GSTDM 2020 Peer Review Final Report

prepared for

Georgia Department of Transportation

prepared by

Modern Mobility Partners, Cambridge Systematics, Inc., AtkinsRéalis

September 2025

Table of Contents

List of Tables

List of Figures

1.0 Executive Summary

A peer review of the 2020/2050 Georgia Statewide Travel Demand Model (GSTDM) was conducted from April 28 to 29, 2025. The review used an in-person and online hybrid format, and the review panel consisted of model experts from public agencies, a university, and a consultant firm. Prior to the actual peer review, a virtual kick-off meeting was held on April 4, 2025. The kick-off meeting included introductions between the panel members and the GDOT team, planned topic areas, and general logistics. The goal of the peer review was to have external third parties evaluate the quality and application of the model, and provide constructive feedback to help improve the model, so the model can better support transportation planning and engineering activities, and a data-backed decision-making process for transportation infrastructure investment. This report summarizes the topics presented and discussed, the focus area questions, and final recommendations.

1.1 Introduction

The GSTDM is a state-of-the-art model first created by the Georgia Department of Transportation (GDOT) in the late 2000s and released in 2010 as a tool for analyzing freight flows. Over time, it has expanded its applications to a broad spectrum of planning and engineering analyses, which include activities such as supporting the Statewide Transportation Improvement Plan update, enabling Capacity and Safety Evaluation (CASE) studies, and providing information to generate growth rates for design traffic forecasts.

To evaluate the GSTDM's technical soundness, methodology, and overall suitability for transportation planning, and to explore new utilization ideas, GDOT sought feedback through peer reviews after each major model release. The previous peer reviews were conducted in 2012 and 2019, after the release of the 2006/2040 and 2015/2050 models, respectively. GDOT's commitment to conducting peer reviews underscores its intention to ensure the model's credibility and to gather valuable feedback for ongoing development. This review represents the third iteration of the peer review process, reinforcing the goal of fostering trust in the model's outputs and its applications in transportation planning.

This comprehensive review focused on key aspects, including the model's representation of travel behavior, the reliability of data sources, calibration techniques, and forecasting accuracy. Reviewers also assessed the model's assumptions and limitations, promoting transparency and identifying areas for potential improvements.

The review was organized to accommodate both in-person and remote participation, bringing together an expert panel from academia and the modeling industry. GDOT and its consulting team provided detailed presentations on the GSTDM, enabling panelists to critically evaluate the model based on the information presented and subsequently offer recommendations for enhancement. Additionally, the documentation for the 2020/2050 GSTDM, which was the focus of this peer review, was provided to the panelists a week in advance. This allowed them to become familiar with the model's inner workings before the review.

Overall, the panelists highlighted GSTDM's strengths while pinpointing opportunities for improvement. This report encapsulates the findings from the peer review process, detailing both the insights gained and the recommendations made for refining GSTDM.

1.2 Panelists

GDOT assembled a panel of model experts across the country with extensive hands-on model development and application experiences. The panelists came from different backgrounds in academia, the public sector, and the transportation planning and modeling practitioners, providing varied perspectives and scrutiny over the model development and applications. Below is a list of the panel members:

» Ram Pendyala, Arizona State University (ASU) Panel Chair (in person)

» David Lee, Tennessee Department of Transportation (TDOT) (in person)

» Alpesh Patel, North Carolina Department of Transportation (NCDOT) (in person)

» Jeremy Raw, Federal Highway Administration (FHWA) (remote)

» Guy Rousseau, Atlanta Regional Commission (ARC) (in person)

» Sarah Sun, Federal Highway Administration (FHWA) TMIP Liaison (remote)

» Krishnan Viswanathan, Whitman, Requardt, and Associates (WRA) (in person)

1.3 GDOT Supporting Team

GDOT staff prepared, organized, and conducted the peer review with support from their consultant team. The GDOT team is listed below:

» Habte Kassa, GDOT

» Brandon North, GDOT

» Stephanie Williams, GDOT

» Shannon Young, GDOT

» Jennifer Zhan, Modern Mobility Partners, LLC

» Jonathan Nicholson, Modern Mobility Partners, LLC

» Sai Gazula, Modern Mobility Partners, LLC

» Abigail Donkor, Modern Mobility Partners, LLC

» Victoria Guan Solomon, Modern Mobility Partners, LLC

» Zhang Huang, AtkinsRéalis

» Sheldon Harrison, Cambridge Systematics

1.4 Topics Covered

The peer review was conducted in a workshop format, with the first major part consisting of presentations by GDOT staff and the supporting consultant team, and discussions with the panel members. While the model is one closely integrated application, the presentation was organized into six (6) general topics to follow the model's development and application process as discussed below.

1.4.1 Overview

The overview covered the history of the GSTDM's development and applications and highlighted the major updates and enhancements in the latest 2020/2050 GSTDM, completed in 2023.

1.4.2 Structure and Inputs

This topic covered the overall structure of the GSTDM, which includes three main components for travel demand forecasting: the freight truck module, the non-freight truck module, and the passenger car module. It also covered the main trip types, input data requirements and development, and how each component operates in a coordinated sequence to produce travel demand.

1.4.3 Component Updates

This topic highlighted the key updates in each of the three primary modules and the highway assignment component, including the data sources, methodologies, and processes utilized during the update.

1.4.4 Calibration and Validation

This session provided a detailed examination of the validation statistics for the 2020 base year, as well as a comparison between the models for 2020 and 2050. The statistics and outputs from the model validation were summarized and compared with observed reference data. This allowed the review panel to assess the validation process and determine whether the GSTDM produces reasonable traffic forecasts suitable for future travel demand forecasting and other planning applications at both statewide and regional levels. Additionally, the panel aimed to offer feedback on how to improve the model's calibration and validation processes effectively to better meet these application needs.

1.4.5 Application and Integration

This topic provided an overview of the current applications of GSTDM. The discussion included how the model links to various data sets to enable strategic planning efforts and how it has been utilized to support planning studies and traffic engineering forecasts. Additionally, the ongoing integration between the GSTDM and Metropolitan Planning Organization (MPO) travel demand models in Georgia was highlighted. The presentation also covered the dashboard visualization of future traffic conditions based on outputs from the GSTDM, as well as the ongoing training and educational resources available for model users at all levels. The discussion focused on the appropriateness and effectiveness of the current applications and explored additional ways to leverage the model in support of planning and engineering activities.

1.4.6 Planned Development and Application

The final topic discussed the planned updates for GSTDM. Some updates will continue the implementation of recommendations from previous peer reviews, as relevant data and tools have become available. The benefits of these updates are becoming more justifiable due to their increasing applications, such as using the model to analyze average weekday conditions and evaluating model platforms. Other updates will focus on leveraging advancements in technology and introducing innovative practices into the GSTDM, such as using machine learning to enhance freight modeling. This topic transitioned into a panel discussion on the next steps for GSTDM and further recommendations.

1.5 Focus Area Questions

GDOT and its model development consultant team engaged in the peer preview process with the objective of obtaining valuable feedback from the review panel to enhance the GSTDM and its applications. Through coordination with GDOT planners, the team prepared ten questions for the panelists that focused on optimal strategies for utilizing the GSTDM, considering emerging trends, ongoing validation and refinement, model performance, integration of the models across Georgia, and recommended approaches for decision-making. The focus area questions and suggestions from the panel members are provided later in this report.

1.6 Recommendations

At the conclusion of the presentation to the panelists, the GDOT team allowed the panel members to discuss the GSTDM in a private setting to facilitate open dialogue amongst themselves. The panel members prepared a list of observations and recommendations and presented these to the GDOT team. After the peer review, the GDOT team categorized the recommendations and identified GDOT's priority and initial timeframe for implementation. The recommendations, priority, and timeframe are provided below in **Table 1.**

Table 1 Peer Review Recommendations

Topic	Peer View Recommendation	Priority	Timeframe
Structure and Inputs	Utilize 10-Year SE Data Forecasts from the U.S. Census Bureau and apply the 10-Year Estimates to the GSTDM prior to performing 30-Year Forecasts	Low	Short-Term
	Enhance our relationship and coordination with the state's demographer.	Medium	Mid-Term
	Make effective use of Freight Analysis Framework (FAF) Data and experiment with County-to-County FAF Data	High	Short-Term
Component Updates	Implement a differentiation of weekday vs. weekend travel patterns and demand in the GSTDM, as well as a corresponding trip table for each	High	Short-Term
	Implement a version control system for GSTDM and MPO Models	High	Mid-Term
Calibration and Validation	Implement new screenlines to enhance validation and calibration of the GSTDM	Medium	Short-Term
	Use additional data sources (e.g., Replica, Geotab) for enhancing the calibration and validation of the GSTDM and provide a deeper dive into the rich context of the individual model components	High	Mid-Term
	Review/Purchase ATRI Data as a supplement to obtain real-time GPS Data of trucks and associate different commodities to actual flows. This might provide a better understanding of tonnage and value in commodities.	Medium	Mid-Term
	Monitor trends and conditions (e.g., work-from-home vs. return-to-office, volumes, speed, e-commerce, etc.) and compare model outputs to more recent ground truth data.	High	Mid-Term
	Use NHTS Add-On Survey Data (New Version) to quantify WFH and RTO trends. Adjust HBW, HBO, HBS, and NHB trip rates based on NHTS Add-On Survey Data	High	Mid-Term
	Conduct a comprehensive literature review on the latest approaches to validating models, given the availability of big data sources and surveys.	High	Mid-Term
Application and Integration	Conduct a comprehensive literature review of how different models are being applied to enhance resiliency planning.	High	Short-Term
	Integrate a GIS Dashboard (e.g., NCDOT) to reflect the integration of GSTDM and MPO Models	Low	Short-Term
	Identify Machine Learning and AI opportunities for different model components	Medium	Short-Term

Topic	Peer View Recommendation	Priority	Timeframe
	Integrate roadway conditions and asset information into associated databases that will inform users via model outputs for project prioritization	Medium	Short-Term
	Make the dashboards fully web-native, so that no special software and licenses are needed. This can begin by involving GDOT IT in the development of the given dashboards.	Low	Mid-Term
	Review VIUS Data, and whether it would be useful for GSTDM. There may be some information related to e-commerce and truck travel.	Low	Mid-Term
	Incorporate People Mobility Metrics (i.e., derive metrics such as access to universities, colleges, medical facilities, restaurants, employment centers, etc.)	High	Mid-Term
	It is recommended that we consider the post-processing of daily model outputs and begin to disaggregate the data by time of day (e.g., peak vs. off-peak travel times)	High	Mid-Term
	Integrate other GIS Applications (e.g., Operations, Safety, etc.) to develop a comprehensive approach for transportation performance assessment and planning	Low	Long-Term
	Map the arrivals and destinations of various commodities in the state's supply chain to understand distribution patterns and freight bottleneck locations	Low	Long-Term
	Coordinate with other state agencies (e.g., Georgia Emergency Management Agency (GEMA), Georgia Department of Labor, Georgia Department of Natural Resources, etc.) and perform use cases to which the model can be applied for their benefit	Medium	Long-Term
	Implement alternate future scenarios based on evolving trends (e.g., work-from-home trends, urban vs. rural population shifts, inland port development, onshoring of manufacturing, etc.)	Medium	Long-Term
	Implement analysis of transit and rail corridors, facilitated by subarea and corridor analysis	Medium	Long-Term
	Incorporate resiliency scenarios and understanding the transportation system's ability to respond to man-made, economic, technological, and natural disasters (e.g., bridge collapses, pricing surges, cybersecurity breaches, hurricanes, flooding, etc.)	High	Long-Term
Planned Development and Application	Incorporate available parcel data and tool (i.e., CommunityViz) to understand development patterns and possible land development futures	Low	Long-Term

2.0 Topic Summaries

This section provides additional details for the topics covered during the peer review.

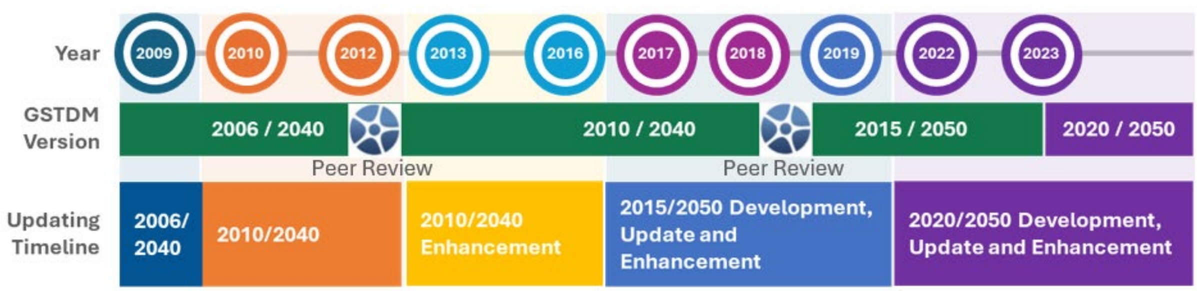
2.1 Topic #1: Overview

To provide background context to the panel members, a general overview of the GSTDM was provided, which included the historical timeline of model development, major updates to the model, the status of past peer review recommendations, and the focus area questions for the panel members to consider.

2.1.1 Model Development Timeline

Work on the initial GSTDM commenced in 2009, and it was initially conceived as an analytical tool to analyze freight flows with a 2006 base year and 2040 horizon year. It has been regularly updated to reflect new base year and horizon year data, with the most recent being the model developed with a 2020 base year and 2050 horizon year, which was completed in 2023. Continual updates are routinely made as new technologies, data, and trends are identified. GDOT has invited panelists on two previous occasions to provide a peer review of the GSTDM. These were done in 2012 and organized under the Travel Model Improvement Program (TMIP), prior to the development of the 2010 base year model, and in 2019, following the completion of the 2015 base year model, and organized by GDOT. **Figure 1** illustrates the development timeline of the model over the years.

Figure 1 GSTDM Development Timeline



2.1.2 Model Updates

The 2050/2050 GSTDM is a significant update from the 2015 model, featuring enhancements to most major components, which will be described later in this document. The following section outlines the key improvements made to specific components.

Freight Model

The freight model was re-estimated from updated 2019 TRANSEARCH and 2020 Waybill data that was purchased by GDOT. This was done following a review of FAF 5.0 data and TRANSEARCH data related to the suitability for application to the GSTDM. The TRANSEARCH data purchased and eventually used included base condition data and horizon year forecasts made by IHS/Global Insight using their proprietary forecasting process. These forecasts reflect faster freight growth when compared with the forecasted tonnages in the prior model. No major updates were made to the non-freight truck model except for minor calibration adjustments to aid in overall truck model validation.

Model Years

The base year was updated from 2015 to 2020. This involved updates of the socioeconomic (SE) data using 2020 Census for population and household information. GDOT purchased 2019 Data Axle USA from the Environmental Systems Research Institute (ESRI) to update the GSTDM's employment data. The traffic counts used for validation were from 2019 to avoid the altered travel behavior observed in 2020 due to the COVID pandemic.

The model's future horizon year was maintained as 2050; however, all 2050 future year inputs were updated based on newer data. This includes all population, household, and other socioeconomic inputs, freight inputs from TRANSEARCH and Waybill, along with special entries based on local planning knowledge of anticipated developments.

In addition to 2020 as the base year and 2050 as the future horizon year, a 2030 intermediate future year scenario with associated SE data was also developed. For each future year, multiple scenario networks were prepared, including the default No Build "worst-case" network, an Existing plus Committed (E+C) network, and a State Transportation Improvement Program (STIP) network.

Linkage to Other Data

Linkages were established between the GSTDM and several data sources to enhance the GSTDM's capability for efficient routine planning analyses across Georgia. The data sources linked to the GSTDM network include the following:

» National Highway System (NHS), Statewide Strategic Highway, Statewide Freight Network, Governor's Road Improvement Program (GRIP), Georgia Hurricane Evacuation Routes

» HERE roadway data

» Bridge data for asset management uses

Additional zone-based data linkages include:

» Social Vulnerability Index (SVI) data

» Environmental Justice Index data, Climate and Economic Justice Screening Tool data

» Boundary data for urbanized areas, MPO's and GDOT districts

Road Curvature Representation

A true shape network based on HERE data that correctly depicts actual geometric roadway alignments with proper curvature was implemented. This network includes links with dual line coding for divided highways, managed lanes, full interchange ramp representation, and Collector-Distributor roadways. This was completed for all Interstates, Principal Arterials, and Minor Arterials in Georgia. Additionally, collectors and local roadways required to provide traffic analysis zone (TAZ) centroid connectivity were also included. The work also involved tagging Traffic Message Channel (TMC) data to links as appropriate. Traffic count stations from the GDOT Traffic Analysis and Data Application (TADA) database, along with supplementary count stations from other sources like the GDOT Road Inventory, were also included in the true shape network attribute list.

Traffic Analysis Zones (TAZs)

The TAZ structure was significantly updated following a thorough review and quality control effort among team members. Census boundaries were used as the primary reference in adjusting the TAZ boundaries. The total number of zones in the model increased from 3,243 to 5,970, which represents a significant increase in zone refinement and fidelity, aiding in model calibration/validation and the ultimate usability of the model, especially in areas with no overlapping MPO model.

Model Network Mileage

The number of route miles represented in the network increased from 23,000 to over 25,000 (11% increase) compared to the prior GSTDM version.

Resiliency Planning

The inclusion of linked attributes related to hurricane evacuation routes, bridge data, the Climate and Economic Justice Screening Tool, and other data enables the model to evaluate scenarios related to resiliency planning for infrastructure development.

Other Updates

Other significant enhancements include an update of the Cube Catalog Flowchart interface, the development of an output dashboard to aid in the dissemination of model information in a user-friendly manner, and the inclusion of geodatabase and KMZ options for sharing model output data.

2.1.3 Previous Peer Review Recommendations

Table 2 outlines the previous peer review recommendations and their implementation status.

Table 2 Previous Peer Review Recommendations

Priority	Peer Review Recommendations (2015-2050 GSTDM)	Corresponding Improvements Completed In the Current 2020 & 2050 GSTDM Updates	
		Status	Description
HIGH	Enable evaluation of high-speed rail	Not implemented	N/A
	Enable evaluation of managed lane facilities	Implemented	Assignment functionality updated.
	Coordination with GDOT rail/transit/freight offices/teams to obtain data and experience using GSTDM	Partially implemented	Continual outreach to other offices is now routine. Training in applications of GSTDM and other coordination.
	Validate county-to-county flows	Partially Implemented	Regional flows validated via desire lines. Work continued to expand to the county level.
	Update freight component using the latest TRANSEARCH and FAF data	Implemented	Freight model re-estimated, updated to 2020/2050, and validated.
	NextGen NHTS (Sampling plan to ensure balance of rural and urban areas and key demographic variables)	Implemented	NHTS is used to update trip generation rates and gravity model friction factors.
	Utilize a true shape network	Implemented	True shape network developed and implemented.
	Consider modeling average weekday traffic	Not Implemented	N/A
MEDIUM	Temporal validation/before & after studies/scenario testing/sensitivity testing	Partially implemented	Post-processing approach is currently utilized.
	Enhance interaction with economic modeling	Partially implemented	Big data and REMI attributes are incorporated in zone and network structure to allow integration.
	Compare congested travel time/speed with observed INRIX data	Partially implemented	Checked as part of validation
	Validate volumes at the link level by direction	Partially implemented	Link level volumes checked as part of validation.
	Validate screenlines by truck/non-truck volumes	Not implemented	N/A
	Validate by regional-level vehicle-miles traveled (VMT) and vehicle-hours traveled (VHT)	Implemented	Comparisons with GDOT 400 series reports is a part of validation/calibration.
	Include automobile ownership	Implemented	Part of the trip generation model updates.
	Enhance socioeconomic and traffic growth data outside of Georgia by checking adjacent state models	Partially implemented	Data in adjacent state demographics checked, particularly values in adjacent models.
	Develop discrete mode choice for all purposes	Not implemented	N/A
	Full integration with MPO Models	Partially implemented	TAZ boundary consistency is being implemented. Network level consistency update is work in progress.

Priority	Peer Review Recommendations (2015-2050 GSTDM)	Corresponding Improvements Completed In the Current 2020 & 2050 GSTDM Updates	
		Status	Description
LOW	Enable evaluation of emerging technologies	Not planned	N/A
	Incorporate big data/passive data	Partially implemented	Big data added to the network where applicable, zonal O-D for freight, passenger car updates, and speeds. Work in progress to implement others.
	Address non-freight commercial vehicle last-mile deliveries	Partially implemented	Non-freight model update attempts to capture this. More work remains to be done, perhaps by utilizing Geotab data, etc.
	Consider a separate trip table for light trucks	Partially implemented	Non-freight truck methodology expansion to include light trucks is being reviewed. Handling the delineation between personal use and commercial is challenging.
	Apply different passenger car equivalent (PCE) factors to differentiate truck classes	Partially implemented	Assignment functionality updated
	Investigate supply chain freight modeling	Not planned	N/A
	Consider destination choice models	Not planned	N/A
	Incorporate population synthesis or household synthesis	Not planned	N/A
	Fully develop time-of-day assignment into model stream (instead of as post-processor)	Partially implemented	Post-processing of daily model outputs currently applied.
	Account for trips that begin in one time period and end in another	Not planned	N/A
	Explore land use forecasting and allocation modeling, including PECAS, UrbanSim, or simpler model	Not planned	N/A
	Consider rebuilding the model from scratch to a new trip- or activity-based model	Not planned	N/A

2.1.4 Questions and Focus Areas

Prior to the peer review, GDOT provided the panelists with 10 questions/focus areas covering four main topical areas: Emerging Trends in Transportation Forecasting, Validation & Performance, Model Integration & Coordination, and Model Application and Decision Support. During the overview session, these questions were discussed with the panelists for them to consider during the remaining topic sessions. More details of the questions/focus areas and panelists' responses are provided later in this report.

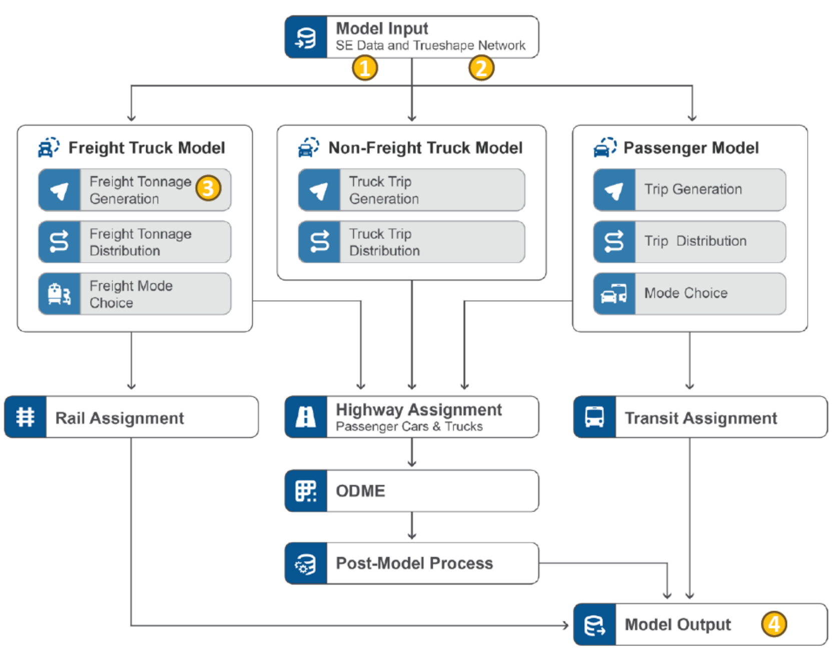
2.2 Topic #2: Structure and Inputs

The GSTDM overall model structure and input data session included information on the primary GSTDM components, TAZs, SE data, highway network, freight, and non-freight trucks.

2.2.1 GSTDM Components

The GSTDM is comprised of three main sub-modules, each capturing different demand components. These components include a passenger car, a freight, and a non-freight truck module. The passenger car module represents trips made by people in autos and light trucks. The freight module represents trips made by commodities to, from, and within Georgia. The non-freight module represents trucks that do not carry commodities, such as service trucks and trucks where no payment is made to an external entity for the service of transportation. Each module contains the same steps of trip generation, trip distribution, and mode split, except for non-freight trucks, which are assumed to be all trucks. While the steps are similar, the inputs and methodologies are not the same due to the differences in the datasets. Each of the modules is executed during a run of the model. **Figure 2** illustrates the overall structure of the GSTDM with the main inputs.

Figure 2 GSTDM Main Components



1. Socioeconomic (SE) data source: 2020 US census and American Community Survey Data for population, households and median income; ESRI/InfoGroup data for employment; Transearch data for freight commodity data. 2050 population forecast data from the Governor's Office of Planning and Budget (OPB), the Regional Conomic Models, Inc (REMI), the Atlanta Regional Commissions forecasts for Metro Atlanta and inputs from GSTDM stakeholders including other regional commissions, Department of Economic Development, and GDOT District engineers.
2. Trueshape network data: HERE data, GDOT Roadway inventory data, Highway Performance Monitoring System (HPMS), and Google Maps.
3. Eighteen commodity groups from Transearch data are used for freight trip generation. A commodity is a raw material used in the production process to manufacture a finished good.
4. Model output include, origin and destination trip estimates by trip purposes; daily volumes for cars and trucks, roadway level of service (LOS), travel time and delay, Vehicle Miles Traveled (VMTs) and Vehicle Hours Traveled (VHTs)

2.2.2 Traffic Analysis Zones (TAZs)

TAZs represent the smallest analysis unit in travel demand models and are the basis for the origin-destination interchanges that drive all model outputs. Within the GSTDM, aggregated SE data at the TAZ level were used to estimate the trip productions and attractions for each TAZ. The TAZs are smaller in size within Georgia to provide more details for analysis of travel within the state, and then progressively become larger as the distance from the state increases. The overall GSTDM TAZ layout structure is shown in **Figure 3**, which displays the extent of each of the TAZ geographic layers.

» State of Georgia: Refined TAZ System (aggregation of Census Blocks)

» Adjacent Census Tracts: Buffer region in counties immediately surrounding Georgia with zones comprised of Census Tracts

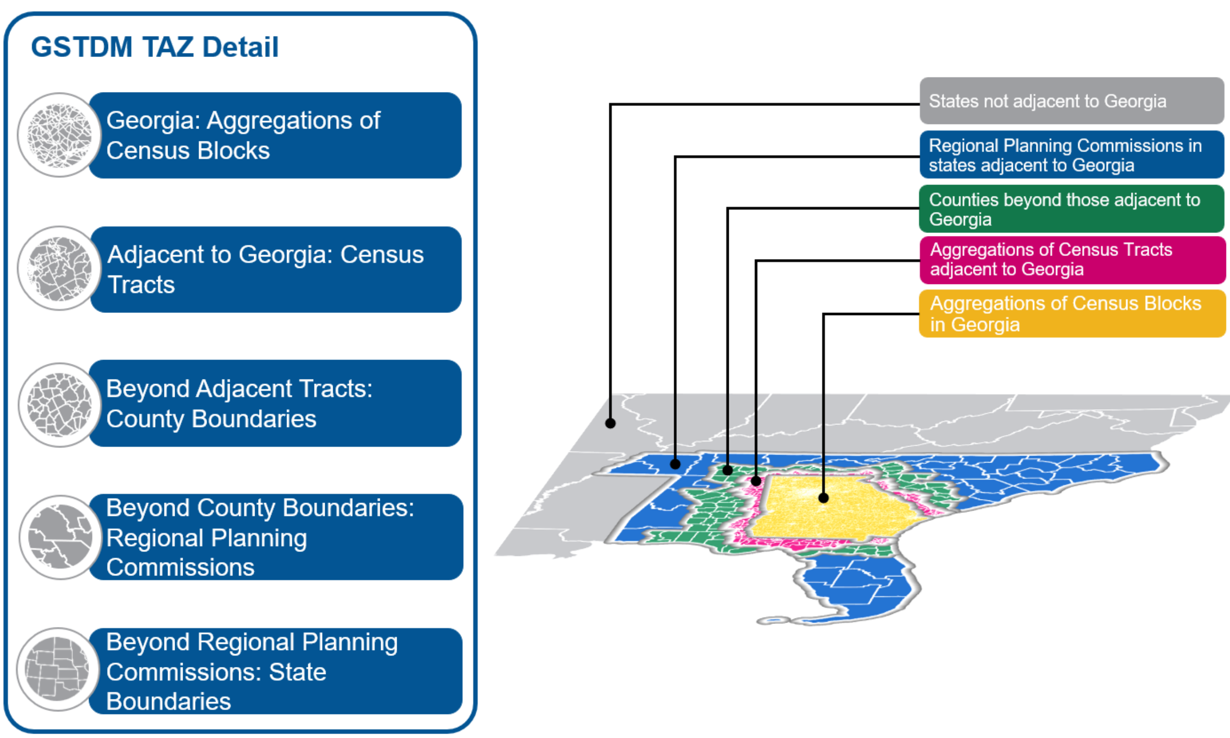
» Surrounding Counties: Counties outside the adjacent Census tract buffer region

» Surrounding Regional Planning Council (RPC) regions: Within adjacent states outside the surrounding county buffer

» Other States: Beyond the 5 states adjacent to Georgia

The 2020/2050 GSTDM maintains this tiered TAZ system with significant updates to be consistent with the new geographic boundaries of the 2020 U.S. Census data.

Figure 3 GSTDM TAZ Structure



A review was conducted in the recent update of the TAZs from the previous GSTDM. Using available reference data, the modeling team implemented a comprehensive TAZ update through both automated and manual processes. The process involved splitting some TAZs, combining others, and adjusting boundaries based on land use, roadway information, and other geographic information system (GIS) data as needed. As a result, the total number of TAZs increased from 3,243 in the previous version of the GSTDM to 5,970 in the GSTDM for 2020/2050. This significant increase greatly enhanced the model's accuracy and reliability. As a result, it improved the reasonableness of predicted travel patterns and increased sensitivity to changes in infrastructure or policies. Additionally, this improvement allows for greater flexibility in scenario testing, particularly in areas where no corresponding MPO model is available. The new TAZ system has census blocks nested in each TAZ to ensure SE data at the census block level can be seamlessly aggregated to the GSTDM TAZ level, producing more accurate SE data inputs for the model by reducing the need for data disaggregation.

2.2.3 Socioeconomic Data

Base Year

The SE data for the GSTDM 2020 Base Year was developed utilizing 2020 U.S. Census population and household data, and 2019 employment data provided by ESRI (initially collected by Data Axle). Within Georgia, the block-level data was collected and aggregated to the TAZ level. For outside of Georgia, data for larger-scale boundaries, like Census tracts, counties, RPCs, and states, were used, respectively. **Table 3** below provides details on the SE data categories and the data source for each category.

Table 3 Socioeconomic Data Variables and Corresponding Source

Data Variable	Data Source
Population	2020 Census block level, tract level and state level data
Households (Occupied Housing Units)	
Total Employment	ESRI 2019 block level data based on workplace
Retail Employment	
Service Employment	
Manufacturing Employment	
Wholesale Employment	
Median Income	2020 American Community Survey (ACS) 5-year estimates at Census tract level
Acres	Geographic Information Systems

The 2019 employment data utilize the North American Industry Classification System (NAICS) at the 3-digit level. This employment data has been aggregated to the TAZ level for both passenger and freight modeling inputs. Because the freight model requires more detailed independent variables for regression analysis, the employment categories are more specific than those used in the passenger model.

The 2020 American Community Survey (ACS) 5-year income estimates at the census tract level were used to develop the TAZ income and reported in 2020 dollars. For some tracts, median income was not reported in the ACS due to low household density and privacy concerns. In these situations, the county-level median income was used.

Forecast Year

The GSTDM 2020/2050 has two future forecast years: 2030 and 2050. The 2050 SE data was developed first as the planning horizon year, and then the 2030 SE data was interpolated using the 2020 and 2050

SE data. During the GSTDM SE data development, the ARC completed the 2020 to 2050 SE forecast for the 21-county region.[1] To maintain consistency with the ARC model inputs, ARC's 2050 forecasts for county population and employment were incorporated in the GSTDM. The data sources used for developing the forecasts for each Georgia region are described in **Table 4** below.

Table 4 GSTDM 2050 Forecast Data Sources

Regions	Population Data	Household Data	Employment Data
Counties within Metro Atlanta 21-county region	ARC's forecast	ARC's forecast	ARC's forecast
GA Counties outside of ARC 21-county region	Georgia Office of Planning and Budget (OPB)'s projections at county level	Developed using TAZ level persons per household ratios from GSTDM 2020 SE data	Regional Economic Modeling Inc (REMI) models
Outside of Georgia	Regional Economic Modeling Inc. (REMI) models	Developed using TAZ level persons per household ratios from GSTDM 2020 SE data	Regional Economic Modeling Inc (REMI) models

For data available only at the county level, a process of disaggregation to the TAZ level was used, which assumed a TAZ's SE data proportion share within the county remained similar between the base year and forecast year. The 2030 intermediate-year SE data were developed based on the annual growth rates calculated from 2020 and 2050 data at the TAZ level.

Stakeholder Outreach

As the GSTDM is used to support numerous planning initiatives in Georgia, GDOT sought feedback from stakeholders throughout the state to review the base year and future year SE data and provide valuable insight for their respective local areas. The coordination efforts leveraged local knowledge in forecasting growth throughout the state and improved transparency in the forecasting process. The stakeholders included planners from all Regional Commissions in Georgia, GDOT District engineers, and staff from the Georgia Department of Economic Development.

Prior to meeting with the stakeholders, the draft SE data for the base year and forecast year of 2050 were thoroughly reviewed against the following data sources for reasonableness:

- GSTDM previous model data
- Longitudinal Employment Household Dynamics (LEHD)
- Georgia Department of Labor (GDOL)
- U.S. Bureau of Labor Statistics (BLS)

The draft SE data were then mapped to counties and shared with stakeholders. A virtual meeting was held with the stakeholders to present the data and provide a survey form for their feedback. In cases where the stakeholders had comments, one-on-one meetings were held to discuss and revise the forecasts, as necessary. Following the stakeholders' inputs and feedback on future growth in their specific

[1] https://33n.atlantaregional.com/21-county-data-dashboard.

region, the 2050 SE data were finalized. The final SE data projections for Georgia and the rest of the contiguous U.S. in the GSTDM 2020/2050 are summarized in **Table 5** below.

Table 5 GSTDM SE Data Summary

Socioeconomic Data	Years	Georgia	Rest of U.S. (48 states)	Total Model Area
Population	2020	10,456,500	310,635,900	321,092,400
	2030	11,451,600	340,764,500	352,216,100
	2050	13,814,300	410,387,100	424,201,400
Employment	2020	4,696,100	147,640,200	152,336,300
	2030	5,132,600	165,635,900	170,768,500
	2050	6,610,900	208,424,700	215,035,600

2.2.4 Highway Network

True Shape Development

The 2020/2050 GSTDM network was completely revised using HERE data following a review of several input sources. Among the sources reviewed were the GDOT Road Inventory Data, INRIX data, HERE, and Intelligent Direct, which is an indirect seller of HERE data. During the review process, the HERE data was selected because it met all criteria for the true shape conversion, and through GDOT's joint data purchase program with ARC, GDOT had access to the HERE data at no extra cost. The HERE data allowed the links internal to Georgia to have a true shape geometric representation with the roadway curvature, ramps, collector-distributor roads, dual line representation of divided highways, intersection turn links, and other items represented. The true shape network allows several benefits for modeling and planning at the statewide level, including:

» The network is no longer a stick/node representation with inaccurate curvature and distances.

» Increased accuracy in the preparation of maps and online dashboards.

» The data allows linkage to the traffic message channels (TMC) for post-processing analysis of historical travel time and speed data.

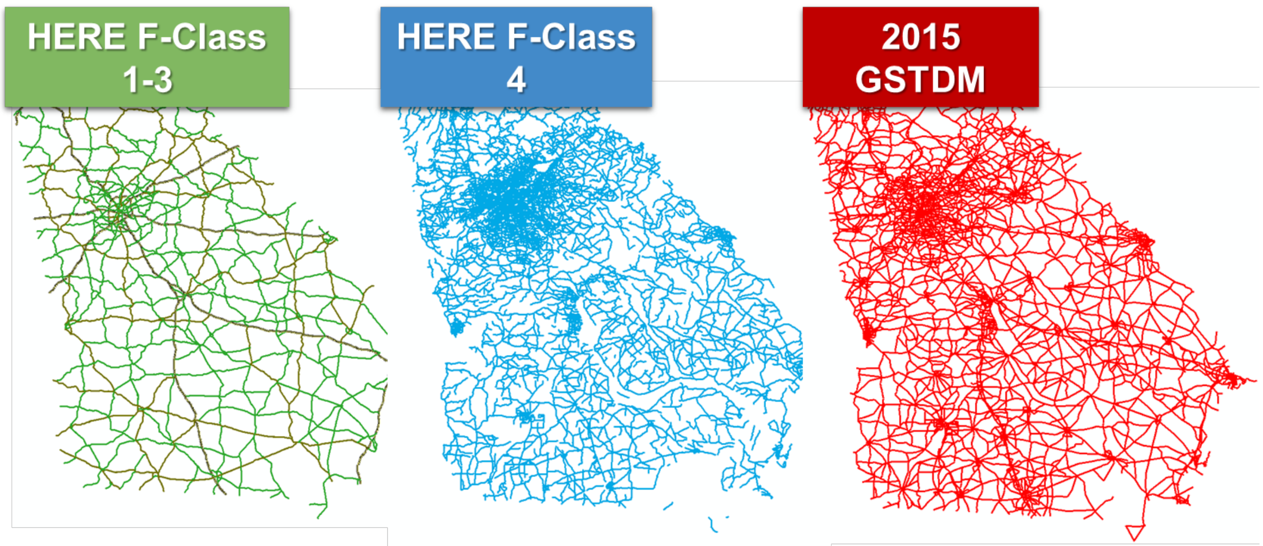
» The data allows better linkage to the large passive data eco-system for the increasingly available "Big Data" from probes and more streamlined integration with traffic counts and crash data.

Figure 4 illustrates an example of the improvements that occurred using true shape coding methodology.

Figure 4 True Shape versus Previous Network Representation

To develop the eventual network used in the model, the team developed and applied a thorough process using databases and spatial queries to filter out the comprehensive HERE network, manipulate the data using GIS, and interface with Bentley's CUBE software. The team also conducted a detailed QA/QC process to ensure that the network accurately represents the roadway infrastructure. **Figure 5** compares the network coverage area between HERE's internal functional classification (F-Class) system and the 2015 GSTDM coverage area. It's important to note that HERE's F-Class system is not consistent with the Highway Performance Monitoring System (HPMS) functional classifications.

Figure 5 HERE Network and Functional Class Network Detail vs 2015 GSTDM



Functional Classification

The GSTDM 2020 update used the functional classification system following the FHWA's guidance. The HPMS functional classification definitions used in the current iteration of the model are described in **Table 6**. Functional classification values reflect the 2020 roadway types in Georgia based on GDOT's 2020 Roadway Inventory Data. The GSTDM includes all roads functionally classified as minor arterial and above. Collectors and local roads are included as necessary based on TAZ and general network connectivity.

Table 6 GSTDM HPMS Functional Classes

FClass	Description
1	Interstate
2	Freeway / Expressway
3	Principal Arterial
4	Minor Arterial
5	Major Collector
6	Minor Collector
7	Local Road

Traffic Counts

GDOT's Traffic Analysis and Data Application (TADA) is its official traffic count database and was used as the primary traffic count data source for GSTDM development and application. To support model validation, approximately 3,900 count stations are included in the GSTDM 2020/2050 network.

Managed Lanes

Managed lanes in Georgia are included in the model network and treated differently from general-purpose lanes. Compared to general-purpose lanes, managed lanes use a capacity-constraining method for traffic assignments. Four types of managed lanes are coded in the 2020/2050 GSTDM:

» High Occupancy Vehicle (HOV) Lane

» High Occupancy Toll Lanes (HOT)

» Express Lanes

» Commercial Vehicle Lanes (CVL)

Rail

The conventional train mode mainly represents Amtrak service. Currently, there are four major services running through Georgia, with the Crescent serving Atlanta and the other three, including the Silver Meteor, the Palmetto, and the Floridian, connecting Savannah to other national destinations along the East Coast. Intrastate travel by rail is limited, given the restricted number of corridors and Georgia stops. The passenger rail network piggybacks off the same network used for the freight rail assignment and remains a stick/node network, unlike the true shape roadway network.

2.2.5 Freight Model

The GSTDM freight model is a state-of-the-practice commodity flow model that relies on TRANSEARCH 2019 data purchased by GDOT. The dataset also includes 2050 projections to assist with the development of future-year commodity flows. The dataset provides information on the tonnage of commodities, the value of the transported commodities, and the number of units, such as trucks, carloads, or twenty-foot equivalent units (TEU's) for intermodal containers. Additionally, the modes used to transport commodities are included, with the key ones being truck, carload rail, intermodal rail, air, water, and pipeline. There are 17 commodity groups used in the GSTDM model, as shown in **Table 7** below.

Table 7 GSTDM Commodity Groups

Number	Name	Abbreviation
1	Agriculture products	AGRI
2	Non-metallic mining	MING
3	Food and tobacco products	FOOD
4	Textile and apparel products	TEXT
5	Lumber, wood, and furniture products	LUMB
6	Paper and printing products	PAPR

Number	Name	Abbreviation
7	Chemical products	CHEM
8	Petroleum and coal products	PETR
9	Rubber, plastic, and leather products	RUBB
10	Clay, stone, glass and concrete products	STON
11	Primary metal products	PMTL
12	Fabricated metal products	FMTL
13	Machinery and transportation equipment	MACH
14	Instruments and miscellaneous manufacturing products	INST
15	Waste and scrap materials	WSTE
16	Mail, freight forward, and miscellaneous freight shipments	MAIL
17	Bulk movement, secondary, intermodal, and warehouse traffic	SECN

Trip Generation

The model uses the standard 4-step process, including freight trip generation, freight trip distribution, mode split, and joint assignment in conjunction with passenger and non-freight truck trips. In trip generation, a regression relationship is derived from each commodity group and the associated NAICS 3-digit employment, as referenced earlier in the write-up on model inputs.

Special generators are used in the model to account for non-standard relationships, such as those that may exist at ports. In these situations, the standard trip generation regression relationships are overridden and replaced with the special generator values. The estimated regression relationships using the 2019 data and employment data may be referenced in the GSTDM documentation.

Trip Distribution

The GSTDM freight gravity models, or commodity trip distribution equations, were developed based on the TRANSEARCH database. A negative exponential function was used to estimate the friction factors of the freight distribution model based on the average travel distance from the origin zone to the destination zone for each commodity group. Owing to the differences between each category, trip distances for external-internal (E-I), internal-external (I-E), and internal-internal (I-I) trips must be considered separately. The outputs of the trip distribution process are trip matrices of freight shipments with trip origin and destination by commodity group. Values in the trip matrix represent trips between the zones where tonnages are produced and the zones in which they are consumed.

Mode Choice

The standard approach for developing future year modal split is to develop a logit model for mode choice. This model relies on the utilities associated with competing modes. The coefficients of the utility equations are developed by fitting the observed modal shares to the modal utilities. Travel times for each mode are calculated using defined network skims and rules related to rest time for drivers, intermodal overhead time for transfers, network travel time, and other factors.

The GSTDM freight mode choice model is an incremental mode choice model that requires an existing mode share table. The required table is derived directly from the modal freight tonnage flow data, categorized by origin, destination, commodity group, and mode. The estimation file is designed to report the percent share of freight flows by each mode for a given origin, destination, and commodity group combination, rather than to report freight flows in tons.

Table 8 presents modal shares by tonnage and percentages. Trucks are the most dominant mode, carrying 77 percent of all freight in the state, followed by carload rail and intermodal rail at 12 percent and 11 percent, respectively. The GSTDM results are consistent with the TRANSEARCH 2019 data (Truck) and Waybill 2019-2020 data (Carload and Intermodal).

Table 8 TRANSEARCH 2019—GSTDM Modal Share Comparison

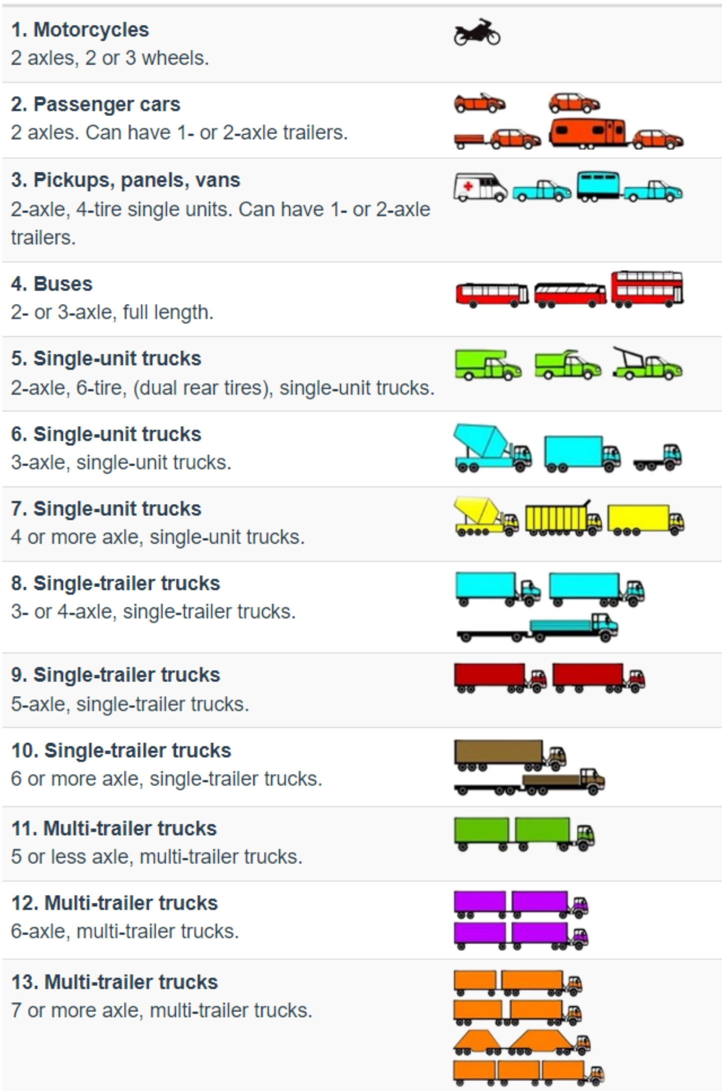
	TRANSEARCH Data 2019		GSTDM	
Mode	Tonnage (million)	Percent	Tonnage (million)	Percent
Truck	496	74.3%	587	77.3%
Carload Rail	89	13.3%	89	11.7%
Intermodal Rail	83	12.4%	83	11.0%

A full description of the model and methodology is available in the GSTDM documentation.

2.2.6 Non-Freight Truck Model

The Non-Freight Truck model captures all the other medium and heavy trucks that do not carry freight as defined in the TRANSEARCH data. They are typically service, maintenance, and construction trucks that travel short distances. The model uses trip generation and trip distribution based on a modified version of the Quick Response Freight Methods (QRFM) that uses borrowed rates from Virginia in the regression equations for trip generation. For trip distribution, a standard gravity model is used with a negative exponential function of the average trip length for each class of trucks. Two types of trucks are represented in the model, including medium and heavy trucks. For assignment purposes, they are assumed to correspond to single-unit and combination-unit trucks, respectively. **Figure 6** illustrates the 13 FHWA vehicle categories, with types 4 to 6 representing single-unit trucks and types 7 through 13 representing combination-unit trucks.

Figure 6 FHWA Vehicle Categories



1. Motorcycles	2 axles, 2 or 3 wheels.
2. Passenger cars	2 axles. Can have 1- or 2-axle trailers.
3. Pickups, panels, vans	2-axle, 4-tire single units. Can have 1- or 2-axle trailers.
4. Buses	2- or 3-axle, full length.
5. Single-unit trucks	2-axle, 6-tire, (dual rear tires), single-unit trucks.
6. Single-unit trucks	3-axle, single-unit trucks.
7. Single-unit trucks	4 or more axle, single-unit trucks.
8. Single-trailer trucks	3- or 4-axle, single-trailer trucks.
9. Single-trailer trucks	5-axle, single-trailer trucks.
10. Single-trailer trucks	6 or more axle, single-trailer trucks.
11. Multi-trailer trucks	5 or less axle, multi-trailer trucks.
12. Multi-trailer trucks	6-axle, multi-trailer trucks.
13. Multi-trailer trucks	7 or more axle, multi-trailer trucks.

2.2.7 Freight and Non-Freight Trucks

The freight trucks and the non-freight trucks are stored in trip tables containing single-unit and combination-unit truck trip O-Ds, which are then assigned along with passenger car O-Ds using user equilibrium methodology to account for the congestion effects.

2.2.8 Questions and Discussion

Several questions and comments were fielded related to SE data preparation, TAZ development, network preparation, and the freight model. Among them were:

» Why was ESRI employment data used, and what methodology was followed in preparation of that data, such as whether LEHD data was used?

- **Answer**: The team considered various sources but determined the ESRI data best met GDOT's needs for this update.

» How well do the GSTDM TAZ boundaries align with MPO TAZ boundaries?

- **Answer**: The overwhelming majority of MPO TAZs nest within GSTDM TAZ boundaries.

» There was a suggestion to perform block group checks in addition to block checks for socioeconomic inputs like population.

- **Answer**: This will be considered as part of ongoing model enhancement.

» How did the team reconcile SE data growth assumptions for the ARC region, and how does the team account for the MPO versus ARC inputs for Cartersville and Gainesville, which are in the ARC domain?

- **Answer**: To ensure consistency, the team used the ARC metrics as the control total for the GSTDM and MPO inputs.

» Why were commodities grouped in the manner they were?

- **Answer:** The commodity groupings in this update were not changed from the previous GSTDM version. Modified groupings could be part of future updates.

» Does the network include STRAHNET facilities and other identifiers?

- **Answer:** Yes, the network includes STRAHNET and several other identifiers (GRIP corridors, Freight Network, etc.).

2.3 Topic #3: Component Updates

After the model structure and input data topic session, the major updates to the model components were discussed. These included updates to the passenger model, freight model, non-freight truck model, and the highway assignment, which are provided below.

2.3.1 Passenger Model Updates

For the passenger model, the key updates involved using the latest NHTS data to update the trip generation household curve, auto ownership, and trip rate information. **Figure 7** provides a comparison of the household size curves between the 2015 and 2020 GSTDM based on the CTPP 2000 and ACS 2020 databases, respectively. **Figure 8** compares trip rates between the 2015 GSTDM and the 2020 GSTDM. In addition to updating the rates based on newer data, the 2020 GSTDM included both location information (urban vs. rural) and household characteristics (auto ownership) to further refine trip rates.

Figure 7 Household Size Comparison

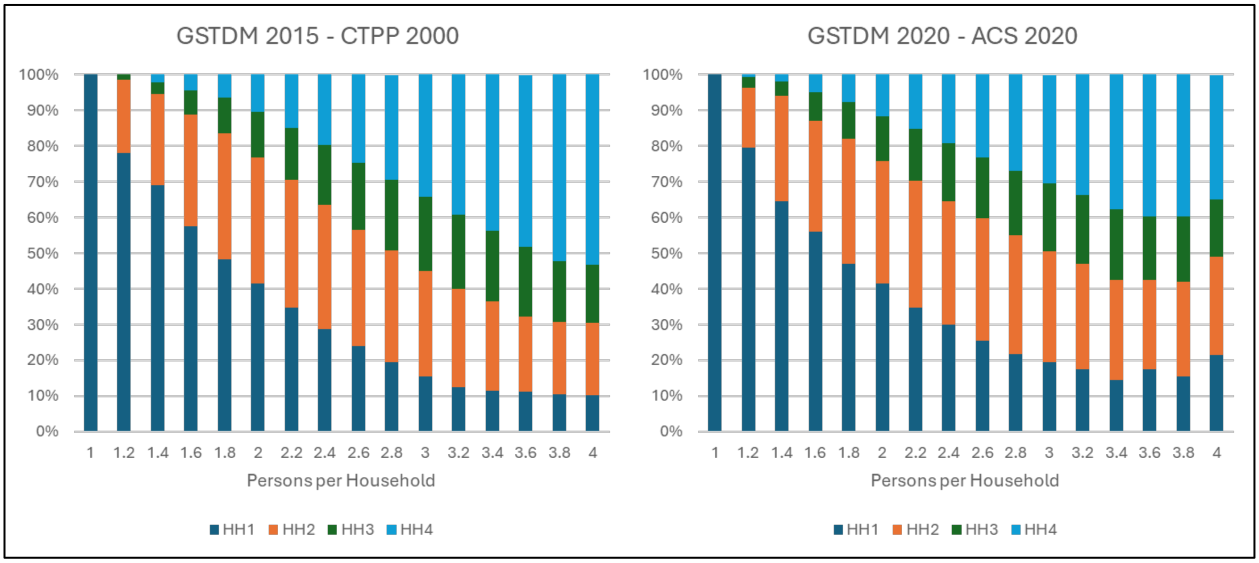
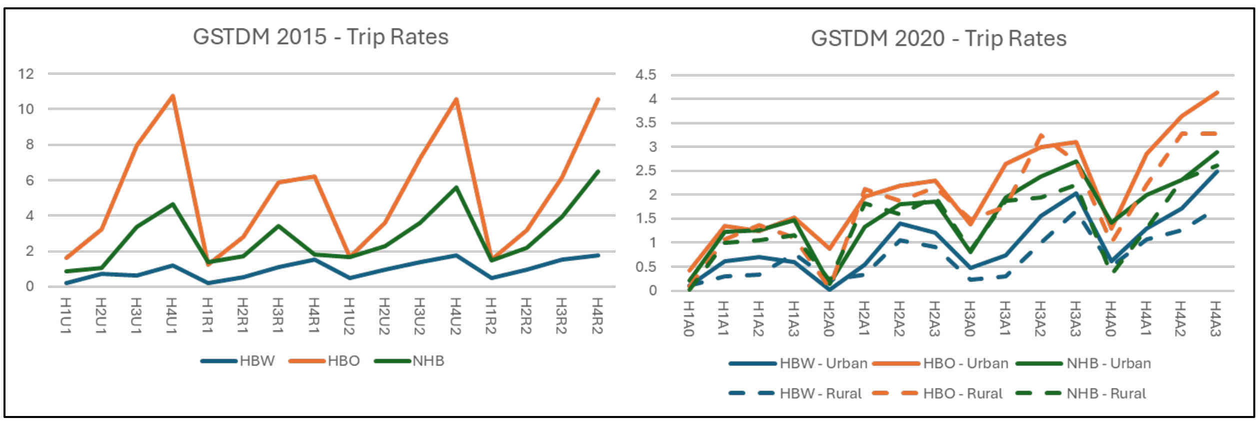


Figure 8 Trip Rate Comparison



The friction factors for the standard gravity model used in trip distribution were updated based on the ACS and NHTS information. The model stratifies trips into short-distance Internal-Internal (I-I) and Internal-External (I-E) and long-distance Internal-Internal (I-I) and Internal-External (I-E) trips.

2.3.2 Freight Model Updates

The updates to the freight model included re-estimation of the regression relationships used in trip generation between employment and commodities by grouped categories, as described earlier for both productions and attractions using 2019 TRANSEARCH and 2020 Waybill data.

For trip distribution, the gravity model was updated to use the reported TRANSEARCH average commodity travel distance in the relationship, where the impedance is the inverse of the average distance by commodity. Skims derived using the true shape network representation were used to derive travel distances and calculate I-E, E-I, and E-E values.

For mode share, the updated TRANSEARCH and Waybill mode shares by tonnage were updated and used as the base for the incremental logit procedure.

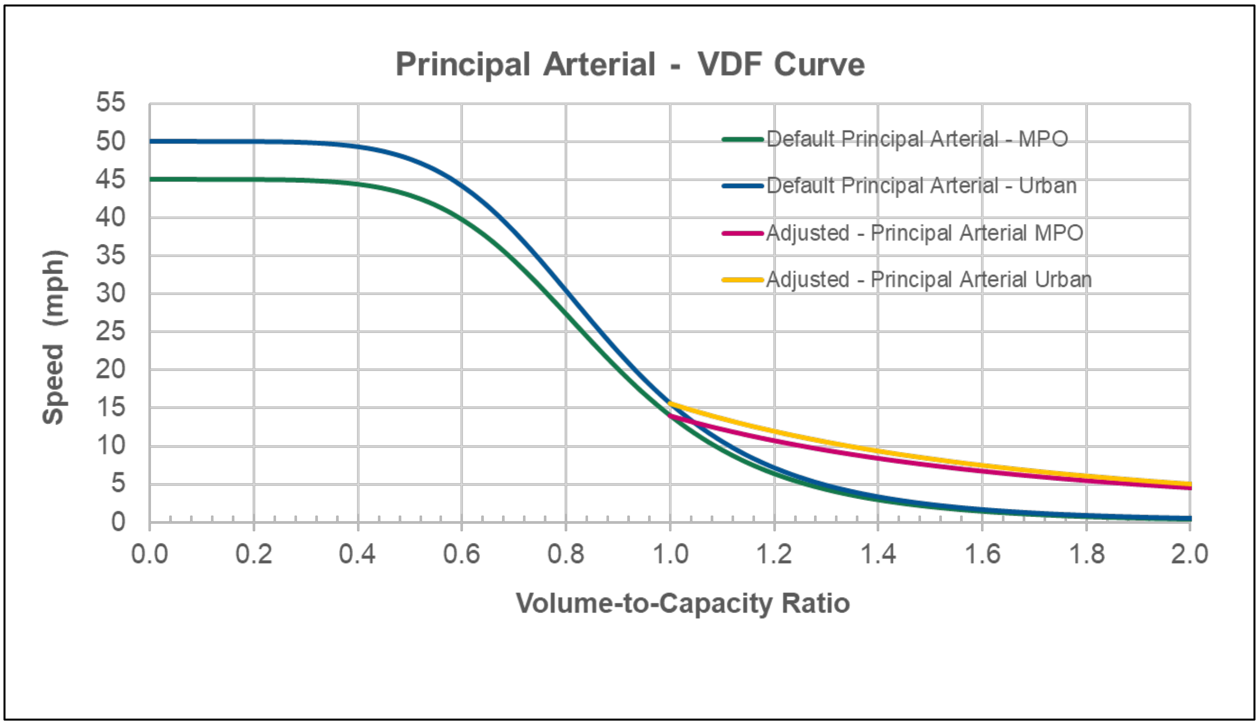
2.3.3 Non-Freight Truck Model Updates

The primary updates to the non-freight truck model involved adjusting the regression rates for medium and heavy truck trip generation and the associated friction factors using borrowed values from Virginia.

2.3.4 Highway Assignment Updates

Updates in the assignment routine primarily involved adjustments to the Volume Delay Function (VDF) in instances where traffic volumes were estimated to be at or above link capacity for arterial functional class links. The adjustments primarily involved flattening the speed decay at volume-to-capacity (V/C) ratios exceeding 1.0. This resulted in traffic flow in highly congested conditions to operate at more reasonable speeds. **Figure 9** illustrates the VDF adjustments implemented for arterials.

Figure 9 VDF Adjustment for Principal Arterials



Other major updates to the assignment routine included changes to the handling of managed lanes' capacity to ensure that managed lanes are shown to perform better than general-purpose lanes under typical congested conditions.

2.3.5 Questions and Discussion

The following were discussed:

» How well does the HERE network match up with OpenStreetMap, aerials, etc.?

- **Answer:** The team responded that checks indicated good representation that was geographically consistent.

» Why was PUMS data not utilized for vehicle occupancy instead of the NHTS?

- **Answer:** The NHTS data was readily available at the time; however, use of PUMS data will be considered for future updates.

» Did the team consider area types for trip rate determination

- **Answer:** Yes, area types were considered for trip rate determination. Additional consideration will be given to the area type adjustments in the next major model update.

2.4 Topic #4: Calibration and Validation

The topic for calibration and validation included results from the base year model covering trip generation, trip distribution, and freight mode choice; however, the primary focus of the session focused on the highway assignment. Additionally, comparisons were presented illustrating the change in total trips and VMT between the base year 2020 model and the future year 2050 model.

2.4.1 Passenger Model

The validation of the passenger model focused on refining the parameters in each step to ensure that the resulting model produces reasonable forecasts that approximate observed travel conditions. The model validation process focused on each step of the four-step process to ensure that input and output metrics fall within reasonable ranges as defined in reference literature and in practice.

Trip Generation

The trip rates were validated against peer statewide models as well as the 2017 NHTS add-on data. **Table 9** summarizes the aggregated trip rates in the passenger trip model along with the range observed in peer statewide models per the *Final Report on the Validation and Sensitivity Considerations for Statewide Models*[2] referred to as the *NCHRP Project 836-B Task 91 Report* for the rest of this document. The aggregated passenger model trip rates are reasonably within the range of other statewide models.

Table 9 GSTDM Trip Rates Compared to Peer Models

Aggregated Trip Rates	GSTDM 2020/2050	Other Statewide Models*
Person Trips/TAZ	8,307	2,134~16,197
Person Trips/Person	4.3	1.95~4.24
Person Trips/Household	11.1	5.41~10.33
Person Trips/Employee	9.5	4.41~8.76

Table 10 compares the model results with the 2017 Georgia NHTS add-on data. The passenger model's trip rates match the NHTS data well.

[2] Final Report: Validation and Sensitivity Considerations for Statewide Models NCHRP Project 836-B Task 91(http://onlinepubs.trb.org/onlinepubs/nchrp/docs/NCHRP08-36(91)_FR.pdf)

Table 10 GSTDM Trip Rates Compared to 2017 NHTS Add-On Data

Trip Rates	GSTDM 2020/2050	2017 NHTS Add-on Data
Person Trips/Household	11.1	10.1
Person Trips/Person	4.3	5.0
% HBW Trips	14.9%	14.5%
HBW Trips/Household	1.5	1.5
HBO Trips/Household	3.5	3.7
NHB Trips/Household	2.8	2.5

Trip Distribution

The trip distribution model was calibrated to match the 2017 NHTS average trip lengths by trip purpose (HBW, HBO, and NHB) and compared against other statewide models. These comparisons are provided in **Table 11**, and as shown, the GSTDM matched the NHTS data well. While the GSTDM resulted in HBW trips longer than other statewide models, preference was given to more closely matching the NHTS data.

Table 11 GSTDM Average Trip Length (Minutes) Comparison with Peer Statewide Models

Trip purpose	GSTDM2020/2050	2017 NHTS Add-on Data	Other Statewide Models*	
			Low	High
HBW	28.2	29.0	11	23
HBO	21.4	21.9	12	20
NHB	19.0	19.1	9	23

Other validation checks included region-to-region desire line flow comparisons and correlation comparisons between the GSTDM and ACS data. **Figure 10** and **Figure 11** illustrate the GSTDM and ACS regional desire line comparisons, respectively.

Figure 10 Region to Region Total Flow — GSTDM 2020

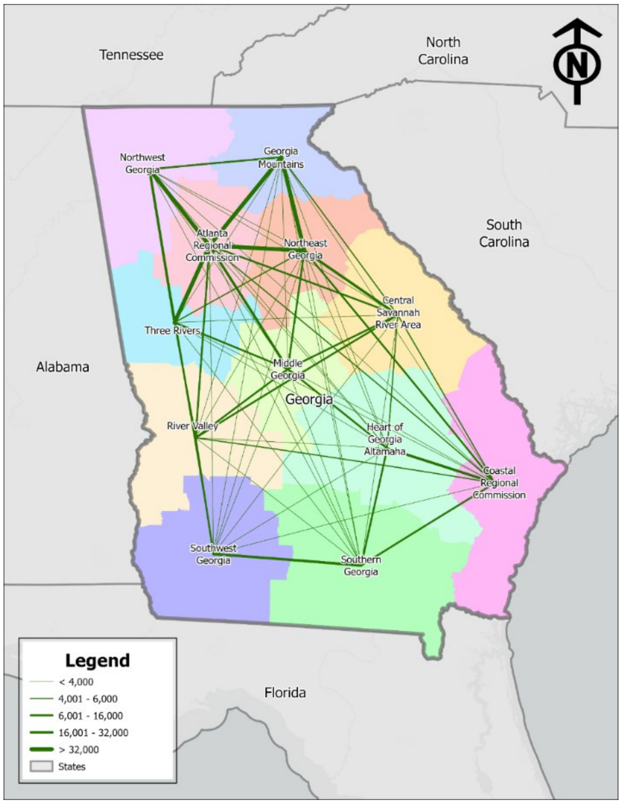
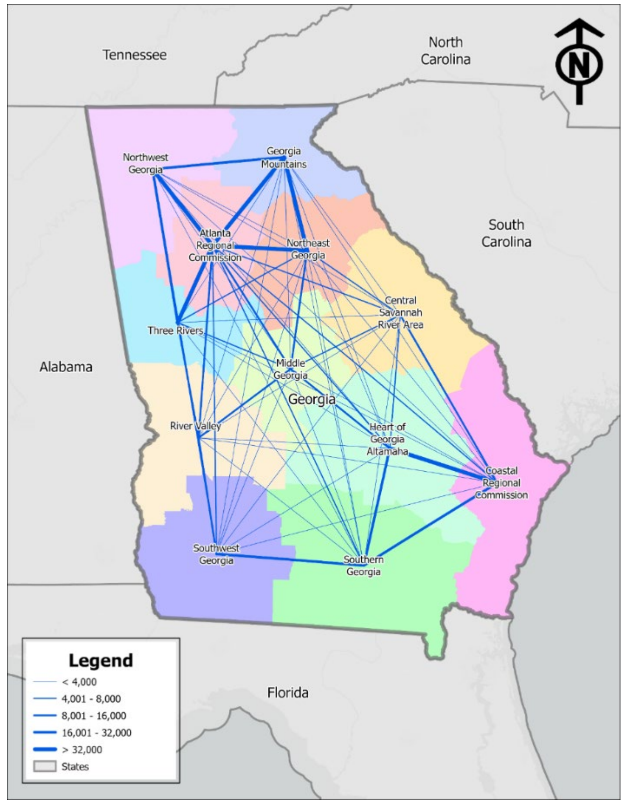


Figure 11 Region to Region Total Flow - ACS



Auto Occupancy

The vehicle occupancies used to convert automobile passenger trips to vehicle trips were validated against those from peer statewide models for different trip purposes and are presented in **Table 12**.

Table 12 Vehicle Occupancy Rate Comparison

Trip Type	Short Trips			Long Trips		
	GSTDM	Other Statewide Models		GSTDM	Other Statewide Models	
		Low	High		Low	High
HBW	1.1	1.1	1.19	1.5	1.19	2.43
HBO	1.5	1.54	1.78	2	1.31	2.69
NHB	1.5	1.56	1.79	2	1.31	2.69
IE/EI	2	1.5	2.26	2	1.5	2.55

2.4.2 Freight Model

Validation of the freight model primarily involved ensuring the outputs from each step produced reasonable tonnages for each combination of commodity group, mode, and O-D pairs. Special generators were utilized where calibration results proved insufficient to provide good validation. Following trip generation, distribution, and mode choice, tonnages and passenger trucks were converted to daily trucks prior to assignment.

2.4.3 Highway Assignment

The highway assignment portion of the model represented the largest calibration and validation effort. GDOT's comprehensive traffic counts were the primary source used for validation. Model volumes were validated against counts at various scales, including the Georgia state line, MPO boundaries, screen lines, roadway functional classifications, volume ranges, and individual link volumes. The validation metrics included volume-to-count ratios, percent Root Mean Squared Error (RMSE), maximum desirable deviation curves, and R-squared illustrations using scatterplots. An example showing the percent RMSE validation by volume group is provided in **Table 13**. As indicated by the table and the other validation measures presented during the peer review, the GSTDM was well-validated compared to observed traffic counts.

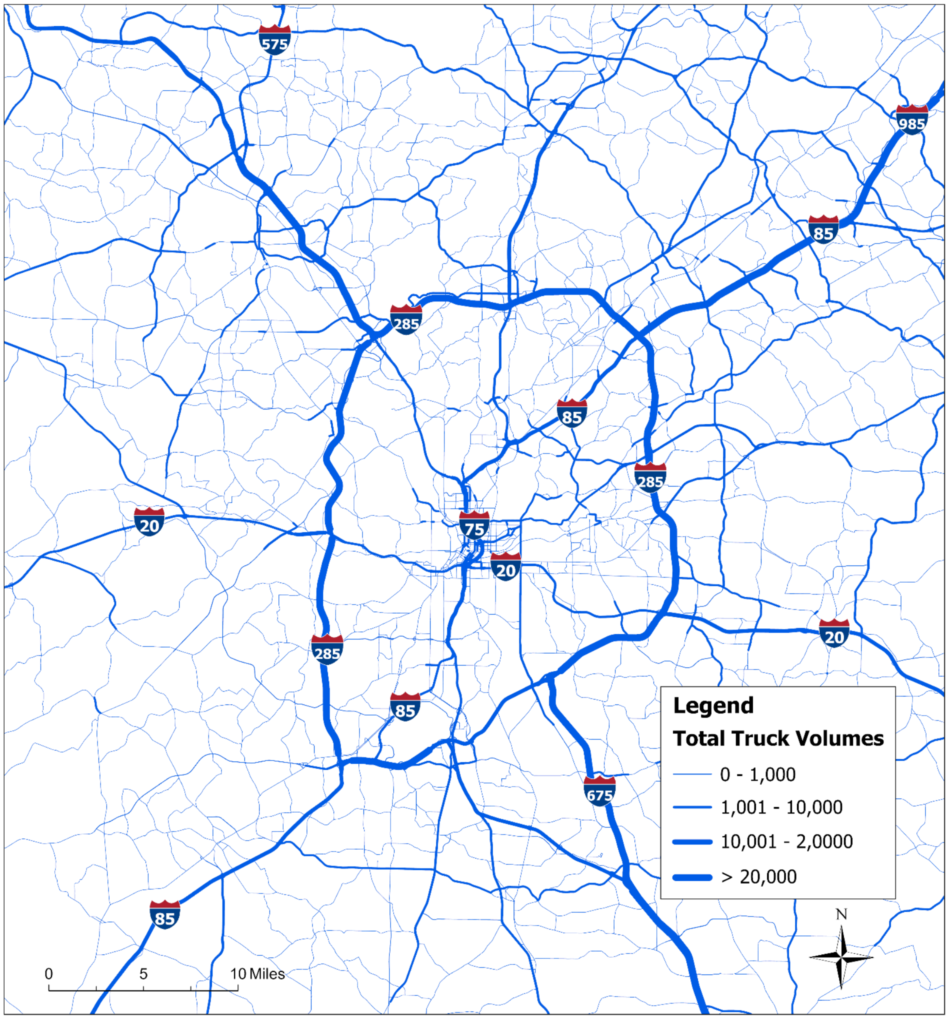
Table 13 Percent RMSE Comparison by Volume Group

Volume Group	Number of Count Locations	% RMSE GSTDM	Other Statewide Models*	
			Low	High
<5000	2,314	86%	22	290
5,000-10,000	2,734	60%	22	114
10,000-20,000	2,328	49%	22	86
20,000-30,000	856	37%	19	57
30,000-40,000	412	29%	14	49
40,000-50,000	186	25%	12	36
>50,000	403	19%	5	41
All Counts	9,233	45%	3	90

In addition to validating the GSTDM against traffic counts, the model-estimated VMT was compared to the observed GDOT VMT by roadway functional classification at both the statewide level and GDOT district level. These comparisons illustrated that the GSTDM matches the observed VMT well.

Given the importance of freight and the resulting truck trips along Georgia's roadway system, the GSTDM estimated truck volumes were compared against GDOT's vehicle classification counts, where available. One key component of the GSTDM's truck validation relates to the prohibition of through-trucks on the Downtown Connector (I-75/I-85) in the City of Atlanta. The GSTDM is structured to prevent these through-trucks from using the Connector, as evidenced by **Figure 12** which illustrates large truck volumes for the I-285 Bypass.

Figure 12 Atlanta Region Truck Assignment



2.4.4 Rail Assignment

Rail tonnage assignment maps were also reviewed to determine if general flows by commodity were logical at a broad planning level. For example, general assessments were made to ensure commodities like coal are imported into the state and not exported, as Georgia is not a coal producer in significant quantities. Reviews were also undertaken to ensure that the travel distances by rail for commodities are reasonable. Line-specific assignment validation was not done owing to the complexities of rail dispatching regarding routes taken, capacity, and other factors like ownership of corridor assets by mode.

2.4.5 Future Year Model and Growth Rates

As part of model validation, it is important to perform a reasonableness check on the predicted future conditions using the calibrated/validated base year model parameters, future SE data, and freight data inputs. This helps identify problems such as negative, low, or no growth in zones, unreasonable assignment indicators, problematic trip patterns, and others that were not apparent in base year development and validation. **Figure 13** provides a comparison between Internal-to-Internal trips for HBW, HBO, and NHB trips. As can be seen, in every case, trips increase between 2020 and 2050. Similar trends were observed for other trip stratifications, for VMT, VHT, and for freight and non-freight trucks.

Figure 14 and **Figure 15** illustrate comparisons between 2020 and 2050 trucks from the freight and non-freight models, respectively. During the peer review, it was noted that the tonnage for petroleum and bulk movement significantly increased between 2020 and 2050, which will be reviewed as part of ongoing GSTDM model updates.

Figure 13 GSTDM Internal Trip Comparison Between Base and 2050 Horizon

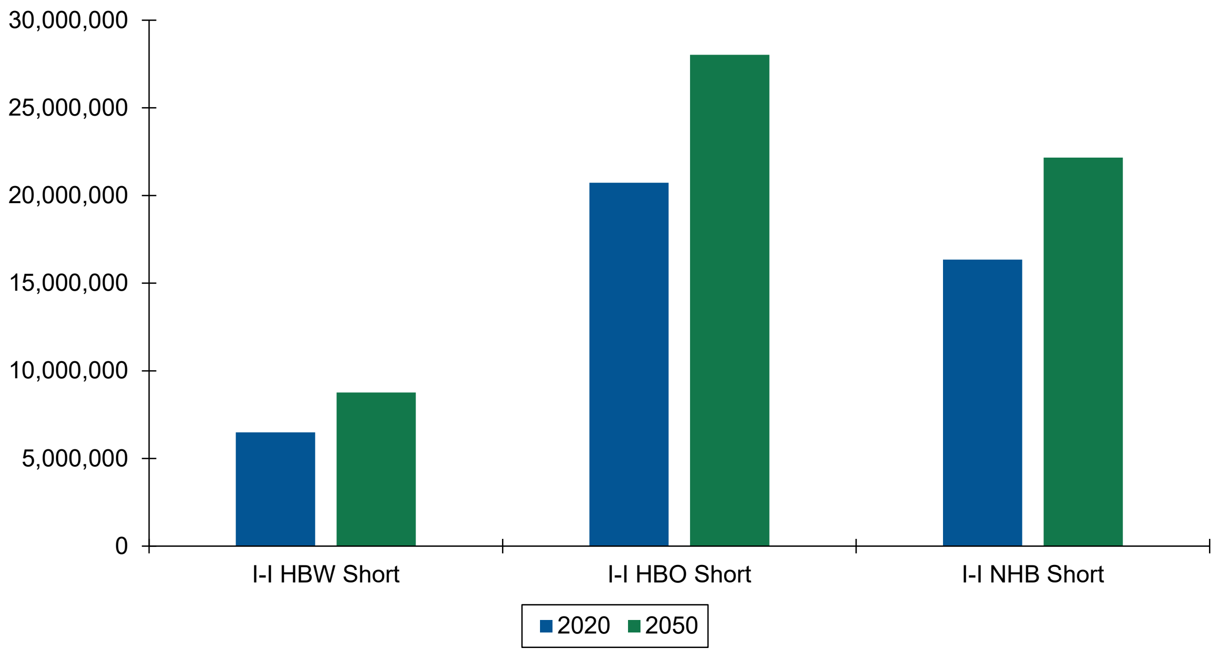


Figure 14 Freight Model Tonnage Comparison between 2020 and 2050

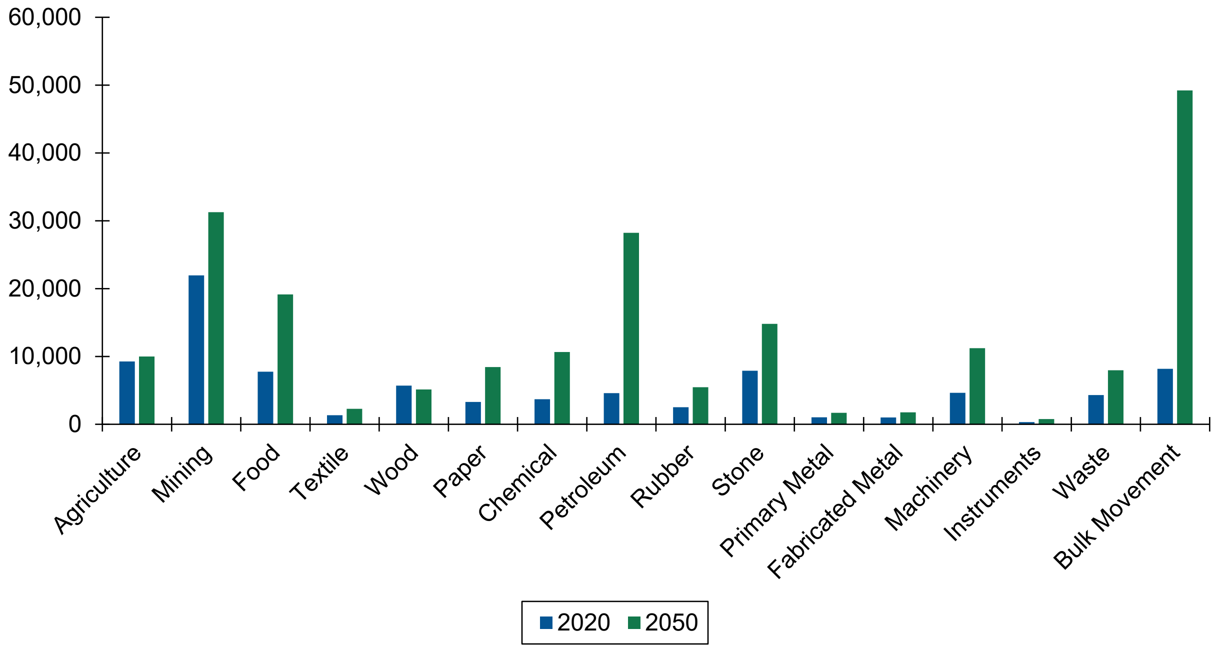
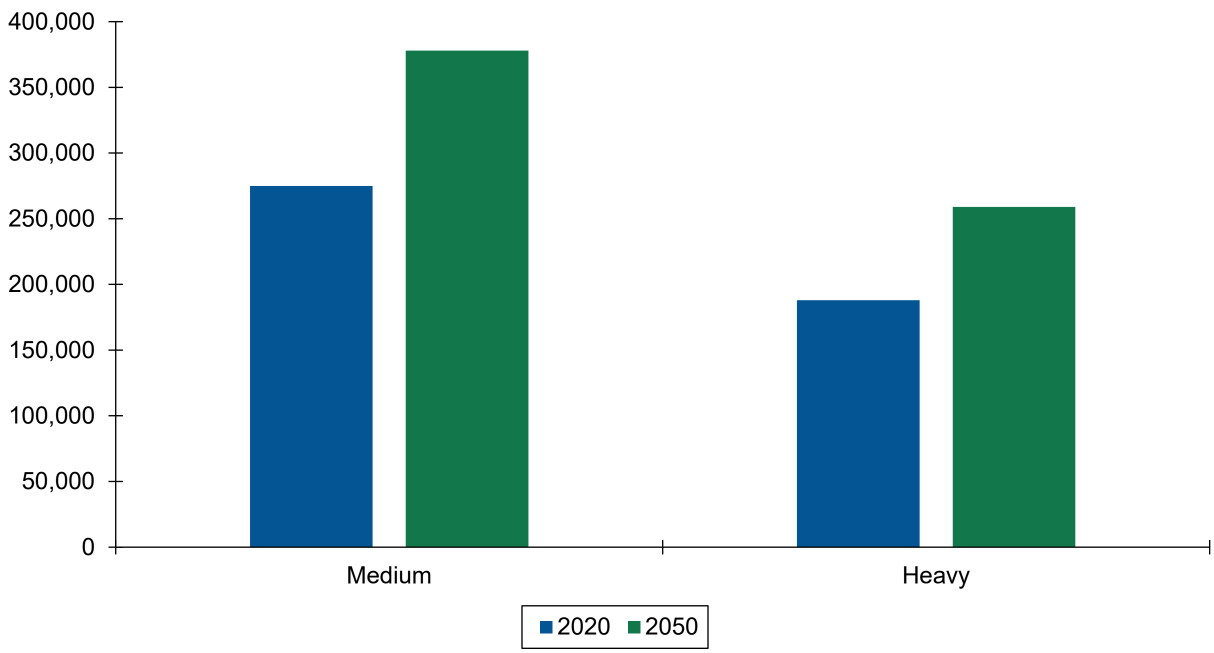


Figure 15 Non-Freight Truck Comparison between 2020 and 2050



2.4.6 Questions and Discussion

The questions related to calibration and validation included:

- Do the summary VMT comparisons done in validation exclude the ARC region?
  - **Answer:** No, the VMT comparisons include the ARC region. Future validation efforts for the GSTDM will include VMT comparisons at different regions.
- How is the GTSDM Level of Service (LOS) defined and reconciled with a daily volume output?
  - **Answer:** The team noted that daily capacity is implied, which is less than the product of hourly capacity and total daily hours to account for peak demand. However, it was agreed that capacity specific to each period is the preferred approach.
- A panel member noted that consistent LOS definitions between ARC, the GSTDM, and other MPO models are important for statewide planning work.
  - **Answer:** The team agreed; however, it was noted that there are differences between the models that make complete consistency difficult. For example, the ARC model includes 5 time periods for highway assignment, while the GSTDM and other MPO models are daily assignments.
- Is the GSTDM post-processed for corridor studies?
  - **Answer:** For corridor studies, the GSTDM can be post-processed for refinement. The GSTDM is also utilized to provide growth rate information for design traffic forecasts, specifically for areas of the state not covered by MPO models.
- Are estimated counts used in the validation process?
  - **Answer:** Yes, GDOT's statewide traffic counting system includes the use of portable count stations, which tend to be counted every two (2) to three (3) years. In the years not counted, these portable stations are estimated. The estimated counts are still utilized for validation to provide a more robust comparison for model outputs.
- Has GDOT considered the use of machine learning in future model updates for calibration and validation?
  - **Answer:** Yes, GDOT is considering machine learning for future updates, which are briefly covered in the future application session later in the peer review.
- The use of probe data from NPMRDS and INRIX as part of the overall validation process was also discussed.
  - **Answer:** The team noted that vehicle hours of delay data from RITIS were used to compare and update the GSTDM; however, it is intended to expand the use of vehicle probe data in future model updates.

2.5 Topic #5: Application and Integration

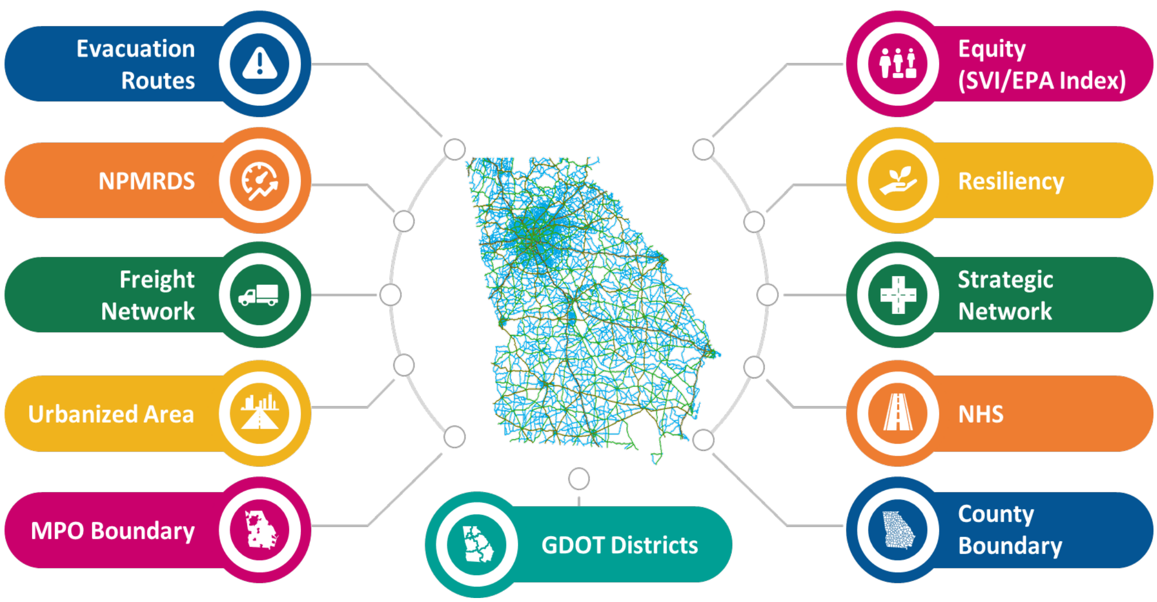
The GSTDM's goal is ultimately to support planning applications within the state of Georgia. During the peer review session for application and integration, the presentation covered topics related to linking the GSTDM to other data sources, assisting with MPO model development, corridor studies, engineering applications, dashboards, and training. More details regarding the session are provided below.

2.5.1 Data Linkage

The GSTDM input and output datasets were specifically revised to incorporate linkages to other data, such as GDOT districts, MPOs, evacuation routes, freight network, etc. This was then used to aid in the efficiency of providing model summaries and tying model outputs to performance-based planning initiatives. **Figure 16** summarizes specific GSTDM data linkages that were used for various planning applications in Georgia, ranging from evacuation route analysis to performance-based planning applications like speeds and reliability from NPMRDS. Other examples include:

- Planning Level Analysis and Cost Estimation (PLA+CE)
- State Transportation Improvement Program (STIP) and STIP-X analysis and prioritization
- Other Planning for Performance (P4P)
- Strategic Capacity and Safety Evaluation (CASE) as a collaboration of GDOT Planning and Districts
- Coordination with MPO models for things like external station development

Figure 16 GSTDM Data Linkages



GDOT continues to enhance its access to multiple big data sources through its joint data program with ARC, which can be linked to the GSTDM for future enhancement and model validation.

2.5.2 Supporting MPO TDM Development

The GSTDM is also being further leveraged in supporting MPO models throughout the state. While GDOT maintains MPO models (except the Atlanta region) throughout the state, previously, MPOs had been responsible for developing the SE data used by the models, with GDOT serving as the reviewer. However, GDOT has recently reversed these roles and will now be leading the SE data development for non-ARC MPOs. In doing so, GDOT can better leverage the GSTDM to streamline and provide a more consistent approach to SE data development for MPO models.

As part of their own on-call modeling work, ARC leveraged the GSTDM to support updates to the external station model, specifically related to the share of IE/EI and EE medium and heavy truck trips for the ARC model coverage area. The presentation to the panel members included details of how subarea matrix extraction was used within the GSTDM to support ARC's model update. The full technical memorandum (*ARC External and Truck Model Update*) can be requested from ARC.

2.5.3 Planning Studies

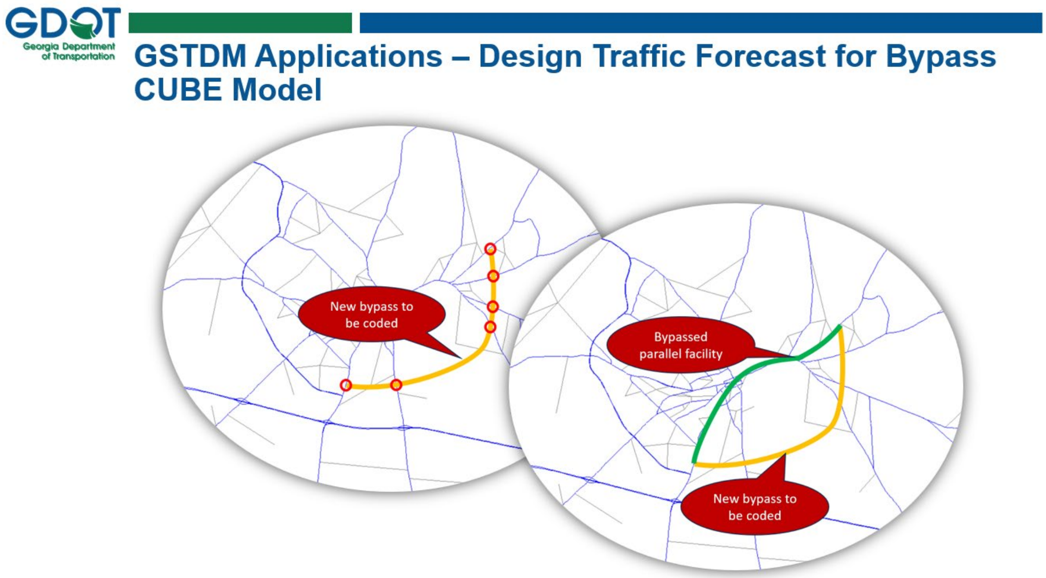
The GSTDM is utilized for multiple statewide studies, including the Statewide Transportation Plan, the Statewide Freight and Logistics Plan, and the State Rail Plan. Additional applications of the GSTDM involve regional transportation plan scenario analysis, especially in regions lacking MPO model coverage. It is also used to provide inputs for air quality analyses, conduct O-D trip analysis, and support corridor analyses, such as the I-75 South Corridor Study, which was briefly discussed during the peer review.

2.5.4 Engineering Application

Engineering-specific applications include providing inputs for project benefit-cost analyses, Intersection Control Evaluation (ICE), and design traffic forecasting. Related to design traffic forecasting, the GSTDM development team has participated in coordination efforts within the Office of Planning for ongoing updates to GDOT's Design Traffic Forecasting Manual (DTFM). This has included creating guidance for the appropriate use of the model based on project types, project coding considerations, and the appropriate model package tiers for preparing traffic forecasts.

Another major focus of the GSTDM's application within engineering is the ongoing and future coordination with the Georgia Section Institute of Transportation Engineers (GA ITE). The team participated in the ITE Simulation Day events in 2023 and 2024, where they discussed how to effectively utilize the GSTDM to support engineering applications. Additionally, once the updated DTFM is released, it is anticipated that future training for engineers on GSTDM usage will be conducted in coordination with GA ITE. **Figure 17** illustrates an example from the guidance for how users should consider a potential bypass project within the GSTDM.

Figure 17 Design Traffic Forecast Process



2.5.5 File Sharing

A structured process has been implemented for requesting and sharing model files, ensuring clarity and efficiency. Individuals wishing to obtain these files must complete a designated request form, which is submitted to the GDOT Office of Planning. Upon receipt, the request is reviewed and routed through the consultant team for evaluation and processing. This systematic approach ensures that the files are shared promptly and accurately with the requester. Additionally, requests are organized into three distinct levels, allowing for tailored access based on the complexity and scope of the information needed. These levels are as follows:

- Level One: Simple analysis that requires only loaded networks.
- Level Two: Requests for assignment-only functionality to analyze specific alternatives without full consideration of trip distribution.
- Level Three: Full analytical capability that includes complete model sets.

Model files are shared with requestors in various formats, including shapefiles and keyhole markup language zipped (KMZ) files, to accommodate users without access to the model's software platform. Additionally, relevant caveats and restrictions on the use and interpretation of output data are provided with the files. **Figure 18** and **Figure 19** Illustrate the GSTDM file sharing process during model requests and the request form, respectively.

Figure 18 GSTDM File Sharing Process

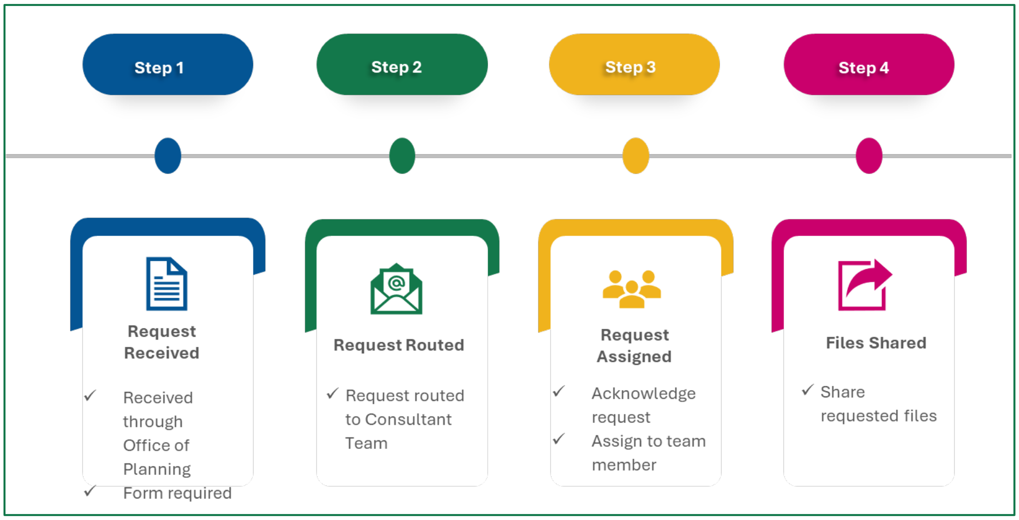


Figure 19 GDOT Model Request Form

Georgia Department of Transportation

Requestor Contact Information

First Name: ______ Last Name: ______

Address: ______

Telephone: ______ Email: ______

Client Type:

○ State ○ MPO ○ County ○ City ○ Private ○ Academic ○ Other

Organization: ______ Job Title: ______

Project Name: ______

Purpose of Request

Subject: ______

Model Scenario(s):

☐ 2020Base Year ☐ 2050 Do Nothing ☐ 2050 E+C ☐ 2050 STIP ☐ 2030 STIP

Data Request: ☐ Output Networks ☐ Entire Model Package

Purpose of Request:

☐ Statewide Planning Effort ☐ Economic Impact Analysis ☐ Design Traffic Forecast

☐ Regional Planning Effort ☐ Corridor Planning and Study ☐ Other

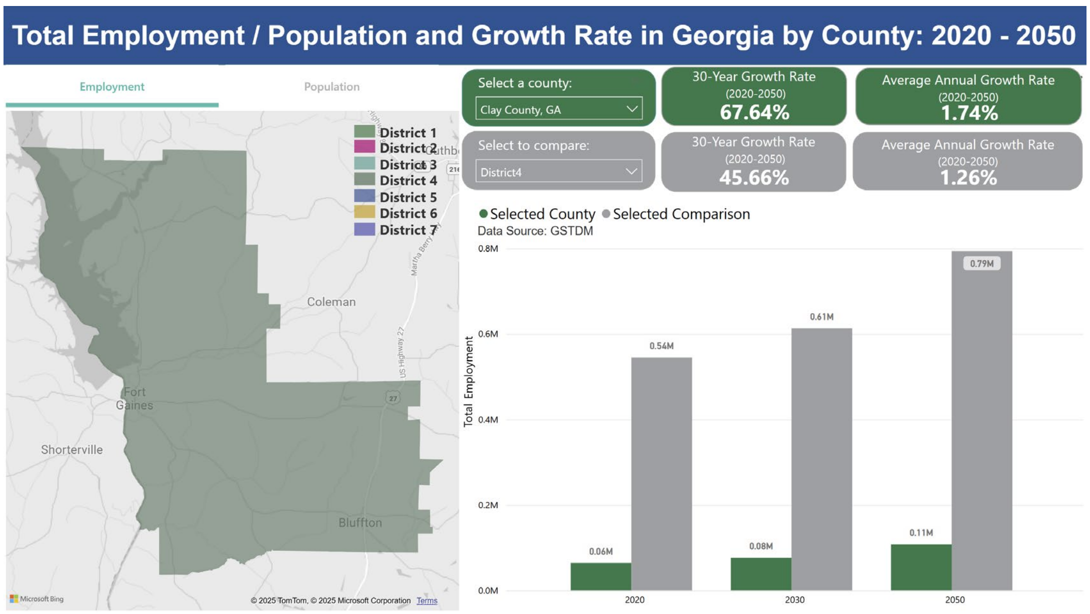
If other, please specify below:

2.5.6 Dashboards

A key element in the latest round of GSTDM development was the introduction of internal dashboards for GDOT planners. These dashboards enable the quick dissemination of model outputs, eliminating the need for specialized modeling software for visualization and analysis.

The reported metrics include standard measures, such as VMT, VHT, LOS, and vehicle hours of delay (VHD) performance at the link, district, and regional levels, along with the changes between scenario years. Additionally, truck-specific information and SE data changes, such as growth in population or employment by region, are reported as depicted in **Figure 20**. The team will continue to utilize the dashboard functionality to enhance the general accessibility of model output information.

Figure 20 SE Data Changes by County



2.5.7 Training

The GSTDM development team has been actively engaged in providing training to the Georgia modeling stakeholder community on the use of models. This training covers general principles of travel demand modeling, as well as specific information about GSTDM. The general training includes various topics related to:

» General principles of travel demand modeling, including the different steps and approaches

» Network structure

» General input requirements

» Development methodologies pertaining to items like calibration and validation

» Output information

GSTDM-specific training involves details related to:

» Model request and acquisition

- History of GSTDM
- Goals of the GSTDM
- Input data requirements
- Model structure and components
- Model applications and use cases

2.5.8 Discussion

During the application and integration session, there were more casual discussions covering a range of topics, rather than a primary focus on additional questions from the panel members. Some key discussion points included:

- Use of the model to report on SE growth trends.
- Dashboard functionality reporting not just the GSTDM outputs, but also the MPOs model outputs, and reviewing potential issues with consistency.
- Use of the freight model in the GDOT Freight Plan.
- The limitations of reporting trip delay processing in macro models.
- There was extensive discussion of the STIP-X process in the model application, with an overarching theme of enhanced dissemination of that information to improve the quality and timeliness of decision-making for project prioritization.
- There was discussion about using models to analyze evacuation impacts and how the process is done in neighboring states like Florida.
- Discussion around inappropriate and potentially malicious use of models and strategies to minimize that risk.
- How rural planning commissions can make use of the model and associated processes.
- One notable aspect was how effectively GDOT utilizes consulting team members to enhance overall planning activities using the model and other available tools. It was noted that an on-call process is the most effective mechanism for facilitating this collaboration.
- Discussion around best practices of dynamic pricing for managed lane facilities and how this is reflected in the models.

2.6 Topic #6: Planned Development and Application

The final session presented to the panel members included some potential enhancements to the GSTDM that are either already ongoing or planned as part of future updates. These included items like freight modeling machine learning, converting from average annual daily traffic (AADT) to average weekday daily traffic (AWDT), and MPO / GSTDM true shape integration.

2.6.1 Machine Learning

Efforts are underway to use machine learning to improve the regression approach used in the freight trip generation model. The concept would be to leverage machine learning with pairwise regression to determine freight flows of specific commodities between given O-D pairs. Machine learning also has the potential to be leveraged in the trip distribution process to replace the simplified gravity model approach. One advantage of using a machine learning approach in the GSTDM freight model is its ability to better predict non-linear relationships compared to the current linear regression approach. This improvement could reduce the need to completely replace actual data from the freight flow dataset, such as TRANSEARCH, with regression outcomes due to poor results. Additionally, it may enhance the accuracy of existing predicted relationships.

2.6.2 Represent Average Weekday Conditions

The GSTDM is currently validated against observed AADT, as that is the data most readily available through GDOT's traffic counting program. However, a planned initiative involves utilizing continuous count locations on major roadways, along with weigh-in-motion data for trucks. The aim is to develop factors that distinguish between weekday and weekend traffic counts, as opposed to relying solely on default average daily values. The ultimate goal is to validate the GSTDM based on the average counts for weekdays.

2.6.3 Discussion

The main discussion regarding planned model development focused on several key items, including implementing time-of-day considerations, increasing the use of available "big data" to guide model development, and exploring topics such as machine learning for calibration, along with various other applications related to modeling.

3.0 Focus Area Questions

As discussed earlier, questions were posed to the panelists regarding the GSTDM under four main themes of interest. These questions were developed to get feedback from the panelists on the best approaches to developing, applying, and streamlining the integration of the GSTDM into the overall planning process in Georgia. During the panel members' presentation to the GDOT team, they included responses to GDOT's questions. The questions and suggestions from the panel members are outlined as follows under the associated themes.

3.1 Emerging Trends

» How should GDOT incorporate the significant growth in e-commerce and delivery services starting in 2020, especially in their impact on last-mile delivery patterns?

- **Answer:** Use location-based service (LBS) data to try to identify delivery and e-commerce vehicles and quantify their magnitude. Explore Geotab and the Vehicle Inventory and Use Survey (VIUS), as they may contain information about e-commerce/truck travel.

» How can the GSTDM incorporate the impacts of remote work trends that emerged during the pandemic and have persisted?

- **Answer:** Currently, remote work appears to be reflected in lower HBW trip rates. Use NHTS add-on survey data to quantify current remote work trends and continue to refine and just HBW trip rates. Consider the implications for HBO and NHB trip rates, as well. May help to further disaggregate trip rates by purpose to reflect implications of remote work on overall travel by purpose.

3.2 Model Integration and Coordination

» How successful has the integration been between statewide and MPO models? What would be the process and benefit for further integration?

- **Answer:** Integration has been quite successful and commendable. Consider developing an NCDOT-style dashboard to reflect the integration of statewide and MPO models.

» How best can asset management be integrated into the model?

- **Answer:** Application of Enterprise GIS for transportation asset management. Integrate roadway conditions and asset information into databases to help model outputs inform project prioritization. Overlay information from different databases and networks about asset conditions. Integrate other enterprise GIS applications (operations, safety, etc.) to build a comprehensive approach to transportation performance assessment and planning.

» How best can resilience be integrated into the model?

- **Answer:** The panel noted that the inclusion of resiliency metrics was a unique capability of the GSTDM and recommended coordination with the next Transportation Asset Management Plan (TAMP) update for linkage to the GSTDM to better reflect resiliency considerations. *Note that the enhanced linkage between TAMP and GSTDM was discussed at the TAMP kickoff meeting.*

3.3 Validation and Performance

» How should GDOT assess the GSTDM's performance in forecasting 2020 to 2025 trends?

- **Answer:** Monitor trends and conditions (e.g., work-from-home vs. return-to-office, traffic volumes, speeds, e-commerce) and compare GSTDM outputs to more recent ground-truth data.

» What validation approaches should be prioritized given the availability of new observed data sources?

- **Answer:** Conduct a literature review of the latest approaches to model validation, given the availability of new big data sources, new survey data, etc. Select the desired metrics for the model to produce and capture and then compare the model against the observed data.

» What mechanisms should GDOT implement for continuous model improvement between major updates?

- **Answer:** GDOT is on the right track with monitoring trends on a two-year cycle with NHTS add-on participation.

3.4 Model Application and Decision Support

» What visualization and communication tools would be recommended to make model output more accessible to decision-makers and the public?

- **Answer:** Efforts involving the development of dashboards are commendable and should continue. Make the dashboards fully web-native so that special software and licenses are not needed. Involve GDOT IT in the development of dashboards for IT compliance. Explore the use of AI tools for making dashboards more user-friendly and customizable.

» How are statewide models being used to support resiliency planning?

- **Answer:** Hurricane evacuation planning is an example. It might be worth conducting a comprehensive literature review to see how models are being applied and enhanced for resiliency planning (possibly through a peer exchange).

» What improvements should be made to the freight module as it is becoming increasingly instrumental for periodic freight plans?

- **Answer:** Make more effective use of FAF data, possibly using the experimental county-to-county FAF data released in early 2025. Purchase ATRI data as a supplement to obtain real-time GPS data of trucks and associate different commodities with actual flows to get a better handle on tonnage and value. Rationale should be tied back to the policy questions, measures of interest, and model applications in the freight arena. Decisions should be driven by what is desired of the model. Supply chain analysis for the state of Georgia may be helpful in better understanding the drivers of freight in the state.

» What is the gold standard source for freight? Federally available, commercial?

- **Answer:** Federally available: FAF; Commercial: TRANSEARCH, Geotab, ATRI.

4.0 Panel Member Presentation and Recommendations

After GDOT and its consultants finished presenting to the panelists, the panel members convened a closed-door session and prepared recommendations that the panel chair then presented to the GDOT team. As part of this report preparation, the panel members' recommendations were categorized by the general topic area and assigned both a priority ranking (low, medium, high) and an initial implementation timeframe (short-term, mid-term, long-term). It is important to note that these priorities and timeframes can, and likely will, evolve over time to align with other GDOT initiatives. The recommendations include the panel members' responses to the focus area questions, as well.

4.1 Overview: Strengths and Merits

Prior to making recommendations, the panel chair presented the strengths of the GSTDM to the GDOT team. These strengths are highlighted below:

- State-of-the-practice model with thoughtful design and considerations of applications for statewide planning and project programming
- Transition to a true shape network is laudable
- Thoughtfulness of available data sources and working with a rich array of data sets
- GDOT's use of the model in the actual decision-making process for project prioritization
- Use of dashboards for visualizing and summarizing model outputs
- GDOT leadership's recognition of the importance and value of the GSTDM is noteworthy and quite unique
- Excellent collaboration and coordination with MPOs
- Inclusion of resiliency metrics is a unique capability incorporated into the model
- Excellent responsiveness to recommendations from the last peer review panel
- Strong integration with STIP and STIP-X processes
- Effective partnership through an on-call approach provides a framework for continuity and long-term model development
- Attention paid to freight and non-freight modeling is noteworthy, and the integration with the statewide freight plan is quite effective
- Integration of freight data from different sources (FAF, TRANSEARCH) provides a strong basis for development and calibration
- Consideration of rail transport demand through the mode choice model and rail assignment of freight is also noteworthy

4.2 Structure & Inputs

*4.2.1 Recommendation #1: Priority = **Low** / Timeframe = **Short-Term***

The panel recommended using 10-year SE data forecasts from the U.S. Census Bureau as inputs to an interim scenario year to evaluate the model's performance before using it for the 30-year horizon performance. This will potentially identify issues using an established dataset, allowing for calibration/validation tweaks if necessary.

4.2.2 Recommendation #2: Priority = **Medium** / Timeframe = **Mid-Term**

There was a recommendation to enhance the relationship and coordination with the state demographer. This will allow more buy-in from stakeholders in the use of the model and help enhance decision-making regarding population and household forecasts, in particular.

4.2.3 Recommendation #3: Priority = **High** / Timeframe = **Short-Term**

The panel recommended leveraging the availability of FAF data as an independent data source for validation. This includes the suggestion to use the newly available experimental county-county disaggregated flow data released in early 2025.

4.3 Component Updates

4.3.1 Recommendation #1: Priority = **High** / Timeframe = **Short-Term**

It was recommended to stratify weekend versus weekday trips, with the default option being weekday travel. For specific geographies, for example, regions or subareas with high seasonal travel patterns, weekend trips from the model are also a useful capability to add.

4.3.2 Recommendation #2: Priority = **High** / Timeframe = **Mid-Term**

Implement a robust version control system to ensure consistency in the development cycle and model application. It may be worth considering opportunities to leverage this work with the MPO modeling process as well to streamline integration.

4.4 Calibration & Validation

4.4.1 Recommendation #1: Priority = **Medium** / Timeframe = **Short-Term**

Increase the number of screenlines to enhance the thoroughness of aggregate validation checks for general traffic flows. Currently, six screenlines are used in the GSTDM, and they are statewide in scope and extend over a number of miles.

4.4.2 Recommendation #2: Priority = **High** / Timeframe = **Mid-Term**

Use additional data sources like Geotab, Replica, and others, where available, to calibrate the GSTDM, as they are currently underutilized. These sources can enhance calibration and validation efforts, particularly given the increasing difficulty of obtaining traditional survey data. With these additional data sources, it is recommended to provide a deeper dive into the rich context of the individual model components.

4.4.3 Recommendation #3: Priority = **Medium** / Timeframe = **Mid-Term**

Purchase additional ATRI data that provides truck-specific GPS data. The data were also suggested to associate truck commodity tonnage with actual flows, which allows for linking unit flows to tonnage and transported freight value.

4.4.4 Recommendation #4: Priority = **High** / Timeframe = **Mid-Term**

Monitoring the latest travel trends and conditions, such as Work-from-Home (WFH) versus Return-to-Office (RTO), the increasing use of e-commerce, and the impacts on congestion and speeds. It was also suggested that we use recent ground truth data, such as probe-sourced speeds, more extensively to enhance calibration/validation. Continuing along this theme, there was an additional recommendation to perform a literature review on the latest approaches to model validation using the newly available "big data" sources. Include a deeper dive into the rich context of the individual model components.

4.4.5 Recommendation #5: Priority = **High** / Timeframe = **Mid-Term**

With the NHTS Add-On being available on a two-year cycle, GDOT should take advantage of the opportunity to monitor trends on a more frequent basis, given the ongoing rapid changes in travel patterns by continuing to participate.

4.4.6 Recommendation #6: Priority = **High** / Timeframe = **Mid-Term**

Conduct a comprehensive literature review on the latest approaches to validating models, given the availability of big data sources and surveys.

4.5 Application & Integration

4.5.1 Recommendation #1: Priority = **High** / Timeframe = **Short-Term**

Conduct a comprehensive literature review on how models are being applied to enhance resiliency planning, possibly through a peer exchange.

4.5.2 Recommendation #2: Priority = **Low** / Timeframe = **Short-Term**

Integrate a GIS-based dashboard to seamlessly depict information related to the integration of GSTDM and MPO models.

4.5.3 Recommendation #3: Priority = **Medium** / Timeframe = **Short-Term**

Expanding on the preliminary work already being undertaken and identifying other machine learning and AI opportunities for various model components. This includes clarifying how machine learning methods will be used for replicating data patterns. Suggestions like how AI may help automate processes like quality control, validation of data summaries, etc., were provided.

4.5.4 Recommendation #4: Priority = **Medium** / Timeframe = **Short-Term**

Integrate roadway conditions and asset information into databases to help model outputs inform project prioritization. This includes overlaying information from different but relevant datasets and networks about asset conditions and integrating other enterprise GIS applications, like safety and operations. This allows us to build a comprehensive approach to transport performance assessment and planning.

4.5.5 *Recommendation #5: Priority = **Medium** / Timeframe = **Short-Term***

Make dashboards fully web-native to avoid the need for special software and associated licenses. Another low-priority medium-term recommendation is to review the Vehicle Inventory and Use (VIUS) survey data to determine whether it may be applicable for GSTDM. This is particularly relevant for information related to e-commerce and truck travel patterns.

4.5.6 *Recommendation #6: Priority = **Low** / Timeframe = **Mid-Term***

Review the Vehicle Inventory and Use (VIUS) survey data to determine whether it may be applicable for GSTDM. This is particularly relevant for information related to e-commerce and truck travel patterns.

4.5.7 *Recommendation #7: Priority = **High** / Timeframe = **Mid-Term***

Incorporating People Mobility Metrics into the modeling process (i.e., derive metrics such as access to universities, medical facilities, restaurants, employment centers, etc.).

4.5.8 *Recommendation #8: Priority = **High** / Timeframe = **Mid-Term***

Consider post-processing daily model outputs and begin to disaggregate the data by time-of-day (e.g., peak vs. off-peak travel times).

4.5.9 *Recommendation #9: Priority = **Low** / Timeframe = **Long-Term***

Integrating other GIS applications related to operations and safety to develop a comprehensive approach to transportation performance assessment.

4.5.10 *Recommendation #10: Priority = **Low** / Timeframe = **Long-Term***

Map the arrivals and destinations of various commodities in the state's supply chain to understand distribution patterns and freight bottleneck locations.

4.5.11 *Recommendation #11: Priority = **Medium** / Timeframe = **Long-Term***

Coordinating with other state agencies, such as the Georgia Emergency Management Agency (GEMA), the Georgia Department of Labor, and the Georgia Department of Natural Resources, to determine each agency's specific needs for which the model may be useful.

4.5.12 *Recommendation #12: Priority = **Medium** / Timeframe = **Long-Term***

Implementing alternate future scenarios to account for rapidly evolving trends like WFH, urban/rural population shifts, inland port development and its impact on freight traveling on Georgia highways, and onshoring of manufacturing.

4.5.13 Recommendation #13: Priority = **Medium** / Timeframe = **Long-Term**

Implement analysis of transit and rail corridors, facilitated by subarea and corridor analysis as necessary.

4.5.14 Recommendation #14: Priority = **High** / Timeframe = **Long-Term**

Incorporating resiliency scenarios into the modeling process to allow analysis of system response to disruptions. These disruptions may be man-made, economic, technological, or natural disasters like hurricanes, floods, bridge collapses, etc.

4.6 Planned Development & Application

4.6.1 Recommendation #1: Priority = **Low** / Timeframe = **Long-Term**

Incorporate available parcel data and a tool (i.e., CommunityViz) into the modeling process to understand development patterns and possible development futures.