the task order, this report:

- Describes the finding of each subtask. This includes:
  - Meetings and coordination (**Chapter 2**)
  - Survey of Tennessee MPOs/Outreach/Workshop (**Chapter 3**)
  - Assembly and analysis of TDOT models and data (**Chapter 4**)
  - National DOT Outreach (**Chapter 5**)
- Includes a comprehensive bibliography of sources and contacts used in the creation of the literature review. URLs for contacts are included when possible (**Appendix F**).
- Notes the OneDrive site created to hold all relevant project deliverables, reports, and studies.

The literature review summarizes ways that other states have dealt with model standardization. It includes a review of TDM best practices, and comments on data sources and schedule requirements. It draws on a Travel Model Improvement Program (TMIP) survey of state departments of transportation, and publications from the Transportation Research Board (TRB), USDOT, the Institute of Transportation Engineers (ITE), university research, and MPOs.

Chapter 2 Meetings and Coordination

The consultant and TDOT began the study with an on-line meeting January 17, 2022. From that point, meetings were held every two weeks to ensure close coordination, facilitate data transfer, and make sure that the study produced the product that TDOT needed. The consultant created meeting notes shortly after each meeting and delivered them to TDOT. Meeting participants were the TDOT staff and Corradino staff.

Before the first meeting, the consultant established a OneDrive site to store all MPO/TPO regional travel demand models, Tennessee Statewide Model (TSM), and data for use by the consultant in the study. This site provides a convenient way to share project files.

Shortly after the first meeting the consultant began to collect reports via the internet from USDOT, state DOT, university, TRB, and MPO sources describing work others have done in the area of model standardization.

Chapter 3 Survey of Tennessee MPOs

In order to build trust with the Tennessee MPOs, and to assess their modeling needs, the consultant conducted an online survey of the MPOs. The survey was conducted using the SurveyMonkey software. An invitation was sent to all MPOs from a list provided by the TDOT staff. The survey invitation, distribution list, and questions appear in the **Appendices A, B and C**. The survey went live on the internet, February 4, 2022, and was closed February 18, 2022. Since the survey was sent to a limited group—the MPOs—nearly 100% participation was achieved.

3.1 Summary Results

Detailed survey responses are presented in **Appendix D**. A summary of responses ranked by small, medium, and large MPOs (size is self-reported by the respondent), interpreted and prepared by the consultant, is as follows:

- Most pressing modeling needs:
  - Most MPOs say they need more data, staff, and training.
  - Almost all MPOs say they need more accurate traffic forecasts.
  - Most say that easier model application is a high priority.
- Most MPOs believe that a system of similar modeling procedures among the MPOs with TDOT support would make their jobs easier.
- Usefulness of possible improvements (ranked):
  - Better and more consistent data was ranked first by small- and medium-sized MPOs, and second by the large MPOs.
  - Consistent data file and variable names was ranked first by large MPOs and second by medium-sized MPOs.
  - Consistent procedures were ranked least important by medium and large MPOs, and second by small MPOs.
- Additional data needs:
  - Ranks vary widely by size.
  - Large MPOs ranked household surveys and external data highly.
  - Medium MPOs expressed their need for more zonal data and traffic counts.
  - Small areas say they need more traffic counts, network data, and a household survey.
- New procedures and post-processors:
  - All MPOs expressed a need for land use forecasting.
  - Air quality tools are important for large area but not for small- and medium-sized areas.
  - Economic analysis tools are needed, especially for small- and medium-sized MPOs.
  - Visualization tools rank lower than expected.
- Model running time in the computer is not an issue.

- Model procedures that need more attention:
    - Small and medium MPOs rank trip generation and distribution models as most important.
    - Large MPOs rank truck, external, and mode choice models as most important.
    - Time-of-day models are important for medium-sized MPOs but rank last for small MPOs.
- Guidelines versus Standards:
    - Large and medium MPOs prefer guidelines over standards.
    - Small areas are evenly split.
- Definition of a good model:
    - Logical/reasonable is rated more important than exact replication for all three sizes of MPOs.
    - Produces good summaries, maps, graphs, and other visualization outputs is ranked as important by small and medium MPOs.
    - Models that run quickly are important to large MPOs.
- Overwhelmingly, MPOs are interested in using a standard TDOT model.
- Elements to be standardized:
    - Large and small specify file standard names.
    - Medium-sized MPOs are most interested in a standard set of model steps.
    - Standard algorithms and constants are important for all MPOs.
    - Standard transit and non-motorized models rank low.
- Interest in serving as part of a committee:
    - The majority of medium and large MPO respondents were interested in serving.
    - Most small area respondents were not interested in serving.

The consultant's recommendations have attempted to consider the preferences of the MPOs.

Chapter 4 Summary of Current Tennessee MPO and Statewide Models

The consultant, with the help of TDOT staff, assembled a library of all current Tennessee Travel Demand Models, including the statewide model. This library is stored on Corradino's OneDrive, and a link has been shared with the TDOT staff.

Including the statewide model, there are 11 travel demand models in use in Tennessee. There are 11 MPOs, but Lakeway and Knoxville use the same model, hence there are only ten regional models. A thorough description of these models would comprise a large report. For this study, the consultant created a summary table of selected attributes and metrics of each model (see **Table 4-1**). The table characterizes each model, describes the model structure, shows some common features, and provides a basis for recommendations that would move TDOT to a standard modeling procedure.

The attributes summarized in the table include:

- Software platform – This is the software used to implement the model. All Tennessee models use TransCAD, which is a product of the Caliper Corporation.
- Year of last update – The year the model was last updated.
- Population – Base year model area population at last update.
- Size – For this table small is less than 200K population, Medium is 200K and larger but less than 1 million, and large is greater than 1 million.
- Year of TAZ data – Base year of the model, indicating whether it is due for an update.
- Model Type – Generally, a trip-based model, an advanced practice ABM, or hybrid.
- Source of Hwy Net – Source of the highway network geography and data.
- Source of Speed data – Source of network speed data.
- Is there a transit network – Indicates whether transit alternatives can be tested?
- Is there a GTFS file – Indicated whether the source of the transit network is a detailed General Transit Feed Specification file?
- Non-motorized purposes – Indicates whether the model can directly estimate non-motorized travel.
- Time periods – Describes the level of time-of-day segmentation.
- Truck or Freight Model – Whether truck and freight are modeled.
- Trip distribution by purpose – Describes the methods used for trip distribution by purpose—generally gravity or destination choice.
- Type of mode choice model – Describes how transit trips and auto occupancy is modeled, and whether mode choice is sensitive to networks, policies, and other attributes.

TABLE 4-1: SUMMARY OF TENNESSEE TRAVEL DEMAND MODELS

MODEL PROFILE	Bristol	Chattanooga	Clarksville	Cleveland	Jackson	Johnson City	Kingsport	Knoxville	Memphis	Nashville	TSM V4.0
Software platform	TransCAD	TransCAD	TransCAD	TransCAD	TransCAD	TransCAD	TransCAD	TransCAD	TransCAD	TransCad	TransCad
Population (base)	113,308	468,105	196,758	114,948	98,636	214,535	134,677	1,038,620	1,332,420	1,748,141	6,910,840
Size	Small	Medium	Small	Small	Small	Medium	Small	Large	Large	Large	NA
Year of last update.	2021	2021	2018	2021	2017	2017	2021	2021	2020	2020	2021
Year of TAZ data	2016	2019	2016	2018	2015	2015	2018	2018	2016	2017	2018
Model Type	Trip	ABM (Daysim)	Trip	Trip	Trip	Trip	Trip	Hybrid	Trip	ABM (Daysim)	Advanced Trip
Source of Hwy Net	2010 Legacy	INRIX, TDOT, GDOT	Legacy	Legacy	TRIMS &HPMS	TRIMS, legacy	Legacy	TRIMS	TRIMS & HERE	TRIMS	TRIMS/NHPM
Source of Speed data	Posted spd	INRIX, TDOT, GDOT	Posted spd	Posted spd	NPMRDS	Posted spd	INRIX	TRIMS	HERE	TRIMS	TRIMS/NPMRDS
Is there a transit network?	No	Yes	No	No	No	No	No	Yes	Yes	Yes	No
Is there a GTFS file?	No	Yes	No	No	No	No	No	No	Yes	Yes	No
Non-motorized purposes?	No	Yes	No	No	No	No	No	Yes	Yes	Yes	Yes
Time periods	4	4	4	4	4	4	4	4	4	4	3
Truck or Freight Model?	Truck	Truck	Truck	Truck	Truck	Truck	Truck	Truck	Truck	Truck	Yes
Trip distribtion by purpose	GM	Daysim	GM	GM	GM	GM	GM	Dest Choice	Dest Choice	Daysim, Visitor:GM	Dest Choice
Type of mode choice model	Occ.Rates	MNL	Occ.Rates	Occ.Rates	Occ.Rates	Occ.Rates	Occ.Rates	MNL	NL	Logit (Daysim)	Logit
Is a feedback loop used?	MSA	Yes	No	No	No	MSA	MSA	Yes	MSA	Yes	Avail/not used
Number of TAZs	150 Int	746	277	138	377(Int), 28 ext	269 int	228	1186	2823	2929	3687
Model segmentation	Trip Purp	Auto, SU, MU trk	Trip Purp	Period	Trip Purp	Trip Purp	Trip Purp	Mode	Mode	Period, occ, truck	Short Dist, Long, Freight, Mode, Internal Purposes
Level of validation											
%RMSE	26%	35%	22.90%	31%	26.50%	34.90%	27.10%	31.30%	31.20%	36.00%	model 54.04%; pivot 39.79%
R-Square	0.94	NA	0.97	0.91	NA	0.90	NA	0.94	0.92	0.89	NA
Volume/Count	0.99	-3.4% dif	1% dif	SL 14.4% err	NA	0.1% dif	0.7% dif	-1.14% dif	-2% VMT by FC	-1%	0.1% diff

- Is a feedback loop used – An indication of whether feedback is used to ensure that consistent travel times are used throughout the model?
- Number of TAZs – This is an indication of the model detail and size.
- Model segmentation – An indication of the detail that is carried through the model to the network loading steps.
- %RMSE – A measure of average error between model flows and traffic counts.
- R-Square – Measure of the degree to which the model replicates traffic counts.
- Volume/Count – A measure of whether the model is replicating the overall amount of traffic on all links in the network.

4.1 Assessment and Commentary

Despite the absence of TDOT travel demand modeling standards, there is high consistency among most Tennessee models, and with the general practice of MPO models throughout the US. Some general comments follow.

Tennessee is well positioned to implement a standard modeling practice. One of the reasons for this is the use of a single software platform, TransCAD. This means that only one software package must be addressed in training activities.

A consistent data source has been used for highway network geography, attributes, and speeds: the Tennessee Roadway Information Management System (TRIMS), the Highway Performance Management System (HPMS), and NPMRDS (FHWA's national data set of average travel times on the National Highway System for use in performance measures and management activities). HERE geography and data, and legacy sources, are used by a few MPOs. All Tennessee models have been updated recently and use relatively recent data. With the recent 2020 Census, and the pandemic, it is yet to be seen how new Census household data and employment data sources can be properly used to update models so that forecasts are reliable. This is because of temporary changes in travel patterns during the reporting period, and changes in personal travel patterns, which might be long-lasting or even permanent. Notable among these effects are dips in traffic volumes and vehicle miles of travel (VMT) and the prevalence of "work-from-home" in place of daily commutes to work.

All models except the statewide model use four time periods. This is an unusually high level of sophistication when compared with other states, where many models estimate only daily travel. All models are able to estimate truck flows, although the types of trucks are not consistent.

The small MPOs do not have transit networks. The three large MPOs (Nashville, Knoxville, and Memphis) and Chattanooga have transit networks, and model transit and non-motorized travel. The mode choice models are logit models, either standalone or part of an ABM, which allocate trips to transit, non-motorized modes, and levels of auto occupancy. The remaining models convert person trips to auto trips using auto occupancy rates. The models with transit networks use destination choice to distribute trips, while the other models use gravity models.

It is also interesting that most models use a travel time feedback loop to ensure travel time consistency throughout the model. This is not the usual case for MPO models throughout the US. Only Clarksville, Cleveland, and Jackson are without a travel time feedback loop.

The level of validation of Tennessee models appears to be in the usual range throughout the state with percent root-mean-square errors ranging from about 23% to 36%. In most of the areas the volume overcount ratios or percent differences from counts appears to be in an acceptable range.

The statewide model, TSM V4.0, is a very complete statewide model which uses many advanced features. It is an advanced trip-based model, which considers short trips, long distance trips, and freight trips for three time periods. The overall daily percent root-mean-square error of 54% is similar to other statewide models. This model adds a "pivot" methodology, which attempts to correct future model estimates by removing the base year error. In short, an ODME-estimated base year trip table is factored by the ratio of the future year model trips divided by the base year model trips. Other modelers have found this to be an effective way to improve forecast accuracy. The "pivot" overall daily percent root-mean-square error is approximately 40%, which is better than most statewide models.

The assessment provided above is based on an examination of model documentation and scripts. The real key to the assessment of the model is whether the model provides useful and reliable travel forecasts and can be used to characterize system wide traffic and travel movements for transportation studies in other planning activities. It will be important to ensure that model outputs are developed in easy-to-understand ways, and provide maps, tables, and other graphics that are useful in the transportation planning process. Results of nearly every model must be adjusted when they are being used to create project-level traffic forecasts.

Chapter 5 Travel Model Improvement Program (TMIP) Outreach

The consultant posted a request on the Travel Model Improvement Program (TMIP) list server, seeking any recent and additional information on modeling standards. The request, posted February 14, 2022, was as follows:

> *We are conducting a study for the **Tennessee DOT** on establishing standards for MPO models. TDOT will develop the standards and eventually provide model structures, scripts, data, and methods for use by the MPOs. We are in the literature review phase of the study. If your state has established such a program, we'd like to know what you have done. We have assembled reports several states, including Florida and Texas, but there is more out there. If you have such materials, please let us know. You can send me reports by email, or links to the reports that we can download. For more information, and **to send reports and links**, please contact Ken Kaltenbach at kkaltenbach@corradino.com. You can also contact Mohammad.Molla@tn.gov at TDOT for more information. Your help would be appreciated.*

The request prompted replies from a number of agencies and modelers. The documents obtained from this outreach are discussed in the literature review. Replies were received from:

- Daniel Beagan, dbeagan@camsys.com – Dan sent information relating to revised volume-delay-functions (VDFs).
- Bettinardi Alexander O * Alex, Alexander.O.BETTINARDI@odot.oregon.gov – A link to Oregon's travel demand model guidelines, which were downloaded and included in the literature review.
- Greg.Giaimo@dot.ohio.gov – A link to ODOT's modeling page. Downloaded the report for the literature review.
- Ronald Milam, R.Milam@fehrandpeers.com – A link to the Caltrans regional transportation plan guidance. Downloaded the report for the literature review.
- Sabina - CDOT, Erik, Erik.Sabina@state.co.us – Made comments but no documents.
- Ramming - CDOT, Scott, scott.ramming@state.co.us – Made comments but no documents.
- Rob Schiffer, rob.schiffer@futureplan.us – Rob sent Florida and Iowa standards. These reports are included in the literature review.
- Sudheer Dhulipala, SDhulipala@wsbeng.com – Sent Twin Cities forecasting guidelines. This report is included in the literature review.

Chapter 6 Other Contacts and Discussions

In addition to the internet search and MPO survey, the consultant contacted officials from three states: Florida, Georgia, and Texas. The contacts were primarily by email, but telephone discussions also were held with Texas A&M staff.

- **Florida Department of Transportation** – The consultant project manager has a long history of working with FDOT, is the author of several FDOT Florida Standard Urban Transportation Modeling Structure (FSUTMS) reports, an active participant in the Model Task Force (MTF) and several committees, developed an early version of the statewide model and freight model, and as the SE Florida MUG representative to the MTF, is a voting member. Although all Florida models and reports are public domain, this involvement has enabled the consultant to know where to look, and provides easy access to data, reports, and models. Thomas Hill, State Modeling Manager at FOT (Thomas.Hill@dot.state.fl.us), and Terrence Corkery (terrence.corkery@dot.state.fl.us) are good contacts at FDOT for FSURMS activities. While there are many Florida reports available, the three most relevant reports, included in the literature review, are:
    - *FSUTMS New Standards and Enhancements* (2006) – This is an overview of the Florida standards for the Cube/Voyager platform. Note the detailed descriptions of model components are found in other reports (https://www.fsutmsonline.net/images/uploads/mtf-files/whitepaper.pdf). All FSUTMS guidance can be found at https://www.fsutmsonline.net.
    - *FSUTMS Model Validation Guidelines* (2022) – Florida's latest validation guidelines. Note that this paper addresses activity-based model results as well as trip-based models (report emailed to TDOT, not yet posted at FSUTMSONLINE).
    - *FSUTMS NextGen White Paper* (2022) – This paper recounts the history of FSUTMS, and outlines some new directions for data, methods, training, and standards, particularly relating to Florida's changes in software platform moving away from Cube/Voyager towards VISUM and TransCAD (https://www.fsutmsonline.net/images/uploads/mtf-files/FSUTMS_Next_Gen_White_Paper.pdf).
- **Georgia Department of Transportation (GDOT)** – Corradino staff contacted Mr. Habte Kassa, Assistant State Transportation Planning Administrator, to request information on GDOT modeling standards. Mr. Kassa sent a useful 2018 report on the integration of Regional MPO Models into the Georgia Statewide Travel Demand Model. The consultant has searched for other Georgia references and found:
    - *The Integration of The Regional MPO Models into the Georgia Statewide Travel Demand Model – Phase 1* (2018) – This report, prepared at Georgia Tech, tells how to link the inputs for the 16 MPO models to the GSTDM zonal system, socioeconomic inputs, and transportation network.
    - *GDOT Statewide Travel Model Peer Review Report* (2012) – This report provided a good description of the Georgia Statewide Travel Demand Model.

  - *Georgia MPO Travel Demand Models Socio-Economic Data Development Guides* (2018) – This report details the steps to be followed to develop socioeconomic data (household and employment) for the regional models.

- **TxDOT and TAMU** – Corradino staff talked to and corresponded with Mr. Kevin Hall, Travel Forecasting Program Manager, and the Texas A& M Transportation Institute (TTI). Mr. Hall sent reports relating to TexPACK, TxTOWN, and the TxDOT online references (http://onlinemanuals.txdot.gov/txdotmanuals/tpp/tdm.htm#i1000467). Many reports from TxDOT and TTI are available at this site. The consultant downloaded several reports for the literature review:
  - *Traffic Data and Analysis Manual* (2001) – TxDOT guidelines for traffic forecasting, including urban models. These procedures have been superseded by newer reports.
  - *TexPACK Model Documentation, The Integrated Texas Package System Version 2.6* (2020) – Model documentation for the TxDOT, TransCAD-based, system of models, includingTxTown.
  - *TEXPACK Integrated Travel Demand Modeling Application* (2016) – A PowerPoint presentation summarizing the Texas travel demand modeling system (TexPACK).

Chapter 7 Literature Review

This study was undertaken by the consultant to establish procedures leading to a standardized travel demand modeling process that would be used by most Tennessee MPOs. The standardized process would benefit TDOT because it would promote good practice throughout the state, resulting in more consistent and reliable travel forecasts. It would benefit the MPOs through a ready, TDOT-approved modeling process, supported by TDOT, along with training, technical assistance, and a modeling community with a common understanding of and interest in the models. Ultimately, it would allow TDOT and the MPOs to acquire consistent data to support the standardized travel demand modeling process.

The objective of this literature review is to assess the approaches that various state agencies have taken at travel demand model standardization, and to support a promising approach that the MPO survey suggests would be supported by model users.

The number of available reports and documentation on travel demand model forecasting is exhaustive. The **List of Reports** (**Appendix E**) shows a list of 44 reports which were downloaded and reviewed. The review focused on the 20 reports listed at the top of the table, in the shaded area, which contained information on statewide systems of models ("X" in the left-most "SW" column). "X" in the right-most TMIP column means that the report was obtained or identified through the TMIP list server outreach. All 44 reports will be made available in the OneDrive folder which will be delivered in conjunction with this report, as they also have some pertinent information on model development and validation.

While most state DOT's have not established a formal set of standard models, much has been published by agencies that have established guidelines or procedures, and reports on best practice and specific models abound. One of the first reports encountered was ***Opportunities for Travel Demand Model, Development and Applications*** (2012), from UT Center for Transportation Research, Knoxville, TN. This report drew heavily from ***TRB Special Report 288, Metropolitan Travel Forecasting Current Practice and Future Direction*** (2007) and adds useful information on the state of travel demand modeling in Tennessee. These reports provide a great starting point for this study, even though they are ten or more years old.

Here are brief descriptions of the modeling activities of the 14 states that have some type of statewide travel demand programs. Most information here was extracted from the agency websites. The listing is alphabetical.

- **California** – State law requires MPOs to use travel demand models in the development of regional transportation plans. One of the reasons for this is the need to model Greenhouse Gas (GHG) emissions. The California Transportation Commission (CTC) is required to provide model guidelines. The models developed and used by the MPOs come under the purview of CALTRANS and have specific requirements. Caltrans specifies validation thresholds and expectations, but does not provide standardized model scripts and setups, nor does it require the use of specific software platforms. MPOs develop and apply their own models and CALTRANS provides technical support (https://dot.ca.gov/-/media/dot-media/programs/transportation-planning/documents/f0009312-2017rtpguidelinesformpos-a11y.pdf, based on email from Ronal Milam of Fehr and Peers).

- **Florida –** Florida has a long-established process for developing models (Standards and Documentation (fsutmsonline.net)). The Model Task Force (MTF), which is a joint body of MPO and FDOT participants, establishes the FSUTMS procedures, provides training, conducts research, secures some software licenses and data, provides sample model setups and scripts, and conducts a collegial forum in which transportation planning policies and procedures are discussed. In essence, the planning a modeling community polices itself. That being said, MPOs are not forced to comply with FSUTMS procedures. Almost everybody complies because it is usually the easiest path to FHWA certification, and the technical support is difficult to pass up. The exchange of data and ideas is facilitated by Florida's "Government in the Sunshine" laws that makes everything that public agencies do available to the public. Since Florida has embraced multi-jurisdictional regional models, much of the modeling work is done under agreements between counties, MPOs, and FDOT. It is also important to note the that the courts have recognized FSUTMS procedures in matters of planning, environmental and roadway disputes. This information is based on Corradino's firsthand experience working with FDOT (see FDOT contacts in **Chapter 6**).
- **Georgia –** Georgia has a statewide model but does not have a GDOT sponsored system for MPO models. However, GDOT has developed a system that allows MPO models and the statewide model to share networks, TAZs, and data. This system encourages some degree of consistency among the MPO models (http://www.dot.ga.gov/InvestSmart/TravelDemandModels/SE_Development_Guildelines.pdf).
- **Illinois –** A 2011 report developed by the Illinois Center for Transportation established a framework for the development, maintenance, and application of models for small- and medium-sized MPOs (https://ccrpc.org/wp-content/uploads/2012/11/FHWA-ICT-11-091.pdf). It also established a statewide model users' group and made recommendations for a statewide model. The report has a disclaimer that says, "This report does not constitute a standard, specification, or regulation." Although many Illinois areas maintain travel demand models, there does not appear to be an IDOT-sponsored standard program besides the recently developed statewide model.
- **Iowa –** The Iowa Department of Transportation (Iowa DOT) has a program for travel demand modeling called the Iowa Standardized Model Structure (ISMS). A 2019 report, *General Travel Demand Modeling/Forecasting Protocols and Procedures,* details the Iowa DOT standards (https://mtmug.iowadot.gov/isms_files/2020_ISMS_v1.1_20201028.pdf). Iowa surveyed nine large MPOs, 6 small/medium MPOs and 6 states in their investigation. Iowa also conducted a survey of model users in 2015 at the MTMUG (Midwest Travel Model User Group – South Dakota, Nebraska, Minnesota, Iowa, Missouri, Wisconsin, Illinois) Meeting in 2015. The report provides detailed descriptions of the ISMS procedures, TransCAD implementation, data, and procedures for its use. The report explains that the travel demand models are developed by a partnership of Iowa DOT and the MPOs. While it is not clear the MPOs are required to use ISMS, they are highly encouraged to do so, and most MPOs need the technical expertise offered by Iowa DOT.
- **Kentucky –** The Kentucky Transportation Cabinet (KYTC, the DOT in Kentucky) has not published modeling standards. However, the consultant is familiar with their procedures. The large MPOs develop and run their models independently from KYTC. These areas

include northern Kentucky/Cincinnati and Louisville Metro. KYTC develops models and provides support for Lexington and smaller MPOs using in-house staff and consultants. KYTC also maintains a Statewide Model. KYTC's models are generally aimed at highway planning and are daily models. Most use a standard TransCAD interface. This information is based on the consultant's firsthand work with KYTC (Scott.Thomson@ky.gov).

- **Maryland** – Maryland has seven MPO models. MDOT maintains multi-resolution statewide models (MSTM, trip-based, and ABM), which draw from these models and other data. Data is shared between the MSTM and the MPO models (MSTM). While data sharing requires consistency in data files, there is no MDOT-sponsored model standardization program.
- **Michigan** – MDOT provides a wealth of support to the small MPOs, who develop and run their own TransCAD-based models. The support is review, technical assistance, and travel characteristics data from a periodic statewide travel survey (most recently, 2016). MDOT's modeling guidance is extensive and complete (https://www.michigan.gov/documents/mdot/UMD_TechReport_669137_7.pdf). The MPOs are free to innovate and depart from the MDOT guidance if they can justify it. The large MPO, Detroit, conducts their own planning process, with some assistance from MDOT.
- **North Carolina** – NCDOT provides detailed guidance to the MPOs on the development of travel demand models (https://connect.ncdot.gov/projects/planning/TransPlanManuals/2012%20Master%20Guidelines%20Chap1-13.pdf). These procedures, while detailed and complete, are not considered policies, and MPOs are not bound by them.
- **Ohio** – ODOT provides guidance, strong technical support, modeling reports, training, and some model components ("calculators") to the MPOs (https://transportation.ohio.gov/static/Programs/StatewidePlanning/Modeling-Forecasting/Vol-3-TravelDemandModeling.pdf). ODOT also provides centralized employment data acquisition/processing and some count coordination. ODOT does not require the MPOs to follow their procedures but attempts to provide such strong support that the MPOs will choose to use the ODOT standards.
- **Oregon** – Oregon is developing a statewide ActivitySim (ABM) application and provides guidance for MPO travel demand models, which is widely followed. That being said, Oregon DOT was not able to provide documentation for their procedures (https://www.oregon.gov/odot/Planning/Documents/APMv2.pdf).
- **Texas** – TxDOT in conjunction with the Texas A&M Transportation Institute (TTI) has developed a TransCAD add-in called TexPACK, which is the Texas standard model. It is a complete highway model and offers a host of standard outputs and visualization. Even though it is a complete package, modelers still must calibrate and validate the model. Texas MPOs are not required to use TexPACK, but use it. The modeling system's extensive visualization methods are available only through TexPACK, which is highly structured. MPOs must adhere to all TexPACK formats and standards to use its components. TexPACK is a three-step highway modeling system, omitting transit networks and mode choice. It can be implemented as a time-of-day or daily model. TexPACK is generally available only to Texas MPOs (http://onlinemanuals.txdot.gov/txdotmanuals/tpp/tdm.htm).

- **Virginia** – VDOT's standard modeling process is implemented through a set of policies published in the *VDOT Travel Demand Modeling Policies and Procedures* manual (VTM) (https://virginiadot.org/projects/resources/vtm/VTM_Policy_Manual.pdf). The manual defines modeling practices as "acceptable practice" or "recommended practice." Acceptable practice represents the minimum standard for modeling in Virginia and applies to all existing models; acceptable practice can be used in future models if resources do not permit meeting recommended practice guidelines. Recommended practice is the preferred standard of practice and should apply to all future model updates if resources permit. The VTM provides detailed guidance on how models should be developed and calibrated but stops short of providing scripts and macros. It does not specify a software platform, and various models use TransCAD or Cube.
- **Wisconsin** – WisDOT is responsible for developing forecasts for the state roadway system (https://wisconsindot.gov/Documents/projects/data-plan/plan-res/tpm/9.pdf). There are 13 models throughout the state. WisDOT's Traffic Forecasting Section (TFS) develops and controls all models and forecasts except for the southeast (Milwaukee), Duluth, and Dubuque regions. WisDOT holds tight control over their models and has a set of procedures and standards. WisDOT's statewide model is used in areas without local models. WisDOT's current software platform is Cube/Voyager.

Chapter 8 Preliminary Recommendations

Following is a set of preliminary recommendations for Tennessee's standard model after the survey of the MPOs, review of current Tennessee modeling practices, review of the literature, and discussions with TDOT and MPO staffs. Following are recommendations for the Tennessee model. **Table 8-1** displays a summary of the recommendations.

TABLE 8-1: SUMMARY OF PRELIMINARY KEY RECOMMENDATIONS

Model Feature	Highway Only	Multi-Modal	Advanced Practice
- Caliper Graphical User Interface	X	X	
- TRIMS-based highway network: master network system	X	X	X
- Transit networks from GTFS, with routes and headways for all periods	X	X	X
- Data file and attribute naming guidelines	X	X	
- TAZ system based on Census geography, nested with statewide model	X	X	X
- Eventual development and use of a statewide land use model	X	X	X
- Household model to produce joint distributions	X	X	
- Trip Generation			
- Cross-class productions	X	X	
- Rates for attractions	X	X	
- Purposes; HBW, HBU, HBSC, HBSP, HBSR, HBPD, HBO	X	X	
- NHB split into NHBW & NHBNW linked to home based attractions	X	X	
- EE, EI, Truck (SU, CU)	X	X	
- Nested logit Mode Choice: Transit modes, DA, SR2, SR3+, non-motorized modes		X	
- Distribution by Destination choice	X	X	
- Post distribtion TOD Model (4 periods)	X	X	
- Highway assignment by TOD and Vehicle Type	X	X	
- Strict capacity restraint convergence (0.001)	X	X	
- BPR vdf by functional class	X	X	
- N-conjugate BFW	X	X	
- Selectd link/zone optional	X	X	
- MSA travel time feedback for all time periods	X	X	X
- Transit Assignment after feedback convergence		X	
- Detailed reporting & visualization automatically created after convergence	X	X	X

8.1 General Conditions

After reviewing practices in other states, it is clear that no DOTs force local MPOs to conform to their set of standards. On the contrary, most seek conformity to statewide standards by providing data, research, methods, and technical support attractive to the agencies. Perhaps Virginia comes the closest to enforcing their standards by defining some methods as "recommended" and other as "acceptable", implying that other procedures are unacceptable. Even so, it is likely that other methods would be found to be acceptable if it can be shown that they produce reliable results. Other states, notably Texas, require MPOs to accept their standard model in order to use the extensive benefits that accompany the standards. This may be desirable or even necessary so that the TxDOT can control the model code, develop it only once, maintain its integrity, and make sure that input data are appropriate for the model.

There are several advantages of a statewide system. Among them are:

- Consistency of forecasting methods among the MPOs
- Ease of training
- Leverage in obtaining and processing data
- Sharing of data and results among the MPOs and statewide model
- Savings of time and resources when developing and using procedures and computer scripts
- A common understanding of transportation forecasting procedures and meanings

There are a few challenges and disadvantages, which are far outweighed by the advantages:

- Some MPOs will have to change their procedures and help develop different data.
- There are cases where one size does not fit all, and standardization could be thought to stymie innovation. Guidelines instead of rigid standards would solve this.
- Some adjustments to the statewide procedures may be required to accommodate schedules and deadlines beyond the control of the MPOs.
- Some agencies may resent top-down state guidelines.

The survey of Tennessee MPOs suggested that most MPO respondents would prefer guidelines over standards. To that end, we recommend that the top-level approaches developed in this study be called the modeling “framework”, methods be called “guidelines”, and calibration/validation values be called “targets.” Furthermore, it is recommended to offer the “framework” as a benefit that is hard to turn down, not as a requirement (i.e., a carrot and not a stick). To this end, modeling procedures and scripts should be transparent and available to the MPOs upon request, or perhaps even published on the TDOT website. While we would prefer a set of TDOT standard file and variable names, when possible, equivalency tables should be part of the software to all local names to be used when necessary. We believe that this softer approach is more likely to get local adoption than a more rigid approach.

Finally, we believe that the Tennessee system should be given a name. An appropriate name of the model would seem to be obvious, but TDOT might want to hold a naming contest (the consultant has found this to be an effective approach for software developed in our firm). Based on this, during the Tennessee Model User Group (TNMUG) on May 19, 2022, ideas were sought from the users for a suitable name of the standard package. Dr. Mohammad Molla from TDOT proposed “TnTown” name and it appears TNMUG participants liked and appreciate the name. Finally, the name “TnTOWN” was confirmed by TDOT management.

TnTown should consist of the following elements:

- Model framework, guidelines, and visualization
- Modeling data and data organization
- Model training and similar resources
- The TNMUG users’ group to seek input, disseminate information, initiate research and

eventually adopt changes and new procedures. While this structure is certainly at the purview of TDOT, a similar structure has worked in Florida for a long time.

8.2 Model Framework, Guidelines, and Visualization

8.2.1 Models by Classification

This section describes how models in Tennessee will vary. Initially, the consultant classified Tennessee's urban models by size: large, medium, and small. As we progressed through the analysis, it appeared that the classification taxonomy should be revised to be:

- MPOs without a transit system (highway models) – This is the largest group. Some MPOs may want to join other groups if they anticipate implementation of a transit system, would like access to additional features, or move to an advanced practice model. The highway models have differences, but many features are the same. We believe they could all use the same model structure. It is significant to note that although the models for six MPOs do not have transit networks, all but one (Cleveland has one deviated route) have fixed bus route service and should join the multi-modal class.
- MPOs with a transit system (multi-modal models) – Currently, this group contains only Memphis, but at least five other MPOs should be added to this group because they have fixed route bus service.
- MPOs with advanced practice models (advanced practice models) – These models, the Chattanooga ABM, the Nashville ABM, and the Knoxville hybrid model, are too different to fit into a single, standard structure. But it should be possible to standardize some input data, perhaps some names and terminology, and to use some standard reporting and visualization, after developing some data interchange scripts. It also should be possible to build some integration of input and output files with the statewide model.

Thus, it is recommended that separate but related procedures be developed for highway models, multimodal models, and advanced practice models.

8.2.2 Graphical User Interface (GUI)

The feature that ties all the modeling procedures together is the GUI. The GUI would provide a standard user interface for all models, making it easier for TDOT and MPO staff to move between models. It would provide a similar and familiar environment for all Tennessee models. While the details of the GUI will be finalized in subsequent phases, the consultant recommends the use of the Caliper interface used in several states including Kentucky, Texas, and some Michigan models. This interface provides access to all procedures and data files, is an effective scenario manager, and can be customized. The basic interface was developed by Caliper. The consultant believes this interface to be more effective and easier to navigate than other TransCAD interfaces. The interface used in the Kentucky Statewide Model is shown in **Figure 8-1**. Note that this interface has sub-dialogs that allow access to all data files and parameters. Also, the TREDIS button is specific to KYTC, and would not be used in TDOT models.

The GUI probably would not apply to the advanced practice models.

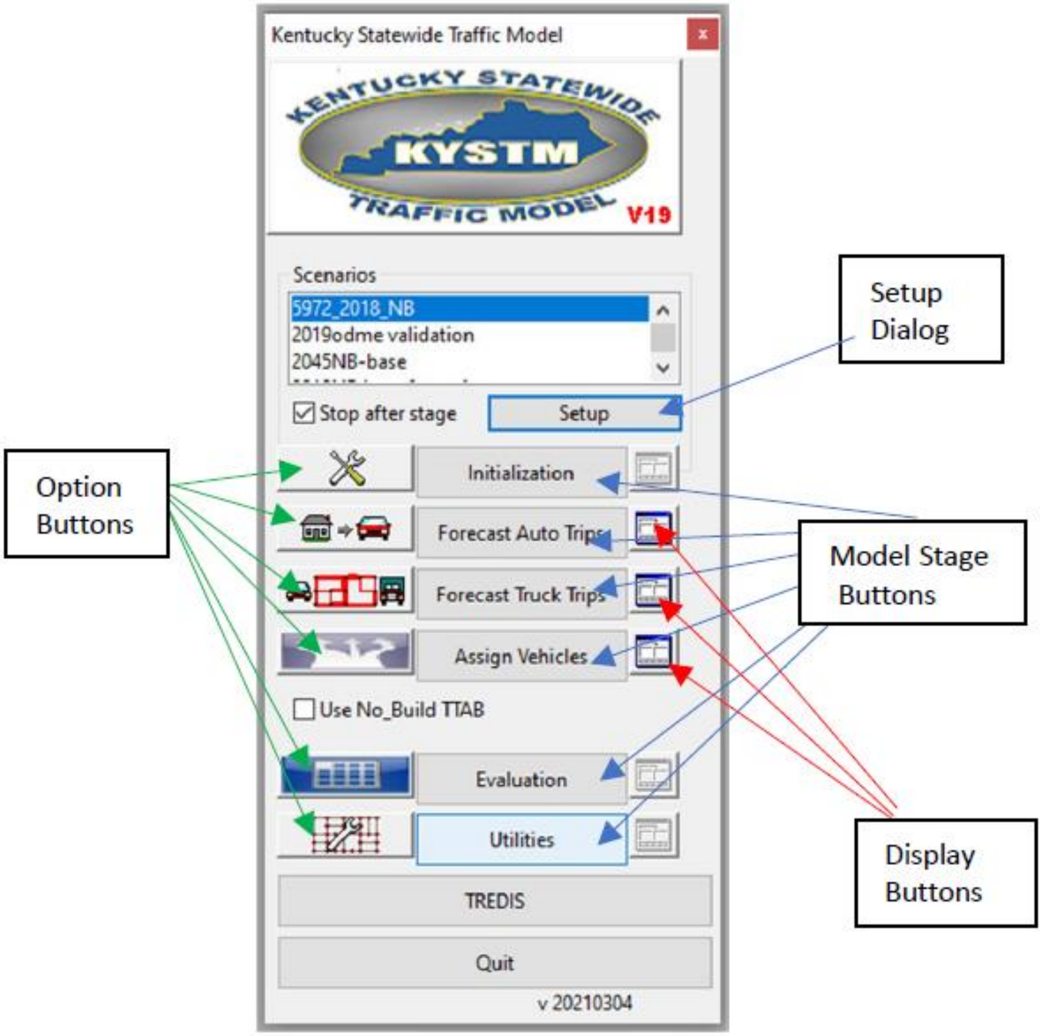


FIGURE 8-1: GRAPHICAL USER INTERFACE

8.2.3 Data File and Attribute Naming

Tennessee models should use a standardized system of folder, data file, and attribute names. There are many possible ways of implementing such a system. Note that we are not specifying specific names here—that is best left to the time when the prototype model script is written, and a data dictionary must be created at that time. Here is a system that we know works well with a system of models and with the TransCAD GUI.

The model "base" folder should be given a name. Let's say for this illustration, it would be called "TnTown" (it actually would be the MPO name).

Under TnTown there would be several folders. A good structure would be:

- GISDK – To hold the code for the model resource (*.rsc) file. Other files stored here would be the compiled script (seven files), and the ".def" file.
- Common – This folder would contain files that are common to all scenarios. Examples would be speed and capacity tables, trip rates, mode choice constants, and other files

that do not change.

- Master – This is the folder that contains the master **network** and **TAZ** geographic files and data. Eventually, this might be the Tennessee Statewide Model, which would hold all network and TAZ modeling data for Tennessee. Other files might reside here, like the base year external-external trip table.
- Alternative folders – A folder should be created for each alternative. The name should be short but should designate the identifier ("A", "B", "Base", "EC", etc.) and the four-digit year. There should be three subfolders under each alternative.
    - *Input* – This folder would hold all input data and geographic files.
    - *Output* – This folder would hold all output data files. The model should be scripted to create this folder if it does not exist, and to create all files written to this folder. Thus, the folder should be able to be deleted by the user and recreated by the model.
    - *Temp* – This folder would hold temporary, intermediate files that may be created and used by the model but not needed otherwise. It could be deleted after the model run has been completed.
    - *Reports* – This folder would hold all reports and visualization files, and the logs created by the TransCAD application.
- Documentation – This folder would hold the model reports and data dictionary.

8.2.4 Model Features

This section provides a brief description of model components for the highway and multi-modal models. The main difference between the two classes of models is the presence of a transit model: transit network, transit path building and skimming, and transit assignment. Both classes would have mode choice components. All model components are discussed, and the differences between the classes are noted.

8.2.4.1 Highway and Transit Networks

The TransCAD **highway network** is built from selected records in a TransCAD line layer. Some Tennessee models use a master network structure, as described later, and ultimately the source of the MPO network should be the statewide model master line layer file. In the interim, an MPO-specific local line layer file would be used.

Details on the list and naming of specific highway network attributes should be specified later in Phase 2 of this project. At that point, a list of recommended network attribute names should be established. However, the consultant believes that an overall specification of the network is in order. The highway network line layer should be built on a geographically accurate data source that is continuously dated and maintained. TDOT's TRIMS database would be appropriate. If the model covers parts of other states, the highway networks from those states should also be used. Common practice is to create a line layer attribute, say "In_Network", to denote the links that are extracted from the line layer and included in the model network. Usual practice is to include all interstates, other freeways, arterials, and collector streets in the network, with other local streets needed for connectivity and transit routes. Although not a comprehensive list, links should have attributes for speed limit, travel time, observed speed and time, area type, functional class, number of lanes, capacity, traffic counts by time period or count station number, political jurisdiction, restrictions on vehicle occupancy or type (trucks), alternative designation, and other geometrics needed for the speed and capacity calculators.

Turn prohibitors must be coded to inform the model of turn restrictions. They are particularly important at freeway interchanges where certain movements cannot be made.

Speeds and capacities must be added to the network database. A good source of existing speed data is the Here Technologies' database. Capacity calculations should follow the Highway Capacity Manual (HCM) methodology. The decision to be made in capacity calculators is whether to use capacities that depend only on link characteristics, or whether to include intersection attributes as well. Most models do not include intersection attributes, but some consideration should be given to procedures which allocate the green time to roads with a higher functional classification at signalized intersections. Use of this type of capacity calculator requires the identification of traffic control devices at intersections, and the scripts are more complex because the procedure must consider node data as well as link data. Note that this type of calculation is not volume-dependent, since capacities are calculated before the assignment is performed. Nevertheless, the consultant believes that the consideration of traffic control devices would improve the highway assignment process and should be considered. HCM-based calculators are available in some Tennessee models, and calculators that consider traffic control devices can be gotten from models in other states.

The line database must also contain centroid connectors to connect the highway network to TAZs. The network guides noted below have guidelines for creating centroid connectors. Issues that are particularly important include:

- Coding speeds and travel times that reasonably represent actual travel conditions.
- Providing connections only where access is possible but allowing access at multiple locations where access is available.
- Making sure that centroid connector capacities are very high so that access is not artificially restricted.
- Prohibiting connections to access controlled roads (like freeways).
- Avoiding connection to the network at actual intersections, so that the model is able to estimate turning movements.

There are many reports online that address model highway network development. Among them are Urban Model Development Technical Report (michigan.gov), and 2020_ISMS_v1.1_20201028.pdf (iowadot.gov). TDOT may want to develop its own guidelines during Phase 2.

The **transit network** in TransCAD is a geographic route system, built on the line layer. If a General Transit Feed Specification (GTFS) file is available, it should be the source of the transit network. GTFS, developed as part of Google Transit, is a text-based specification for a transit system. Many transit agencies now produce GTFS data for their transit systems. TransCAD can import GTFS feeds and convert them to a TransCAD route system which can be used to create a transit network. The highway line layer used for the highway network should be used as the underlying line layer for GTFS import. It is important to update the highway line layer to include all of the streets and segments used in the GTFS feed. The transit route system created from a GTFS feed is the best and most accurate way of creating a transit network. Transit service should be coded for all four time periods, including headways and route configurations. Transit travel times should begin with congested times from the highway network on which the transit lines were built, modified to reflect running time on the base year transit lines. Area type, facility type, and number of stops on the line should be used to estimate the running times in the GTFS schedule. Fixed guideway service running times should be based on timetables.

8.2.4.2 Master Networks

Currently, each model has a unique network geographic file for each alternative. For the short term, this practice can be continued. Eventually, the regional networks should be gotten from the statewide model network database. In this case, the statewide model network database should be expanded to contain all streets and roads. While every link will not be included in the model, every existing street and roadway should be included in the "all-streets" map. TRIMS, HERE, and INRIX are examples of sources that could provide these data. It is also an option to set up all-streets master networks for each regional model. Currently, TDOT has access to Live INRIX Probe Data and the RITIS Probe Data Analytics Suite that includes historical data back to May 2017. INRIX and RITIS provide a rich source of network data.

While it is a little more complicated, transit routes also could be maintained in a master file. TSM_V4 does not include a transit network, so a statewide transit network would not be available until such a network is developed.

The ultimate goal here would be to share the data, with data flowing both ways, allowing statewide network data to be access from the local models, and allowing the local models to update the statewide network. A system of version control would need to be implemented to manage such a system.

8.2.4.3 Traffic Analysis Zones (TAZs)

As noted in the next section, the **TAZ system** eventually should be a subset of the TSM_V4. Until the MPO models can be linked to the statewide models, they are likely to use a local TransCAD area geographic database. In general, the database should contain all TAZ variables used in the model—there should not be other TAZ data kept in other files. Until a statewide system can be developed, a unique file will be developed and maintained for every year and every alternative. Attributes should include all data needed for the trip generation, destination choice, and mode choice models. Attributes also should include Census and political jurisdiction codes, area types, and metrics used in land use models. It is also useful to create "dummy" polygons to hold data associated with external stations.

The references listed earlier from Michigan and Iowa are good guidelines for the formation of TAZs, as well as A Recommended Approach to Delineating Traffic Analysis Zones in Florida (fsutmsonline.net). In Phase 2 of this project, a comprehensive list of recommended attributes and names will be developed. The Florida report presents the following issues that must be considered when defining TAZ, and also lists some specific recommended guidelines:

- Highway network compatibility:
  - Existing and planned transportation facilities
  - Centroid connector loadings
- Boundary compatibility:
  - Physical geography
  - Census geography
  - Political geography
  - Planning District/Sector boundaries
  - Irregular zone geography
- Socioeconomic data (existing and future):
  - Homogeneous land uses, where feasible
  - Special generators
  - Trips per zone
  - Large, planned developments
- Access:
  - Transit access
  - Freight/intermodal facilities
- Other considerations:
  - Zone size and intrazonal trips
  - Internal versus external zones

Where possible, TAZ boundaries should next with Census boundaries. This might not be possible, and compromises might be required when Census boundaries conflict with physical and political boundaries, or when major roadways transect TAZs. It is important to allow roadways to form TAZ boundaries wherever possible. It is poor practice to allow a major highway to transect a TAZ.

8.2.4.4 Land Use Models

One of the primary functions of a travel demand model is to create forecasts of future travel. These forecasts are based on future year TAZ socioeconomic data of household and employment data. While traffic forecasts are directly related to the socioeconomic data forecasts, most MPOs do not have a well-developed program of land use data forecasting. Some larger MPOs—like Greater Nashville, Memphis, and Chattanooga—have formal land use forecasting programs, and these models are highly customized to fit the one urbanized area. The University of Memphis has developed a land use model that might be appropriate for the TDOT modeling process, the Large-Scale 20 Land Use Model (LS-LUM). The model was developed by Ali Riahi Samani, Sabyachee Mishra, and Mihalis M. Golias at the University of Memphis, David Lee at TDOT, and Jerry Everett at the Center for Transportation Research at the University of Tennessee.

LS-LUM is a promising tool for forecasting land use and producing the required model socioeconomic data. A project would have to be initiated to make it an operational component of the TnTown system. An attractive and promising system would be to structure LS-LUM to produce data for Tennessee on a statewide basis, for all model TAZs combined into a statewide file. This comprehensive data file, estimated for a range of forecast years, would be maintained by TDOT.

Land use data for the TSM_V4 could be extracted from this database, as could TAZ data for all MPO models. Another component of the system would be for the MPOs to examine and edit the TAZ data and upload it to the TDOT central database for use in the statewide model and for other uses. Just as for the highway network system, a version control system would need to be implemented to manage the statewide TAZ data and land use model.

8.2.4.5 Model Structure and Steps

8.2.4.5.1 Household Model

The trip production model described in the subsequent section requires the joint distribution of households by the trip production variables. The recommended model should consider using the following household characteristics:

- Household Size (Persons: 1, 2, 3, 4+)
- Income (4 or more classes)
- Children (0, 1, 2+)
- Workers (0, 1, 2, 3+)

The model will require not only the distribution of each of the variables in each TAZ, but also the joint distribution of:

- Workers and Income class
- Household Size and Workers
- Household Size and Children
- Household Size and Income class

A good way of the joint distribution is to develop a household model from CTPP and ACS data. A similar method was used in the Memphis MPO model. Using the distribution of data in the base year, a system of logit equations can be developed to estimate the individual distribution of the variables for each TAZ based on zonal averages. These estimates become the marginal values of the joint distributions for each TAZ. Then an iterative proportional fitting model can be used to estimate the joint distributions. Such a system will allow the distributions to be estimated for future year alternatives, when data for the marginal values grow at different rates (for example, if average household occupancy declines, the number of households would increase faster than the population).

Additionally, multi-modal models might need households to be classified by auto ownership, so it might be important to add this dimension to the household model. Most transit mode choice models require auto ownership or auto availability.

8.2.4.5.2 Trip Generation Models

In a trip-based model, the trip generation step estimates the number of trip ends at each TAZ. At the trip generation stage, nothing is decided about the mode of travel or the linkage between the beginning or ending locations of a trip. The specification of a trip generation model would include a list of the independent variables, trip purposes, and general structure of the models.

Trip generation models usually estimate trip ends as trip productions and trip attractions. By convention, for home-based trip purposes, where one end must be the home location, productions always are located at the home end of the trip, and attractions occur at the non-home end. Productions occur at the home end, regardless of whether the direction of the trip is from the home or to the home. This leads to the modeling terminology of P-A trips, and O-D trips. P-A trips identify the home and non-home ends without regard to trip direction (for a round trip to work there are two productions at home and two attractions at the non-home end). O-D trips identify the travel direction but loose the information of the home end. A P-A trip table can be converted to an O-D trip table, but the process cannot be reversed without adding information.

8.2.4.5.2.1 Trip Productions

Since trip productions are generated at the home location, they usually depend on household data, generally from the Census in the base year, and forecast into the future by a land use model or other procedure. The recommended and commonly used type of trip production model is a cross-classification model. In this type of model, all households in a TAZ are classified into cells or categories, and the number of trip productions generated by the TAZ for a given trip purpose is the sum over all cells of the number of households X trip rate for the cell category for the cell.

$$Prod_{ip} = \sum_c (HH_{ic} * rate_{cp})$$

where,

- $Prod_{ip}$ = productions at zone i for purpose p
- c = classification cell
- p = trip purpose
- $rate_{cp}$ = trip rate for cell c and purpose p
- HH_{ic} = number of households in TAZ i and cell c
- i = TAZ number
- $\sum_c$ = sum of values of the expression where c=1 to the number of cells

The input data needed for this model are the number of households in each TAZ, and the classification data. In this example, the classification variables are number of persons, number of workers, number of children, and income class.

Trip rates are best calculated from the results of a household travel survey. The assumption here is that these rates are stable over time. Adjustment to rates developed from previous surveys might be required post-COVID, which has affected travel behaviors for some purposes in most areas. Similarly, the household classification structure is best determined with the help of a household travel survey, where the structure that is best at estimating the number of trips would be chosen.

In the absence of recent local household survey rates, classifications could be borrowed from an earlier study, from another MPO, or from FHWA/TMIP guidance, or from other standard models. The consultant believes that while it would be possible to use the same general structure for the trip production model, as described here, the rates and household classification structure are likely to vary between MPOs depending on the availability of data, and study needs. The consultant proposes to develop a “default” household classification structure, and production rates, in the implementation phase of this project.

8.2.4.5.2.2 Trip Attractions

Trip attraction models are usually much simpler than production models, but base data are harder to obtain. Trip attraction independent variables are usually number of employees, stratified by North American Industry Classification System (NAICS) code. Possible sources of employment data are discussed later, and include the US Bureau of Labor Statistics, state unemployment insurance records, commercial sources, and Longitudinal Employer-Household Dynamics (LEHD) data. The US Census does not provide employment data at the geographic resolution required for a travel demand model. In the case of special purposes, like university and school, place of school and university enrollment also may enter the equations. For some purposes, like home-based-other and home-based-social-recreational trips, which include visiting other households, the number of households may enter the attraction equation.

Like trip productions, attraction models are best developed from a statistical analysis of a household survey, expanded to represent all households. Usually, attraction models are simple trip rate equations of the form:

$$Attr_{ip} = k_{1p}E_{1i} + k_{2p}E_{2i} + k_{3p}E_{3i} \ldots$$

where,

$Attr_{ip}$	=	attractions at zone i for purpose p
k_{xp}	=	trip rate for employment type x and trip purpose p
E_{xi}	=	number of employees of type x working at TAZ i
P	=	trip purpose
x	=	employment type
i	=	TAZ number

Usually, these equations should not include an additive constant to ensure that no trip attractions are calculated by an empty TAZ.

As noted earlier, employment should be obtained and identified by NAICS coded, and the use of three-digit codes is the usual case. However, more often than not, employment is grouped so that the categories have a logical and intuitive relationship to the trip purpose. When grouping employment, it is important to clearly define the constituent NAICS categories so there is a well-defined way of developing and updating the data. An example employment grouping as used in Memphis is: Retail, Wholesale, Service, Office, Agriculture, Mining, Construction, Manufacturing, and Transportation/Communications/Utilities.

Like trip productions, rates and classifications could be borrowed from an earlier study, from another MPO, or from FHWA/TMIP guidance, or from other standard models, in the absence of a recent local household survey. The consultant believes that while it would be possible to use the same general structure for the trip attraction model, as described here, the rates are likely to vary between MPOs depending on the availability of data, and study needs. The consultant proposes to develop a "default" set of attraction rates, in the implementation phase of this project.

8.2.4.5.2.3 Trip Purposes

Trips are usually stratified by the purpose of the trip. The primary reasons for differentiating trip purposes are because the production and attraction land uses are different (e.g., work productions should not be sent to recreational areas), and the trip lengths are difference (e.g., work trips are typically longer than other internal purposes). The various trip purposes account for these differences. A common trip purpose structure is:

- Internal Home-Based Trips
- Internal Non-Home-Based Trips
- Special generators

- External-External (through) Trips
- External-Internal and Internal-External Trips
- Truck Trips (addressed in another section)

The preceding discussion of productions and attractions pertains to **internal home-based trips**. A common structure for these trips is, for example:

- Home-based work (HBW),
- Home-based university (HBU),
- Home-based school (HBSC),
- Home-based shopping (HBSP),
- Home-based social-recreational (HBSR),
- Home-based pick-up drop-off (HBPD), and
- Home-based other (HBO).

Another class of trip purpose is **non-home-based (NHB)**. These are internal trips that neither begin nor end at the home of the travelers. Current best practice subdivides these trips into non-home-based-non-work, in which neither trip end links to a work trip, and non-home-based-work, in which at least one trip end links to a work trip. NHB trips are problems in most models that use them—NHB trips comprise a large fraction of all trips but are unrelated to the zonal data. Their productions and attractions usually look like home-based (HB) attraction equations, but they may be unrelated to the TAZ where they are generated because the traveler doesn't live there. A recent practice is to create NHB trip ends as a function of HB attractions. Usually, the trip ends are calculated as a fraction of the HB attractions. The deficiency here is that a constant fraction if often incorrect, as the fraction in a rural area probably should not be the same as the fraction in an urban area. Recent research suggests that the fraction also should include an accessibility measure. Using this concept, the NHB trip ends at each TAZ could be modeled as:

$$Y = kA^c \sum_p b_p X_p$$

where,

Y	=	NHB trip ends (productions = attractions)
k, c, b	=	calibration constants
A	=	a measure of accessibility to nearby TAZs
X	=	home-based attractions by purpose
P	=	trip purpose
$\sum_p$	=	sum over all trip purposes

The NHB model could be estimated from a local survey with a sufficient number of NHB trips. Otherwise, it could be borrowed from other areas and adjusted to match local conditions. An appropriate measure of accessibility could be calculated as the denominator of the gravity model, which would sum the nearby attractions divided by a function of the travel time or distance between each NHB zone and the nearby attractions. Some studies suggest that this type of model should be developed and applied by travel mode, and this too should be investigated for use in multi-modal models.

Most modelers avoid using **special generators**. However, there are times where they are needed to represent travel that is not estimated correctly by the TAZ data. Examples might be military bases, parks, and airports. Productions and attractions from special generators, usually based on special traffic counts and studies, should be allocated to the internal trip purposes. Special generators should be used only when an acceptable highway assignment cannot be achieved with the standard trip purposes.

The **external-external (EE)** trip purpose doesn't use a trip generation model in the usual sense, because the number of EE trips is not related to characteristics of internal TAZs. EE trips are usually forecast using external station-specific growth factors related to regional and statewide growth. A good source of EE trip data is the statewide model, which strengthens the argument for relating statewide and MPO networks and TAZ systems.

External-internal (EI) represent trips with one end inside the model area and the other end outside. The usual convention is to treat the external station as the production zone and internal TAZs as the attraction zone. This formulation ensures that the number of EI trips at the external stations are the same as EI productions, and thus match traffic counts and forecasted station volumes. A common convention is to establish parameters representing the split between EI and EE at each external station based on surveys and traffic counts, and then to forecast the growth at each station. EI and EE trip ends are then estimated using the EI/EE split parameters. Since the Tennessee models use four time periods, the EI and EE trip tables must be split by time and direction. EI trips at the internal stations are usually estimated using a linear equation, based on household and attraction (employment, school, and university enrollment) variables.

Internal-internal (I-I), EI and EE trips must include **truck components**. The *Quick Response Freight Manual (QRFM)* can be used to estimate internal truck travel in the absence of other data. QRFM, TRANSEARCH, and ATRI data, along with the forecasts from the TSM_V4, are good sources of truck data. A common procedure is to use QRFM to estimate I-I single unit (SU) and combination (CU) trips. These models estimate truck trip ends based on TAZ employment data and distribute them with gravity models. Similarly, EI trip may be estimated from traffic counts at the external stations and equations based on TRANSEARCH commodities at the internal TAZs. Gravity models are commonly used for trip distribution. For EE truck trips, a seed trip table of EE movements can be estimated from TRANSEARCH data, and the seed trip table can be estimated using a FRATAR (TransCAD growth factor model) to match truck trip volumes at each external station.

8.2.4.5.3 Mode Choice Models

In most traditional three- or four- step models trip distribution is listed before mode choice. However, in this model mode choice is listed before trip distribution because the utilities calculated in mode choice are inputs to the destination choice (distribution) model.

A nested logit model (NL) should be used in multi-modal models, which include transit trips and non-motorized modes. There are many options for structuring NL models. The best structure will depend on the details of the available transit modes and other factors. It is likely that different structures will be used in each trip purpose. The NL uses the utilities for making the trip by each mode to calculate the share for that mode. The logsums of the utilities for all submodes are used to calculate the share for the parent mode. In addition to travel times, travel costs and traveler income are usually components of the utility expressions for each mode.

NL models estimate mode share is in a hierarchical fashion, where in most (not all) cases the choices are binary, and the utilities include the LogSum utilities of their constituent modes, so as to avoid IIA consequences (too much to explain here). The standard logit formulation is:

$$P_i = \frac{e^{U_i}}{\sum_m e^{U_m}}$$

where,

P_i = the probability of using mode i
U_i = the utility of mode i
e = the natural logarithm

In the nested logit formulation, the utility (U) of each mode would contain the LogSum of the utilities of its constituent modes, and a nesting coefficient ϴ (0 < ϴ < 1). Utilities generally contain measures of travel times and costs, and the models are stratified by trip purpose and other variables such as auto availability or sufficiency. An example LogSum for drive-alone and shared-ride modes is:

$$LogSum_A = \text{-}\ln[e^{U_{DA}} + e^{U_{SR}}]$$

Estimation of mode choice models requires a household travel survey, enriched with responses from the choosers of each mode containing the household classification data, such that the sample size is roughly the same for each mode and submode. Thus, in most cases it is best to use the existing model for the region or transfer a model from a similar region. These models can then be updated (mode-specific constants adjusted), so the model results match observed travel choices. The main effort in implementing or updating this type of model is to develop the observed choice targets for each mode and trip purpose. Mode choice models should be applied by time period, ensuring that the correct travel times and costs are used. Later, these times should be adjusted and updated using a travel time feedback loop.

MPOs without transit service can use the highway model structure and apply constant auto occupancy rates to each trip purpose. The limitations here are that it would not be possible to model non-motorized travel, and auto occupancy would be a constant and not sensitive to travel times and costs and parking costs. It would be possible to construct a NL model without transit, but the costs would be high and the benefits small.

8.2.4.5.4 Trip Distribution (Destination Choice) Models

Traditionally, trip-based models use a gravity formulation to distribute trips. Distribution pairs trip productions with trip attractions, thus producing a matrix of travel from productions zones to destination zones. The marginals of the matrix are the production and attraction vectors. Most often, the only data that are provided to a gravity model are productions, attractions, and a matrix of travel time impedance. Impedance is usually a linear combination of travel time, travel distance, and travel cost. Gravity models also may include K-factors, which encourage or discourage interactions between certain zones or sets of zones. A typical gravity model formulation is:

$$T_{i,j} = P_i * \frac{A_j * F_{i,j} * K_{i,j}}{\Sigma^1_j (A_j * F_{i,j} * K_{i,j})}$$

where,

$T_{i,j}$ = the number of trips between zone i and zone j
P_i = the trip productions for zone i
A_j = the trip attractions for zone j
$F_{i,j}$ = is an accessibility factor associated with the measure of travel impedance from zone i to zone j
$K_{i,j}$ = is the socio-economic or physically related factor for all movements between zone i and zone j

More recently, destination choice models have become the preferred method for trip distribution. While destination choice models allow additional information to be added to the trip distribution process, resulting in trip tables that are a closer match to actual trip patterns, it should be noted that gravity models are just special cases of destination choice models. Destination choice models typically use more independent variables than gravity models, provide a more rational way to account for conditions K-factors are intended to model, and allow the model to include characteristics of the traveler and destinations in the form of zonal data. Additionally, destination choice models usually use the LogSum of modal impedances in the impedance function. Thus, all modes impact the distribution of trips. The destination choice form should be considered for all Tennessee models. In most cases, such a model could be created using existing data. If additional data on travel movements can be obtained, (for example, from Big Data sources), the destination choice models could be enhanced to better replicate actual travel patterns. Additionally, if for example it is understood that the distribution model is distributing work trips between high income areas and low paying jobs, the destination choice model could be used to take advantage of incomes and employment types.

The destination choice equation is similar to the logit mode choice equation, except that the choices are destination zones instead of modes. The utilities contain size terms, similar to trip attractions, measures of travel distances, and the LogSum of the mode choice utilities for the i-j pair of TAZs.

Trips should be balanced by purpose so that the sum of productions equals the sum of attractions. In general, HBW, HBSC and HBU trips should be doubly constrained, while others should be singly constrained.

8.2.4.5.5 Time-of-Day (TOD) Models

All Tennessee trip models use four time periods, which is adequate. The specifications of time periods should be based on travel surveys, traffic counts, or Big Data. The TOD models are applied post-distribution. The TOD models should consider the amount of travel that occurs in each time period, and the direction of travel. For example, morning travel will have a heavier home-to-school and home-to-work movement than the afternoon period. Again, household surveys, traffic counts, and Big Data should be used to estimate the size and directional splits.

8.2.4.5.6 Highway Assignment Models

TransCAD offers a variety of highway assignment methods. In most cases the TransCAD “MMA” process would be appropriate. An exception might be for long-distance EE trips, and freight trucks, where most drivers will choose the free-flow minimum path because they are not familiar with alternative paths. Some additional thought might be required here, as the fraction of long-distance trips that are informed by real-time data through ITS signage and cell-phone applications is increasing.

The MMA process allows independent assignment of multiple classes of vehicles. Individual model applications should be implemented for each time TOD period. Within each period, it will be important to use different classes to account for varying passenger car equivalent values (PCE's) and path restrictions (HOV lanes, truck restrictions, etc.):

- Drive-alone autos
- Carpool autos (2+, or 3+, depending on the need to model HOV lanes)
- Single unit trucks (PCE=1.5)
- Combination trucks (PCE=2.0)

The Bureau of Public Roads (BRP) formation is recommended for the volume/delay function (VDF). The values for alpha and beta should be guided by the values recommended in NCHRP 716. Highway capacities should be time-period-specific, representing the amount of daily capacity available at each time period.

Experience has shown that the value chosen for the capacity restraint conversion can significantly affect assignment results. A value 0f 0.001 or smaller should be chosen; the temptation to use a larger value to reduce the computer running time should be resisted, as larger values can distort the assignment, particularly when parallel roadways serve the same trips. N Conjugate should be set at 2, and the "BFW" method should be used.

Finally, for highway assignment, a procedure to create selected link and selected zone assignment should be added to the procedure and GUI. Similarly, the model should incorporate a method to save, and to use a static set of trip tables so that "locked trip tables" runs can be made to measure the effect of roadway alternatives, without the changes in trip tables which might result from the changes in the roadway network. Such assignments are commonly needed for corridor and interchange studies.

8.2.4.5.7 Travel Time Feedback

The modeling steps described above change travel times on the highway network due to congestion. Thus, travel times are not consistent through all modeling steps. This gives rise to an iterative feedback procedure in which the congested skims for each time period are adjusted after assignment and fed back to the model. If done correctly, the process will converge so that the travel times at the current iteration are substantially the same as the travel times at the previous iteration.

While there are many ways to implement feedback, TransCAD's highway assignment procedures offer a Method of Successive Averages (MSA) process that is easy to implement, and which will converge. The entire process is based on estimating a travel time that would result from the MSA flow on each link, and the model VDF. The recommended measure of convergence is to compare the RMSE between the link flows in successive iterations. When the error falls below the specified convergence RMSE threshold, the feedback loop stops. Commonly, the threshold is set at an RMSE of 10. It is wise to specify a maximum number of iterations, and that value too is usually set at 10, although in practice this threshold is seldom reached. The feedback criteria must be met for all time periods.

The model usually will take several iterations to converge if it is started with travel skim matrices based on free flow times. Much computer running times can be saved if the process is initiated with a skim matrix from a prior run. This way, the assigned highway travel times and volumes begin closer to the converged answer. To implement this procedure, the TransCAD script should be developed to save the required skim matrices and trip tables, and to allow them to be used to begin a new model application. In practice, this usually allows the model to converge in about three iterations. Note that every model run would require at least two iterations to create the link flows needed to measure convergence.

8.2.4.5.8 Transit Assignment Models

There are several modeling steps that should not be run until model feedback convergence is achieved. This is because these steps require time to run, but do not impact model feedback convergence. The steps are transit assignment, model reporting (except a log reporting feedback progress) and visualization, and air quality analysis.

TransCAD's transit assignment macros should be used to assign the transit trip tables to the transit network, by time period. The assignment procedures can be used to create:

- Link and line level transit passenger flows
- Route level boardings and alightings
- Summaries of boardings and alightings by access modes
- Summaries of transfers between modes

8.2.4.5.9 Reporting and Visualization

The model should produce a standard set of reports and maps. There are many options here and the details should be specified in Phase 2. Here are some options and guidelines:

- The standard Caliper GUI can be used to create a set of displays, called interactively. The *Display Buttons* on the proposed GUI, shown earlier, can activate these displays. These displays could be created to use a set of standard colors and values, so that maps, colors, and thresholds would be consistent for all MPOs. These buttons can be used to produce standard and consistent maps such as:
  - Flow volume band widths
  - Color-coded maps by volume/ count and volume/capacity
  - Selected link loadings
  - Maps of any desired highway line layer attribute
  - Maps of zonal data and attributes using dot densities, colors, pie and bar charts, and other symbols.
  - Trip table desire lines
  - Combinations of maps
- TransCAD has functions that can be used in the model script to create a wide range of tables and reports. The advantage of using TransCAD-based reporting is that no other software and procedures are needed. Generally, the reporting function should be called every time the model is run, without special user intervention. Any data available in the model can be accessed, displayed and reported. The outputs are organized in XML-format files and are written to the standard TransCAD log files. The TransCAD log files can be redirected to the model alternatives **Reports** folder. Reports can be created for any set

of data available to the model. Commonly, reports are stratified by political jurisdictions, and other link and TAZ attributes. Also, screenline maps and reports can be created. In general, reports should be developed for each model step. Two sets of reports should be developed:

- Model validation reports (run only for validation). These reports usually compare link flows to traffic counts.
- Alternative reporting, reporting the forecast of an alternative. These reports usually compare link flows to capacities.

- Lately, the consultant has developed highly customized reporting applications and dashboards to display model outputs. These applications are developed in Python and R. The mapping, formatting, and reporting capabilities exceed the capabilities of TransCAD, but the applications can be closely linked to and called from TransCAD. The issue of a dependency on a specific version of R can be solved easily by delivering a static version of the R software as part of the model distribution and directing all software calls and library references to the static version. The R and Python versions provide rich displays with interactive capabilities, which can be redirected to external reports and hardcopy when needed. These applications can be developed to produce consistent displays and maps for all MPOs. In the event that some MPOs use non-standard file and attribute naming, an interface file can be used to translate between the local model and the standard application.

Opportunities for Standardizing Travel Demand Models in Tennessee (UT Center for Transportation Research, 2012), presented a comprehensive list of standard model output tables. While this is an excellent list for the base year and validation, the consultant believes an expanded list would be desirable. This list could be organized by major model steps, all by political jurisdiction and total:

- Zonal Data:
    - Sum of all zonal data: households, workers, autos, income by class, school enrollment, university enrollment, population, employment by classification
    - Population/household
    - Population/employment
- Highway network:
    - Link layer total miles
    - Link layer "In-network" total miles and subtotals by:
        - ✓ One-way
        - ✓ By functional classification
        - ✓ By area type
        - ✓ By number of lanes
        - ✓ Lane miles
        - ✓ Average posted speed
    - Intersections (nodes with more than two legs):
        - ✓ Total

- ✓ Number with traffic control devices
- ✓ Number with turn penalties or prohibitors

- Transit network:
  - Number of routes
  - List of modes
  - Average headway by mode and time period
  - Average stops per mile by mode
  - Route miles and vehicle miles by mode
- Trip Generation:
  - Number of Productions and Attractions by trip purpose
  - Trips per household by purpose
  - Truck trips by type (CU, SU)
- Trip Distribution:
  - Number of trips by purpose
  - Average trip time, distance, and speed by purpose (include trucks by type)
  - Number and percent of intrazonal trips by purpose
- Mode choice:
  - Trips by mode, submode, and purpose
  - For validation trips versus targets, and shares, by mode, submode and purpose
- Highway Assignment:
  - Validation Metrics:
    - ✓ Screenline volumes and counts (include external stations)
    - ✓ Flow/Count by Functional Class, Area Type, and Volume Group
    - ✓ Flow vs. Count %RMSE and correlation coefficient by Functional Class, Area Type, and Volume Group
    - ✓ (Flow VMT)/(Count VMT) by Functional Class, Area Type, and Volume Group
    - ✓ (Flow VMT)/(HPMS VMT) by Functional Class, Area Type, and Volume Group
    - ✓ (Flow VHT)/(Count VHT) by Functional Class, Area Type, and Volume Group
    - ✓ Congested speed by Functional Class, Area Type, and Volume Group
  - Alternative Evaluation Metrics (expand to estimate all links):
    - ✓ Screenline volumes and capacities
    - ✓ Flow/Capacity by Functional Class, Area Type, and Volume Group – expanded to all links
    - ✓ (Flow VMT)/(Capacity VMT) by Functional Class, Area Type, and Volume Group
    - ✓ Congested speed by Functional Class, Area Type, and Volume Group
- Transit Assignment:
  - Validation Metrics:
    - ✓ Model vs boarding counts by route, mode and time period
    - ✓ Model vs counted transfers by time period and modes

- Alternative Evaluation Metrics:
  - ✓ Estimated boardings by route, mode and time period
  - ✓ Estimated transfers by time period and modes

- **Mobile source AQ emissions** could be added as a standard report, based on modeled VMT and speeds, and MOVES-based emission rates calculated for each MPO, outside the travel demand model. Reports could be structured to meet conformity requirements.

The models also should create standard maps and graphs for model output. Each should use a standardized set of colors, breaks, and line withs. The consultant has created R scripts to create interactive dashboard displays of the following data, called automatically from the TransCAD model. The advantage here is that the data are created or refreshed every time the model is run. While options are many, the details should be determined in Phase 2, here are some general guidelines.

- Bar charts can be used to illustrate the distribution of persons per household, and autos per household by political jurisdiction.
- Stacked bar charts can be used to illustrate the distribution of person trips by purpose and time period.
- Pie charts can be used to display the distribution of trips by trip purpose, trips by time-of-day, or any other vector.
- Grouped bar charts can be used to display trips by purpose and mode.
- Bar charts can be used to display the distribution of household by number of trips.
- Bar charts and line graphs can be used to display the trip length frequency of trips by trip purpose, and political subdivision.
- The highway assignment validation metrics can be displayed as line graphs, along with validation targets.
- Scatter plots can be created showing modeled flows and traffic counts, and goodness-of-fit metrics.
- Thematic maps can be used to show mode shares by TAZ. These plots and those described below can use “OpenStreetmap” as the base map.
- Zonal data, and growth in zonal data between base and future years can be shown as color coded thematic maps. Scripts can be established so the map elements (colors, line widths, and groupings) are the same every time the scripted routines are used.
- Line width maps can be used to show highway flow, and colors can indicate flow versus count or capacity.
- Plots can be made of functional classification for use in quality control.
- Desire line plots can be used to display movements of groups of trips, such as EE, EI, and truck trips.

8.3 Data Resources

There is a wealth of data that can be assembled to support travel demand models, and TDOT and their consultants have obtained and used these data to develop the current TDOT and MPO models. A key goal would be to organize the data and make it easy and inexpensive for the MPOs to acquire it for use in their models. Florida is tackling this issue. One of the primary recommendations of the FSUTMS NextGEN process is the creation and use of the "Mobility Data Integration Space" (MDIS). This system is being developed by FDOT's Forecasting and Trends Office to organize most transportation data needed for travel demand models and other studies and make it available to the model developers and users. The MDIS would also hold data created by the statewide model and the MPO models. The consultant believes that a similar system could be implemented at TDOT to provide modeling data. One of the challenges with a unified data source would be the various timelines that the MPOs must meet for their plan updates. These constraints should be resolved in Phase 3 among TDOT and the MPO participants in the study.

Data required by the models, and which should be considered for integration into the MDIS include the following:

- Traffic counts – TDOT uses the MS2 Transportation Data Management System. Count data can be gotten from the MS2 system and added to the MPO models. At some point, when a relationship is established between the MPO models and the statewide model, the statewide model network could serve as the source of travel demand model traffic counts.
- Highway network geography and data – TRIMS should be the source of highway network data. The statewide model could be used as the vehicle to provide the specific data needed by models after a relationship is established between the MPO models and the statewide model. Travel times, counts, and speeds also are available from other sources, and these data also would be useful to supplement TRIMS:
    - *NPMRDS* - (FHWA's national data set of average travel times on the National Highway System for use in performance measures and management activities)
    - *HERE* – Location data and attributes
    - *INRIX* – A suite of travel and location data
- Transit data – The best source of transit network data is likely to remain the GTFS files and operating data from the transit system operators.
- Passive "Big Data" – It would be helpful if TDOT could secure a statewide source of "Big Data." The selection of sources would depend on the agreement that could be negotiated with a vendor through the state's procurement process. The consultant's experience is that it is desirable to compare data from two sources, or at least make reasonableness checks on data obtained from these vendors. Possible vendors include:
    - AirSage – Anonymous mobile location data
    - StreetLight – Smart phone data
    - American Transportation Research Institute (ATRI) - Trucking
    - Wejo – Connected car data

  - Strava – Running and cycling data from smart phones
  - Replica – A commercial source. Replica is an enterprise data platform that delivers critical insights about the built environment — across people, mobility, economic activity, and land use. Replica uses their data to create an activity-based model. Replica provides data extracted from their model. FDOT has a Replica subscription.

- Other travel characteristics data:
  - Data available from the MPO home interview surveys
  - 2017 National Household Travel Survey (NHTS) – National sample only, limited information for Tennessee

- Socioeconomic data (household and employment data) – The Census is usually the best source of base year household data. With an integration of the statewide model and the MPO models, the data could be kept in the statewide model, and be provided to the MPO models. Employment data at various levels of resolution are available from the US Bureau of Economic Analysis (BEA) (US Dept. of Commerce), Bureau of Labor Statistics (BLS): Quarterly Census of Employment and Wages (ES-202) (US Dept. of Labor) and state unemployment insurance files. ACS, PUMS, and the Longitudinal Employer-Household Dynamics (LEHD). Commercial sources of employment data include:
  - Woods & Poole
  - InfoUSA is now Data Axle USA
  - Dun & Bradstreet

- Future socioeconomic data would be created by a land use model or an ad hoc procedure. Here again, the statewide model would be a good way to organize land use model forecasts.

- Freight and truck data – There are several sources of freight and truck data, including:
  - The Freight Analysis Framework (FAF) from USDOT
  - S&P Global Transearch
  - The American Transportation Research Institute (ATRI)

8.4 Road Map and Schedule

Opportunities for Travel Demand Model, Development and Applications (2012), from the UT Center for Transportation Research, presented a five-year plan for implementing a standard procedure. The consultant believes that many of the unknowns mentioned in that paper have been resolved, and many (but not all) of the procedures needed for the model recommended in this current project have been developed and tested somewhere—many in Tennessee, and some in other states. Thus, with this Phase 1 Study, we believe that TDOT is further down the road to implementation than in 2012. Here are the **Phase 2** steps.

8.4.1 Confirm and Adjust the Phase 1 Plan

The plan outlined here is a good starting point for implementation. Nevertheless, it is fully expected that TDOT will request some changes in the plan. TDOT and consultant staffs will meet and correspond to finalize the recommendations.

8.4.2 Phase 2: Develop One Prototypical Model

The RFP specifies 1) Tri-Cities (Kingsport, Bristol, and Johnson City) MPO TDM area, and 2) Jackson Area MPO TDM as the areas for developing the first four-step models. The consultant recommends developing the first for Jackson because it is a relatively small area, and its general characteristics are typical of many Tennessee MPOs. This would be a good testbed for the standard model. After this model is completed, it could be tested on the Tri-Cities. In the Tri-Cities, the model could be implemented for each of the three cities individually. TDOT may want to consider developing a combined model for the three cities, although special issues might be encountered in a multi-centered area. Thus, a combined model should not be developed unless there are compelling special reasons to do so.

There are several issues that would be finalized during the development of the prototype model. During the development of the prototype, specifications will be recorded and compiled into a guidelines document. The guidelines from Florida, Michigan, and Iowa will be consulted in the detailed development of attribute and file names. Among the issues are:

- Specification of file names
- Specification of the highway network attributes and names
- Specifications of TAZ attributes and names
- Specification of an initial set of reports, graphs, and visualizations

When possible and appropriate, development will begin with the existing model. Major steps that would be conducted for the Jackson model are as follows:

- Assemble all data sources for:
  - Highway and transit networks and data
  - TAZ data: Census and Employment sources
  - Travel characteristics
  - Big Data for external trips
  - Truck data
- Develop the TAZ system, and master/alternative network system
- Assemble the GUI interface to implement the model described above
- Develop TransCAD scripts to implement the model specified above
- Estimate and update model components
- Develop model reporting and visualization procedures
- Assemble model components into a TransCAD supplication
- Validate and test the model
- Develop the detailed model guidelines based on the prototype Jackson model

It is expected that the development of the first Phase 2 model would require approximately 18 months.

After the initial model is completed, work on the Tri-Cities models can begin. Development of these models would take about a year, and the three models can be developed in parallel. It is likely that experience gained in the development of the Tri-Cities models will result in modifications to detailed model guidelines.

8.4.3 Phase 3: Data Integration

Phase 3 would begin after the completion of Phase 2. Issues that would be addressed in Phase 3 would include:

- Development of a highway-only model if there is an MPO with no transit service at the time.
- Development of standard TDOT modeling procedures that could be used by the Advanced Practice models. This is expected to be reporting, visualization, and sharing of input data sources.
- Two-way integration of data inputs and outputs in the statewide model.
- Development of the land use model, and integration into the Tennessee statewide model, which also would provide data to the MPO models.

Chapter 9 Conclusions

This report documents the work and findings of Phase 1, Development of Travel Demand Modeling Standards task order, and presents a roadmap of how TDOT could implement a standard travel demand model program. It also provides a summary of travel demand modeling practices in Tennessee, how several other states have approached model standards, presents a literature review, provides recommendations on what TDOT's model would look like with descriptions of major model elements, and suggests the next steps that TDOT should take.

The study confirms that it would be a good idea to develop standard model guidelines and procedures and recommends that TDOT follow this path. The survey conducted during the study suggests that such a program would be accepted by the MPOs, and that it would be recognized as an improvement to their transportation planning process while reducing their workload.

A prototypical model is outlined in this report. It is a four-step model which implements best-practice procedures. It recognizes that many of the procedures would not apply to the three MPOs with advanced practice models (Chattanooga, Knoxville, and Nashville), but that even these areas might benefit from statewide programs to obtain and distribute data, and to display and summarize model results.

This report presents Phase 1 of a three-phase effort, with recommendations for Phases 2 and 3. It is recommended that Phase 2 develop and implement a prototypical model for: 1) the Tri-Cities (Kingsport, Bristol, and Johnson City) MPO TDM area; and, 2) the Jackson Area MPO. This would include the development, validation, and implementation of the models, and development of guideline documents. Phase 3 would address: 1) development of a highway-only model if there is an MPO with no transit service at the time; 2) development of standard TDOT modeling procedures that could be used by the advanced practice model areas relating to reporting, visualization, and sharing of input data sources; 3) two-way integration and sharing of data inputs and outputs in the statewide model; and, 4) development of the land use model. The land use model would be integrated into the Tennessee statewide model, which would provide land use data to the MPO models.

Appendix A – MPO Survey Invitation

From: Mohammad Molla <Mohammad.Molla@tn.gov>
Sent: Friday, February 4, 2022 10:37 AM
To: Max Baker <mbaker@gnrc.org>
Cc: Chris McPhilamy <Chris.McPhilamy@tn.gov>; David Lee <David.Lee@tn.gov>; Ken Kaltenbach <Kkaltenbach@CORRADINO.com>; Shengnan Lou <slou@CORRADINO.com>; Stacy Morrison <Stacy.Morrison@tn.gov>
Subject: Take our brief survey to provide your input for TDOT's Study of Travel Demand Modeling Needs and Concerns

TN TDOT Department of Transportation

Take our brief survey **to provide your input for TDOT's Study of Travel Demand Modeling Needs and Concerns**

Hello Max,

The TDOT Long Range Division/ Forecasting Office is developing a standard travel demand model package using the TransCAD platform for potential use throughout the State for MPOs, urban areas, and/or future MPOs. This brief survey is your opportunity to tell us how we should do this to best meet your transportation planning needs.

The survey should take less than 10 minutes. Survey responses will be discussed at the February 28 Workshop, and summarized in the project report. The survey includes basic questions and does not collect any private information. However, if you want to be anonymous, please let us know by email through kkaltenbach@corradino.com, Mohammad.molla@tn.gov; or chris.mcphilamy@tn.gov.

We are eager to hear about your modeling needs. The survey will help TDOT's long-range planning division understand your forecasting needs and serve you better.

While you are completing the survey, you can go back and edit your responses. But after you submit it, it cannot be changed. You can submit the survey only once. The survey will be closed February 11th.

Don't miss out on providing your feedback. Thank you for your time!

TAKE SURVEY

TN TDOT Department of Transportation

Mohammad Molla, Ph.D | Forecasting Planning Supervisor
Long Range Planning Division/Forecasting Office
James K. Polk Building, 10th Floor
505 Deaderick St, Nashville, TN 37243
p. 615-350-3441
mohammad.molla@tn.gov

Appendix B – MPO Survey Distribution List

	Contact	*MPO*	*Email*
1	Bristol	Steven Mott	smott@bristoltn.org
2	Chattanooga	Yuen Lee	ylee@chattanooga.gov
3	Clarksville	Stan Williams	stanwilliams@cityofclarksville.com
4	Cleveland	Greg Thomas	gthomas@clevelandtn.gov
5	Jackson	Stan Pilant	spilant@jacksontn.gov
6	Johnson City	Glenn Berry	glennberry@jcmpo.org
7	Kingsport	Bill Albright	BillAlbright@KingsportTN.gov
8	Lakeway	Rich DesGroseilliers	richd@mymorristown.com
9	Knoxville	Mike Conger	mike.conger@knoxtpo.org
10	Memphis	Pragati Srivastva	Pragati.Srivastava@memphistn.gov
11	GNRC	Max Baker	mbaker@gnrc.org
12	GNRC	Hary Prawiranata	hary@gnrc.org

Appendix C – MPO Survey Questionnaire and Contents

Survey of Tennessee MPO Travel Demand Model Needs and Concerns Tennessee Department of Transportation, Long Range Planning Division

Welcome

The TDOT Long Range Division/ Forecasting Office is developing a standard travel demand model (TDM) package using the TransCAD platform for potential use throughout the State for MPOs, urban areas, and/or future MPOs. Use of this model will be optional. TDOT anticipates that smaller agencies will find standardization to be beneficial. At the completion of this program, TDOT would provide modeling procedures, specify data, and help in the acquisition and development of data. This would eventually reduce staff workloads and costs, as most MPOs would no longer need to develop their own standalone model. Nevertheless, the decision to incorporate these potential modeling standards will be at the discretion of the individual agencies.

To begin this effort, TDOT has contracted with The Corradino Group (Corradino). Our first major effort is to conduct an on-line survey through SurveyMonkey. The main objective of this online survey is to identify MPO modeling needs, concerns, and priorities. Results will form the basis of the upcoming Workshop, February 28.

The survey should take less than 10 minutes. Your responses will be summarized in the project report. The survey includes basic questions and does not collect any private information. However, if you want to be anonymous, please let us know by email through kkaltenbach@corradino.com, Mohammad.molla@tn.gov; or chris.mcphilamy@tn.gov.

We are eager to hear about your modeling needs. The survey will help TDOT's long-range planning division understand your forecasting needs and serve you better.

You can complete the survey once, but you can edit your responses until the survey is closed on February 11th. Questions marked with an asterisk (*) are required.

If you have any questions about the survey, please email us: kkaltenbach@corradino.com, Mohammad.molla@tn.gov; or chris.mcphilamy@tn.gov.

We really appreciate your input!

The questions used to create the online SurveyMonkey questionnaire follow:

1. Area size question
2. What is your most pressing modeling need? Shengnan, *I want them to rank these – either with a number or moving them (whatever is easier) most important first*
    a. Traffic forecast accuracy
    b. Getting data
    c. Getting staff
    d. Staff training
    e. Computer running time
    f. Ease of model application, model reliability, identifying errors
    g. Analyzing transit alternatives
    h. Analyzing non-motorized modes
    i. Analyzing TNC modes like Uber & Lyft
    j. Better displays and visualization
    k. Need for additional model capabilities **(please specify)**
    l. Other **(please specify)**
3. What procedures should be improved? **(please specify) open-ended Optional**
4. If most MPOs in Tennessee used similar modeling procedures, and TDOT supported them with scripting and training, would that make your job easier? **(Y/N)**
5. Please **rank** these issues (most important first) in order of usefulness
    a. Consistent data file and variable naming conventions
    b. Consistent procedures among the MPOs
    c. Better and more consistent data – like networks, base year zonal data, future zonal data, traffic counts, travel time data, transit ridership data, freight and goods movement data, survey data (type, need for more data), use of "Big Data."
6. What is your biggest additional data need **(please rank)**?
    a. Network data & geometry
    b. Observed travel time data
    c. Base year zonal data
    d. Future zonal data
    e. Traffic counts
    f. Transit ridership data
    g. Freight and goods movement data
    h. Survey data (type, need for more data)
    i. A local origin-destination survey.
    j. "Big Data."
7. Do you see a need for new procedures and post-processors **(please rank)**?
    a. Air quality tools
    b. Economic analysis tools

   c. Land use forecasting and allocation models
   d. Visualization tools

8. Is model running time or computer hardware an issue? **(Y/N)**

9. What procedures need to be improved or added to you model (**please rank**)

   a. Trip generation models
   b. Trip distribution models
   c. Mode choice & auto occupancy procedures
   d. Traffic assignment methods
   e. Transit model procedures
   f. Model evaluation & reporting
   g. Model feedback methods
   h. DTA or micro-assignment
   i. Tour & ABM Models
   j. Distribution, and assignment feedback convergence
   k. Connected and autonomous vehicles
   l. External traffic model
   m. Tuck or Freight model
   n. Seasonal tourist estimates.
   o. Time of day model.

10. Should TDOT provide standards, or just guidelines (please specify **standards** or **guidelines**)?

11. What is your definition of a good model (**please rank**)?

   a. Exactly replicates observed data.
   b. Produces logical, reasonable forecasts.
   c. Runs quickly.
   d. Easy to run and requires little training.
   e. Produces good summaries, maps, graphs and other visualization.

12. If TDOT developed a standard model, would your agency be interested in using it now or future? (Y/N) OPTIONAL

13. If TDOT developed a standard model, what elements would you want to be standardized? Please check all that apply.

   a. File names
   b. Model steps
   c. Model algorithms for trip generation, distribution, mode choice, highway assignment.
   d. Model constants such as trip generation rates, friction factors, mode choice constants, convergence thresholds, model performance reporting.
   e. Transit modeling procedures.
   f. Non-motorized methods.

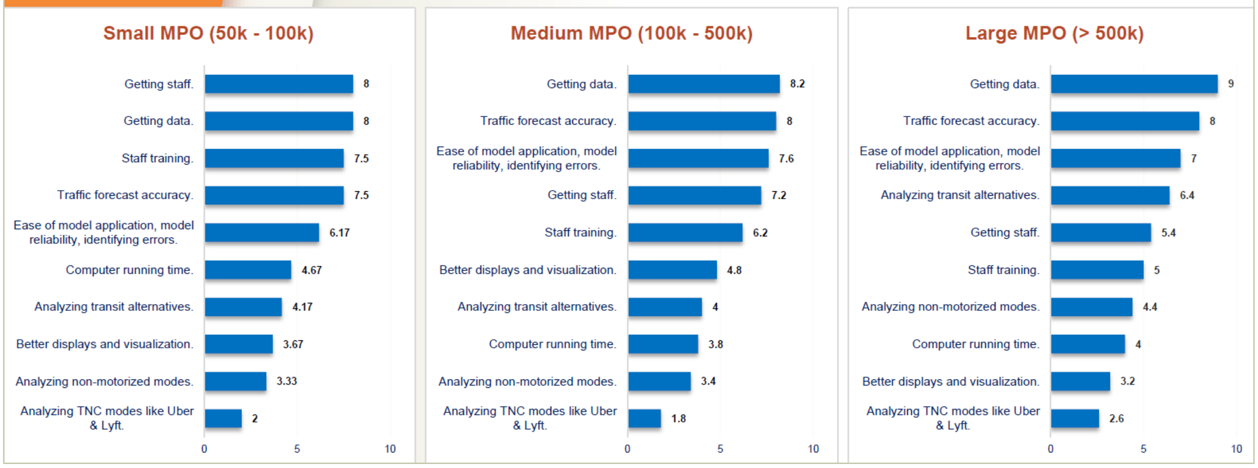
14. Would you or your office be interested in serving as part of a committee for this project task order or future task order (Y/N)
15. Please tell about any concerns you might have about a Standard MPO Travel Demand Modeling Framework. Your response can include things we have not mentioned here. (open ended text) OPTIONAL

Thank you for taking your time to complete this survey.

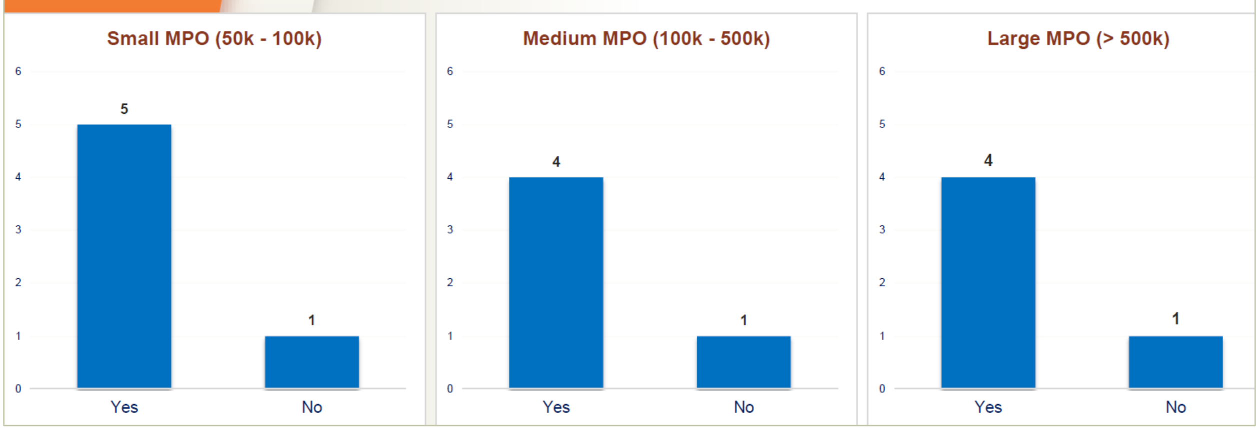
Chris McPhilamy, GISP|Planning Manager
Long Range Planning Division/Data Visualization/Forecasting

Appendix D – Detailed MPO Survey Results

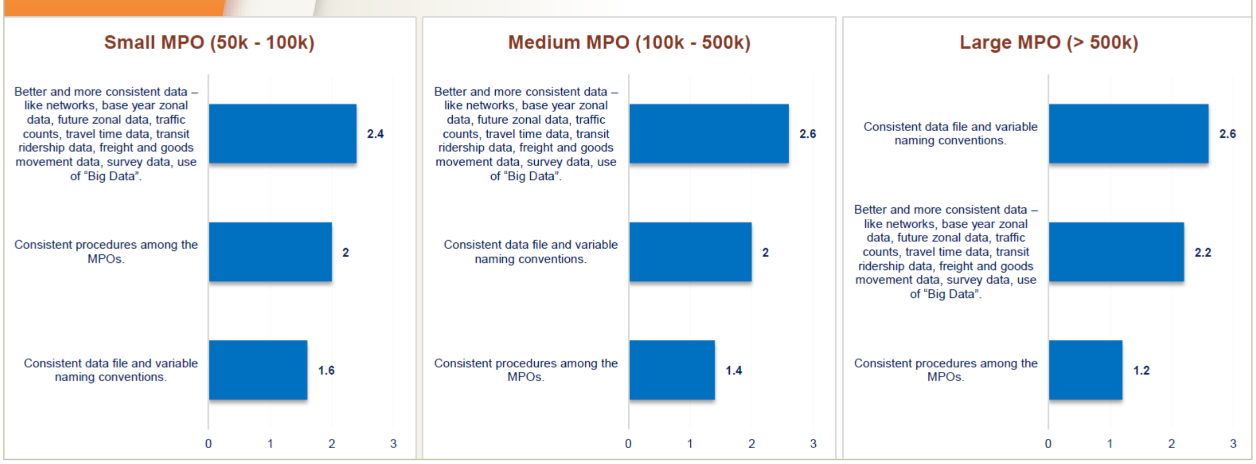
Most Pressing Modeling Needs

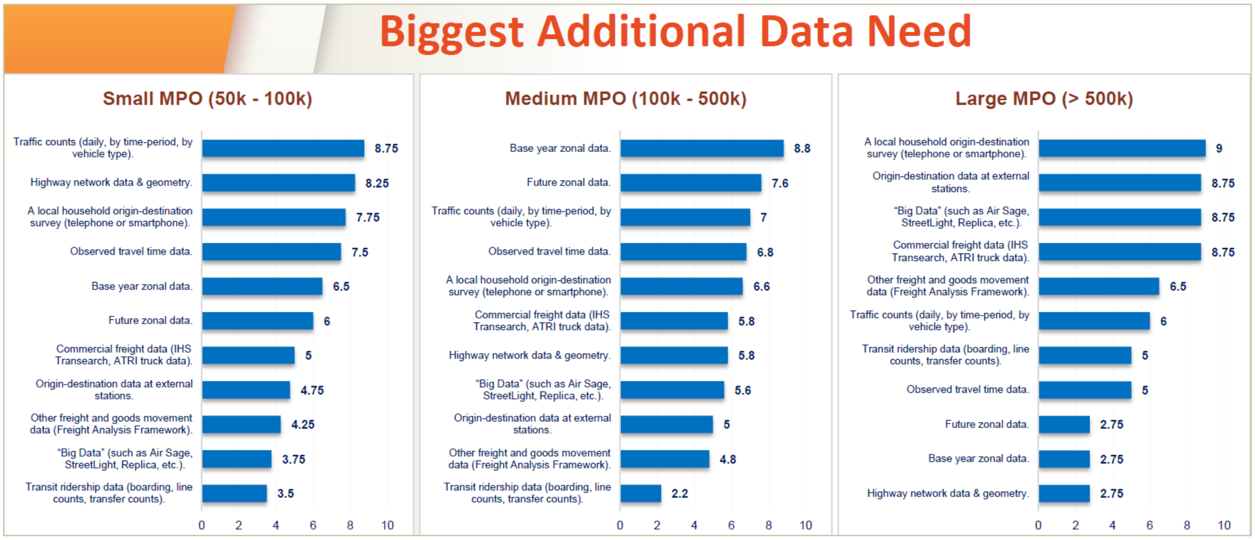


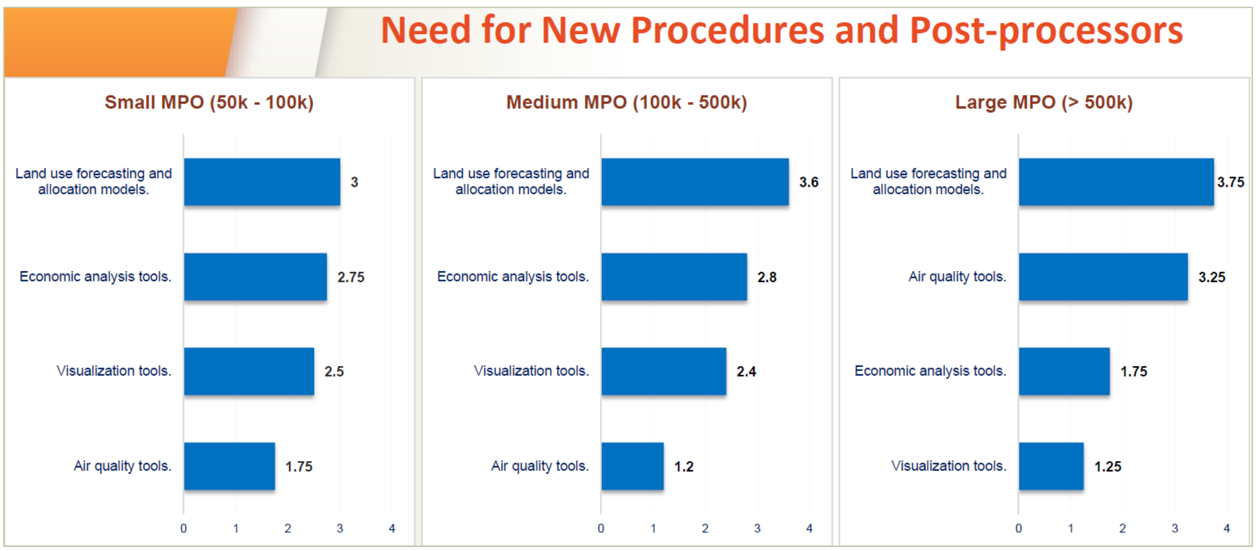
If similar modeling procedures are used and TDOT provides support, would that make your job easier?

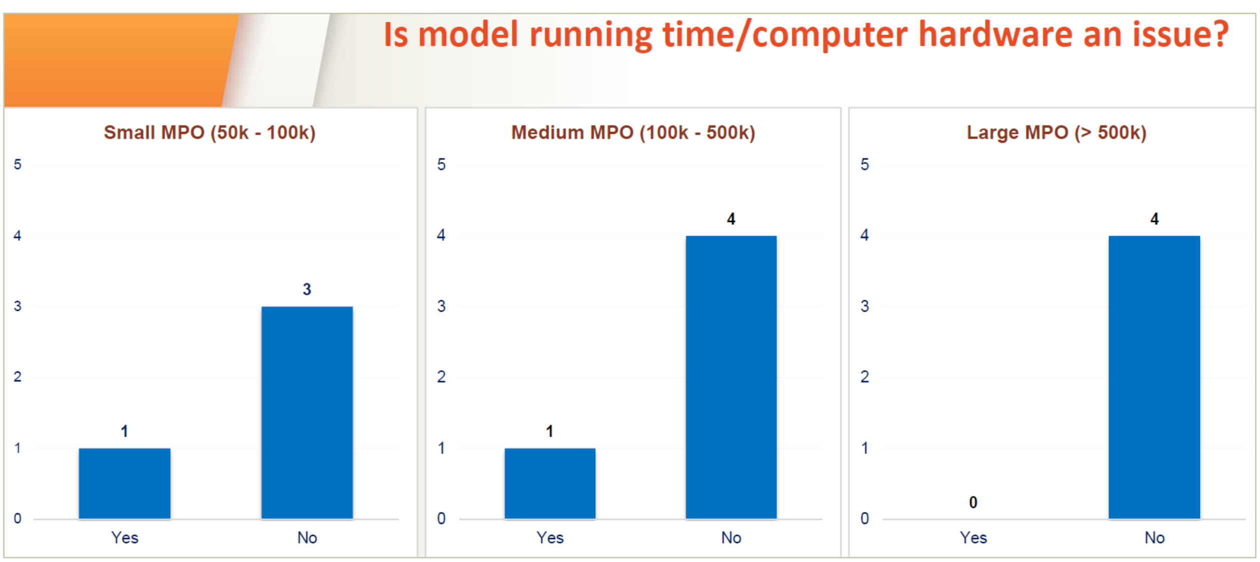


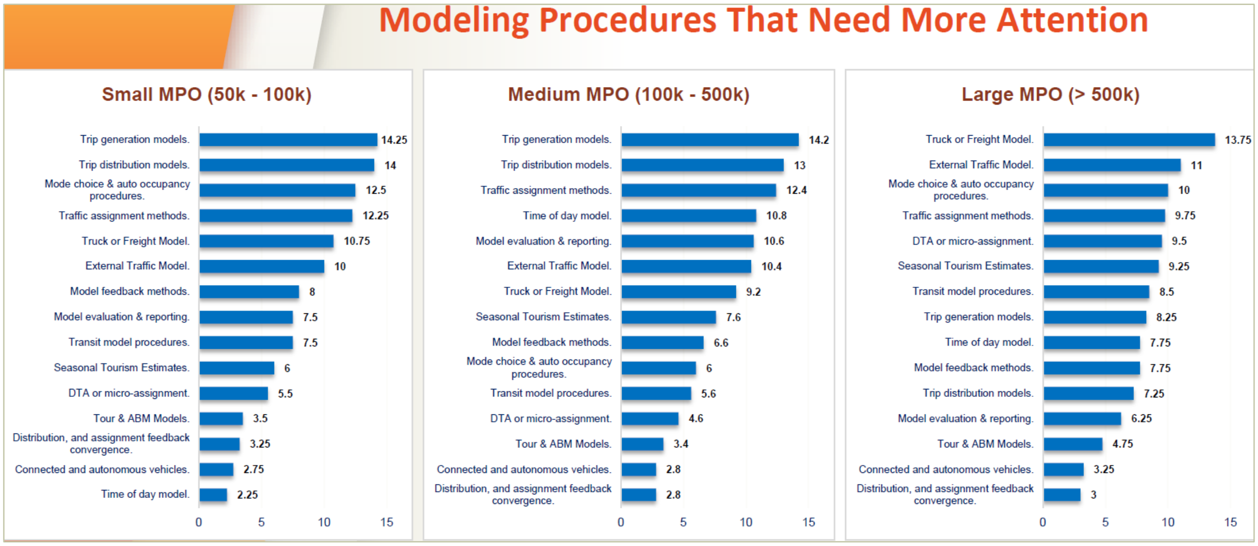
Rank of Usefulness

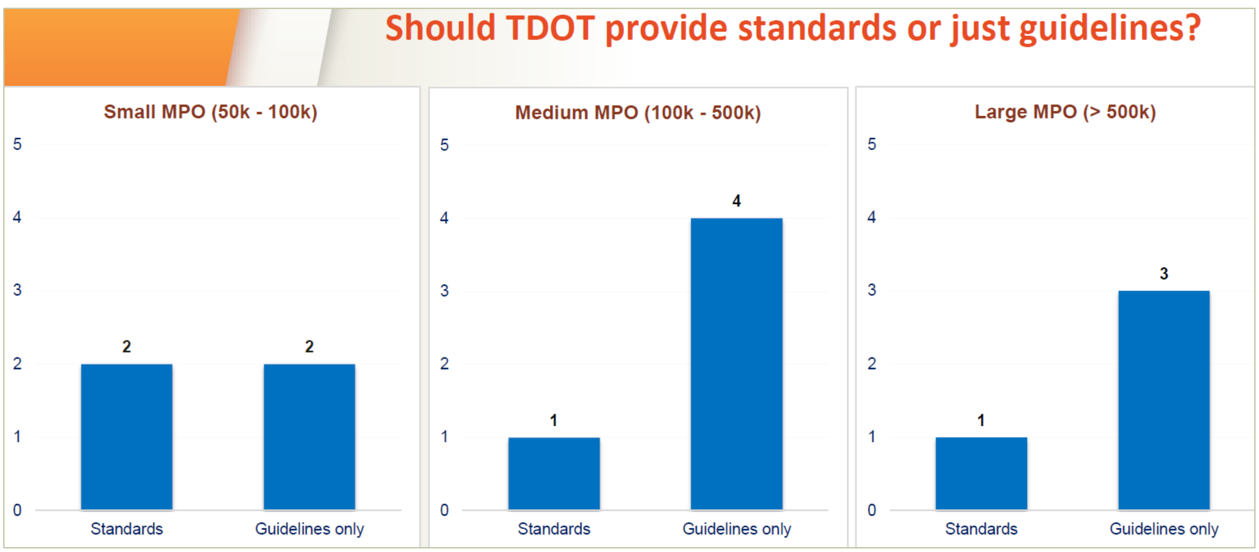


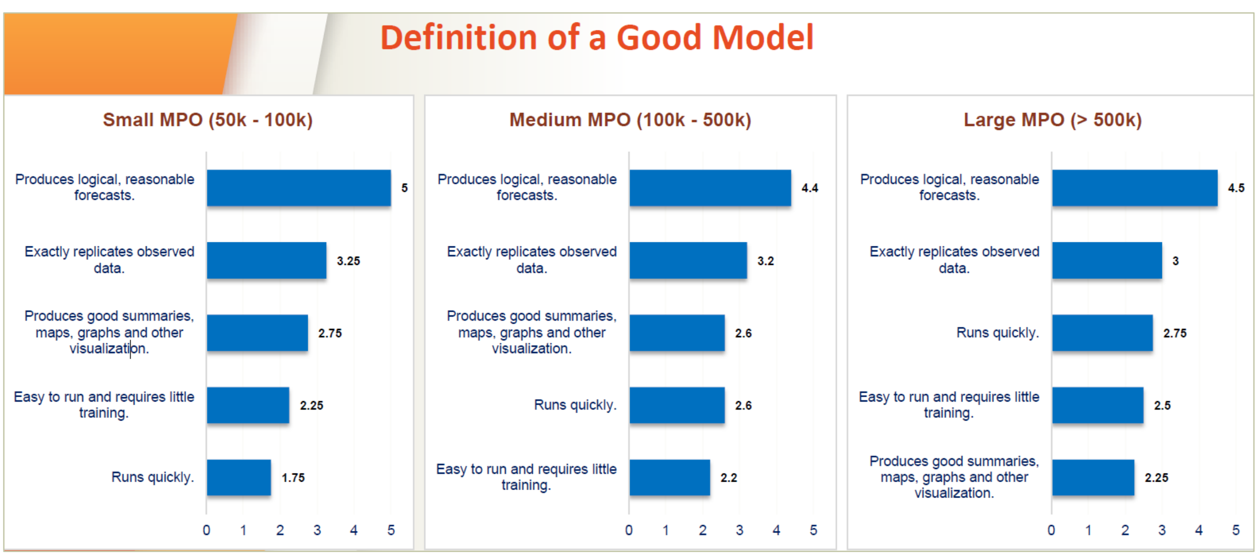

Biggest Additional Data Need
Small MPO (50k - 100k)
Traffic counts (daily, by time-period, by vehicle type). 8.75
Highway network data & geometry. 8.25
A local household origin-destination survey (telephone or smartphone). 7.75
Observed travel time data. 7.5
Base year zonal data. 6.5
Future zonal data. 6
Commercial freight data (IHS Transearch, ATRI truck data). 5
Origin-destination data at external stations. 4.75
Other freight and goods movement data (Freight Analysis Framework). 4.25
"Big Data" (such as Air Sage, StreetLight, Replica, etc.). 3.75
Transit ridership data (boarding, line counts, transfer counts). 3.5
0 2 4 6 8 10
Medium MPO (100k - 500k)
Base year zonal data. 8.8
Future zonal data. 7.6
Traffic counts (daily, by time-period, by vehicle type). 7
Observed travel time data. 6.8
A local household origin-destination survey (telephone or smartphone). 6.6
Commercial freight data (IHS Transearch, ATRI truck data). 5.8
Highway network data & geometry. 5.8
"Big Data" (such as Air Sage, StreetLight, Replica, etc.). 5.6
Origin-destination data at external stations. 5
Other freight and goods movement data (Freight Analysis Framework). 4.8
Transit ridership data (boarding, line counts, transfer counts). 2.2
0 2 4 6 8 10
Large MPO (> 500k)
A local household origin-destination survey (telephone or smartphone). 9
Origin-destination data at external stations. 8.75
"Big Data" (such as Air Sage, StreetLight, Replica, etc.). 8.75
Commercial freight data (IHS Transearch, ATRI truck data). 8.75
Other freight and goods movement data (Freight Analysis Framework). 6.5
Traffic counts (daily, by time-period, by vehicle type). 6
Transit ridership data (boarding, line counts, transfer counts). 5
Observed travel time data. 5
Future zonal data. 2.75
Base year zonal data. 2.75
Highway network data & geometry. 2.75
0 2 4 6 8 10


Need for New Procedures and Post-processors
Small MPO (50k - 100k)
Land use forecasting and allocation models. 3
Economic analysis tools. 2.75
Visualization tools. 2.5
Air quality tools. 1.75
0 1 2 3 4
Medium MPO (100k - 500k)
Land use forecasting and allocation models. 3.6
Economic analysis tools. 2.8
Visualization tools. 2.4
Air quality tools. 1.2
0 1 2 3 4
Large MPO (> 500k)
Land use forecasting and allocation models. 3.75
Air quality tools. 3.25
Economic analysis tools. 1.75
Visualization tools. 1.25
0 1 2 3 4

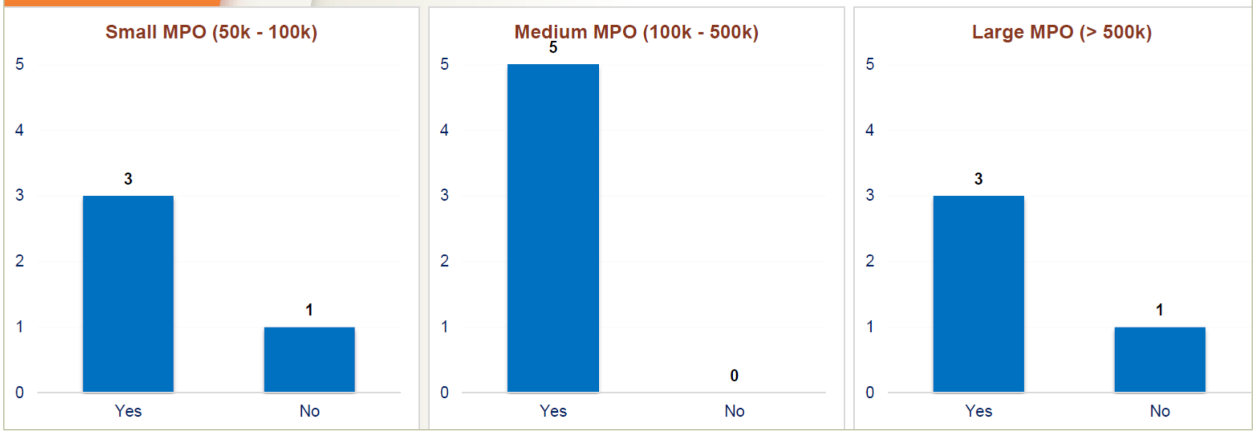

Is model running time/computer hardware an issue?
Small MPO (50k - 100k)
0 1 2 3 4 5
Yes 1
No 3
Medium MPO (100k - 500k)
0 1 2 3 4 5
Yes 1
No 4
Large MPO (> 500k)
0 1 2 3 4 5
Yes 0
No 4


Modeling Procedures That Need More Attention
Small MPO (50k - 100k)
Trip generation models. 14.25
Trip distribution models. 14
Mode choice & auto occupancy procedures. 12.5
Traffic assignment methods. 12.25
Truck or Freight Model. 10.75
External Traffic Model. 10
Model feedback methods. 8
Model evaluation & reporting. 7.5
Transit model procedures. 7.5
Seasonal Tourism Estimates. 6
DTA or micro-assignment. 5.5
Tour & ABM Models. 3.5
Distribution, and assignment feedback convergence. 3.25
Connected and autonomous vehicles. 2.75
Time of day model. 2.25
0 5 10 15
Medium MPO (100k - 500k)
Trip generation models. 14.2
Trip distribution models. 13
Traffic assignment methods. 12.4
Time of day model. 10.8
Model evaluation & reporting. 10.6
External Traffic Model. 10.4
Truck or Freight Model. 9.2
Seasonal Tourism Estimates. 7.6
Model feedback methods. 6.6
Mode choice & auto occupancy procedures. 6
Transit model procedures. 5.6
DTA or micro-assignment. 4.6
Tour & ABM Models. 3.4
Connected and autonomous vehicles. 2.8
Distribution, and assignment feedback convergence. 2.8
0 5 10 15
Large MPO (> 500k)
Truck or Freight Model. 13.75
External Traffic Model. 11
Mode choice & auto occupancy procedures. 10
Traffic assignment methods. 9.75
DTA or micro-assignment. 9.5
Seasonal Tourism Estimates. 9.25
Transit model procedures. 8.5
Trip generation models. 8.25
Time of day model. 7.75
Model feedback methods. 7.75
Trip distribution models. 7.25
Model evaluation & reporting. 6.25
Tour & ABM Models. 4.75
Connected and autonomous vehicles. 3.25
Distribution, and assignment feedback convergence. 3
0 5 10 15

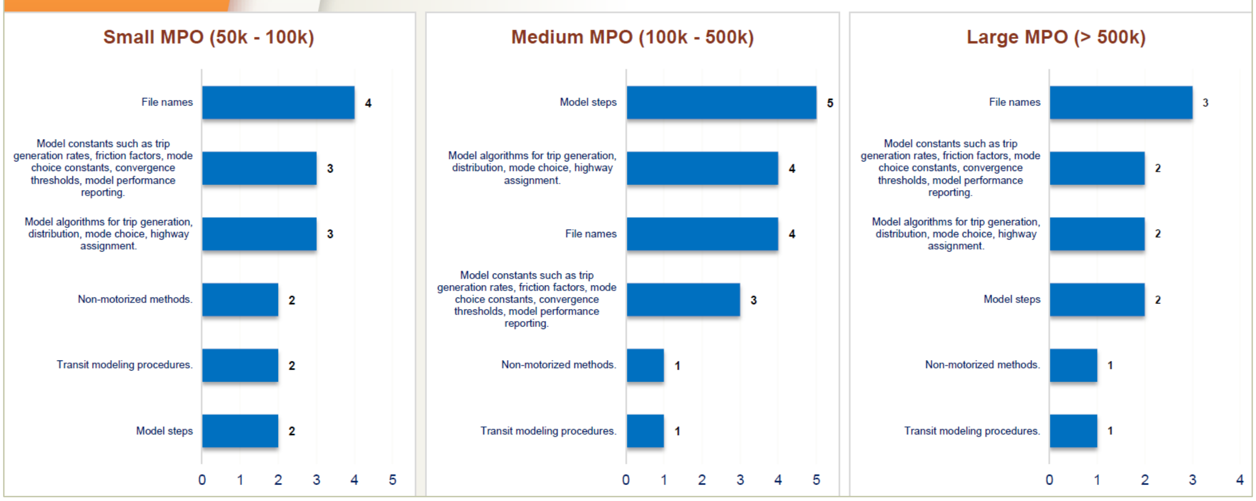

Should TDOT provide standards or just guidelines?
Small MPO (50k - 100k)
0 1 2 3 4 5
Standards 2
Guidelines only 2
Medium MPO (100k - 500k)
0 1 2 3 4 5
Standards 1
Guidelines only 4
Large MPO (> 500k)
0 1 2 3 4 5
Standards 1
Guidelines only 3


Definition of a Good Model
Small MPO (50k - 100k)
Produces logical, reasonable forecasts. 5
Exactly replicates observed data. 3.25
Produces good summaries, maps, graphs and other visualization. 2.75
Easy to run and requires little training. 2.25
Runs quickly. 1.75
0 1 2 3 4 5
Medium MPO (100k - 500k)
Produces logical, reasonable forecasts. 4.4
Exactly replicates observed data. 3.2
Produces good summaries, maps, graphs and other visualization. 2.6
Runs quickly. 2.6
Easy to run and requires little training. 2.2
0 1 2 3 4 5
Large MPO (> 500k)
Produces logical, reasonable forecasts. 4.5
Exactly replicates observed data. 3
Runs quickly. 2.75
Easy to run and requires little training. 2.5
Produces good summaries, maps, graphs and other visualization. 2.25
0 1 2 3 4 5

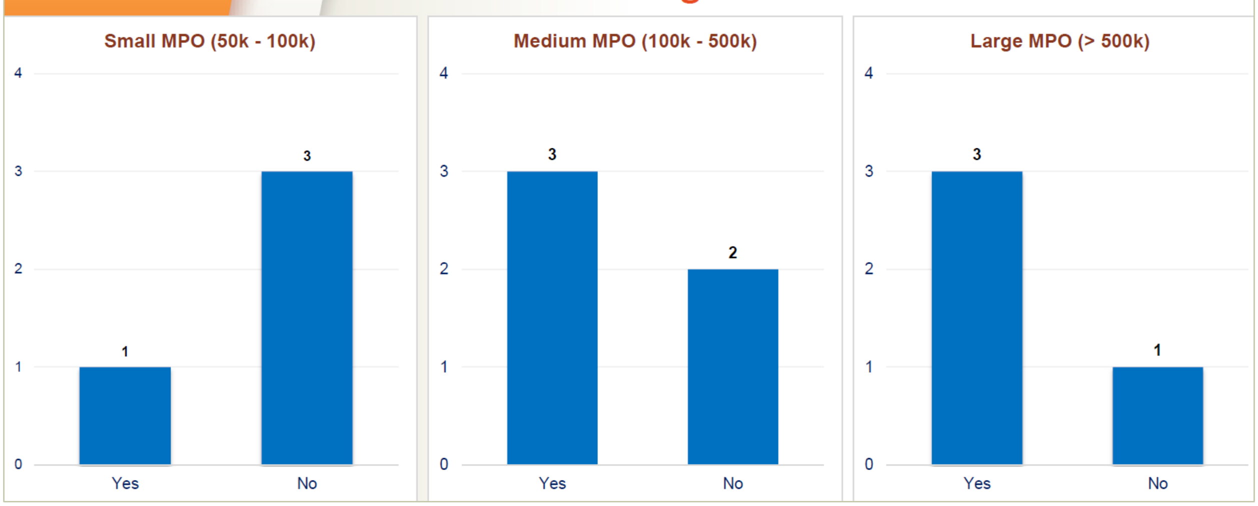
Would Your Agency Be Interested in Using the Standard Model TDOT Develops?



Elements to be Standardized



Interest in Serving as Part of a Committee



Appendix E – List of Reports

SW	Documents	Date	Agency	Subject	Comments	TMIP
X	CALTRANS f0009312-2017rtpguidelinesformpos-a11y.pdf	2017	CALTRANS	Planning framework, process, background - no model descriptions	Guidelines and validation targets	X
X	FSUTMS NEW STANDARDS AND ENHANCMENTS	2006	FDOT	Model Standards	FDOTs current systems	
X	FSUTMS validation guidelines 3-11-22.docx	2022	FDOT	Latest FDOT Calibrartion Standards	Latest FSUTMS	
X	FSUTMS_Next_Gen_White_Paper.pdf	2022	FDOT	FDOT Plans for Model improvements	FSUTMS Direction	
X	Georgia MPO Travel Demand Models Socio-Economic Data Development Guides	2018	GDOT	Guidelines on Zonal Data development	Preparing data for the SWM	
X	CCRPC-SMALL-MEDIUM-MPOS-IL.pdf	2011	Illinois Ctr for Transp	TRAVEL DEMAND MODELING FOR THE SMALL AND MEDIUM SIZED MPOS IN ILLINOIS	See literature review in this paper	
X	iowa-2019_ISMS_v1.0_10312019.pdf	2019	Iowa DOT	Iowa Model Descriptions	Includes model descriptions and validation targets	X
X	Urban Model Development Technical Report	2019	Michigan DOT	Michigan Urban Models - Guidelinesn	Description of methods	
X	MI Travel Counts III	2016	Michigan DOT	Statewide Travel Survey Results	Travel characteristics	
X	Small Area Travel Demand Model Guidelines	2008	North Carolina DOT	Guidelines for Small areas	Best practice guidelines	
X	Small Area Travel Demand Model Guidelines	2008	North Carolina DOT	Besr practice procedurs for Small areas	Best practice procedures	
X	ODOT Traffic Vol-3-TravelDemandModeling.pdf	2018	Ohio DOT	OHIO DESIGN TRAFFIC FORECASTING MANUAL	Project forecasting	
X	Oregon-DOT-guidelines.pdf	1995	Oregon DOT	Travel Demand model Development and Application Guidelines for Oregon Urban Areas	Urban Best practice methods (1995)	
X	Oregon APMv2_Ch17.pdf	2019	Oregon DOT	High-level Description of Oregon statewide and urban models	High level descriptions	X
X	Data Touring Summary 2019 Final To Print_v2.pdf	2019	TDOT	Transportation Data Inventory	Transportation Data Inventory & Plans	
X	txpack2016.pdf	2016	TxDOT	Planning Conference Presentation	Texas Methods (TEXPACK)	
X	TexPACK Version 2.6 Application Guide.pdf	2020	TxDOT/TTI	Texas Integrated Modeling System	TexPACK manual	
X	Final Phase 1 Report - Opportunities for Travel Demand Model(UTK).docx	2012	UTK	Various approaches by other states, Model inventory	TN Inventory and Other states, definition of variables, useful prototype	
X	VTM_Policy_Manual.pdf	2014	VDOT	VDOT Modeling Standards	Corradino early contributor	
X	Wisconsin Standards.pdf	2020	Wisconsin DOT	Overview of Wisconsin Traffic Forecasting	Some guidelines	X
	Caltrans travel-forecasting-guidance-survey-of-practice-pi-a11y.pdf	2019	CALTRANS	References to procedures in other states, and USDOT	No model descriptions	X
	Florida Validation_Calibration_Standards.pdf	2009	FDOT	Presentation on standards to MTF	Presentation	
	FSUTMS-Cube Framework Phase II Model Calibration and Validation Standards	2008	FDOT	FDOT Calibration Standards	Statewide Standards	
	Use of the Florida Statewide Model	2018	FDOT	Statewide Model	SWM	
	fundamental_knowledge_to_support_ld_passenger_model.pdf	2015	FHWA	Long Distance Travel Demand	Applicable for Statewide Models	
	Highway Capacity Manual, 7th Ed	2022	FHWA	Highway capacity, volume/delay, speeds, etc.	Essential support	
	Model Validation and Reasonableness Checking Manual	2010	FHWA	Model validation methods and targets	Essential support	
	Quick Respnse Freight Methods, Third Ed. (dot_56114_DS1.pdf)	2019	FHWA	Forecasting Freight (models and manual methods)	Essential support	
	GA 16-12.pdf	2018	GDOT	Georgia Statewide model	SWM	
	ILSTDM.pdf	2020	IDOT	Presentation of Illinois SWM	Statewide Model	
	ITE Trip Generation Manual, 11th Edition	2021	ITE	Trip generation rates	Support	
	KYTC Traffic Demand Model Frequently Asked Questions.pdf	2016	KYTC	Specification of software	Quick Facts	
	Maryland-DOT.pdf	2020	MDOT	Multi-resolution Statewide Model	Multi-resolution model	
	Twin Cities Forecast Guidelines_10 April06.pdf	2006	Minnesota DOT	Brief overview of Mn Models	No model descriptions	X
	TMIP Report on Findings of the Peer Review Panel NCDOT.pdf	2004	NCDOT	Report on NC Modeling	No SWM or statewide program	
	NCHRP-570.pdf	2007	NCHRP	Freight Planning Guidelines	Planning, not models, see Table 1-1 for history; 2.4 for references	
	NCHRP765.pdf	2014	NCHRP	Project-Level Demand Forecasting	Focuses on projects	
	STDM-peer-exchange.pdf	2005	TRB	Statewide Travel Demand Modeling: A Peer Exchange (Circular Number E-C075)	Survey of practice for Statewide Models	
	Metropolitan Travel Forecasting Cuurent Practixe and Future Direction	2007	TRB	Special Report 288	Current practice throughout the US	
	NCHRP Report 365 - Travel Estimation Techniques for Urban Planning	1998	TRB	Classic Guidelines for modeling - not size specific	Update of NCHRT Report 187 "Quick Response"	
	NCHRP Report 716 - Travel Demand Forecasting: Parameters and Techniques	2012	TRB	Update of 365	Kaltenbach on Peer Review	
	NCHRP Synthesis 406 Advanced Practices in Travel Forecasting	2010	TRB	Tour and Activity-Based Models	Support	
	txDOT2001.pdf	2001	TxDOT	Texas Forecasting Methods	Old	
	TN valid.pdf	2012	UTK	Minimum Travel Demand Model Calibration and Validation Guidelines for State of TN	Validation targets	

Appendix F – Bibliography

CalTrans District 11, *Travel Forecasting Guidance: Survey of Practice.* Caltrans Division of Research, Innovation and System Information, 2019.

State Highway Administration. *TRAVEL DEMAND MODELING ACTIVITIES AT MDOT SHA.* Maryland Department of Transportation, n.d.

Analysis Procedure Manual Version 2. Oregon Department of Transportation, 2019.

Kittelson Associates, Oregon System Analytics LLC, and Keith Lawton Consulting LLC. *Method Selection for Travel Forecasting.* Washington DC: Transportation Research Board : the National Academy of Sciences, 2017.

Barton-Aschman Associates, Inc. &Cambridge Systematics inc. *Model Validation and Reasonableness Checking Manual.* Travel Model Improvement Program, 1997.

Parsons Brickerhoff, and TU Munich. *Statewide and Megaregional Travel Forecasting Models: Freight and Passenger.* Washington DC: Transportation Research Board : The National Academy of Sciences, 2017.

Parsons Brickerhoff. *NCHRP Synthesis 406 : Advanced Practices in Travel Forecasting.* Washington DC: Transportatio Research Board of the National Academies, 2010.

Parsons Brickerhoff. *Small Area Travel Demand Model.* North Carolina Department of Transportation , 2012.

Parsons Brickerhoff. *Small Area Travel Demand Model Guidelines.* North Carolina Department of Transportation, 2012.

California Transportation Commission. *Regional Transportation Plan - Guidelines for Metropolitan Planning Organizations.* State of California, 2017.

Champaign County Regional Planning Commission. *Travel Demand Models for the Small and Medium Sized MPOs in Illinois.* Champaign: Illinois Center for Transportation, 2011.

HNTB Corporation. *Georgia MPO Travel Demand Model - Socio Economic Data Development Guides.* Georgia: Georgia Department of Transportation, 2018.

School of Civil and Environmental Engineering. *THE INTEGRATION OF THE REGIONAL MPO MODELS INTO THE GEORGIA STATEWIDE TRAVEL DEMAND MODEL – PHASE 1.* Federal Highway Administration, 2018.

Institute of Transportation Engineers. *Trip Generation Manual 11th Edition.* Institute of Transportation Engineers, 2021.

Committee for Determination of the State of the Practice in Metropolitan Area Travel Forecasting. *Metropolitan Trael Forecasting - Current Practice and Future Direction.* Washington DC: Transportation Research board of the National Academies, 2007.

Grogory T Giaimo, and Robert Schiffer. *Statewide Travel Demand Modeling .* Washington DC: Transportation Research Board of the National Acadamies, 2005.

Texas A&M Transportation Institute. *The Integrated Texas package System v2.6.* Texas Department of Transportation, 2020.

Michael Baker International. *Ohio Design Traffic Forecasting Manual Vol 3 : Travel Demand Modeling.* Office of Statewide Planning & Research, 2018.

Ken Cervenka, North Central Texas Council of Governments, and New York Metropolitan Transportation Kuo-Ann Chiao. *Report on Findings of the Peer Review Panel for the North Carolina Department.* Transportation Model Improvement Program, 2004.

Maren Outwater, Mark Bradley, Nazneen Ferdous, (RSG) Ram Pendyala, Venu Garikapati (Arizona State University) Chandra Bhat, Subodh Dubey (University of Texas at Austin) Jeff LaMondia (Auburn University) Stephane Hess, Andrew Daly (University of Leeds). *Foundational Knowledge to Support a Long-Distance Passenger Travel Demand Modeling Framework.* Washington DC: USDOT - Federal Highway Administration, 2015.

William A Martin, and Nancy A McGuoKin. *NCHRP Report 365 : Travel Estimation Techniques for Urban Planning.* Washinton DC : Transportation Research Board National Research Council , 1998.

Parsons Brinckerhoff, Quade & Douglas, Inc. *TRAVEL DEMAND MODEL DEVELOPMENT AND APPLICATION GUIDELINES.* Oregon Department for Transportation, 1995.

Center for Transportation Research. *Home.* n.d. https://tnmug.utk.edu/.

UT Center for Transportation Research. "Opportunities for Standardizing Travel Demand Models in Tennessee." Knoxville, 2012.

Robert Schiffer, AICP, Cambridge Systematics. *FSUTMS Calibration and Validation Standards.* MTF Model Advancement Committee, 2009.

RSG. *Illinois Statewide Travel Demand Model.* Illinois Department of Transportation, 2018.

CDM Smith, Alan Horowitz, Tom Creasey, Ram Pendyala, and Mei Chen. *Analytical Travel Forecasting Approaches for Project-Level Planning and Design.* Washington DC: Transportation research Board of the National Academies, 2014.

Cambridge Systematics. *Quick Response Freight Methods Third Edition.* Federal Highway Administration, 2019.

Cambridge Systematics. *Travel Demand modeling Policies and Procedures.* Virginia Department of Transportation, 2014.

Cambridge Systematics, TransManagement, and TransTech Managment. *Guidebook for Freight Policy, Planning, and Programming in.* The National Academic Press, 2007.

Cambridge Systematics, Vanessa Hangen Brustkin, Gallop Corporation, and Chandra R. Bhat. *NCHRP Report 716 : Travel Demand Forecasting : Parameters and Techniques.* Washington DC : Transportation Research Board of the National Acadmies, 2012.

Iowa Standardized Model Structure Team. *General Travel Demand Modeling/Forecasting Protocols and Procedures.* Iowa: Iowa Department of Transportation, 2019.

Florida Department of Transportation. *FSUTMS Model Validation Guidelines.* Tallahassee: FSUTMS, 2022.

Florida Department of Transportation. *FSUTMS New Standards and Enhancements - A User Oriented Approach.* Tallahassee: FLorida Model Task FOrce, 2006.

Florida Department of Transportation. *FSUTMS Next Gen.* Tallahassee: FSUTMS, 2022.

Florida Department of Transportation. *Use of the Florida Statewide Model.* Florida Department of transportation, 2018.

Michigan Department of Transportation. *Urban Model Development Technical Report.* MDOT, 2019.

Minnesota Department of Transportation. *Revised Guidelines for Twin City Travel Demand Forecasts Prepared for the Metropolitan District.* Minnesota Department of Transportation, 2006.

Tennessee Department of Transportation. *Data Touring Summary.* Tennessee Department of Transportation, 2019.

Texas Department of Transportation. "TEXPACK - Integrated travel Demand Modeling Application." Texas Department of Transportation, June 2016.

Wisconsin Department of Transportation. *Transportation Planning Manual .* Wisconsin Department of Transportation, n.d.

University of Kentucky, CTG, Jacobs, UrbanLabs, and UCLA. *Traffic Forecasting Accuracy Assessment Research.* Washington DC: Transportation Research Board : The National Academies Press, 2020.

Westat, *Michigan Travel Counts III.* Lansing: Michigan Department of Tansportation, 2016.

Appendix G – On-line Resources

Following is a list of some of the on-line resources used in this report:

- https://tnmug.utk.edu
- https://www.fsutmsonline.net/
- https://tfresource.org/
- https://tmip.org/
- https://www.txdot.gov/inside-txdot/forms-publications/publications/transportation-planning.html