Appendix G: Scenario Planning

GREATER HARTFORD
MOBILITY STUDY

CONNECTICUT DEPARTMENT OF TRANSPORTATION

Purpose

The Scenario Planning Baseline Tech Memo outlines the purpose and the methodology of the GHMS Scenario Planning Tool. The Scenario Planning Tool is an exploratory modelling tool developed using the CRCOG regional travel demand model as the base. The tool is based on data-driven, performance-based, and scenario planning methodologies to study and evaluate future uncertainties in land use, travel behavior, mobility policy, and emerging technologies at a regional or sub-regional scale. The tool uses an easy-to-understand graphical user interface (GUI) for users to:

- Quickly build scenarios using various network, technology, land use, demographics, growth, and policy inputs;
- Evaluate scenario impacts with quantitative performance measures; and
- Assess potential risks and opportunities associated with each scenario.

Key Components

The Scenario Planning Baseline Memo focuses on the following topics:

1. Scenario Input Variables
2. Land Use Allocation and Travel Demand Modules
3. Model Configuration, Calibration and Validation
4. Key Performance Indicator Outputs
5. 2020 Existing and 2050 Future No-Build Baseline Scenario Results

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Introduction

Several defining events of the current century, such as the COVID-19 pandemic, climate change, economic recessions, an influx of Connected and Automated Vehicle (CAV) technologies, ridesharing, smartphones, and digitalization are affecting demographic trends, travel behavior, land use, and transportation systems. Scenario planning tools have thus gained increased interest as they allow users to create and assess how plausible future scenarios can affect the social, environmental, and infrastructure systems in a region.

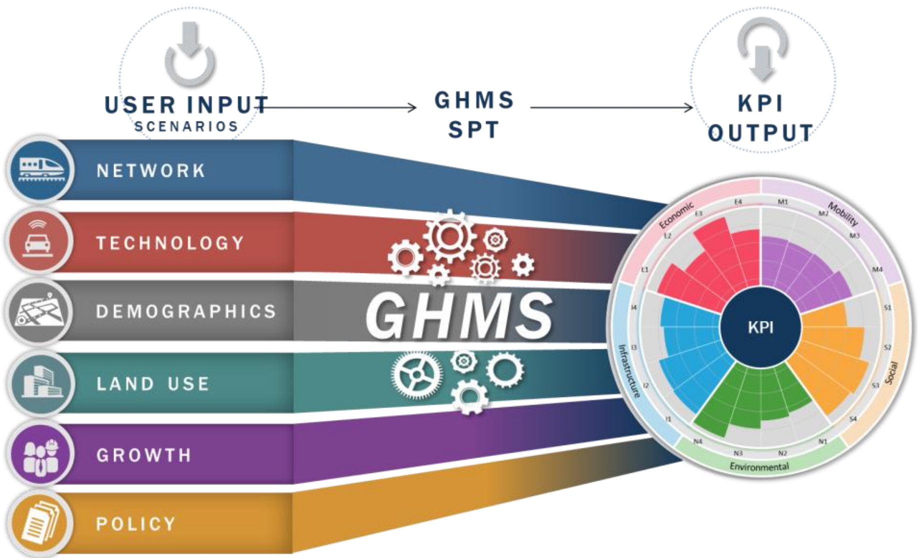
The Greater Hartford Mobility Study – Scenario Planning Tool (GHMS-SPT) is an **exploratory modeling** tool based on **data-driven**, **performance-based,** and **scenario planning** methodologies to study and evaluate future uncertainties in land use, travel behavior, mobility policy, and emerging technologies at a regional or sub-regional scale. The tool has an easy-to-understand graphical user interface (GUI) for users to:

- quickly build scenarios using various network, technology, land use, demographics, growth, and policy inputs;
- evaluate scenario impacts with quantitative performance measures; and
- assess potential risks and opportunities associated with each scenario.

GHMS-SPT simulates different scenarios that demonstrate the cause-and-effect relationships between input variables and performance indicators, as illustrated in Figure 1. This technical memorandum describes the configuration of the GHMS-SPT, including the user inputs, land use allocation model, travel demand model, and Key Performance Indicator (KPI) engine. Through Phase 1 of the GHMS, the Existing (2020) and Future No-Build Baseline (2050) scenarios were developed to test the configuration of the SPT and to validate output from the CRCOG Travel Demand Model. The Existing scenario used the 2020 network, and the Future Baseline scenario used the 2050 network, including the existing and funded transportation projects. The Existing and Future Baseline results are also presented in this memo.

The tool will help regional transportation investment and policy decision makers explore future uncertainties and make better informed decisions about transportation funding allocation and investment priority areas (e.g., modal priorities, locational needs such as specific corridors or neighborhoods, etc.).

Figure 1: GHMS-SPT Modeling Process



Scenario Input Variables

Selecting input variables to build scenarios that exhibit plausible alternative views of the future is the foundation of effective scenario development. The set of user inputs in the GHMS-SPT is based on combination of the project team's research experience from a recent similar project for TxDOT Houston District – the West Houston Regional Planning Study and GHMS study area specific inputs received from the client and Greater Hartford area stakeholders. The GHMS-SPT will focus on sustainable transportation and development related trends and uncertainties and will act as a starting point to inform key domains where most disruption will occur in the future.

The following critical questions provided a basis to make the preliminary list of user inputs specific to the Greater Hartford region.

1. *What are GHMS study vision and goals?*
2. *What are the top concerns and trends in the region?*
3. *How would the stakeholders describe the change they wish to see in their communities and prepare for uncertainties related to changes in land use, mobility technology, transportation policy, etc.? What is their vision for the Greater Hartford area?*
4. *What future improvements and/or public policies related to the concerns and trends the stakeholders seek in their region?*

The GHMS project team held workshops with the CTDOT project team, and stakeholders such as local MPO partner Capitol Region Council of Governments (CRCOG) for insights into these questions. Essential takeaways from the workshops included stakeholders desire for improved mobility, resilience, multimodal transportation systems, enhanced quality of life, social equity, and economic growth. Hence, the user inputs in the GHMS-SPT tool that users may modify for each scenario supply options to model future demographic growth, improvements in transportation networks and land use, prevalence of advanced mobility-related technologies, and policy implementations in the region.

The GHMS-SPT is designed to allow for the development of many "Scenarios" that may be defined by alterable characteristics or "user inputs." Appendix G-1 illustrates the various types of user inputs available to modify for a given scenario, organized by six categories: **Growth, Network, Technology, Demographics, Land Use, and Policy**. Inputs are either binary which users can turn off/on or require users to enter a threshold value. Default values for the threshold selections were set in the SPT based on transportation research and mobility/land use trends in the Greater Hartford region as well as projections from the CRCOG travel demand model. Users of the SPT are able to change most default values for user inputs through the SPT GUI. Defaults for growth were based on population projections from the Travel Demand Module. Network defaults for the existing and future network are based on the CTDOT existing network and planned network improvements. Default values for technology, demographics, and land use are based on the minimum values expected in transportation research. Policy user inputs are binary in the GUI but can be adjusted by advanced users. Default parameters for policy are based on reasonable values used in similar policies in transportation literature. Appendix G-1 describes user input defaults in greater detail.

Scenario Definition

A GHMS Scenario is defined by the user inputs in the six categories above. In addition to these categories, the user may select the timeframe of the scenario (2020, 2035, or 2050). To select these inputs, the GHMS project team developed a graphical user interface (GUI) to build scenarios. Table 1 summarizes how the user inputs are defined. Most user inputs are flexible and adjustable on a sliding scale by the user, or by multiple categories that represent a wide array of possible outcomes under a specific category. For example, Figure 2 shows how the user can set inputs for demographic variables. However, most network user inputs are not able to be changed on the fly within the user-facing GUI to create a unique scenario. Roadway, Transit, Rail, and Bike & Ped network changes in the SPT are limited to the "existing" and "existing + funded/planned/future" options. Advanced users with needs to analyze additional network changes beyond those coded into the SPT may contact the project team to develop scenarios with these changes.

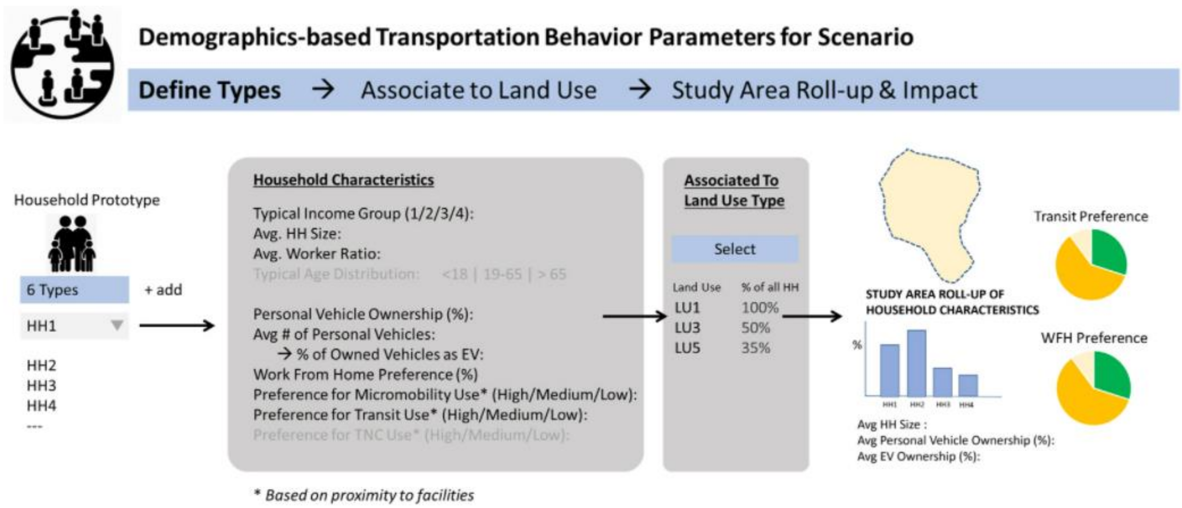
Table 1: Scenario Building in GHMS-SPT with User Inputs

<table>
<tr><th colspan="6">1) TIMEFRAME – user selects one of the following</th></tr>
<tr><td colspan="2">2020</td><td colspan="2">2035</td><td colspan="2">2050</td></tr>
<tr><th colspan="6">2) GROWTH</th></tr>
<tr><td colspan="6">2.a) User Selects One of the Following pre-selected growth scenarios:</td></tr>
<tr><td colspan="2">Low</td><td colspan="2">Moderate</td><td colspan="2">High</td></tr>
<tr><td colspan="6">2.b) Adjustments – User may adjust total population and employment growth manually, either as a % of total growth or raw added population and employment</td></tr>
<tr><th colspan="6">3) NETWORK</th></tr>
<tr><td colspan="6">3.a) Roadways – user selects one of the following:</td></tr>
<tr><td colspan="3">Existing Network</td><td colspan="3">Existing + Funded</td></tr>
</table>

<table>
<tr><th colspan="6">NETWORK (continued)</th></tr>
<tr><td colspan="6">3.b) Transit – user selects one of the following:</td></tr>
<tr><td colspan="3">Existing Transit</td><td colspan="3">Existing + Planned</td></tr>
<tr><td colspan="6">3.c) Rail – user selects one of the following:</td></tr>
<tr><td colspan="3">Existing Rail</td><td colspan="3">Existing + Future</td></tr>
<tr><td colspan="6">3.d) Park & Ride (P&R)/Mobility Hub (MH) – user-defined additions in study area and beyond</td></tr>
<tr><td colspan="2">Keep existing P&R/MH Network</td><td colspan="2">Add park & rides</td><td colspan="2">Add mobility hubs</td></tr>
<tr><td colspan="6">3.e) Bike & Ped Trail Network – user selects of the following:</td></tr>
<tr><td colspan="3">Existing Trails</td><td colspan="3">Existing + Planned Future</td></tr>
<tr><th colspan="6">4) TECHNOLOGY</th></tr>
<tr><td colspan="6">4.a) Options – pre-selected levels of technology adoption; can be further modified in 4.b) Parameters:</td></tr>
<tr><td colspan="2">Low</td><td colspan="2">Moderate</td><td colspan="2">High</td></tr>
<tr><td colspan="6">4.b) Parameters:</td></tr>
<tr><td colspan="6">Electric Vehicles Penetration Rate – user selects a rate between 0 – 100%</td></tr>
<tr><td colspan="6">Connected Vehicles Penetration Rate – user selects a rate between 0 – 100%</td></tr>
<tr><td colspan="6">Automated Commercial Vehicle Penetration Rate – user selects a rate between 0 – 100%</td></tr>
<tr><td colspan="6">Automated Vehicle (Level 3) Penetration Rate – user selects a rate between 0 – 100%</td></tr>
<tr><td colspan="6">Automated Vehicle (Level 4) Penetration Rate – user selects a rate between 0 – 100%</td></tr>
<tr><td colspan="6">Automated Vehicle (Level 5) Penetration Rate – user selects a rate between 0 – 100%</td></tr>
<tr><td colspan="6">Truck Platooning Penetration Rate – user selects a rate between 0 – 100%</td></tr>
<tr><td colspan="6">On-Demand Delivery – user selects a rate between 0 – 100%</td></tr>
<tr><td colspan="6">Advanced Air Mobility – user selects a rate between 0 – 100%</td></tr>
<tr><th colspan="6">5) DEMOGRAPHICS– user selects demographic options for household types – users can define how many HH types (see Figure 2)</th></tr>
<tr><td colspan="6">5.a) Characteristics – user defines the following:</td></tr>
<tr><td colspan="6">Income Group: 1, 2, 3, or 4</td></tr>
<tr><td colspan="6">Household Size: Average, defined by user, from 1+</td></tr>
<tr><td colspan="6"># Workers: Average, defined by user from 0+</td></tr>
<tr><td colspan="6">Vehicle Ownership: Average, defined by user from 0+</td></tr>
<tr><td colspan="6">Age: Average, defined by user</td></tr>
<tr><td colspan="6">5.b) Preference – user defines the following:</td></tr>
<tr><td colspan="6">Working from Home: Rate of work from home (0-100%)</td></tr>
<tr><td colspan="6">Micromobility: Low, Medium, or High</td></tr>
</table>

DEMOGRAPHICS – user selects demographic options for household types – users can define how many HH types (continued)
Transportation Network Company: Low, Medium, or High
Transit: Low, Medium, or High
6) LAND USE – user selects a variety of preferences for future land use
6.a) Residential Use
6.b) Non-Residential Use
6.c) Mixed Use
6.d) Activity Centers – user can use map-based tool to add the following at any location in the study area:
Major/Medium/Minor job centers
Major/Medium/Minor residential nodes
6.e) Residential Greenfield – user can use map-based tool to select whether the 7 study corridors are high, medium, or low-growth for this place type
6.f) Non-Residential Greenfield – user can use map-based tool to select whether the 7 study corridors are high, medium or low-growth for this place type
6.g) Infill – user can select the balance between infill and greenfield development in 5% increments from 0-100%
6.h) Parking- user can select downtown parking lots for potential replacement with infill development.
7) POLICY – the user can toggle on certain policy inputs. Advanced model users are able to adjust the values in the following choices
7.a) Road user charging – 10 cents per mile
7.b) Parking Management – 2 dollars per automobile trip added to parking cost
7.c) Gasoline Tax – 5 cents per mile
7.d) Employer Incentive Program – 80% reduction in transit fare for commute trips
7.e) Increased bus route frequencies – 2x operations frequency for all transit routes

Figure 2: Demographics User Input Definition Process



Once a scenario has been run through GHMS-SPT, outputs are translated into the Key Performance Indicators that determine how changes in the input variables affect mobility in the region along with considerations for social equity, environmental and economic impacts.

Land Use Allocation Model

As part of the scenario planning process, the land use allocation module allocates growth to census blocks. The user provides high level scenario inputs through the graphical user interface, including growth, network, and land use. The land use module translates these into acres of land needed by development typology; it calculates land allocation priorities with rules based on attractors, detractors, and constraints; and it allocates development accordingly to accommodate growth. Finally, the land use module summarizes outputs at different levels (such as grids and TAZ) that can be used by other modules (i.e., Travel Demand Module and KPI calculators) in the scenario planning process.

Development Typology

Development Typology is a combination of uses and built (building) typologies that allow for easy visualization of the development landscape with different densities and features. It is more comprehensive than the traditional land use categories, as it can capture characteristics such as open space, parking, sidewalks, bike lanes and general walkability and other factors. These characteristics are incorporated into the land use module as parameters to inform Travel Demand Model to further adjust travel demand behaviors and KPI performance.

Land Use

Key steps used in the Land Use process are described as follows. Appendix G-2 describes the land use process in further detail.

Step 1: Define Growth Parameters

- In this step, the user provides annual growth rates for population and employment for the scenario (i.e. 2050).
- The user also provides a high-level increase of basic employment categories.

Step 2: Select Preferred Development Types

- The user/scenario developer selects preferred residential, non-residential, and mixed-use place types, translating to a percent of growth assigned to each development types.

Step 3: Set Location Preferences to Guide Where Future Development Occurs

- Once the preferred place types have been selected, the user can provide high-level guidance on where growth should be prioritized by:
  - Setting the percentage of growth as In-fill type or Greenfield areas;
  - Setting general zones where new growth would be concentrated;
  - Setting locations for new activity centers and growth epi-centers; and
  - Identifying potential parking replacement opportunities.
- An automated process assigns land use across a large study area based on 'allocation' rules and probabilities of growth set by the module.

Step 4: Generate Land Use Summary

- Validation of results of the allocation and manual adjustments occur
- The SPT provides a summary of the land use allocation as well as an aggregation by TAZ to highlight where the new development has been projected to occur.

To predict the impacts of future development, where development occurs and how it would impact mobility, safety, infrastructure, and economic indicators are important. The Land Use Allocation Module spatially allocates land use that accommodates the prescribed population and employment growth in accordance with certain development rules. The module is automated based on various high-level scenario inputs. More detailed information is generated for allowing deep-dive analytics in the Travel Demand Module and KPI Engine which will be introduced in the upcoming sections.

Land Use Model Calibration

The land use module was calibrated and validated primarily based on existing land use and the socio-economic input data of the CRCOG Travel Demand Model. The land use module was limited to the study area and therefore was calibrated using Travel Demand Model's information within the study area.

It should be noted that the calibration was performed at three different levels:

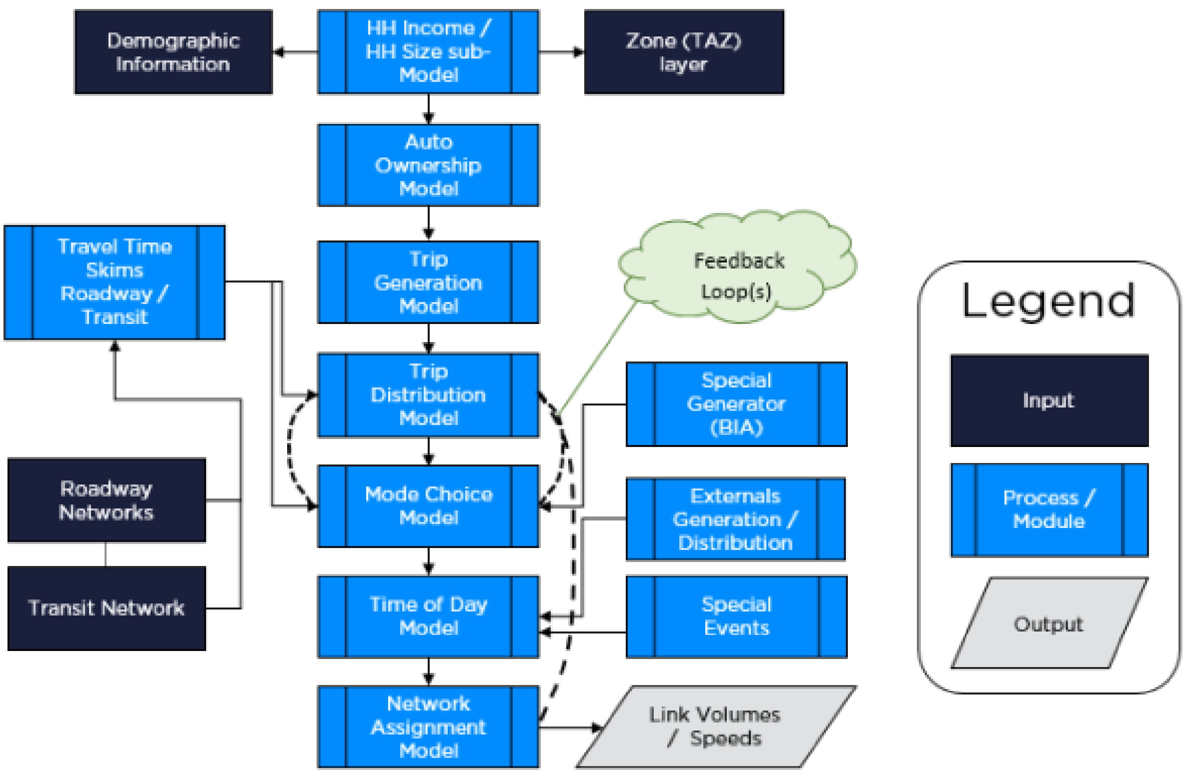
1) At the study area level, the growth prediction of population and employment between 2020 and 2050 was fed into the land use module to ensure consistent overall growth prediction in population and employment.
2) At the TAZ level, the change in population and jobs between 2020 and 2050 was integrated to inform the land use module in allocating reasonable amount of development for each TAZ.
3) At census block level, multiple considerations were factored in such as densities, land use, zoning, roadway networks, transit services, and land values. These helps predict suitable development types and densities at appropriate locations.

Travel Demand Module

The travel demand module (TDM) in GHMS-SPT translates user input parameters from the tool interface, zonal outputs from the land use allocation model, transportation network improvements, and the choice of various transportation policy alternatives into travel demand and transportation network performance metrics. These metrics are fed into the Key Performance Indicators (KPI) module to develop KPIs.

The TDM in GHMS-SPT features a standard four-step process with customized enhancements, based on the Capitol Region Council of Governments (CRCOG) travel demand model. Figure 3 shows the model structure. The full modeling methodology, configuration, calibration, and validation are presented in Appendix G-3.

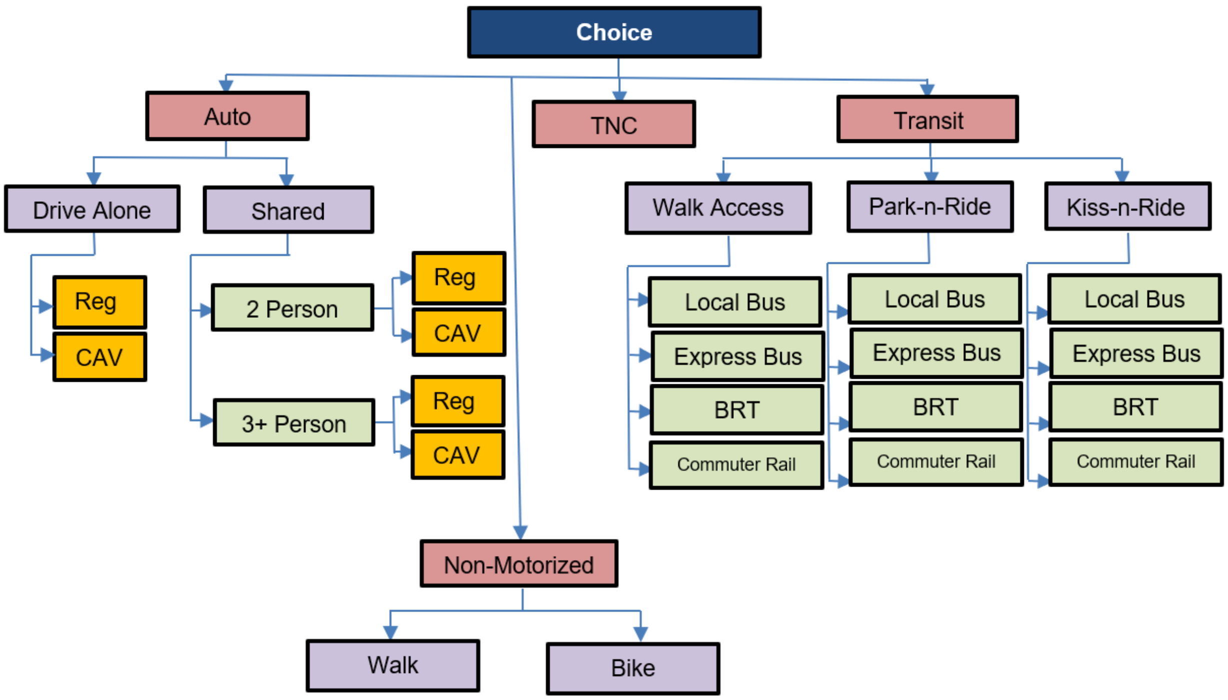
Figure 3: Four-Step Process in TDM



Source: Technical Memorandum – Travel Demand Modeling System–Wide Calibration, CRCOG 2019

Modifications from the CRCOG four-step model include the expansion of transportation mode nesting structure to determine the impacts of regional vehicle technology market penetration rate (RVTMPR) of Connected and Automated Vehicles (CAV) and Electric Vehicles (EV); truck platooning; transportation network companies (TNC); and on-demand delivery (ODD). Figure 4, below, shows the updated transportation mode nesting structure for the GHMS-SPT. The TDM in GHMS-SPT also analyzes five policies in three policy categories, including incentivizing transit usage, managing regional travel demand, and pricing the usage of the transportation system to mitigate traffic congestion.

Figure 4: Transportation Mode Nesting Structure in GHMS Tool



In addition to the GHMS-SPT user inputs, the travel demand module uses the same model parameters and input data as used by the CRCOG model. Editing model parameters and input data requires the use of TransCAD software and may only be completed by advanced users. All the scenario transportation networks used in GTMS-SPT are pre-developed. The user may choose between these pre-developed networks (e.g., N1, N2, and N3) for constructing a scenario. Additional networks can be built offline and run in the travel demand module. The GHMS-SPT TDM does not use CRCOG's interactive model user interface. The universal model parameters used in the CRCOG model are coded in GHMS-SPT TDM scripts for streamlined tool application. Four other customized parameter files are also used to supplement the universal model parameters: a land use data file, user input parameter file, GHMS model parameter file, and GHMS policy inputs file.

TDM output is produced in many ESRI shapefiles and CSV files. These files are processed with the GHMS Key Performance Indicator (KPI) engine to summarize scenario results through key metrics aligned with the GHMS goals.

To expand the nested mode structure, model calibration was conducted and focused on ensuring the model estimates proper mode share for TNC mode. The estimated TNC mode share matched the target values derived from the Metropolitan Washington Council of Governments (MWCOG) Travel Survey (available in Appendix G-3). MWCOG travel survey is one of the few existing travel surveys that investigate TNC trips. Model calibration also included the customized mode utility function to incorporate the CAV market penetration rate from GTMS-SPT user input. The calibrated TDM in GHMS-SPT produced identical or similar results to those from the CRCOG model for the existing year 2020 and 2050 baseline scenarios.

Key Performance Indicators

The GHMS performance-based planning process is the foundation of KPI development. The rationale is largely based on the five Ds of the built environment that significantly influence travel demand and mobility – Density, Land Use Diversity, Pedestrian-oriented Design, Destination accessibility, and Distance to transit[1]. These KPIs were crafted to align well with the MAP-21's seven national goal areas:

1) Safety

2) Infrastructure condition

3) Congestion reduction

4) System reliability

5) Freight movement and economic vitality

6) Environment sustainability

7) Reduced project delivery delays

GHMS-SPT also includes KPIs related to social equity, including the share of commuting costs as a % of income per household and environmental justice (EJ) population walk access to destinations, The methodologies to calculate these KPIs are consistent with USDOT requirements.

KPIs were refined further for the Greater Hartford region. The new GHMS KPI framework has emerged to answer some critical questions related to sustainability and future transportation in the region. These are:

1) Does the indicator reflect the broader goals and vision of the Metropolitan Transportation Plan for the region?

The 2019-2045 CRCOG Metropolitan Transportation Plan (MTP) and other relevant CTDOT documents such as the Freight Plan, Active Transportation Plan influenced the development of a set of indicators that closely align with the MTP goals. A list of plans that were reviewed is illustrated in Appendix G-4.

2) What insights do studies in peer-reviewed research journals and whitepapers offer for a given indicator?

Research in peer-reviewed journal articles supports the rationales and methodologies behind these indicators. For example, the National Cooperative Highway Research Program (NCHRP) *Guidebook for Sustainability Performance Management for Transportation Agencies* cites many performance measures as supportive of indicating progress towards transportation goals[2]. These include travel time index supporting transportation system functionality and efficiency; and job accessibility supporting economic development and prosperity. Other sources referenced in developing the KPIs include MAP-21

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[1] Reid Ewing & Robert Cervero (2017) "Does Compact Development Make People Drive Less? The Answer is Yes," Journal of the American Planning Association, 83:1, 19-25, DOI: 10.1080/01944363.2016.1245112.

[2] National Academies of Sciences, Engineering, and Medicine 2011. A Guidebook for Sustainability Performance Measurement for Transportation Agencies. Washington, DC: The National Academies Press. https://doi.org/10.17226/14598.

Performance Management[3], and *Federal Transit Administration's Mobility Performance Metrics for Integrated Mobility and Beyond*[4].

3) **Can this indicator be easily measured? What are the data sources required? Are these sources readily available given the study area and the context of the problem?**

The needed data were collected and analyzed to calculate the performance measure. A methodology was developed consistent with federal and MPO requirements. KPIs for which the supporting data is not available were removed.

4) **Is this indicator clearly understood? If not, how can it be easily understood by the users of the tool?**

Indicators are named in a way that the users can quickly comprehend.

5) **Lastly, does this indicator capture key concerns of CTDOT and stakeholders?**

Workshops with CTDOT and stakeholders were held to gain their feedback on the indicators and make changes.

A cross-domain outcome map linked the MTP goals to the GHMS-SPT KPI domains and measures within it (Appendix G-5). The GHMS-SPT Key Performance Indicators (KPIs) address the aspects of traffic and pedestrian **mobility**, **infrastructure** availability and gaps in the study area, and **social** implications of transportation infrastructure on user behavior. Indicators in two overarching domains – **economic** and **environment** supplement the framework to give holistic KPIs to address sustainable ways of integrating future transportation in the Greater Hartford region. Together, these five domains cover the KPI assessment module for the tool.

Each of the five domains is further divided into its respective sub-domains. **Mobility** includes multimodal options for transit and performances such as duration of congestion and reliability of transit systems. **Infrastructure** adopts conventional metrics from traffic engineering supplemented with land-use efficiency measures and the sustainability of developed urban structures. **Social** measures look at accessibility, equity, safety, and convenience of transit users. The **economic** outcomes of existing transit conditions are captured in the sub-domains of investments, job-housing balance, freight, and macro-outcomes of economic development in the study area. The dimension of sustainability is captured through the measurement and monitoring of **environmental** indicators, which are divided into the sub-domains of air quality, greenhouse gas emissions, and the existence of urban heat islands.

A detailed breakdown of the KPIs can be found in Appendix G-6. The spatial nature of these developed indicators allows the user to monitor and diagnose the extent to which future transportation can be integrated sustainably in the region. The results of all the performance indicators are available at the roadways and TAZ levels for ease of planning and implementation.

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[3] https://www.fhwa.dot.gov/map21/factsheets/pm.cfm#top

[4] Federal Transit Administration 2020. Mobility Performance Metrics for Integrated Mobility and Beyond. Washington, DC: Office of Research, Demonstration and Innovation U.S. Department of Transportation. https://www.transit.gov/about/research-innovation

Configured Scenario Results

With the configured scenario planning tool, two baseline scenarios were developed and completed as part of the validation process. Scenario 1 is Existing (2020), and Scenario 2 is the Future Baseline Condition (2050). Figure 5 shows the summary of performance for the Existing Scenario. This will serve as a baseline of comparison to identify trends over many different scenarios. The scored results alone should only be held as a means of comparison – the actual values of the KPIs, as presented in Appendix G-7, indicate the real-world performance of each scenario. Figure 6 shows the Future Baseline Condition (2050) results, which will be used as a basis to compare differences across other future build year scenarios. Appendix G-7 shows a comparison table with the full calculated KPI results for the two configured scenarios.

Figure 5: Existing Condition (2020) KPI Results

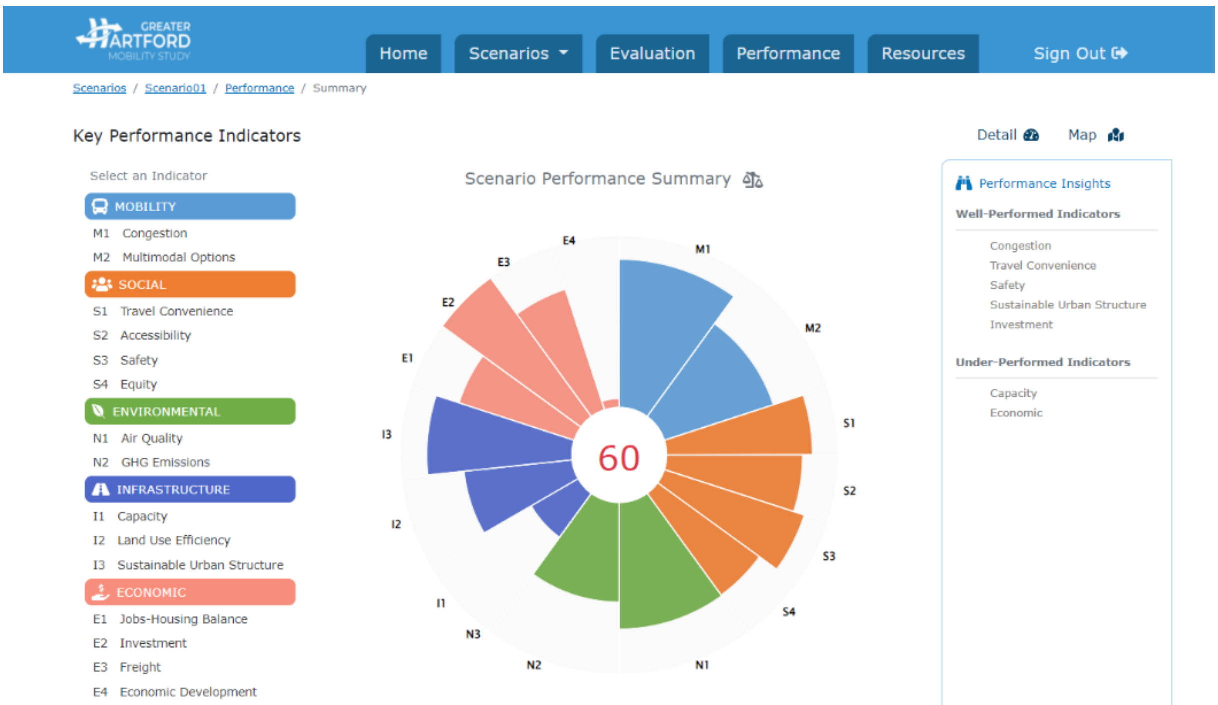


Figure 6: Future Baseline Condition (2050) KPI Results

Summary

The GHMS-SPT can help explore a wide range of parameters delineating future uncertainties, model and evaluate their impacts, construct feasible scenarios, identify future needs, and provide insight on how they collectively affect the regional goals. Phase I of the GHMS included developing and validating the 2020 and 2050 base scenarios. In Phase II, the GHMS-SPT will be used to evaluate and compare the impacts of various scenarios through the KPIs.

Appendix G-1: User Inputs

Area	User Input	Details
Timeframe	Year	Present (2015), Mid-term (2035), Long-term (2050)
Growth	Population Growth	User-input population growth (-0.2% - 50%)
Growth	Employment Growth	User-input employment growth (-0.2% - 50%)
Network	Roadway Network	Existing, Existing + Committed, Existing + Committed + Modifications
Network	Rail network	Existing, Existing + Committed, Existing + Committed + Modifications
Network	Transit Network	Existing, Existing + Committed, Existing + Committed + Modifications
Network	Park and Ride/Mobility Hubs	Existing / Planned
Network	Parking	Existing, Small Reduction, Large Reduction
Network	Bike / Ped Network	Existing, Existing + Committed, Existing + Committed + Modifications
Technology and Emerging Trends	Overall Growth Projection	Low, Steady, Optimistic
Technology and Emerging Trends	Connected Vehicles Penetration %	0 - 100%
Technology and Emerging Trends	Electric Vehicles Penetration %	2015: 0 - 100%; 2035: 25 - 100%; 2050: 50 - 100%
Technology and Emerging Trends	Truck Platooning Penetration %	0 - 100%
Technology and Emerging Trends	On-Demand Delivery Penetration %	0 - 100%
Technology and Emerging Trends	Advanced Air Mobility (AAM) Penetration %	0 - 100%
Technology and Emerging Trends	Automated Personal Vehicles	0 - 100%
Technology and Emerging Trends	Automated Commercial Vehicles	0 - 100%
Demographic Profile	Private vehicle ownership (shift to MaaS)	0 - 100%
Demographic Profile	Work from Home Percentage	0 - 100%
Demographic Profile	Micromobility Usability	0 - 100%
Demographic Profile	Average Household Size	Dropdown menu: 1 - 7 people

Area	User Input	Details
Land Use	Residential Density	Low / Medium / High Density Residential
Land Use	Non-Residential Density	Commercial Low / High, Industrial, Institutional
Land Use	Mixed-Use Density	Mixed-Use Medium / High Density
Land Use	Parking Replacement	If "Parking" = Small Reduction or Large Reduction, select the land use and density to replace
Land Use	Map: Major Activity Centers	Minor / Medium / Major Employment Center, Minor / Medium / Major Residential Node
Land Use	Infill Percentage	0 - 100% Infill, 0 - 100% Greenfield
Land Use	Greenfield: Residential Low/Medium/High Growth Quads	Low / Medium / High Growth Quads
Land Use	Greenfield: Non-Residential Low/Medium/High Growth Quads	Low / Medium / High Growth Quads
Land Use	Allocate: % Mixed Use	0 - 30%
Policy Options	Transit Investment: Employer Incentive Program	Reduce transit fare value by 80%
Policy Options	Transit Investment: Intelligent Transit Stops	5.8-minute reduction of in-transit-vehicle travel time
Policy Options	Transit Investment: Increasing Bus Route Frequencies	Increase service frequency per transit route by 100%
Policy Options	Transit Investment: Electronic Payment & Universal Fare Cards	Reduce in-transit-vehicle travel time by 0.15 min, reduce transit transfer penalty by 20%
Policy Options	Pricing: Parking Management	Increase parking cost by $2 for all auto SOV and HOV trips
Policy Options	Pricing: Road Usage Charges (RUC)	Increase vehicle operating cost by $0.10 per mile
Policy Options	Pricing: Increase in the gasoline tax	Increase vehicle operating cost and TNC fare rate

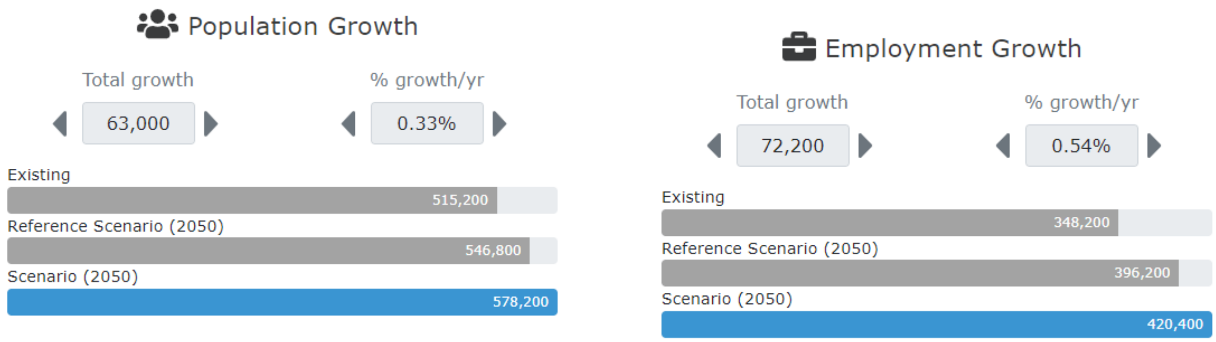
Appendix G-2: Land Use Allocation Module Process

This appendix describes in more detail the Land Use Allocation Module Process, including with progress screenshots from the GHMS SPT graphical user interface.

Step 1: Define Growth Parameters

In this step, the user provides annual growth rates for population and employment to set the overall new population and employment being added within the timeframe for the scenario (i.e., 2050). The user also provides a high-level increase of basic employment categories (see Figure 7.

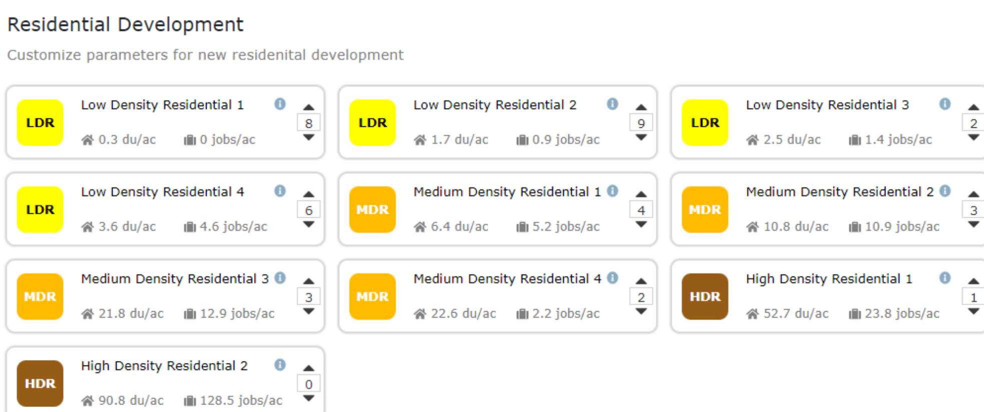
Figure 7: Population and Employment Growth User Inputs



Step 2: Select Preferred Development Types

The next step is to select the preferred development typologies that would accommodate the growth. The user/scenario developer selects preferred residential, non-residential, and mixed-use place types by assigning a relative priority to each category (shown in Figure 8). This is ultimately translated to a percent of growth assigned to each development types.

Figure 8: Place Type Prioritization in Land Use Allocation Module



Step 3: Set Location Preferences to Guide Where Future Development Occurs

Once the preferred Place types have been selected, the user can provide high-level guidance on where growth should be prioritized. This can be done in four distinct ways:

- Set the percentage of growth as Infill type or Greenfield areas (Figure 9);
- Set general zones where new growth would be concentrated;
- Set locations for new activity centers and growth epi-centers; and/or
- Identify potential parking replacement opportunities (Figure 10).

Figure 9: User Inputs for Infill and Greenfields Development Rates

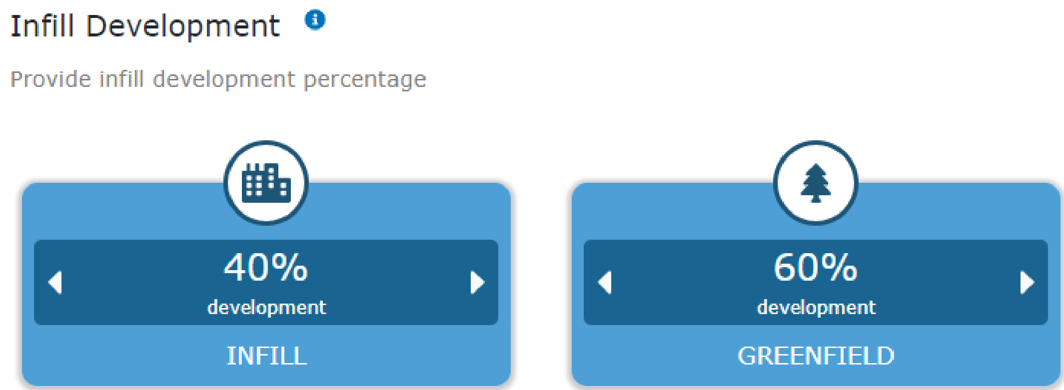
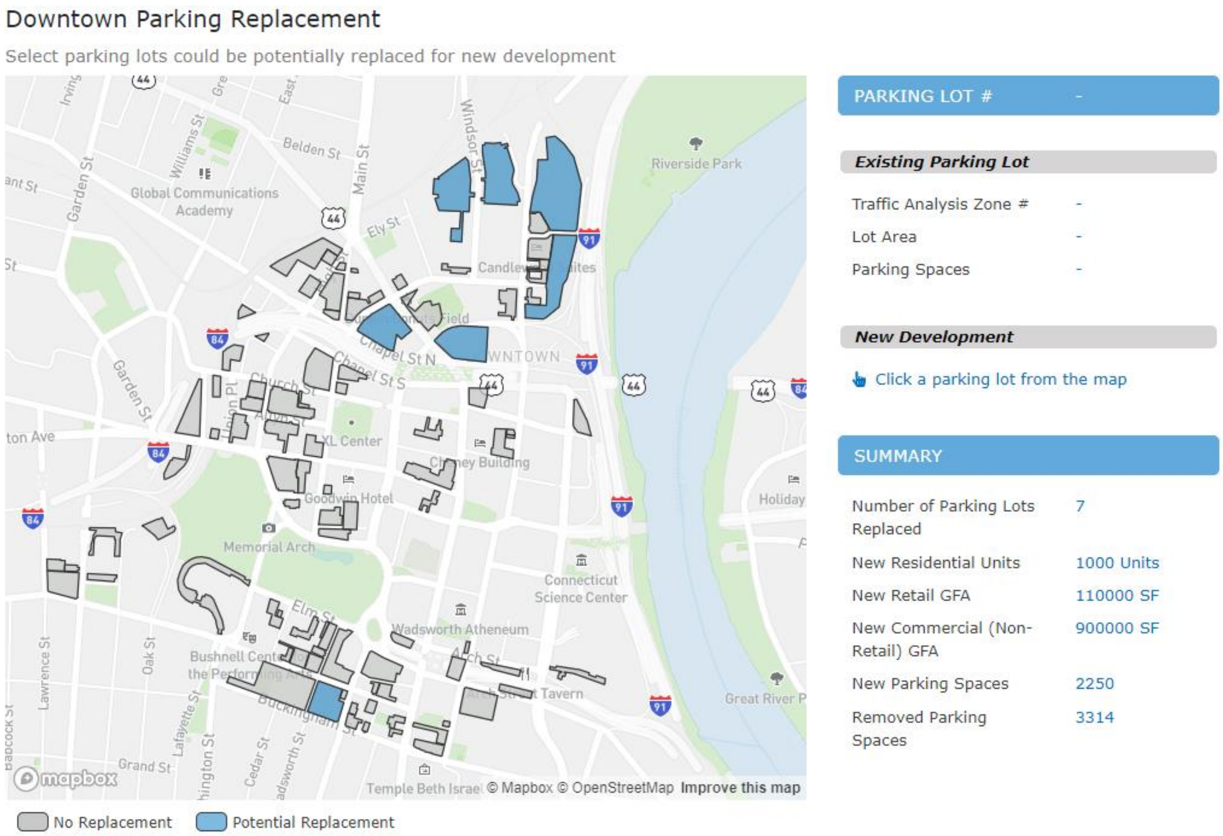
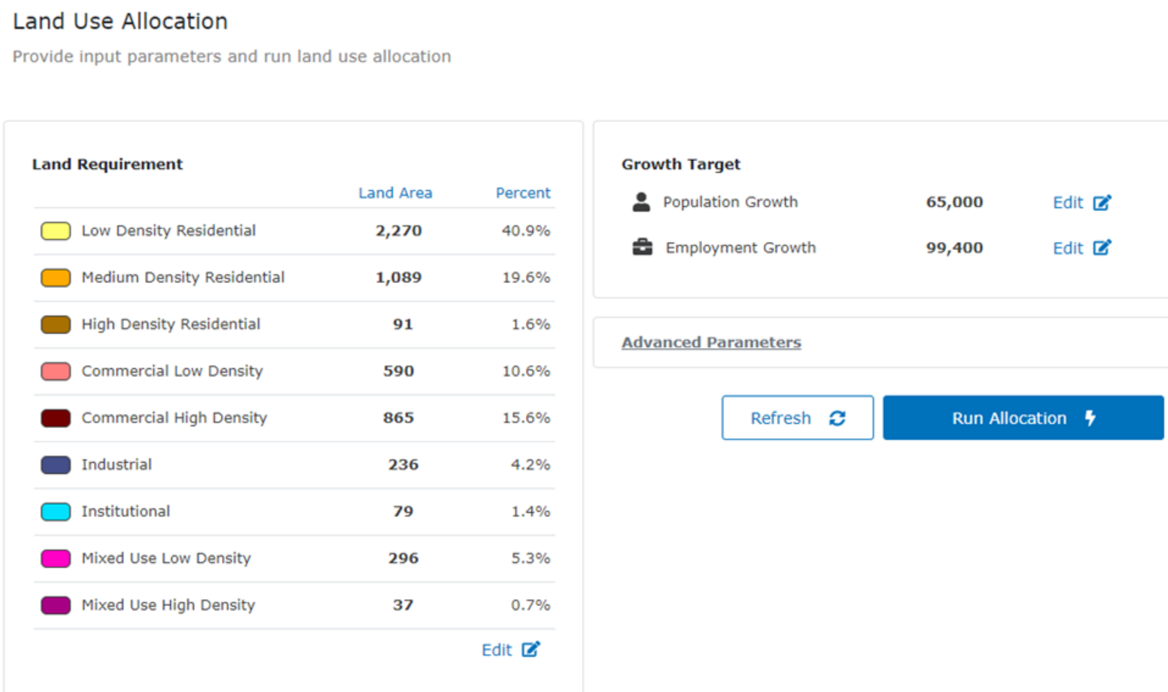


Figure 10: User Inputs for Parking Replacement with New Developments



The land use allocation module utilizes an automated process to assign land use across a large study area based on 'allocation' rules and probabilities of growth set by the module. Table 11 shows the summary of land use allocation input parameters before an allocation run.

Figure 11: Land Use Allocation Input Summary



Step 4: Generate Land Use Summary

The final step of the scenario land use allocation process is to validate the results of the allocation and manual adjustments. The Scenario Planning Tool provides a summary of the land use allocation as well as an aggregation by TAZ to highlight where the new development has been projected to occur. Figure 12 shows the summary of land use allocation results dashboard and Figure 13**Error! Reference source not found.** shows the TAZ level map showing population as the result of the land use allocation.

Figure 12: Land Use Allocation Module Results - Land Use

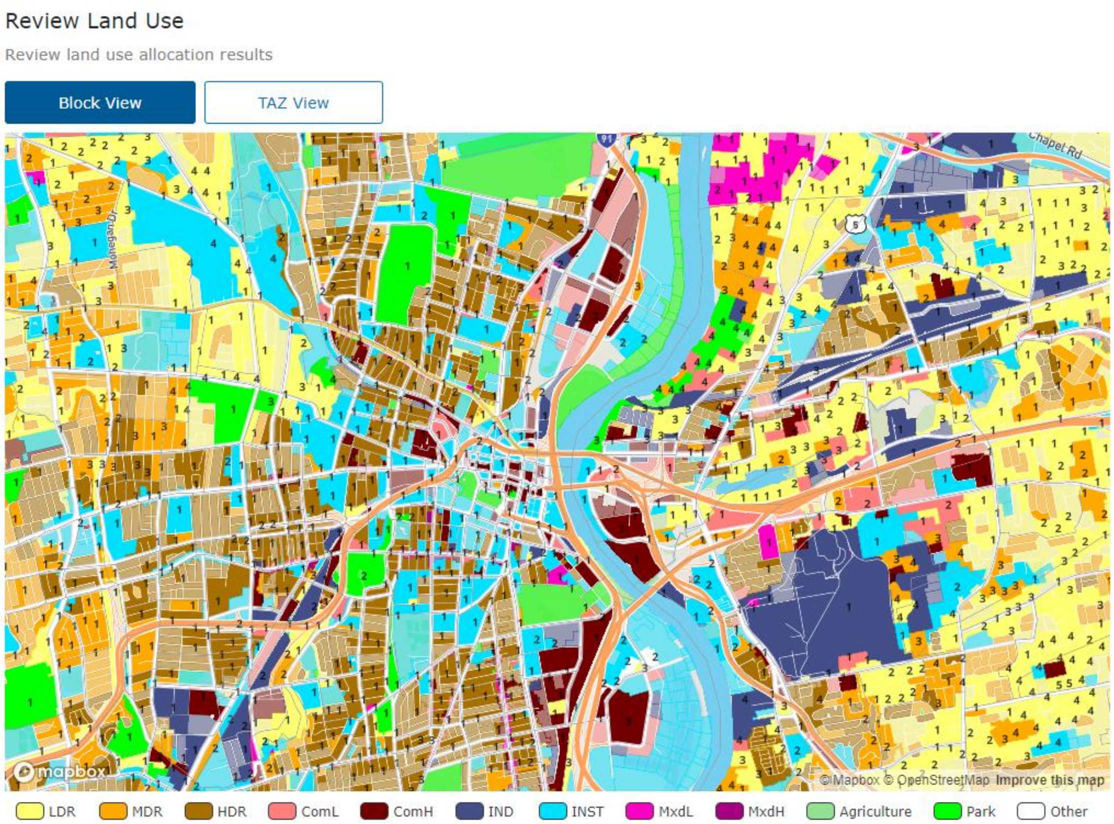
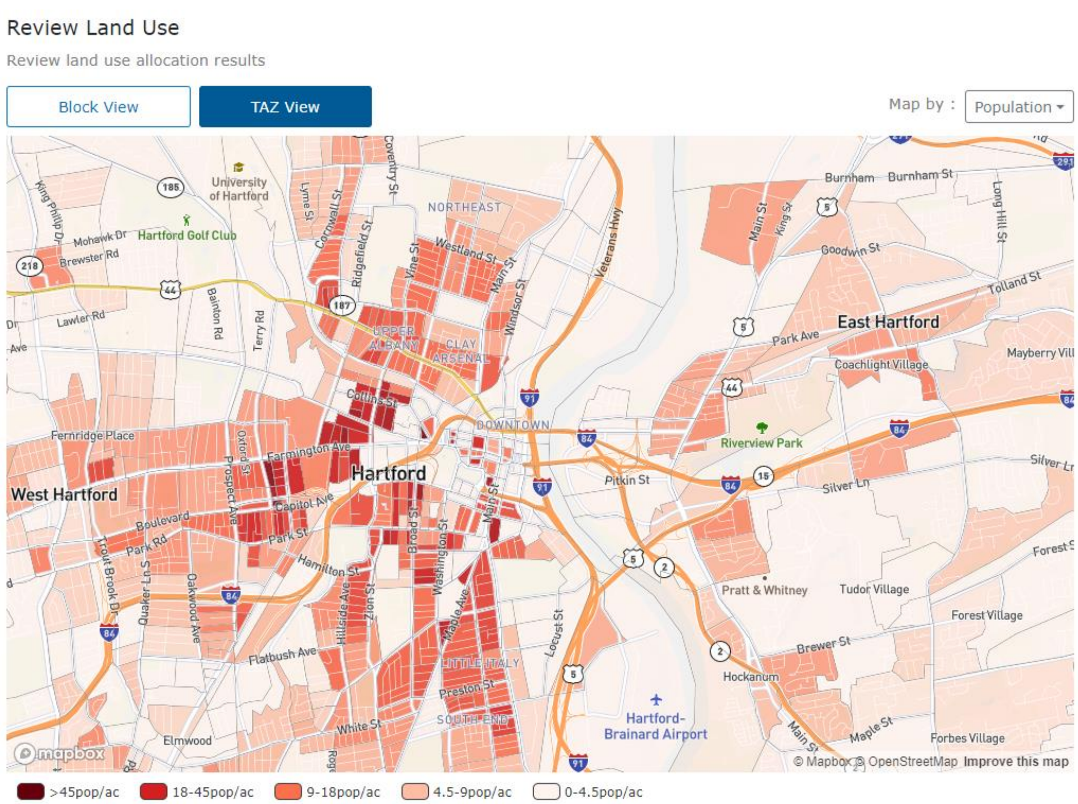


Figure 13: Land Use Allocation Module Results - Population



Appendix G-3: Travel Demand Module Configuration, Calibration, and Validation

Introduction

The Travel demand module (TDM) in GHMS tool translates the user input parameters from the tool interface, the zonal outputs from the land use allocation model, specified transportation network improvements and various transportation policy alternatives into travel demand and transportation network performance metrics. These metrics are fed into the Key Performance Indicators (KPI) model to develop KPIs.

Modeling Methodology

The TDM in GHMS tool is developed based on the latest version of CRCOG four-step model received in 2021, as illustrated in figure 2. A Detailed CRCOG model calibration and validation can be found in the Technical Memorandum – Travel Demand Modelling System–Wide Calibration, CRCOG 2019*.*

The TDM also features several model enhancements to ensure suitable analysis capacity that is sensitive to several scenario planning components.

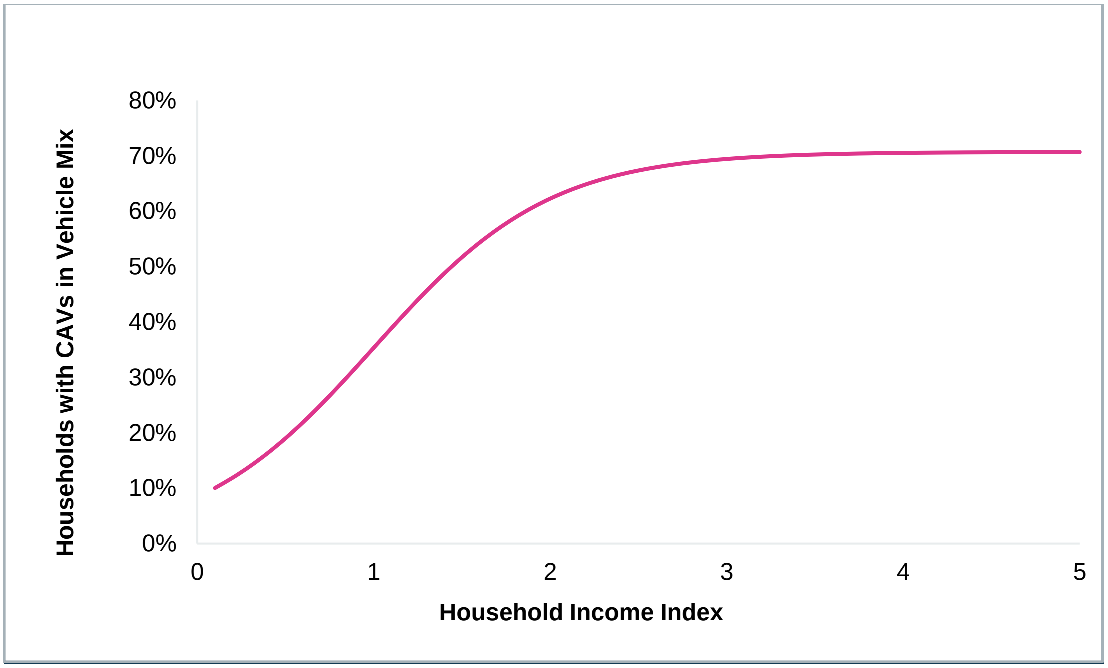
- ### **Transportation Mode Structure**

The transportation mode nesting structure in the CRCOG model was expanded to include a branch for Transportation Network Companies (TNC), e.g., Uber and Lyft, in parallel with the other three main modes, Auto, Transit and non-motorized. Each of the sub-auto modes is further split into the autos equipped with traditional and connected/autonomous vehicle (CAV) technologies to support CAV-centered analyses, as in figure 3.

- ### **CAV and Other Vehicle Technologies**

The regional vehicle technology market penetration rate (RVTMPR) for CAV and electric vehicles (EVs) is a key user input in the GHMS scenario planning tool. In the TDM in GHMS-SPT, vehicle technology modeling starts with a household vehicle ownership sub-model that estimates the shares of vehicle technologies in privately owned vehicle fleets based on household income. This model assumes earlier adoption of advanced vehicle technologies by higher-income households. Figure 14 gives an example of how the share of CAV in privately owned vehicles alters with household income index (HII) when the regional CAV market penetration rate is set to be 50%. Household income index is defined as the ratio of zonal household income to the regional average household income.

Figure 14: CAV% in Privately Owned Vehicles Fleets - RCMPR 50%



The underlying formulas to calculate Household Vehicle Technology Share (HVTS) are based on both the regional vehicle technology market penetration rate and household income.

*L = RVTMPR/[(1/RVTMPR)***Alpha*]*

*HVTS= RVTMPR / (L + (1- RVTMPR)***Beta** * Exp(**Gamma** * (HII - 1)))*

Alpha, ***Beta,*** and ***Gamma*** are parameters that advanced users can specify for each modeled vehicle technology.

➢ Latent Travel Demand

The TDM in GHMS tool assumes advanced vehicle technologies stimulate latent travel demand. With this assumption, the estimated vehicle technology rates are used to estimate the growth of trip generation rates.

The TDM in GHMS tool sets maximum trip generation growth rates (as shown in Figure 15) applied to four trip purposes to constrain the demand growth due to adoption of advanced vehicle technologies. The four purposes include home-based work (HBW), home-based school (HBSCH), home-based other (HBO), and non-home-based (NHB). These rates can be specified by advanced tool users.

Figure 15: Maximum Growth Rates for Trip Generation Rates

Trip Purpose	Maximum Growth Rate
HBW	2.0%[1]
HBSCH	0.0%
HBO	5.0%[2]
NHB	1.0%[3]

[1]Various studies and reports including NCHRP report 896 suggest low increase of trip generation rate for HBW purpose which should largely account for telecommunication population.

[2-3]Asserted parameters based on best educated judgement. In general, they agree with other studies that also include strong assumptions and asserted parameters, including 'Estimating the trip generation impacts of autonomous vehicles on car travel in Victoria, Austrailia' by Lon T Truong, etc

The GHMS-SPT assumes that different vehicle technologies stimulate the latent travel demand to different degrees. A weighting-strategy-based methodology is applied by the TDM in GHMS-SPT to adjust trip generation rates using the weights in Figure 15. For instance, 1 percent of level-5 CAV is equivalent to 26.5 percent of electric vehicles (EV) or AV1_3 (level 1 through 3) in terms of stimulated growth of demand.

Figure 16: Vehicle Technology-Specific Weights for Trip Generation Rate Adjustment

Vehicle Class	Adjustment Weight	Description
EV	1[1]	EV only
AV1_3	1[1]	AV1-3 only
EAV1_3	2[1]	Both EV and AV1-3
AV4	6[1]	EV and AV4
CAV4	7.5[1] AV4*1.25[1]	EV, CV, and AV4
CAV5	26.25[1] (EV+AV1_3[1])*1.25[1]	EV, CV, and AV5
MAX	**26.25**	**MAX**

[1]asserted parameters from best educated judgement. No weighting strategy similar to what is used in SWIFT was identified from the literature review.

➢ Perceived Travel Time

The TDM in GHMS tool assumes advanced vehicle technologies improve driving experience and riding comfort, convert drive time to productive work time, and hence reduce the perceived travel time for drive modes. This in turn simulates longer trips made by autos with advanced vehicle technologies and encourages auto mode usage in general. The TDM in GHMS tool applies a reduction rate of 0.75 to perceived auto travel time for level-5 CAV with full automation and a rate of 0.9 for level-4 CAV with high automation.

- **Vehicle Operating Cost**

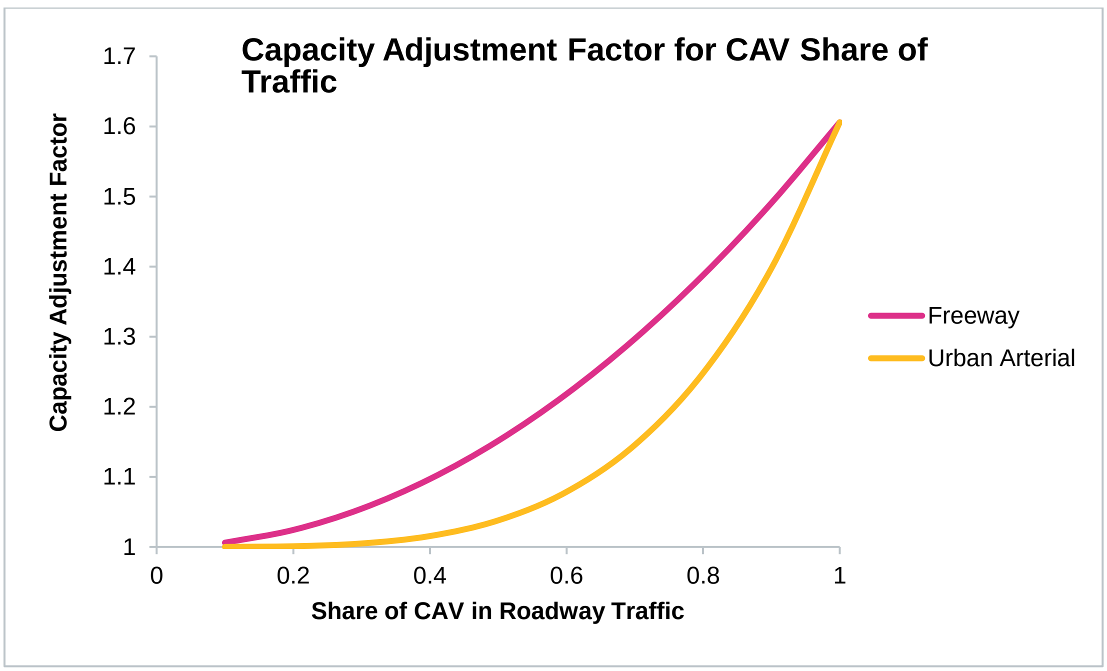
Vehicle operating cost is an important part of overall travel cost when driving. The TDM in GHMS tool assumes advanced vehicle technologies reduces vehicle operating cost due to electrification. This further stimulates longer trips made by autos with advanced vehicle technologies and encourages auto mode usage overall.

The TDM in GHMS-SPT assumes the operating cost of fully electric vehicles is lower than that for regular vehicles using fossil fuel. The operating cost reduction rate is 50% by default, but it can also be specified by advanced tool users.

- **Roadway Capacity**

The TDM in GHMS tool assumes level-5 CAV with full automation technology improves roadway capacity, accounting for shorter CAV operation headways and coordinated operation of connected vehicles.Figure 17 illustrates how roadway capacity improves with the CAV share in roadway traffic for both freeways and urban arterials.

Figure 17: Share of CAV in Roadway Traffic



As shown in Figure 17, the TDM in GHMS tool assumes that the capacity of freeways carrying uninterrupted traffic flow benefits earlier and in general to a larger degree from CAV technology than that of urban arterial streets carrying interrupted traffic flow. GHMS-SPT also assumes both types of facilities would receive same degree of capacity improvement when the entire regional vehicle fleet becomes CAV.

The parameters defining the capacity curves include a CAV operation headway, a regular vehicle operation headway and a shape factor, all of which can be specified by advanced tool users for more detailed and in-depth scenario analysis.

➢ Truck Platooning

Truck platooning is the use of connected vehicle technology to group freight trucks together, reducing their headways on the freeway, and coordinating braking and acceleration. The TDM in GHMS-SPT assumes truck platooning also improves roadway capacity. However, this assumption is implemented only for freeway facilities where truck platooning is most feasible and meaningful. The coordinated truck operations via platooning on freeways shortens the truck vehicle operation headway and reduces the needs and occurrences of truck acceleration/deceleration. Specifically, the following equation is used to adjust the number of Regular Truck Equivalents (RTE) to account for the truck traffic operation efficiency improvement due to truck platooning.

$$RTE = Trucks * (1 - \text{Percent of Platooning Trucks} * 0.46)$$

➢ Emerging Transportation Modes

Transportation Network Company (TNC), as a shared mobility mode, is assumed by the TDM in GHMS-SPT to have earlier and more extensive deployment of advanced vehicle technologies. Specifically, EV and CAV adoption rates for TNC is assumed to be 20% higher than the average regional rates. However, this default rate can be changed by advanced tool users.

A simplified finance model is used by GHMS-SPT to simulate the TNC service fare mechanism. This mechanism assumes that the 50% of TNC fare is from driver labor cost, 30% from vehicle operating cost and 20% from other costs accounting for business management, profit margin, etc. It is worth noting that all three pricing parameters can be easily adjusted in the TDM by advanced tool users to better represent the dynamics in local shared mobility market and for more detailed scenario analyses. The simplified TNC finance model is sensitive to advanced vehicle technologies such that EV technology lowers vehicle operating cost and CAV technology reduces driver labor cost. The TNC fare is also sensitive to urban density.

$$\text{TNC Per-Mile-Rate Reduction \%} = [(EV(\%) * 0.25 * 0.5 + (1-EV(\%) * 0.25)*1.0)*0.3) + (1-AV5(\%) * 0.75)*0.5]/(0.3 + 0.5)$$

Where:

- *EV(%) and AV5(%)* represent EV and AV technology rates applied to TNC.
- EV reduces vehicle operating cost by 50% and level-5 CAV eliminates driver cost.
- Only 25% (hard coded) of the TNC vehicle operating cost reduction is reflected in TNC per-mile-rate.
- Only 75% (hard coded) of the driver cost reduction is reflected in TNC per-mile-rate
- The other parameters used by the TDM in GHMS tool to determine the TNC fare are shown in Table 2.

Table 2: Default TNC Fees

TNC Fare Components	Value ($)
Booking Fee	$7.00
Per Mile Rate	$1.60

The overall TNC fare is further adjusted based on area types in Table 3. Average TNC waiting time is also set to vary with area types in GHMS-SPT. Advanced GHMS-SPT users can customize these parameters based on local travel and shared mobility market conditions.

Table 3: TNC Fee Adjustment Rates by Area Type

Area Type	TNC Fare Adjustment Rate	TNC Waiting Time (Min)
CBD	0.85	3
Urban	0.90	4
Suburban	1.00	7
Suburban Fringe	1.10	12
Rural	1.20	20

An example given below can help understand how TNC fare is calculated in GHMS tool.

- Trip length: 5 miles
- Pickup location: Suburban Fringe
- TNC CAV Penetration Rate: 10%
- TNC EV Penetration Rate: 50%
- Fee Parameters: Default

TNC Per-Mile-Rate Reduction % = *[(50%*0.25*0.5+(150%*0.25)*1.0)*0.3) + (1-10% *0.75)*0.5]/(0.3 + 0.5) = 0.93*

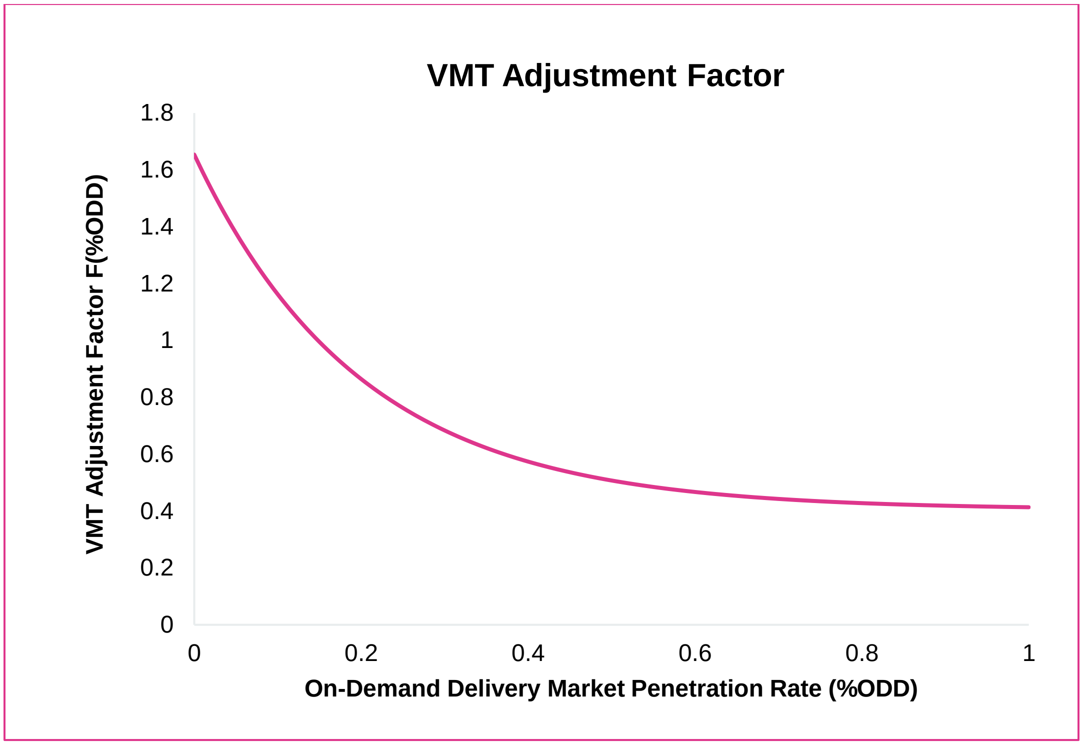
TNC Fare: (7+5*1.6*0.93)*1.1 = **$15.88**

On-Demand Delivery (ODD)

It is assumed in GHMS tool that on-demand delivery would replace many of household daily shopping activities for groceries, meals, and household goods.

A typical on-demand delivery trip makes multiple stops to serve multiple households. When on-demand delivery is widely accepted and resulting delivery stops are dense and close to each other, on-demand delivery potentially improves the transportation system performance by reducing total VMT otherwise generated by households making individual shopping trips. On the other hand, before on-demand delivery saturates to a certain level, the on-demand delivery stimulates the latent shopping demand, and the delivery trips may not be coordinated optimally or chained efficiently enough to reduce overall VMT for shopping. With both arguments accounted for, on-demand delivery market level is used by GHMS-SPT to estimate a VMT adjustment factor from a curve depicted in Figure 18.

Figure 18: VMT Adjustment for On-Demand Delivery



The TDM in GHMS tool adjusts the household shopping trips by the percentage read from the curve in Figure 18 using the equation below.

*[Adjusted HB Shopping Trips] = [HB Shopping Trips] * F(%ODD)*

Where:

- *%ODD* is the on-demand delivery market level user specifies in GHMS-SPT for scenario planning analysis.
- *F(%ODD)* is underlying function that determines the Y-axis value read from the curve using %ODD as the X-axis value in Figure 18.

Currently, the function is hard coded in the modeling process, and the GHMS tool does not allow the users to modify the function that underlies the curve in Figure 18.

The CRCOG travel demand model uses three trip purposes, HBW, HBO and NHB with HBO consolidating the home-based trips supporting shopping and all other non-work activities. For applying home-based shopping trip adjustment factor, the splitting parameters, 0.373 for shopping and 0.627 for non-shopping, were borrowed from Houston-Galveston Area Council's four-step travel demand model to separate home-based shopping and home-based non-shopping trips in HBO purpose. With these parameters, the adjustment due to on-demand delivery is applied directly to HBO trips using the equation below.

*[Adjusted HBO Trips] = [HBO Trips] * (1- 0.373 + 0.373 * ((1-%ODD) + %ODD * F(%ODD))*

➢ Transportation Policies

GHMS evaluates six policies in three policy categories to incentivize transit mode usage, manage the regional travel demand and price the usage of transportation system to mitigate traffic congestion as shown in Table 4

Table 4: GHMS Transportation Policy Alternatives

Policy ID	GHMS Policy Alternatives
TRANSIT	
1	Employment Incentive Programs
2	Increasing Bus Route Frequencies
TRAVEL DEMAND MANAGEMENT (TDM)	
3	Work from Home (WFH)
PRICING	
4	Parking Management
5	Roadway Usage Charges (RUC)
6	Increase in Gasoline Tax

The evaluation of transportation policy alternatives is performed by the TDM in GHMS-SPT through:

- Parameterizing the key features of the policies as shown in Table 5; and
- Quantifying the policy impacts on all relevant travel behavioral areas and resulting traffic congestion and transit ridership.

In Table 5, the parameters in percent form are applied as a multiplier and the other parameters as net additive difference to the relevant parameters used by TDM in GHMS-SPT to account for the policy impacts on travel behavior.

Table 5: Policy Parameters Implemented in the TDM in GHMS-SPT

Policy Category	Policy	Implemented Policy Parameters					
		Transit Fare Change (%)	Transit Headway Change (%)	HBW Trip Rate Change (%)	Parking Cost Change (Cent)	Vehicle Operating Cost Change (Cent/ Mile)	Vehicle Fuel Cost Change (%)
Transit	Employer Incentive Program	-80	0	0	0	0	0
	Increasing Bus Route Frequency	0	-50	0	0	0	0
TDM	WFH	0	0	-10	0	0	0
Pricing	Parking Management	0	0	0	200	0	0
	Road Usage Charges (RUC)	0	0	0	0	10	0
	Increase in Gasoline Tax	0	0	0	0	0	5

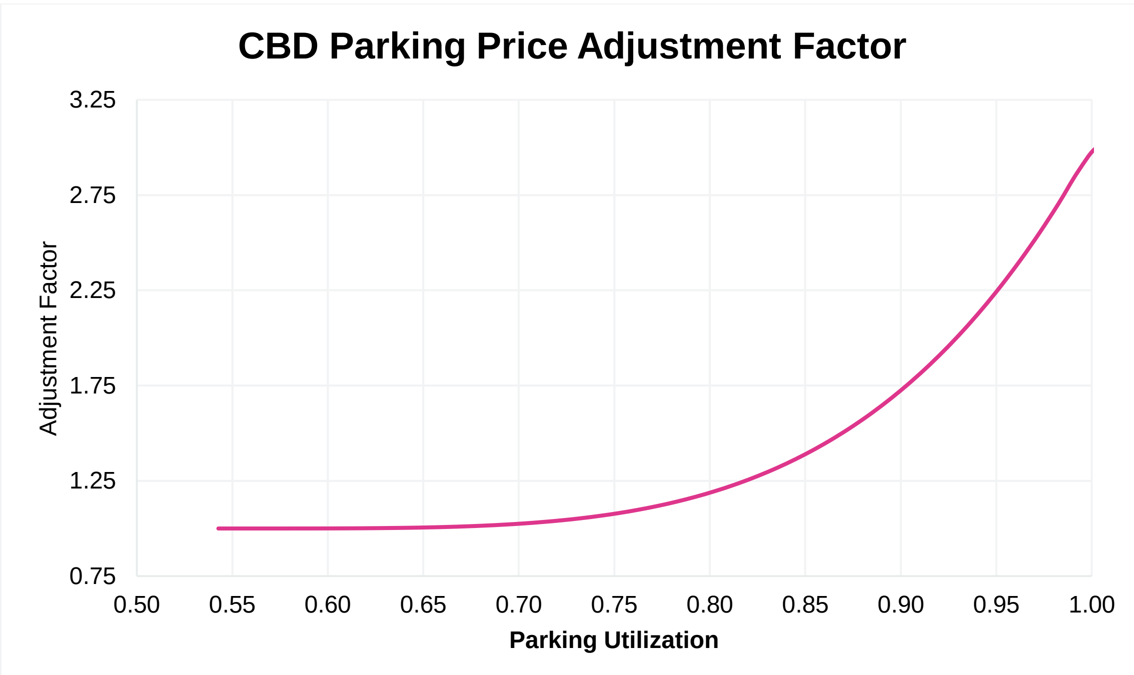
The WFH policy parameter is specified from the GHMS-SPT GUI by tool user. The other policy parameters in Table 5 are all managed in the GHMS policy parameter table and can be adjusted by the advanced GHMS-SPT users for more precise transportation policy analysis.

- For WFH arrangement and policy analysis, the TDM of GHMS-SPT implements a sophisticated algorithm that uses the information from both the origin and destination of HBW trips to assess WFH eligibility and estimate WFH likelihood. The algorithm assumes WFH is only eligible for non-retail workers. Workers from higher-income households are more likely to be eligible for WFH arrangements. The default likelihood weights (1,1,1,2,2) for five household categories (zero-car, Low-Income-Insufficient-Auto, Low-Income-Sufficient-Auto, High-Income-Insufficient-Auto and High-Income-Sufficient-Auto categories) can be calibrated by advanced GHMS tool users to the local trend and conditions for WFH arrangement.
- Transit fare change ratio is to adjust transit fare for HBW trips.
- Transit headway change ratio is to adjust transit service headways for all trips.
- Parking cost change is applied to all TAZs to increase the parking cost at trip destinations and escalates the generalized travel cost for drive mode trips, including both drive alone and shared ride.
- Vehicle operating cost change adds per-mile vehicle operating cost into the generalized travel cost for all auto modes, including both personal autos and TNC. The added vehicle operating cost for TNC is further incorporated into TNC fare through the developed finance model.
- Vehicle fuel cost change only applies to non-EV auto modes on a per-mile basis, including both personal autos and TNC. The added vehicle operating cost for TNC is further incorporated into TNC fare through the developed finance model.

➢ Land Use – Redevelopment and Parking Demand/Supply Rebalancing

The GHMS-SPT allows users to select existing parking lots or structures in the Hartford central business district (CBD) area for redevelopment. GHMS-SPT users can further specify the type and size of redevelopment, as well as the new parking spaces coming with the redevelopment. When the land use allocation completes, the land use model compiles updated parking supply information and includes it in the land use data file for the study area that is subsequently passed to the TDM. In the TDM, the updated parking supply data is compared with the parking demand in the Hartford CBD area to estimate parking utilization ratio. The estimated parking utilization ratio will be used to determine a parking price adjustment factor with the curve in Figure 19 to adjust the parking cost coded in the travel demand model.

Figure 19: CBD Parking Cost-Adjustment Factor



The CBD parking price adjustment factor curve was developed based on the assumption that higher parking facility utilization drives up average parking cost but the total parking revenue for the entire CBD area remains unchanged.

➢ External – External Truck Trips

The CRCOG model currently estimates through trips without providing vehicle classification rates. The rates of through truck trips had to be estimated using data sources from the States of Massachusetts and Connecticut combined with the CRCOG model through trip O-D matrix. External gate TAZs from the CRCOG model were identified from the CRCOG TAZ file. These were isolated and used to identify locations on the CT and MA statewide maps with traffic count and classification data. Most external gates were in Connecticut and the remainder of gates were located to the north in Massachusetts.

Connecticut and Massachusetts state traffic count maps were used to collect vehicle count and classification data. From Connecticut DOT's Traffic Monitoring Station Viewer and Massachusetts DOT's Transportation Data Management System, the year of data collection, average annualized daily traffic, cardinal direction of traffic (north, south, east, west), and classification data (rates of medium and heavy trucks as a percent of total traffic) were collected in the direction leading away from the study area at each external gate. For example, at the northernmost gate in Massachusetts, the truck volume as a % of AADT was collected in the northbound direction.

Due to lack of origin-destination data specifically for trucks, it was assumed that the truck through trips as a percent of all through trips was equal to the truck volume as a percent of all AADT at each external gate location.

$$\frac{Truck\ thru\ trips}{All\ thru\ trips} = Truck\ Volume\ as\ \%\ of\ AADT$$

The estimated through truck volume percentages were applied to the row and column totals of the base-year through trip O-D matrix to generate a P/A styled table. Fratar method was then employed to develop through truck O-D trip table using the estimates in the table as truck trip production and attraction totals and the base-year through trip O-D as the seed matrix. Review and reasonableness checking of the Fratar method results led to a few improvement adjustments to the estimated truck through trips. Estimated truck through O-D trips and total through O-D trips were then used to calculate the truck through trip ratio for each external TAZ to external TAZ matrix cell and these ratios will be multiplied by the future year through trips to estimate future year truck through O-D trips.

This resulted in a rough estimate of the through trips that can be classified as trucks in the TDM in GHMS tool. This estimate may eventually be verified through other sources such as origin-destination studies with vehicle classification, or Streetlight data. At the time of estimation, Streetlight data used for the study did not yet incorporate truck traffic in origin-destination metrics.

TDM Input

The TDM in GHMS tool uses the same model input data of the CRCOG model as used by the CRCOG. However, editing most of model input data requires to use TransCAD software and it usually can be done only by advanced users.

- **Model Parameter File**

The TDM in GHMS tool no longer uses CRCOG model's interactive model user interface and thus do not use the universal model parameter file. The included parameters are currently coded in the model scripts to facilitate the integration with other modules in GHMS-SPT.

However, the TDM in GHMS SPT uses four other scenario specific data/parameter files to support its applications.

Landuse.csv

This data file contains the updated land use information for all TAZs in the GHMS study area, including households, population, employment and parking supply. This file is produced by the land use allocation module and GHMS-SPT users should not change the data or file format under most circumstances.

_parameters.csv

This file includes the GHMS tool user inputs generated by the GHMS tool when the user interacts with the GHMS-SPT GUI, such as vehicle technology market penetration rates, transportation policy choices, transportation networks for scenario configuration. GHMS-SPT users should not change the data or format of this file.

GHMS_Para.bin

This TransCAD format binary file includes most modeling parameters that support the travel demand model enhancements described in this appendix. Although default parameter values are provided in the file, many of them are not locally estimated. Advanced GHMS-SPT users may find it beneficial to calibrate some of the parameters to local data for more meaningful scenario evaluation.

GHMS_PolicyMatrix.bin

This TransCAD format binary file supplies the policy parameters included in Table 5. The parameter values in this file are only intended to provide one example of the possible 'impacts' from the transportation policies. The GHMS-SPT users are encouraged to adjust the parameter values to best fit their scenario evaluation needs.

TDM Output

The TDM does not develop output data that are intended for direct interaction with the GHMS-SPT users. However, the TDM produces many data files in both CSV format and ESRI shapefile format to summarize the highway/transit network performance metrics and regional demographic and accessibility information to support KPI development and congestion mapping.

Travel Demand Module Calibration and Validation

Detailed model validation information is included in this section.

- **Model Parameter File**

As a part of expanding the nested mode structure in the GHMS model, model calibration focused on mode choice was conducted with assumed TNC mode share target values shown in Table 6. TNC survey data in the Hartford region was not available for this study. The 2017-2018 regional household travel survey of the Metropolitan Washington Council of Governments (MWCOG) region was reviewed to help with the development of TNC mode share target values. MWCOG's household travel survey is one of the few existing surveys that provide TNC information. This survey revealed 0.1% - 4.1% and 0.2%-2.9% of Taxi/Ride-Hail trips for commute and non-commute purposes respectively with lower rates observed in rural and low-density suburban areas and higher rates from activity centers and high-density urban cores. The review of land use pattern and population density in the Greater Hartford area suggested the average regional TNC mode usage should reside in the lower portion of the above ranges.

Table 6: Mode Choice Model Calibration Target Values for TNC

Trip Purpose	Market Segment	TNC Share (%)
HBW	Zero Auto	1.20%
	Low Income & Insufficient Auto	1%
	Low Income & Sufficient Auto	1%
	High Income & Insufficient Auto	1.50%
	High Income & Sufficient Auto	1.20%
HBO	Zero Auto	0.25%
	Low Income & Insufficient Auto	0.20%
	Low Income & Sufficient Auto	0.15%
	High Income & Insufficient Auto	0.30%
	High Income & Sufficient Auto	0.20%
NHB	All	0.25%

The mode choice model calibration was also supported by the customized mode utility formulation for CAVs and regular vehicles, understanding that the mode utilization probability estimation in the CRCOG model is underlaid by the assumption implying no capacity restraints on 'available' modes even when the mode availability is limited. However, this may not reflect what this scenario planning tool is intended to do. One of the inputs the tool user needs to specify is the market penetration rate of CAVs in the regional vehicle fleet. In the modeling process, the specified regional penetration rate is translated to the percentages of personal vehicles with CAV and traditional technologies for each household type. An algorithm is developed and embedded in the model to ensure the mode choice reflects these percentages which approximately represent the availability of the modes. Specifically, the developed process introduces extra negative utility to adjust down the result of the exponential function of each vehicle type's utilization, being approximately the original values multiplied by corresponding percentages. In this way, when CAV market penetration rate is zero, the mode choice model in the GHMS model will replicate the results from the CRCOG model.

➢ GHMS Model Validation

The calibrated GHMS model is intended to produce similar results to those from the CRCOG model for the baseline scenarios for both 2020 and 2050. Model validation is to examine the closeness of two sets of modeling results from the GHMS model and CRCOG model respectively at an appropriately aggregate level. Specifically, the Travel Model Improvement Program (TMIP) Travel Model Validation and Reasonableness Checking – 2nd Edition is used to guide the model validation, using the model estimates from the CRCOG model as the observed data (or ground truth data).

Trip Generation

The residential person trips were summarized for both the CRCOG and GHMS models as shown in Table 7.

Table 7: Total Residential Person-Trips

Travel Markets	2020				2050			
	CRCOG	GHMS	Dif	% Dif	CRCOG	GHMS	Dif	% Dif
HBW_zero	68,366	68,366	0	0%	72,280	72,280	0	0%
HBW_low_insufficient	66,004	66,004	0	0%	65,160	65,160	0	0%
HBW_low_sufficient	233,587	233,587	0	0%	258,749	258,749	0	0%
HBW_high_insufficient	88,897	88,897	0	0%	91,270	91,270	0	0%
HBW_high_sufficient	737,909	737,909	0	0%	833,883	833,883	0	0%
HBW_All	**1,194,763**	**1,194,763**	**0**	**0%**	**1,321,341**	**1,321,341**	**0**	**0%**
HBO_zero	287,567	287,567	0	0%	321,630	321,630	0	0%
HBO_low_insufficient	119,855	119,855	0	0%	117,747	117,747	0	0%
HBO_low_sufficient	1,145,836	1,145,836	0	0%	1,331,471	1,331,471	0	0%
HBO_high_insufficient	158,928	158,928	0	0%	163,092	163,092	0	0%
HBO_high_sufficient	2,194,718	2,194,718	0	0%	2,571,845	2,571,845	0	0%
HBO_All	**3,906,904**	**3,906,904**	**0**	**0%**	**4,505,786**	**4,505,786**	**0**	**0%**
NHB	1,663,087	1,663,087	0	0%	1,905,031	1,905,031	0	0%
All purposes	**6,764,754**	**6,764,754**	**0**	**0%**	**7,732,159**	**7,732,159**	**0**	**0%**

Total number of person trips for all trip purposes and each sub travel market, for both 2020 and 2050, are exactly same for the GHMS and CRCOG models. Both models produce identical residential trip generation results when model inputs are same.

For the non-residential part of the CRCOG model, through truck trips were separated out from overall through vehicle trips, with the total remaining the same. Therefore, no validation review is required for non-residential trips.

Trip Distribution

Trip length distribution in 1-mile increments up to 50 miles was developed for each trip purpose and all trips for both CRCOG and GHMS models, as shown in Table 8, Table 9 , and Figure 20 through Figure 23. The trip length distributions from both models match almost perfectly, difference being within 1%.

Table 8: Trip Length Distribution - 2020

Distance (Mile)	Cumulative %							
	CRCOG Model				GHMS Model			
	HBW	HBO	NHB	All	HBW	HBO	NHB	All
1	3%	8%	9%	7%	3%	8%	9%	7%
2	12%	36%	36%	32%	12%	35%	36%	31%
3	19%	51%	44%	44%	19%	50%	44%	43%
4	24%	62%	52%	53%	24%	62%	51%	53%
5	30%	69%	57%	59%	30%	69%	57%	59%
6	35%	74%	62%	64%	35%	74%	62%	64%
7	41%	79%	65%	69%	41%	79%	65%	69%
8	46%	82%	69%	73%	46%	82%	68%	73%
9	50%	85%	71%	75%	50%	85%	71%	75%
10	54%	87%	73%	78%	54%	87%	73%	78%
11	57%	88%	75%	80%	57%	88%	75%	80%
12	60%	90%	77%	81%	60%	89%	77%	81%
13	64%	91%	79%	83%	64%	91%	78%	83%
14	68%	92%	80%	85%	68%	92%	80%	85%
15	71%	94%	82%	87%	71%	94%	82%	87%
16	73%	95%	84%	89%	73%	95%	84%	89%
17	76%	96%	86%	90%	76%	96%	86%	90%
18	78%	97%	88%	92%	78%	97%	88%	92%
19	80%	98%	90%	93%	80%	98%	89%	93%
20	82%	98%	91%	94%	82%	98%	91%	94%
21	84%	99%	92%	95%	84%	99%	92%	94%
22	86%	99%	93%	95%	86%	99%	93%	95%
23	87%	99%	94%	96%	87%	99%	94%	96%
24	89%	99%	95%	96%	89%	99%	95%	96%
25	90%	100%	96%	97%	90%	100%	96%	97%
26	91%	100%	96%	97%	91%	100%	96%	97%
27	92%	100%	97%	98%	92%	100%	97%	98%
28	93%	100%	97%	98%	93%	100%	97%	98%
29	94%	100%	98%	98%	94%	100%	98%	98%
30	95%	100%	98%	99%	95%	100%	98%	99%
31	95%	100%	98%	99%	95%	100%	98%	99%
32	96%	100%	99%	99%	96%	100%	99%	99%

Distance (Mile)	Cumulative %							
	CRCOG Model				GHMS Model			
	HBW	HBO	NHB	All	HBW	HBO	NHB	All
33	97%	100%	99%	99%	97%	100%	99%	99%
34	97%	100%	99%	99%	97%	100%	99%	99%
35	97%	100%	99%	99%	97%	100%	99%	99%
36	98%	100%	99%	99%	98%	100%	99%	99%
37	98%	100%	99%	100%	98%	100%	99%	100%
38	98%	100%	100%	100%	98%	100%	100%	100%
39	99%	100%	100%	100%	99%	100%	100%	100%
40	99%	100%	100%	100%	99%	100%	100%	100%
41	99%	100%	100%	100%	99%	100%	100%	100%
42	99%	100%	100%	100%	99%	100%	100%	100%
43	99%	100%	100%	100%	99%	100%	100%	100%
44	99%	100%	100%	100%	99%	100%	100%	100%
45	99%	100%	100%	100%	99%	100%	100%	100%
46	100%	100%	100%	100%	99%	100%	100%	100%
47	100%	100%	100%	100%	100%	100%	100%	100%
48	100%	100%	100%	100%	100%	100%	100%	100%
49	100%	100%	100%	100%	100%	100%	100%	100%
50	100%	100%	100%	100%	100%	100%	100%	100%

Table 9: Trip Length Distribution - 2050

Distance (Mile)	**Cumulative %**							
	CRCOG Model				**GHMS Model**			
	HBW	**HBO**	**NHB**	**All_Purposes**	**HBW**	**HBO**	**NHB**	**All_Purposes**
1	3%	7%	9%	7%	3%	7%	9%	7%
2	12%	35%	36%	31%	11%	35%	35%	31%
3	18%	49%	43%	43%	18%	49%	43%	42%
4	23%	61%	51%	52%	23%	61%	50%	52%
5	29%	68%	56%	58%	29%	68%	56%	59%
6	34%	74%	61%	64%	34%	74%	61%	64%
7	39%	78%	65%	68%	40%	78%	64%	68%
8	45%	82%	68%	72%	45%	82%	68%	72%
9	49%	85%	71%	75%	49%	85%	70%	75%
10	53%	86%	73%	77%	53%	87%	73%	77%
11	56%	88%	75%	79%	56%	88%	75%	79%
12	59%	89%	77%	81%	59%	89%	77%	81%
13	63%	91%	78%	83%	63%	91%	78%	83%
14	67%	92%	79%	85%	67%	92%	79%	85%
15	70%	94%	82%	87%	70%	94%	82%	87%
16	73%	95%	84%	89%	73%	95%	84%	89%
17	75%	96%	86%	90%	75%	96%	86%	90%
18	77%	97%	88%	91%	78%	97%	88%	91%
19	80%	98%	89%	93%	80%	98%	89%	93%
20	82%	98%	91%	94%	82%	98%	91%	94%
21	84%	99%	92%	94%	84%	99%	92%	94%
22	85%	99%	93%	95%	85%	99%	93%	95%
23	87%	99%	94%	96%	87%	99%	94%	96%
24	88%	99%	95%	96%	88%	99%	95%	96%
25	89%	100%	96%	97%	90%	100%	96%	97%
26	91%	100%	96%	97%	91%	100%	96%	97%
27	92%	100%	97%	98%	92%	100%	97%	98%
28	93%	100%	97%	98%	93%	100%	97%	98%

Distance (Mile)	Cumulative %							
	CRCOG Model				GHMS Model			
	HBW	HBO	NHB	All_Purposes	HBW	HBO	NHB	All_Purposes
29	94%	100%	98%	98%	94%	100%	98%	98%
30	95%	100%	98%	99%	95%	100%	98%	99%
31	95%	100%	98%	99%	95%	100%	98%	99%
32	96%	100%	99%	99%	96%	100%	99%	99%
33	96%	100%	99%	99%	96%	100%	99%	99%
34	97%	100%	99%	99%	97%	100%	99%	99%
35	97%	100%	99%	99%	97%	100%	99%	99%
36	98%	100%	99%	99%	98%	100%	99%	99%
37	98%	100%	99%	100%	98%	100%	99%	100%
38	98%	100%	100%	100%	98%	100%	100%	100%
39	98%	100%	100%	100%	99%	100%	100%	100%
40	99%	100%	100%	100%	99%	100%	100%	100%
41	99%	100%	100%	100%	99%	100%	100%	100%
42	99%	100%	100%	100%	99%	100%	100%	100%
43	99%	100%	100%	100%	99%	100%	100%	100%
44	99%	100%	100%	100%	99%	100%	100%	100%
45	99%	100%	100%	100%	99%	100%	100%	100%
46	99%	100%	100%	100%	100%	100%	100%	100%
47	100%	100%	100%	100%	100%	100%	100%	100%
48	100%	100%	100%	100%	100%	100%	100%	100%
49	100%	100%	100%	100%	100%	100%	100%	100%
50	100%	100%	100%	100%	100%	100%	100%	100%

Figure 20: HBW Trip Distribution Curves (2020 Distance)

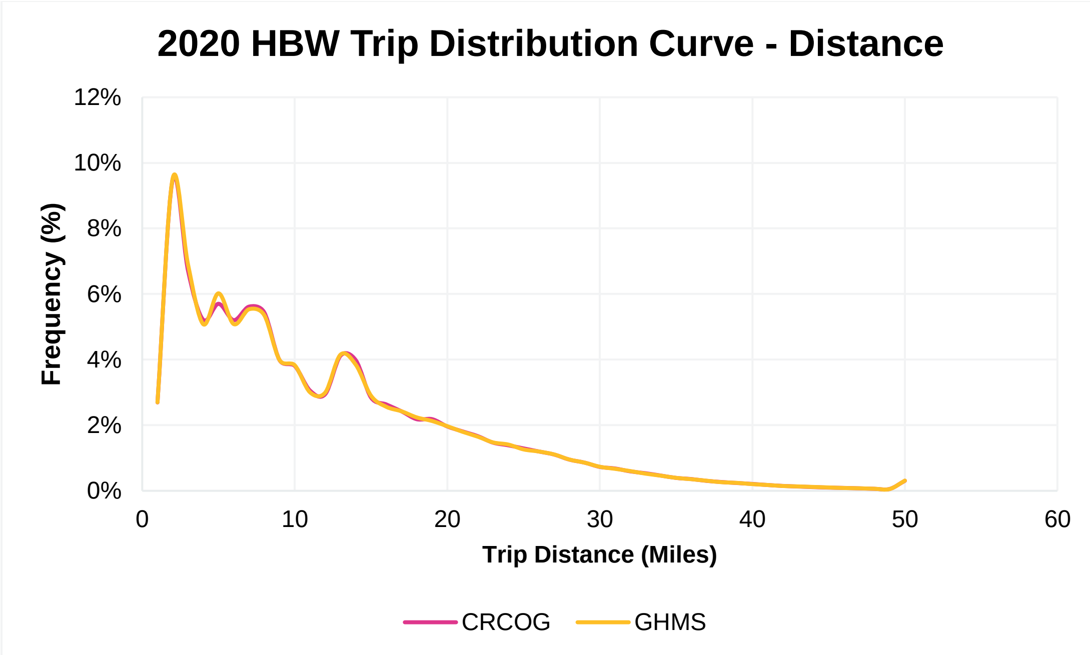


Figure 21: HBO Trip Distribution Curves (2020 – Distance)

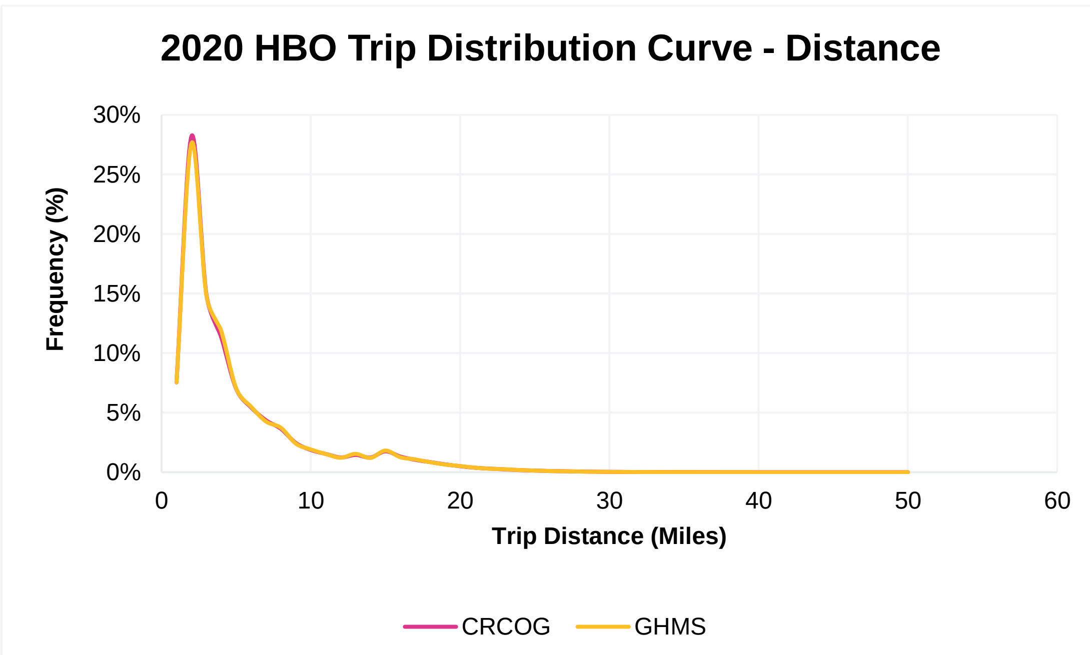


Figure 22: NHB Tri-p Distribution Curves (2020 – Distance)

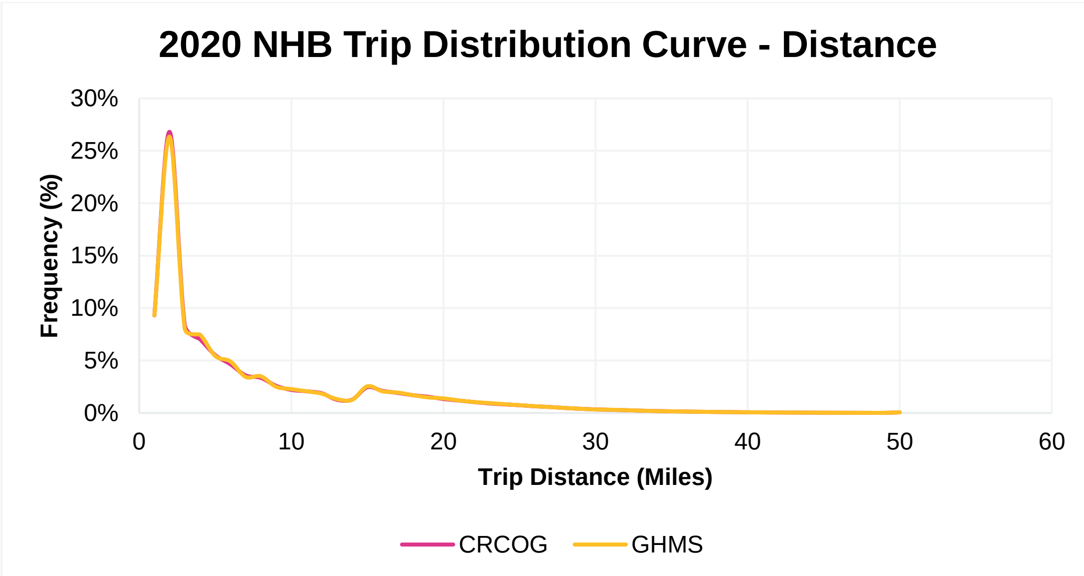


Figure 23: All Purpose Trip Distribution Curves (2020 – Distance)

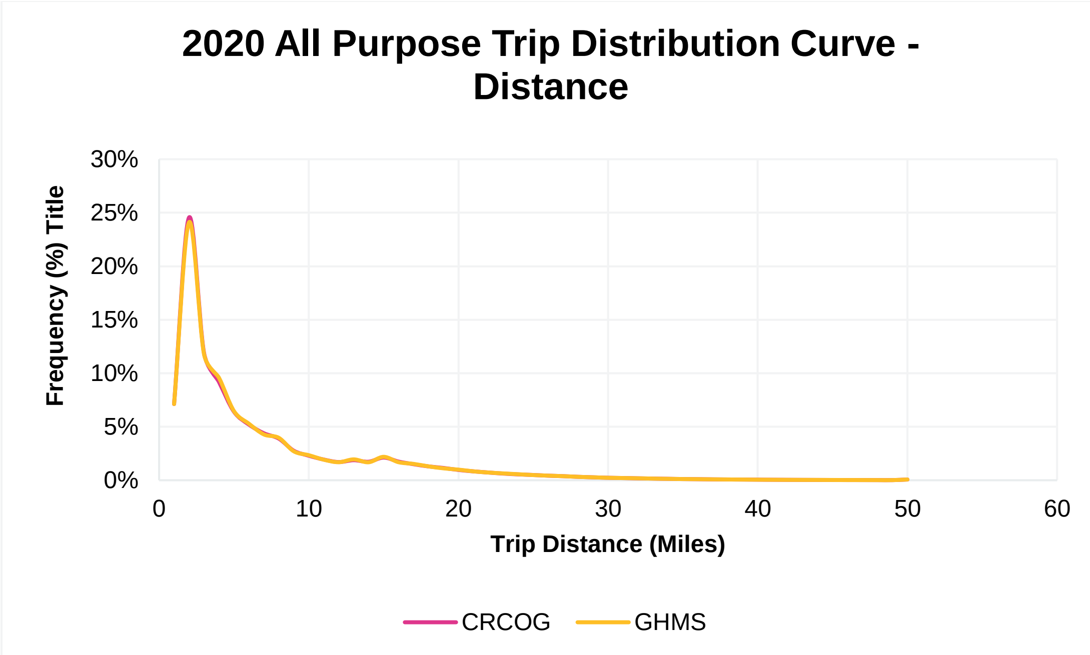


Figure 24: HBW Trip Distribution Curves (2050 – Distance)

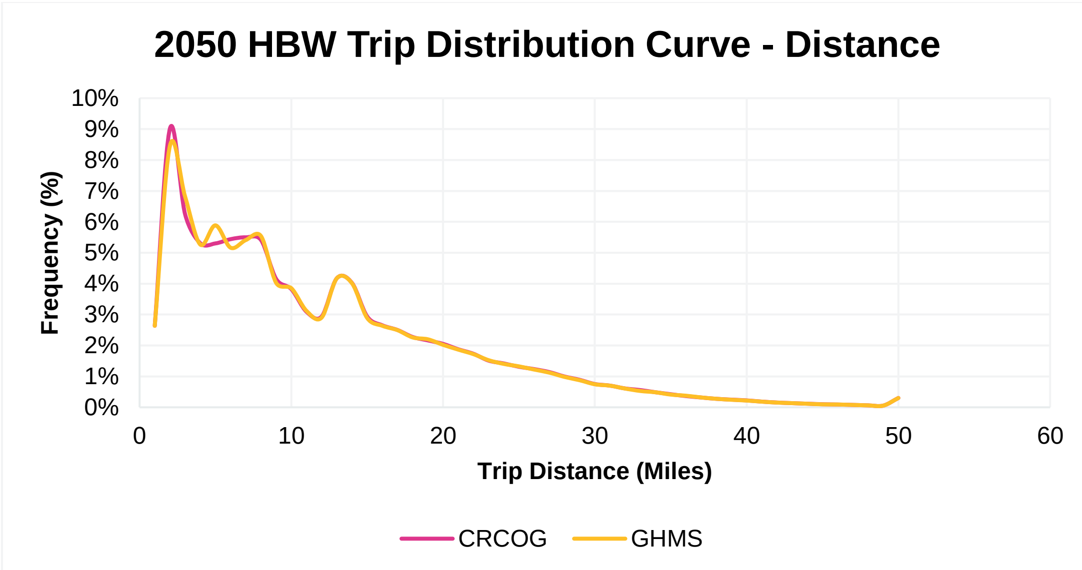


Figure 25: HBO Trip Distribution Curves (2050 – Distance)

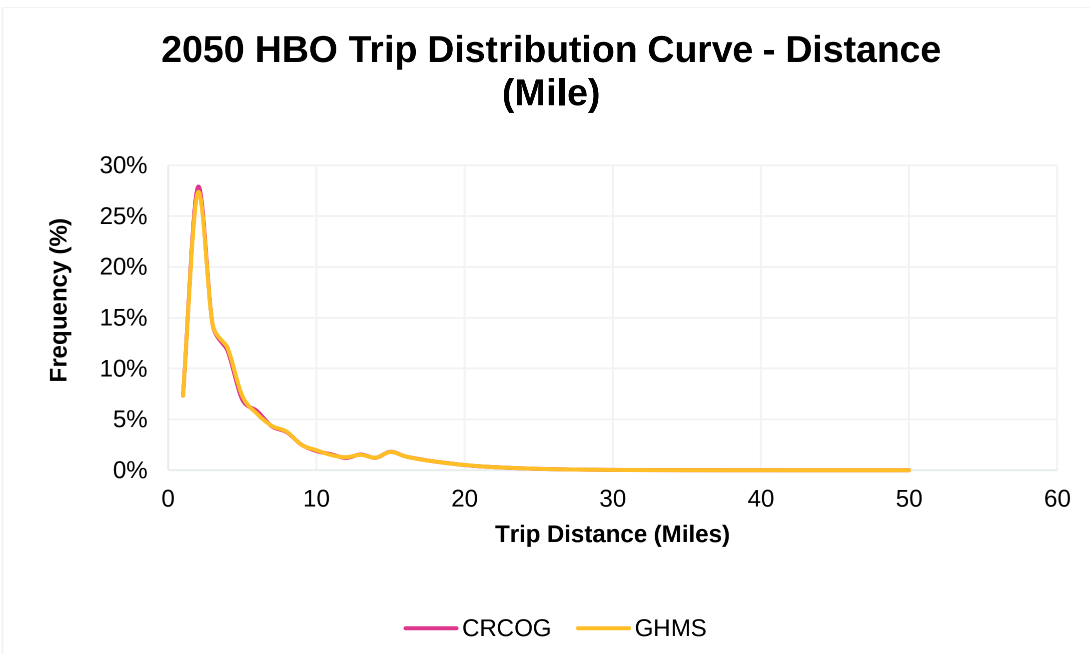


Figure 26: NHB Trip Distribution Curves (2050 – Distance)

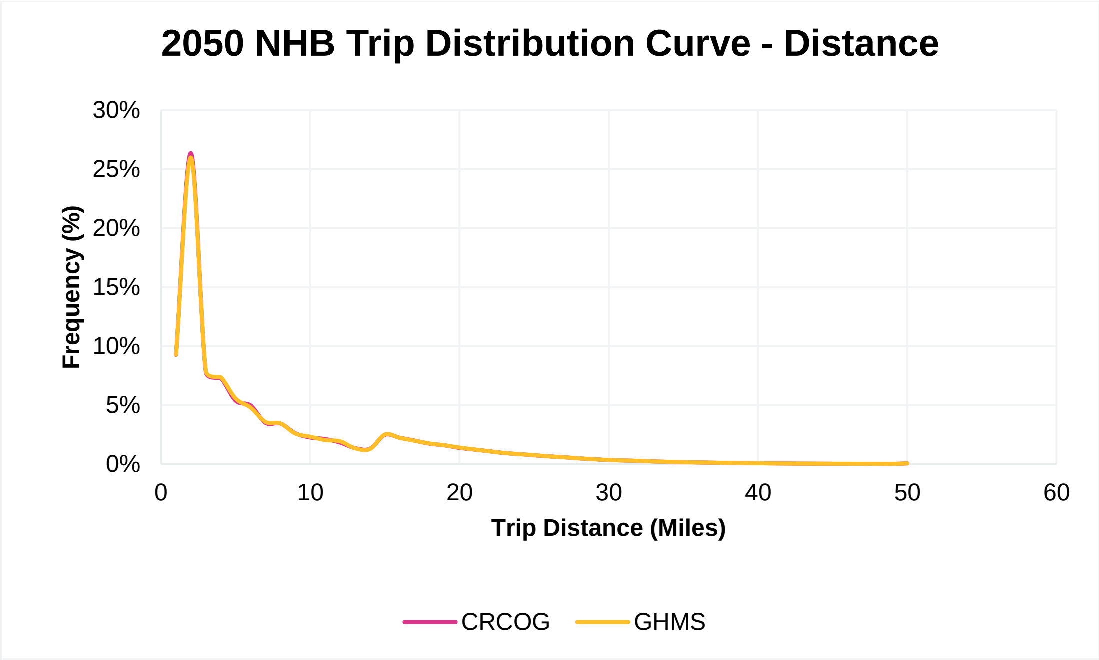
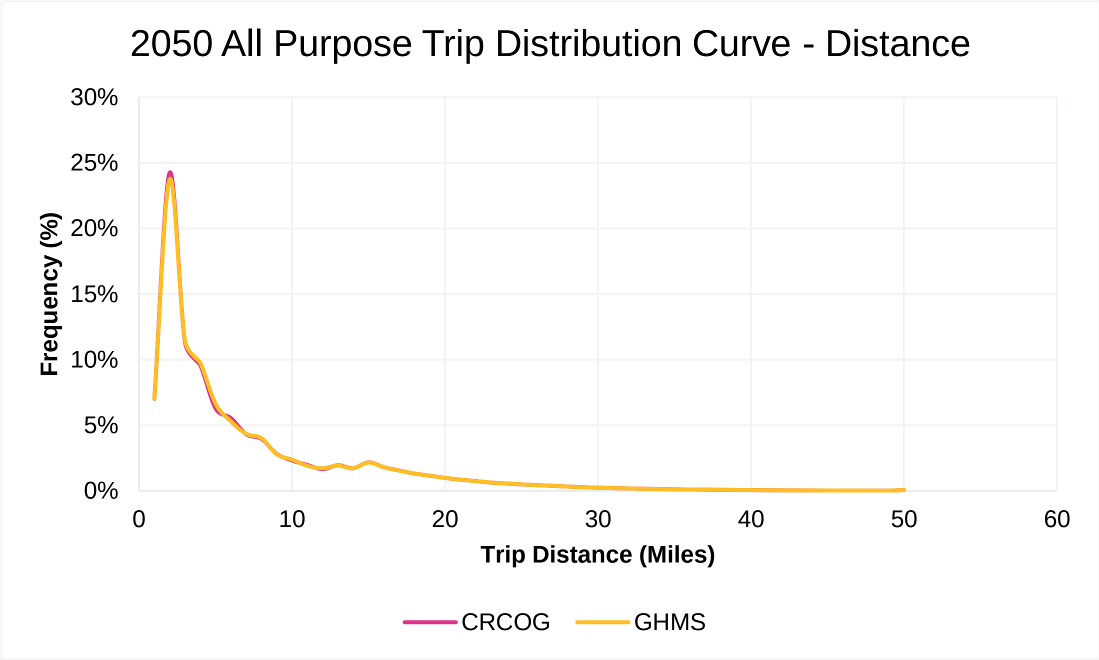


Figure 27: All Purpose Trip Distribution Curves (2050 – Distance)



Average trip distance and time, as well as the coincidence ratios calculated based on trip distance distributions are summarized in Table 10. The differences and coincidence ratios all suggest the GHMS model in general replicates the CRCOG model in trip distribution.

Table 10: Average Trip Length and Coincidence Ratio

Trip Purpose	2020					2050				
	Time (Min)		Distance (mile)			Time (Min)		Distance (mile)		
	CRCOG	GHMS	CRCOG	GHMS	Coincidence Ratio	CRCOG	GHMS	CRCOG	GHMS	Coincidence Ratio
HBW	22.1	22.1	11.6	11.6	0.98	23.8	23.7	11.8	11.8	0.97
HBO	10.0	10.0	4.8	4.8	0.98	10.4	10.4	4.9	4.9	0.98
NHB	13.5	13.5	7.3	7.4	0.97	14.1	14.2	7.4	7.4	0.99
All	13.0	13.0	6.6	6.7	0.98	13.6	13.6	6.7	6.7	0.98

Mode Choice

Mode choice model validation is tricky due to added new transportation modes of CAV and TNC in the GHMS model. With the previously described model calibration efforts, the mode shares for primary transportation modes for each trip purpose and all trips were summarized in Table 11 and Table 12.

Table 11: Mode Share for Primary Transportation Modes - 2020

Transportation Mode		CRCOG Model				GHMS Model			
		HBW	HBO	NHB	All	HBW	HBO	NHB	All
Drive Alone	Regular	82.4%	38.9%	52.1%	49.8%	81.5%	38.8%	52.0%	49.6%
	CAV	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Shared Ride	Regular	12.5%	47.7%	36.4%	38.7%	12.3%	47.6%	36.4%	38.6%
	CAV	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Transit		1.8%	0.5%	0.2%	0.7%	1.8%	0.5%	0.2%	0.7%
Nonmotorized	Walk	2.5%	11.6%	10.5%	9.7%	2.5%	11.5%	10.3%	9.6%
	Bike	0.9%	1.4%	0.8%	1.1%	0.8%	1.4%	0.8%	1.1%
TNC		0.0%	0.0%	0.0%	0.0%	1.2%	0.2%	0.2%	0.4%

Table 12: Mode Share for Primary Transportation Modes (CRCOG & GHMS) – 2050

Transportation Mode		CRCOG Model				GHMS Model			
		HBW	HBO	NHB	All	HBW	HBO	NHB	All
Drive Alone	Regular	82.9%	39.1%	52.3%	49.9%	82.0%	39.1%	52.2%	49.6%
	CAV	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Shared Ride	Regular	12.2%	47.8%	36.6%	39.0%	12.0%	47.8%	36.5%	38.9%
	CAV	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Transit		1.7%	0.5%	0.2%	0.6%	1.7%	0.4%	0.2%	0.6%
Nonmotorized	Walk	2.4%	11.2%	10.1%	9.5%	2.4%	11.2%	9.4%	9.4%
	Bike	0.8%	1.3%	0.8%	1.1%	0.8%	1.3%	1.1%	1.1%
TNC		0.0%	0.0%	0.0%	0.0%	1.1%	0.2%	0.2%	0.4%

The mode choice results from the GHMS model reasonably approximate those from the CRCOG model with the largest difference of 0.9% for HBW purpose. The difference is largely due to the inclusion of the TNC mode in GHMS model. Although no validation criteria are recommended in Travel Demand Model Validation and Reasonableness Checking Manual, it can be easily concluded that for the baseline scenario, both the GHMS and CRCOG models produce practically the same results for mode choice.

Assignment

Assignment is the culmination of the modeling process and, in effect, validates the entire process. There are many ways to validate the traffic assignment results produced by the GHMS model against those from the CRCOG model. Total vehicle miles traveled (VMT) by facility type was first compared as shown in Table 13.

Table 13: VMT (millions) Comparison Summary by Facility Types (GHMS& CRCOG)

Facility Type	**CRCOG**		**GHMS**		**Difference (%)**	
	2020	**2050**	**2020**	**2050**	**2020**	**2050**
Interstate	22,761,791	24,496,545	23,022,689	24,766,854	1.1%	1.1%
Principal Arterial-Freeway	451,874	503,397	454,246	505,617	0.5%	0.4%
Principal Arterial-Other	9,979,947	11,350,937	10,083,552	11,463,821	1.0%	1.0%
Minor Arterial	6,096,239	6,880,940	6,164,255	6,964,147	1.1%	1.2%
Collector	8,491,955	10,013,667	8,572,667	10,139,343	1.0%	1.3%
Local	1,700,206	2,039,626	1,716,049	2,059,328	0.9%	1.0%
Ramps	1,430,397	1,567,725	1,436,812	1,575,949	0.4%	0.5%
Total	50,912,409	56,852,838	51,450,270	57,475,058	1.1%	1.1%

The total VMT from both the CRCOG and GHMS models closely replicate each other for all facility types and entire highway network. GHMS produces a slightly larger amount of VMT due to the added TNC mode and separated through truck trips. Each truck was counted as 2 passenger car equivalents (PCE) in VMT calculation for the GHMS model. However, all the differences are less than 1.4% and far better than the sampled guidelines included in the Travel Demand Model Validation and Reasonableness Checking Manual for several states as shown in Figure 28.

Figure 28: Example VMT Guidelines by Functional Class and Area Type (Source: TMIP Travel Model Validation and Reasonableness Checking Manual – 2nd Edition)

Stratification	Modeled Versus Observed VMT				
	Ohio[a]	Florida[b]		Michigan[c]	FHWA-1990[c]
Functional Class		Acceptable	Preferable		
Freeways/Expressways	±7%	±7%	±6%	±6%	±7%
Principal Arterials	±10%	±15%	±10%	±7%	±10%
Minor Arterials	±10%	±15%	±10%	±10%	±15%
Collectors	±15%	±25%	±20%	±20%	±20%
All Links		±5%	±2%		
Area Type					
CBD	±10%	±25%	±15%		
Fringe	±10%	±25%	±15%		
Urban	±10%	±25%	±15%		
Suburban	±10%	±25%	±15%		
Rural	±10%	±25%	±15%		

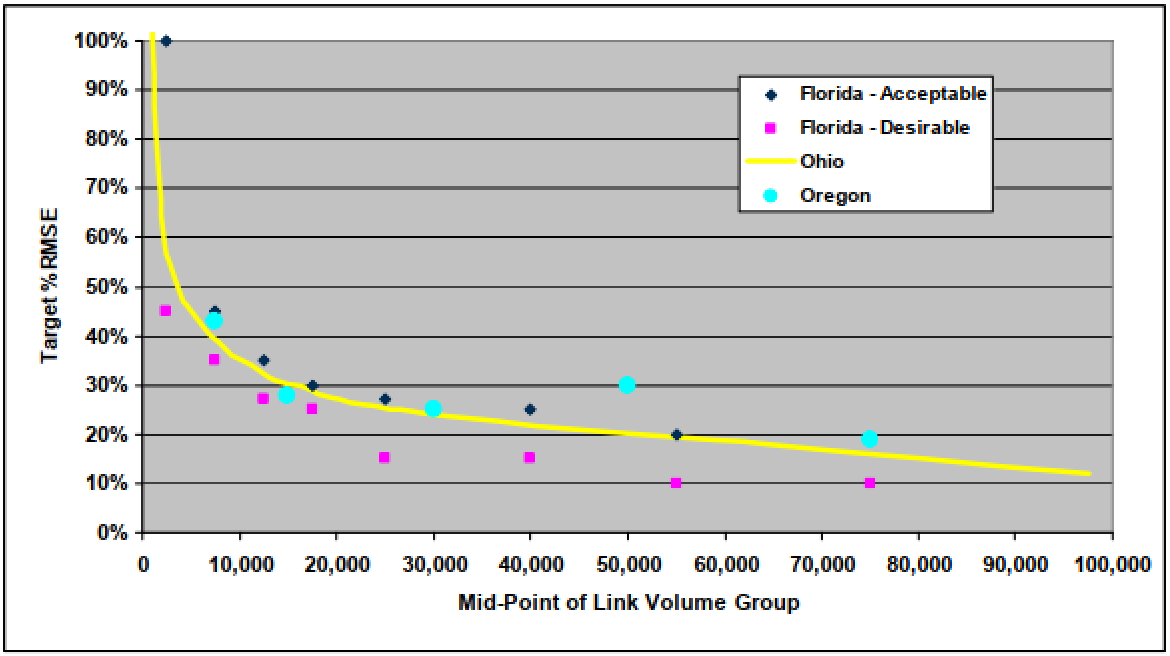
Percent root mean squared error (%RMSE) and ratio of traffic estimates were also calculated to examine how two models replicate each other in producing traffic estimates at link level, as summarized in Table 14.

Table 14: % RMSE Of Traffic Estimates by Facility Type

Facility Type	Average Traffic Volume				GHMS/CRCOG (%)		%RMSE	
	CRCOG		GHMS					
	2020	2050	2020	2050	2020	2050	2020	2050
Interstate	35,942	38,628	36,296	38,969	101.0%	100.9%	1.6%	1.4%
Principal Arterial-Freeway	26,413	29,556	26,568	29,702	100.6%	100.5%	0.7%	0.6%
Principal Arterial-Other	12,047	13,477	12,161	13,593	100.9%	100.9%	1.9%	1.7%
Minor Arterial	9,293	10,403	9,348	10,482	100.6%	100.8%	3.5%	2.5%
Collector	4,643	5,343	4,685	5,400	100.9%	101.1%	4.2%	2.9%
Local	2,281	2,671	2,297	2,695	100.7%	100.9%	7.0%	5.6%
Ramps	6,705	7,251	6,740	7,289	100.5%	100.5%	2.6%	1.9%
Total	9,096	10,118	9,176	10,207	100.9%	100.9%	2.9%	2.3%

Similar to VMT, the difference of average traffic volumes produced by both CRCOG and GHMS models are all within no more than 1% of each other for all facility types and entire highway network. %RMSE values are all less than 7% and well below the sampled thresholds recommended in The Travel Model Validation and Reasonableness Checking Manual as shown in Figure 29 below. This also confirms the two models produce similar highway assignment results.

Figure 29: Example % RMSE Guidelines (Source: TMIP Travel Model Validation and Reasonableness Checking Manual – 2nd Edition)



As transit assignment and other detailed transit analysis is not the intended usage area of GHMS-SPT, no additional validation other than what is described in mode choice model section is essentially necessary, and hence not included in this document.

Appendix G-4: List of CT Plans

Study	Goals
2019-2045 CRCOG Metropolitan Transportation Plan	See Appendix G-5
CT Statewide Freight Plan 2017	Safety, Security, and Resilience
	State of Good Repair
	Liveability and Resilience
	Economic Competitiveness and Economic Efficiency
CT2030 Plan	Driver Safety and Reliability
	Fewer Crashes
	Freight Enhancement
	Congestion and Delay
	Quality of Life
Let's Go CT 2015	Congestion and Delay
	State of Good Repair
	Age of Facility
	Corridor Capacity
	Expanded Rail Service to/from NYC
	Expanded Bus Service
CT River Flood Control	N/A
I-84 Auxiliary Lanes Improvements	Safety and Operational Improvements
I-91/I-691/Route 15 Interchange Improvements	Safety and Operational Improvements
Relocation of I-91 NB Interchange 29	Safety and Operational Improvements
Route 2 Resurfacing, Bridge and Safety Improvements	Safety and Operational Improvements
Route 2 Safety and Operational Improvements	Safety and Operational Improvements
Route 4 Transportation Safety and Improvements Study	Safety and Operational Improvements
	Expanded Multimodal Options
	Improved Access for New Developments

Appendix G-5: MTP 2045 Cross-Domain Outcome Map

	CRCOG MTP Goals	GHMS-SPT KPIS
1	**TRANSIT AND RAIL SYSTEM**	
1.1	High ridership	1. % transit person-trips 2. % of Work Trips by Mode (drive alone, carpool, transit)
1.2	Lower public subsidy	1. Average cost of a work trip
1.3	Reduced environmental impact through lower vehicle miles traveled	1. Total on-road Mobile Emissions (kg/day) 2. GHG Emissions from Light-duty Vehicles (Auto)
1.4	Promote transit-oriented development	1. Land use diversity in TOD areas 2. Proximity to multimodal hubs
1.5	Ensure that everyone has access to some transit	1. Walk Access to Transit 2. Transit Service Area 3. Usage Rate of Public Transit
1.6	Provide lifeline services to those who don't have access to a personal vehicle	1. Transit Facilities Available per 1,000 Capita (disadvantaged vs. non-disadvantaged) 2. Percent commute trips within Accessible Transit Shed (disadvantaged vs. non-disadvantaged) 3. % disadvantaged population with walk access to essential destinations
1.7	Provide access to those with severe needs. "lifeline" service	
1.8	Enhance First Mile/Last Mile Connections	1. Walk Access to Transit 2. Walk Access to Essential Destinations 3. Percent Non-SOV trips
2	**FEDERAL-AID HIGHWAY NATIONAL GOALS**	
2.1	To achieve a significant reduction in traffic fatalities and serious injuries on all public roads	1. Number of Motorized Fatal and Serious Injury Crashes 2. Number of Non-Motorized Fatal and Serious Injury Crashes
2.2	To maintain the highway infrastructure asset system in a state of good repair	Not applicable
2.3	To achieve a significant reduction in congestion on the National Highway System	1. Percent of freeway VMT by travel speed by mode 2. Travel Time Index 3. Failing LOS Index 4. Duration of Congestion
2.4	To improve the efficiency of the surface transportation system	1. Roadway Capacity per 1,000 Capita
2.5	To improve the national freight network, strengthen the ability of rural communities to access national and international trade markets, and support regional economic development	1. % Truck VMT (Peak Hour) 2. % Truck VMT (Daily) 3. Average Costs per Truck Trip

2.6	To enhance the performance of the transportation system while protecting and enhancing the natural environment	1. Total on-road Mobile Emissions (kg/day) 2. GHG Emissions from Light-duty Vehicles (Auto)
2.7	To reduce project costs, promote jobs and the economy, and expedite the movement of people and goods by accelerating project completion	1. Costs per Thousand VMT 2. Infrastructure Costs 3. Creation of New Jobs 4. New Revenue Sources
3	**COMPLETE STREETS**	
3.1	Implement the Regional Complete Streets Network	1. Walk Access to Transit 2. Walk Access to Essential Destinations 3. % disadvantaged population with walk access to essential destinations 4. Intersection Density
3.2	Support CTrides Program	1. Transit Utilization 2. Percent Transit Commute Trips 3. Percent Jobs within Accessible Transit Shed
3.3	Support Providing Bicycle Amenities	1. Miles of Bike lanes per 1,000 Population 2. Level of bicycle stress
4	**AIRPORT ACCESS**	
4.1	Support the establishment of a transit connection between the airport and the CTrail Hartford Line	1. Miles of Bike Lanes per 1,000 capita
4.2	Provide sufficient roadway access to the airport	1. Access to major highways 2. Rodway capacity per 1000 capita
5	**FREIGHT TRANSPORT SYSTEM**	
5.1	Address truck bottlenecks along with the regional highway system.	1. Daily truck hours of delay
5.2	Coordinate Short-Haul Trucking Deliveries (short-haul trucking demand and last-mile delivery needs)	1. Percent Truck VMT 2. Cost per Truck Trip
5.3	Consider the potential development of a private truck parking facility in the Hartford area;	1. Area of Roads and Parking Spaces
6	**NEW AND EMERGING TECHNOLOGIES**	
6.1	Support integration of micro-mobility with complete streets	1. Walk Access to Transit 2. Walk Access to Essential Destinations
6.2	Support enhancing connectivity between new and emerging technologies and TOD zones	1. Proximity to Multimodal hubs
7	**SPECIAL EMPHASIS AREAS**	

7.1	Encourage Transportation Demand Management Programs	1. Average Cost of Work Trip 2. Annual Average Transportation Costs 3. Total on-road Mobile Emissions (kg/day)
7.2	Support Rideshare Programs and CTrides Initiatives	1. Transit Utilization 2. Percent Non-SOV Trips 3. Percent Jobs within Accessible Transit Shed
8	**INNOVATIVE FINANCE**	
8.1	Further explore the implementation of the innovative funding strategies	1.New Revenue Sources
9	**ENVIRONMENTAL JUSTICE**	
9.1	Better Bus Service in Disadvantaged Communities	1. Transit Facilities Available per 1,000 Capita (disadvantaged vs. non-disadvantaged) 2. Percent commute trips within Accessible Transit Shed (disadvantaged vs. non-disadvantaged) 3. % disadvantaged population with walk access to essential destinations

Appendix G-6: GHMS-STP KPIs

ID	KPI	Definition
MOBILITY		
M1	**Congestion**	
M1-1	Travel time Index	The travel time index is the ratio of the peak-period travel time ("rush hour") to free-flow travel time (when traffic flows at the speed limit)
M1-2	Percent of freeway VMT by travel speed by mode	Percent of freeway VMT by travel speed (0 to 35 MPH, 35 to 55 MPH, and greater than 55 MPH)
M1-3	Reduction in System Reliability	Failing LOS Index estimates how close a facility is to reaching its maximum capacity or unacceptable level of service (LOS D, E, and F) during peak periods.
M1-4	Duration of Congestion	Duration of congestion is the average number of hours during a typical weekday in which road sections are congested.
M2	**Multimodal Options**	
M2-1	Transit Facility Coverage	This indicator calculates the average number of transit facilities per 1,000 population per TAZ.
M2-2	Transit Utilization	Percentage of daily Transit Person Trips over daily total person trips
M2-4	Ridesharing/Carpooling Utilization	Percent of Non-SOV VMT (includes only HOV2, HOV3+) over total VMT during a typical weekday.
M2-5	Transit Commute Mode Share	It is the percentage of transit person-work trips over total person-work trips by mode during a typical weekday.
M2-6	% of Non-SOV Person Trips	This KPI calculates the share of non-SOV person trips (HOVs, transit, walk, and bike) during a typical weekday.
SOCIAL		
S1	**Travel Convenience**	
S1-1	Average Work Trip Time	The average time taken for a work trip by mode (drive alone, carpool, TNC, transit) during weekday peak periods.
S1-2	Average Work Trip Length (Auto)	It is the average distance for a work trip by auto modes (drive alone, carpool, TNC) during weekday peak periods.
S1-3	Average Annual Auto Transportation Costs	It is the annual average dollars spent on transportation-related costs per household. Transportation costs here include auto ownership and commuting costs.

ID	KPI	Definition
S1-6	% person-miles traveled in HOV Lanes	Percent of person-miles traveled in HOV lanes in the study area.
S2	**Accessibility**	
S2-1	Walk Access to Transit	This indicator calculates the percentage of jobs within a 10-minute walk to transit.
S2-2	Walk Access to Essential Destinations	This indicator calculates the percentage of households within a 10-minute walk to essential destinations (jobs+retail).
S2-3	Proximity to a multimodal hub	% of the population within a certain multimodal radius – TOD related
S2-4	Access to Major Thoroughfare	Access to major thoroughfare calculates the percentage of the population within a half-mile distance from highways.
S2-5	Percent jobs within Accessible Transit Shed	Jobs within an accessible transit shed are defined as the average number of jobs reached by a 30-minute transit ride per TAZ.
S3	**Safety**	
S3-1	Number of Motorized Fatal and Serious Injury Crashes	This KPI calculates the total number of fatal and serious injury crashes in an incident involving motorized vehicles.
S3-2	Number of Non-Motorized Fatal and Serious Injury Crashes	This KPI calculates the total number of ped and bike fatal and serious injury crashes
S4	**Equity**	
S4-1	Percent of work trips accessible in 30 minutes in peak periods (disadvantaged zones)	Percent of work trips with travel time less than 30 minutes originating from the TAZ in the study area in EJ TAZs
S4-2	% disadvantaged population with walk access to essential destinations	% of EJ population with walkable access to office, retail, and transit
S4-3	Average Commuting Costs as % of income	This indicator calculates the average annual costs for a work trip per household as a percentage of annual household income.
ENVIRONMENT		
N1	**Air Quality**	

ID	KPI	Definition
N1-1	Total on-road Mobile Emissions (kg/day)	This indicator calculates the daily on-road CO, NOx, and VOC emissions by all vehicle modes, considering congestion and idling.
N2	**GHG Emissions**	
N2-1	GHG Emissions from Light-duty Vehicles (Auto)	Through this indicator, the annual GHG emissions from regular and EV autos (including TNCs), considering tailpipe and upstream emissions, are calculated.
	INFRASTRUCTURE	
I1	**Capacity**	
I1-1	Roadway Capacity per 1,000 Capita	This indicator calculates the capacity of roadways per 1,000 population
I1-2	Usage Rate of Public Transit	This indicator calculates the utilization rate of public transit in the study area, defined as the percentage of daily transit trips over daily transit capacity.
I1-3	Miles of Bike lanes per 1,000 Population	This indicator calculates the total length of bike network per 1,000 population
I2	**Land Use Efficiency**	
I2-1	Land Use Diversity within TOD areas	It is the extent of land use mix within the study area, ranging from maximally mixed or heterogeneous to homogeneous
I3	**Sustainable Urban Structure**	
I3-1	Activity Population per acre	This indicator calculates activity population per acre of developed land
I3-2	% of Local Trips	Percent of local trips is the percentage of trips beginning and ending in the same local geographic unit
I3-3	% Area of Roads and Parking Spaces	This indicator calculates the percentage of area covered by roads and parking
	ECONOMIC	
E1	**Job-Housing Balance**	
E1-1	Job Accessibility	Job Access Shed is the average percentage of employment that is accessible within 15 minutes' drive or transit time from any TAZ in the study area.

ID	KPI	Definition
E2	**Investment**	
E2-2	Infrastructure Cost	Infrastructure cost is defined as the estimated cost for constructing new transportation projects.
E3	**Freight**	
E3-1	% Truck VMT (Daily)	Percent truck VMT (daily) is the percentage of truck vehicle mile traveled out of total vehicle mile traveled.
E3-2	% Truck VMT (Peak Hour)	Percent truck VMT (peak hour) is the percentage of truck vehicle mile traveled out of total vehicle mile traveled during peak periods
E3-3	Average Costs per Truck Trip	This indicator is the average cost of a truck trip starting or ending in a TAZ within the study area during peak periods.
E3-4	Daily truck hours of delay	This KPI calculates the daily hours of truck delay on major roads
E4	**Economic Development**	
E4-1	Creation of New Jobs	This indicator measures the number of direct jobs generated from new investments in highway projects. Direct jobs are occupations that work directly on the project.
E4-2	Average Work Trip Costs per Person (Auto)	This KPI calculates the average commuting costs by all modes during peak periods on a typical weekday.
E4-3	New Revenue Sources ($/year)	This KPI estimates additional annual traffic revenues owing to VMT based fees and cordon-line congestion pricing

Appendix G-7: Configured Scenario Results (Existing 2020 and Future Baseline Condition 2050)

ID	KPI	Configuration Scenarios' KPI Results	
		Scenario 1 - Existing (2020)	Scenario 2 - Future Baseline Condition (2050)
MOBILITY			
M1	**Congestion**		
M1-1	Travel Time Index	1.57	1.73
M1-2	Freeway Peak-Hour Speed 0-35mph	26.86%	36.60%
M1-3	Reduction in System Reliability	5.81%	8.69%
M1-4	Duration of Congestion	6.47	6.84
M2	**Multimodal Options**		
M2-1	Transit Facility Coverage	0.11	0.11
M2-2	Transit Utilization	2.08%	1.91%
M2-3	Ridesharing/Carpooling Utilization	15.94%	16.11%
M2-4	Transit Commute Share	5.46%	5.12%
M2-5	Non-SOV Person-Trips	54.18%	53.80%
SOCIAL			
S1	**Travel Convenience**		
S1-1	Average Work Trip Time	21.0	21.7
S1-2	Average Work Trip Length	9.51	9.46
S1-3	Average Auto Transportation Costs	$9,243	$9,320
S1-4	Percent HOV VMT	3.04%	4.82%
S2	**Accessibility**		
S2-1	Walk Access to Transit	73%	72%
S2-2	Walk Access to Essential Destinations	49%	47%
S2-3	Proximity to Multimodal Hub	22%	22%
S2-4	Access to Major Thoroughfare	44%	45%
S2-5	Percent Jobs Within Accessible Transit Shed	8.69%	7.69%

ID	KPI	Configuration Scenarios' KPI Results	
		Scenario 1 - Existing (2020)	Scenario 2 - Future Baseline Condition (2050)
S3	**Safety**		
S3-1	Fatal & Injury Crashes (motorized)	15,376	17,034
S3-2	Fatal & Injury Crashes (non-motorized)	774	849
S4	**Equity**		
S4-1	Work Trip Sheds (peak)	92.39%	91.58%
S4-2	EJ Population with Walk Access to Destinations	64%	63%
S4-3	Commuting Costs as a % of Income	5.37%	5.24%
ENVIRONMENTAL			
N1	**Air Quality**		
N1-1	Total Mobile Emissions	76,532	24,194
N2	**GHG Emissions**		
N2-1	GHG Emissions (light-duty vehicles)	16,180	10,972
INFRASTRUCTURE			
I1	**Capacity**		
I1-1	Roadway Capacity per 1,000 Capita	17,193	16,344
I1-2	Usage Rate of Public Transit	0.39%	0.37%
I1-3	Miles of Bike Lanes per 1,000 Population	NA	NA
I2	**Land Use Efficiency**		
I2-1	Land Use Diversity within TOD Areas*	-	0.47
I3	**Sustainable Urban Infrastructure**		
I3-1	Activity Population per acre	8.45	8.89
I3-2	% of Local Trips	10.37%	10.38%
I3-3	Road and Parking Areas	20%	20%
ECONOMIC			
E1	**Job-Housing Balance**		

ID	KPI	Configuration Scenarios' KPI Results	
		Scenario 1 - Existing (2020)	Scenario 2 - Future Baseline Condition (2050)
E1-1	Job Accessibility	48%	46%
E2	**Investment**		
E2-1	Infrastructure Cost	NA	$6,832,670
E3	**Freight**		
E3-1	Truck VMT (Daily)	10.29%	9.49%
E3-2	Truck VMT (Peak Hour)	9.15%	8.49%
E3-3	Average Costs per Truck Trip	$19.42	$19.37
E3-4	Daily Truck Hours of Delay	13.12	14.94
E4	**Economic Development**		
E4-1	Creation of New Jobs**	-	-
E4-2	Average Work Trip Costs per Person	$11.12	$11.29
E4-3	New Revenue Sources**	-	-

*Not applicable for base scenarios

**KPIs are not calculated for base scenario – no new jobs or new revenue sources; new jobs and revenue come from future construction, tolls, or other economic benefits from transportation infrastructure