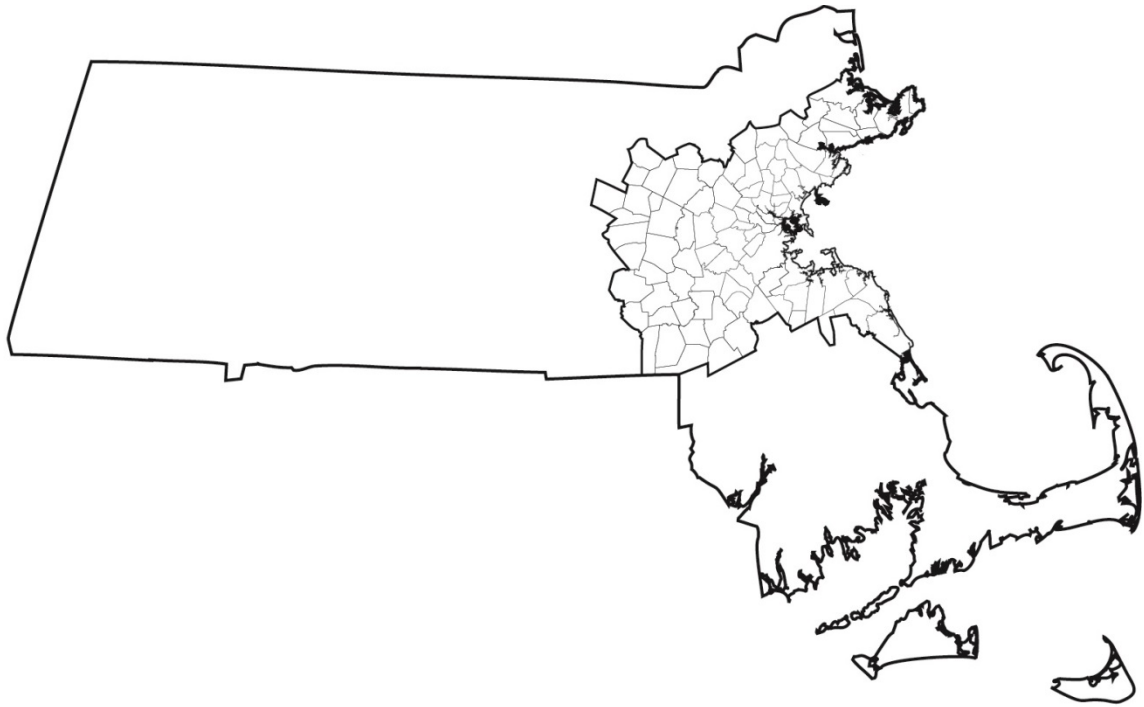


TDM23: Structures and Performance

TDM23 Version 2.0

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March 2025



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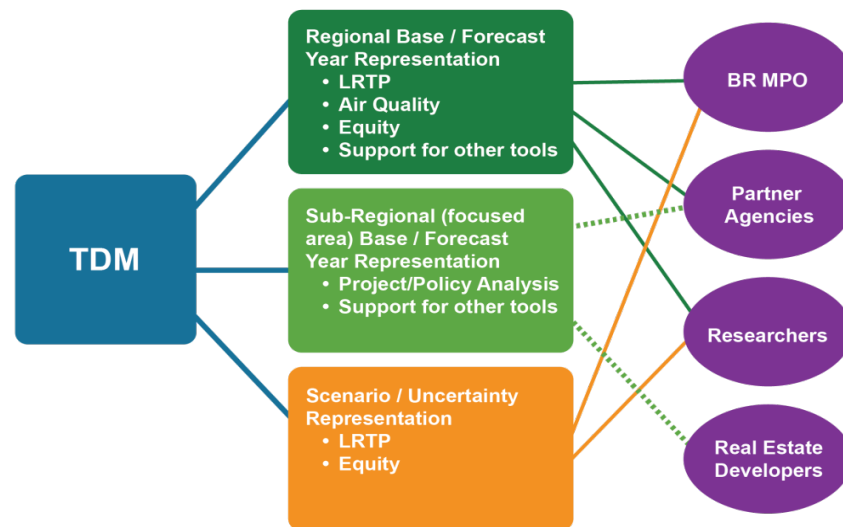
APPENDICES

- Appendix A: Scenario Definitions
- Appendix B: Model Versions

Executive Summary

A variety of stakeholders use travel demand model (TDM) outputs to support regional investment plans, state and federal filings, and project and policy analyses. Figure E-1 shows the major products of the Boston Region Metropolitan Planning Organization's (MPO) TDM and the direct stakeholders connected to each product. For the purposes of this document, the needs of the public are represented through the MPO. There is a growing need for the TDM to represent scenarios and uncertainties.

Figure E-1
TDM Products and Major Stakeholders



BR MPO = Boston Region Metropolitan Planning Organization. LRTP = Long-Range Transportation Plan.

Central Transportation Planning Staff (CTPS) manages the MPO's current travel demand model, TDM23, which was developed for the MPO's 2023 Long-Range Transportation Plan (LRTP), *Destination 2050*. TDM23 will be used for project and policy analyses by MPO members, stakeholders, and researchers. TDM23 includes an update of the model base- and forecast-year scenarios to 2019 and 2050 respectively. CTPS also took advantage of this opportunity to establish a sound platform for future travel modeling work based on stakeholder needs and agency resources.

CTPS developed TDM23 to be reliable and accessible to the modeling groups within CTPS and to be organized and documented to a standard that would enable sharing the model outside the agency.

ES.1 TDM23 STRUCTURES

TDM23 is a trip-based demand estimation model with static transit and highway assignment. While activity-based models (ABM) are the state of the practice for MPO regions the size of the Boston Region MPO's planning area, these approaches require a robust household survey to develop and calibrate the demand models as well as purpose-built software to represent the demand components. These challenges were restrictive for TDM23 as the most recent household travel survey was completed in 2011 and the LRTP schedule ruled out adoption of a more complex demand structure. Furthermore, ABMs have a longer run time than trip-based models; thus, many scenarios are more difficult to evaluate. Given the need to evaluate uncertainty, the Boston Region MPO requires a model that can evaluate a broad set of scenarios. Now that this need is better met with TDM23, the MPO may adopt other tools to produce finer detail in the demand representation.

The geography covered by TDM23 includes the entire states of Massachusetts and Rhode Island and southeastern New Hampshire (see Figure E-2). TDM23 is primarily implemented in [Caliper's TransCAD](#) Version 9 travel demand software and uses Python for several demand components and post-processors.¹

**Figure E-2
Model Area**



¹ <https://www.caliper.com/tcovu.htm>

Table E-1 summarizes the demand components of TDM23, and the following Table E-2 summarizes the supply components. Major post-processing actions are summarized in Table E-3.

Table E-1
Demand Component Functionality, Inputs, and Outputs

| Component | Estimates | Sensitive To |
|----------------------|---|---|
| Vehicle Availability | Household vehicle availability relative to household drivers (zero, fewer than drivers, greater than or equal to drivers) | <ul style="list-style-type: none"> Household size, income, workers, and children Transit access density |
| Work from Home | Share of commute vs. work at home days | <ul style="list-style-type: none"> Regionally specific inputs of work-from-home levels |
| Trip Generation | Resident average daily trips within region by purpose produced and attracted by zone | <ul style="list-style-type: none"> Person type Household size, income, and vehicles Household children, seniors, and non-workers Employment by category |
| Peak/Off-peak | Segmentation of trips into peak period (AM or PM) and off-peak (MD or NT) | <ul style="list-style-type: none"> Trips by zone, purpose, and market segment |
| Trip Distribution | Flow of trips between zones | <ul style="list-style-type: none"> Trip productions and attractions by peak/off-peak Path impedances Mode choice utilities |
| Mode Choice | Mode shares and flow of trips by mode | <ul style="list-style-type: none"> Trip tables by purpose, market segment, and peak/off-peak Path roadway and transit level of service |
| University Travel | Generation and distribution of off-campus university student travel | <ul style="list-style-type: none"> Commuter enrollment Household population |

| Component | Estimates | Sensitive To |
|------------------------------|--|---|
| Truck Trips | Generation, distribution, and time of day of medium, and heavy truck trips | <ul style="list-style-type: none"> • Employment • Path distances |
| Airport Ground Access | Distribution, time of day, and mode of airport traveler trips | <ul style="list-style-type: none"> • Airport non-transferring enplanements and deplanements |
| Special Generator, Externals | Non-average daily trips (airport) and non-resident/outside of region trips (through trips) | <ul style="list-style-type: none"> • Trips produced/attracted by zone |
| Time of Day | Outbound and inbound trip time of day period | <ul style="list-style-type: none"> • Trip tables by purpose, market segment, peak/off-peak, and mode |
| MD = midday. NT = nighttime. | | |

Table E-2
Supply Component Functionality, Inputs, and Outputs

| Component | Estimates | Sensitive To |
|--------------------|--|---|
| Access Density | Access density category of TAZ | <ul style="list-style-type: none"> • Population and employment density • Transit location by mode |
| Highway Assignment | Congested speed and volumes by roadway segment | <ul style="list-style-type: none"> • Trip tables by vehicle type and occupancy, market segment, and time of day • Roadway network |
| Transit Assignment | Transit activity (Park-and-Ride [PnR]), boardings, alightings, and transfer) by line segment | <ul style="list-style-type: none"> • Trip tables by transit access mode, market segment, and time of day • Transit network |

TAZ = travel analysis zone.

Table E-3
Model Post Processors

| Component | Estimates | Sensitive To |
|----------------------|------------------------------|--|
| Equity Analysis | Metrics by equity population | <ul style="list-style-type: none"> • Impedances and transit level of service between zones • Demographic data • Trip tables by market segment |
| Air Quality Analysis | Air quality metrics | <ul style="list-style-type: none"> • Roadway network with volumes and congested speeds • Transit network |

ES.2 TDM23 PERFORMANCE

The validation and calibration of TDM23 focused on the Boston Region MPO area. Calibration was conducted in a sequential manner, progressing through each model component to verify correct operation and avoid propagating errors from skewed results. After the component sequence was calibrated, a series of system-level checks were conducted to validate and calibrate the model to data that was not used in estimation, such as origin-destination flows from Big Data platforms Streetlight and Replica, transit boardings, and highway volumes.

Evaluation of TDM23 was conducted and summarized through a series of validation reports. The validation reports can be run interactively as Jupyter notebooks and published as HTML files. Where useful, the validation reports include guidance thresholds for model fit to aid the modeler in identifying areas of concern. However, matching specified standards is neither necessary nor sufficient to prove model validity. TDM23 users should not assume that the model calibration implies a level of accuracy and applicability for any study within the model region.

A list of the datasets used for performance evaluation is presented in Tables E-4, E-5, and E-6.

Table E-4
Survey Datasets Used for Model Evaluation

| Dataset | Use |
|------------------------------------|---|
| 2011 Massachusetts Travel Survey | Vehicle availability Trip distribution Mode choice University travel |
| 2012-16 American Community Survey | Work trip distribution |
| 2018 Massport Ground Access Survey | Airport ground access trips |
| 2015-17 MBTA Rider Survey | Transit path building |
| 2018 MAPC Fare Choices Survey | Ride-source mode choice |
| 2019 Public Use Microdata Sample | Vehicle availability |

MAPC = Metropolitan Area Planning Council. Massport = Massachusetts Port Authority. MBTA = Massachusetts Bay Transportation Authority.

Table E-5
Big-Data Datasets Used for Model Evaluation

| Dataset | Use |
|---|--|
| 2019 Streetlight Origin-Destination Flows by Vehicle Type | Trip distribution Commercial vehicles |
| 2019 Replica Origin-Destination Flows by Vehicle Type | Trip distribution Commercial vehicles |
| 2019 Replica Origin-Destination Person Trip Flows by Mode | Trip distribution Mode choice |
| 2019 RITIS Speeds | Highway assignment |

Table E-6
Count Datasets Used for Model Evaluation

| Dataset | Use |
|---|---------------------------------------|
| 2019 MS2 Counts (raw and balanced) | Trip generation Highway assignment |
| 2019 HPMS | Trip generation Highway assignment |
| 2018 MBTA Transit Boardings | Mode choice Transit assignment |
| 2019 Massachusetts Department of Public Utilities TNC Trip Data | Mode choice |
| 2017-2018 MBTA Park-and-Ride Lot Utilization | Transit assignment |

HPMS = Highway Performance Monitoring System. MBTA = Massachusetts Bay Transportation Authority. MS2 = Modern Traffic Analytics. TNC = Transportation Network Company.

A summary of the model performance by component and system level is provided in Table E-7.

Table E-7
Component-Level Performance

| Component | Performance Notes |
|----------------------|--|
| Vehicle Availability | <p>Matches vehicle sufficiency and number of vehicle trends across household and TAZ attributes</p> <p>Vehicle sufficiency well estimated across all segments</p> <p>Average vehicles underestimated due to model process to convert sufficiency to vehicles</p> |
| Trip Generation | <p>Calibrated trip rates by worker and household are consistent with national averages</p> <p>Adjustments implied underreporting of trips in previous household survey</p> |
| Trip Distribution | <p>Average trip distances and trip length distributions are calibrated to vehicle availability market segment by purpose</p> <p>Geographic distributions aggregated to MPO, district, ring, and corridor are consistent with observations</p> |
| Mode Choice | <p>Calibrated mode share included a multistep introduction of ride-source mode that is not present in previous household survey data</p> |
| Time of Day | <p>Mode-specific time-of-day trends are not captured in the model, particularly higher transit and ride-source use in the nighttime period</p> |
| University Travel | <p>Calibrated with relaxed thresholds due to limited observations of student travel and data on student home locations</p> |

| Component | Performance Notes |
|-----------------------|---|
| Truck Trips | <p>Calibrated with relaxed thresholds due to limited observations</p> <p>Assignment and distribution comparisons indicate underestimates of long-distance heavy truck trips</p> |
| Airport Ground Access | Consistent distribution and mode patterns with observations by resident/visitor and business/leisure market segments |

TAZ = travel analysis zone.

Table E-8
System-Level Performance

| Model Area | Performance Notes |
|--------------------|--|
| Travel Flows | <p>Trip types generated and distributed by area are reasonable</p> <p>Auto flows are consistent with observations</p> <p>Nonmotorized and transit flows are reasonable from the model, but inconsistent with some Big Data observations</p> |
| Transit Assignment | <p>TDM23 estimates boardings by mode are consistent with observations with the exception of express bus and ferry</p> <p>Line level boardings have larger discrepancies, especially for less used services</p> |
| Highway Assignment | <p>Estimated interstate volumes are very similar to HPMS estimates</p> <p>Volumes on other facility types are well fit, but the error on some arterials and lower volume roadways are high</p> <p>CBD and Dense Urban areas on average have higher volumes than observed</p> |

CBD = central business district. HPMS = Highway Performance Monitoring System.

As part of the performance evaluation, TDM23 was also run through a series of sensitivity tests to demonstrate the model response to different scenario inputs. Sensitivity tests are run to analyze and understand model sensitivities to potential project and policy applications, but the results are not intended for use as application or policy recommendations. The sensitivity tests conducted and key results from each are summarized in Table E-9.

Table E-9
Sensitivity Test Results

| Sensitivity Test | Description | Key Results |
|------------------------------------|---|--|
| Work From Home | Remote work levels for worker and employment set to spring 2023 levels. | <p>Transit has the largest percentage change in trips by mode</p> <p>Commuter rail and ferry have the largest percentage decrease</p> <p>This scenario has the largest reduction in VMT and emissions, but auto mode share increases slightly as congestion is reduced</p> |
| Increased Ride-Source Availability | Ride-source waiting time and fares reduced by 50% | <p>Increase in ride-source trips mostly shifts from transit</p> <p>Added congestion leads to negative impacts on VMT, air quality, and equity metrics</p> <p>Equity populations experience a larger negative impact</p> |
| Electric Bike | Bike modes are 25% faster and can travel 25% farther | Large increase in nonmotorized trips, shifting from transit, auto, and school bus use |

| Sensitivity Test | Description | Key Results |
|-----------------------------------|--|---|
| Highway Toll Increase | All highway tolls increased by 100% | <p>This scenario has the smallest impact on mode share of any sensitivity test</p> <p>Because of the toll increase, the destinations changed and the auto trips and transit boardings both decrease</p> |
| Transit Fare Decrease | Transit fares decreased by 30% | <p>Increases transit linked trips by 3.5% and boardings by 4%</p> <p>The largest increases are on the most expensive modes (commuter rail, ferry, and regional bus)</p> |
| LRTP Highway and Transit Projects | 2050 LRTP scenario highway and transit | |
| Disable Bus Lanes | All bus lanes disabled | |

LRTP = Long-Range Transportation Plan. VMT = Vehicle-Miles Traveled.

Chapter 1—Introduction

1.1 DOCUMENT PURPOSE AND AUDIENCE

This particular document is intended for model users, the Central Transportation Planning Staff (CTPS) Model Steering Committee, and stakeholders of travel demand modeling for the Boston region and across Massachusetts. The Model Steering Committee consists of staff to the Boston Region Metropolitan Planning Organization (MPO) involved with the MPO activities and client-directed applications of the model. The steering committee has included representatives from the Metropolitan Area Planning Council's (MAPC) data services group and the Massachusetts Department of Transportation's (MassDOT) Office of Transportation Planning, the Regional Transportation Advisory Council, and the Boston Region MPO. Stakeholders are those who work with travel model outputs outside of the direct model platform, i.e., in plan summaries or inputs to other tools, and need to understand the model capabilities and limitations.

1.2 TRAVEL DEMAND MODELING

Travel demand models can be an effective means of quantifying demand and assessing the impacts of alternative projects, policies, and programs to guide long-range transportation planning that considers financial constraints and determines which alternatives are effective and financially feasible.

1.2.1 Model History and Purpose

CTPS has maintained a model to estimate average weekday travel behavior in the Boston region for more than four decades. The current model, TDM23, was used by the MPO for the 2023 Long-Range Transportation Plan (LRTP) and is being released to support growth rate calculations in addition to client-directed roadway and transit studies. The previous model developed for the 2019 LRTP, TDM19, is being used for legacy model applications and was officially retired at the end of 2023.

Prior to TDM23 and TDM19, the regional model geography was merged with the geography of the statewide model maintained by MassDOT. The model geography covers all of Massachusetts and Rhode Island as well as southeastern New Hampshire. However, the demand components are more typical of a regional travel demand model than a statewide travel demand model. The travel demands estimated by TDM23 are personal average-weekday travel, truck flows, and regional transit usage, whereas a statewide model would measure long-distance travel, freight flows, and intercity transit usage.

The main applications of TDM23 are to support the MPO's LRTP, conduct other project and policy analyses, and support research. In the development of TDM23, staff identified challenge areas for TDM19 to be addressed in the TDM23 update. These topics include the following:

- The ability to explore input and assumption uncertainty with the model and understand how model outputs vary as inputs are changed
- Segmentation of travel by low-income households for equity analyses
- Alignment of model requirements for socioeconomic inputs with outputs from MAPC's land-use model
- Representation of connected and autonomous vehicles and transportation network company (TNC) mobility services
- Model run time and usability, including ease of scenario development, availability of model inputs and outputs in open standards-compliant software, and documentation

1.2.2 TDM23 Overall Structure

TDM23 uses trip-based demand estimation with static transit and highway assignment. This approach is driven by the emphasis on uncertainty over accuracy in model needs and allows the Boston Region MPO to bypass the established state of the practice with activity-based models (ABM) and instead develop a regional model that can perform as a strategic tool to explore many scenarios.

Trip- vs. Activity-Based Modeling

Arguably, ABMs are the state of the practice for MPO regions the size of the Boston Region MPO's planning area. ABM approaches are attractive for the straightforward behavioral theory that travel is generated by a desire to conduct activities and for the disaggregate representation of demand that provides a potential for detailed metrics.

However, ABMs require a robust household survey to develop and calibrate the demand models as well as purpose-built software to represent the demand components. These requirements posed significant challenges in the development of TDM23 as the most recent household travel survey was completed in 2011 and the LRTP schedule constraints ruled out adoption of more complex demand structure. While development of an ABM for the Boston Region MPO area was not feasible for the 2023 LRTP, resource constraints also precluded the simultaneous development of an ABM along with TDM23.

As mentioned above, ABMs require more computational cycles than a trip-based model. The longer run-time of an ABM makes it more difficult to evaluate many scenarios. Given the need to evaluate uncertainty, the Boston Region MPO is better served with a model that can evaluate a broad set of scenarios than one producing finer detail in the demand representation.

1.3 DOCUMENT ORGANIZATION

This document consists of two main chapters covering

- TDM23 structure, including the platform, inputs, process, and outputs; and
- TDM23 performance reporting key metrics compared to observations and industry standards as well as sensitivity tests.

There are also several appendices associated with this document, including

- scenario input and output summaries for preset 2019 and 2050 LRTP Plan scenarios;
- version change log, including the feature, bugfix, and input data changes included in each version; and
- model application considerations, limitations, and guidance (forthcoming).

Chapter 2—Structures

2.1 OVERVIEW

TDM23 is a trip-based aggregate travel demand model with a static highway and transit assignment. It represents surface travel on an average weekday for the Boston region and Massachusetts.

Inputs

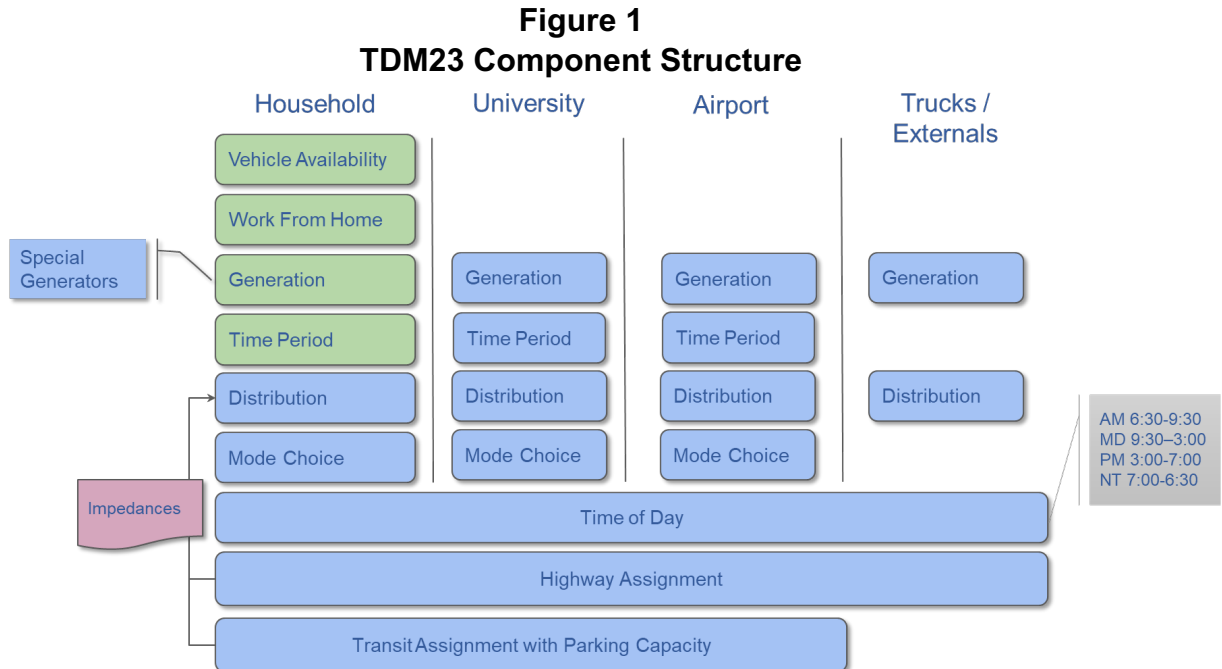
Inputs to TDM23 include zonal demographic and employment estimates from Metropolitan Area Planning Council's (MAPC) UrbanSim land use model, a disaggregate population synthesis and allocation model that produces annual estimates of population and employment for Massachusetts between 2010 and 2050.

TDM23 is a regional model with a statewide extent. The geography covers the entire states of Massachusetts and Rhode Island and southeastern New Hampshire. The model includes a higher resolution of transit representation than typical statewide models. However, it does not include a freight model component or a long-distance travel component, which are often found in statewide models. The network and zone system are more detailed in the Boston Region MPO area than the rest of Massachusetts.

All costs in TDM23 are in 2010 dollars to match income from the demographic data. Where necessary, input costs, such as transit fares and parking fees, are converted to 2010 dollars using a consumer price index.

Components and Market Segments

An overview of the model components by trip category (household, university, airport, trucks, and externals) is shown in Figure 1.



The travel behavior is estimated at different levels of aggregation depending on the trip category and attributes. Generally,

- work-related trips and work-from-home behavior are estimated at the worker level;
- non-work-related regular household trips and vehicles available are estimated at the household level; and
- irregular household trips, non-resident household trips, and truck trips are estimated at the zonal level.

From trip distribution onwards, trips are aggregated to the zonal level. Trips estimated by household and worker are segmented by vehicle availability. The market segments by trip purpose for regular household trips are shown in Table 1.

Table 1
Market Segments by Trip Purpose for Regular Household Trips

| Trip Purpose | Estimated By | Distribution Segments |
|---------------------|---------------------|--------------------------------------|
| HBW | Worker | Vehicle Sufficiency Worker Income |
| HBPB | Household | Vehicle Sufficiency |
| HBSR | Household | Vehicle Sufficiency |
| HBSC | Household | Vehicle Sufficiency |
| HBU | TAZ | NA |
| NHBW | Worker | NA |
| NHBNW | Household | NA |

HBPB = home-based personal business. HBSC = home-based school. HBSR = home-based social recreation. HBU = home-based university. HBW = home-based work. NA = not applicable. NHBNW = non-home-based non work. NHBW = non-home-based work. TAZ = travel analysis zone.

Market segments by trip purpose for non-regular household produced trips are shown in Table 2.

Table 2
Market Segments by Trip Purpose for
Non-Regular Household Produced Trips

| Trip Category | Segments |
|-----------------------|--|
| Special Generators | Personal Business Social Recreation |
| Airport Ground Access | Resident/Visitor Business/Leisure |
| Externals | Auto Medium Truck Heavy Truck |
| Trucks | Medium Truck Heavy Truck |

Mode availability specific to the trip category and purpose is shown in Table 3.

Table 3
Mode Availability Specific to Trip Category and Purpose

| Mode | Model Abbreviation | Home-Based Trips (Except School) | Home-Based School | Non-Home-Based | Airport |
|-------------------------------|---------------------------|---|--------------------------|-----------------------|----------------|
| Drive Alone (SOV) | DA | x | x | x | |
| 2 Person Shared Ride (HOV2) | S2 | x | x | x | |
| 3+ Person Shared Ride (HOV3+) | S3 | x | x | x | |
| Walk | WK | x | x | x | |
| Bike | BK | x | x | x | |
| Auto Access to Transit | TA | x | x | | x |
| Walk Access to Transit | TW | x | x | x | x |
| Ride-sourcing | RS | x | x | x | x |
| School Bus | SB | | x | | |
| Drive and Park | DP | | | | x |
| Pickup or Drop-off | PU | | | | x |
| Logan Express | LX | | | | x |
| Rental Car | RC | | | | x |

HOV = high-occupancy vehicle. SOV = single-occupancy vehicle.

Implementation

TDM23 is implemented as a hybrid of Caliper's TransCAD software platform and Python and is primarily run using TransCAD's Flowchart User Interface.

TDM23 is calibrated to a 2019 base year and thus assumes the transferability of pre-pandemic travel behavior to future scenarios. A work from home component is included to test scenarios with varying levels of remote work behavior.

Outputs

TDM23 generates outputs at each step in the model. The outputs are produced at the most disaggregated segment and can be aggregated as desired.

Table 4
TDM23 Output Data Categories

| Segment | Metric |
|--------------------|---|
| Households | Household trips by purpose Vehicles |
| Persons | Worker trips |
| TAZ | Person trips by mode Truck trips |
| Roadway Link | Vehicle volume by time of day Congested speeds |
| Transit Route/Stop | Ons/offs/loading by time of day |

TAZ = travel analysis zone.

2.2 MODEL COVERAGE

This section describes what TDM23 represents in terms of geography and time.

2.2.1 Geographic Representation

Prior to TDM23, the Central Transportation Planning Staff (CTPS) regional travel demand model geography was joined with the Massachusetts statewide model. The model then covered all of Massachusetts and Rhode Island and southeastern New Hampshire. TDM23 maintains this geographic extent. However, due to the different origins and purposes of the combined models, there is a difference in network and zonal detail within the Boston Region MPO area of the network and the rest of Massachusetts.

Figure 2
Model Area



The geography is divided into travel analysis zones (TAZ). The TAZ boundaries are inherited from previous travel demand models and do not perfectly align with 2010 or 2020 Census block boundaries. Previous updates made minor adjustments to the zone boundaries following the 2010 Census. In the current zone system, there are approximately 2,000 Census blocks that are split among multiple zones. Allocation of split blocks to TAZs is done using a uniform distribution of overlapping land area.

The distribution of TAZs is shown in Table 5.

Table 5
TAZ Distribution

| TAZ Area | Count |
|------------------------|-------|
| Model Region | 5,839 |
| Inner Core Communities | 1,044 |
| Boston Region MPO | 1,901 |
| Massachusetts | 4,497 |
| New Hampshire | 430 |
| Rhode Island | 812 |
| External Stations | 100 |
| Key External Stations | 9 |

TAZ = travel analysis zone.

2.2.2 Temporal Representation

TDM23 represents a full “average weekday” of travel. The day is divided into times of day for the supply components and time periods for the demand components.

There are four times of day to estimate volumes and boardings for the roadway and transit networks respectively. There are two time periods to estimate the demand response to roadway congestion and transit service.

The times of day were defined to be as homogeneous in demand as possible to reduce aggregation error in the static assignment. The limits were determined through a visual analysis of the distribution of trips in the household survey, traffic counts, transit service and boardings, and trips in the Streetlight/Regional Integrated Transportation Information System platforms.

The TDM23 times of day are as follows:

- AM Peak: 6:30 AM—9:30 AM
- Midday: 9:30 AM—3:00 PM
- PM Peak: 3:00 PM—7:00 PM
- Night: 7:00 PM—6:30 AM

The time periods used for demand response are peak and non-peak. The association of time period to time of day is as follows:

- Peak time period = AM Peak time of day
- Non-Peak time period = Midday time of day

2.3 PLATFORM

TDM23 is Windows-based and requires Caliper’s TransCAD and Python to run. TDM23 is self-contained within a single folder and, with the necessary software, can run without other data dependencies.

2.3.1 Software

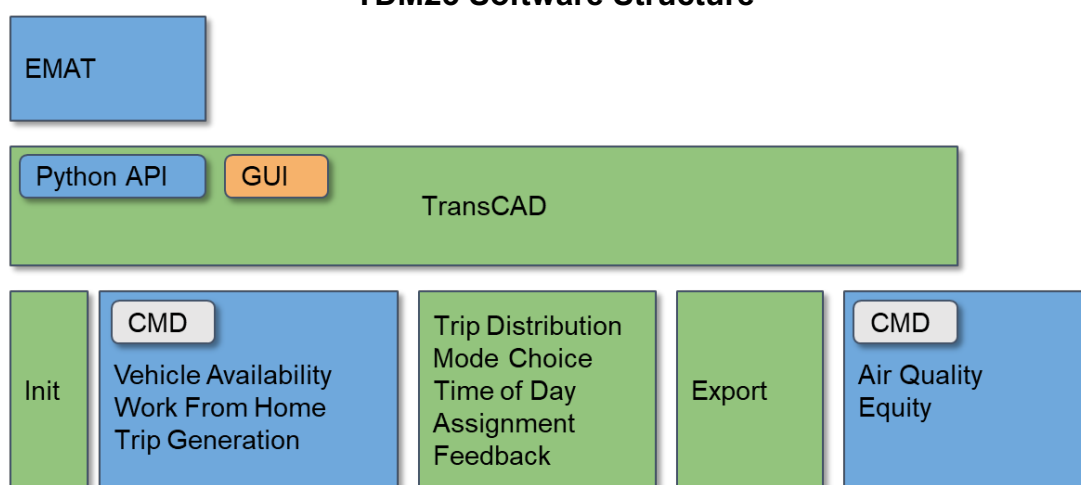
TDM23 is primarily implemented in Caliper’s TransCAD Version 9 travel demand software and is controllable through graphical and programmatic interfaces (graphical user interface [GUI], application programming interface [API]).² The GUI is through TransCAD’s flowchart interface that presents major components in a simplified visual format. All functions of the flowchart interface are also

² <https://www.caliper.com/tcovu.htm>

available through a python API, which is used by TMIP-EMAT to programmatically setup and run TDM23.³

TDM23 itself is a mix of TransCAD and Python components. The initial components are implemented in Python until skims are needed, at which point TDM23 will leverage TransCAD functions through GISDK. Figure 3 shows the mix of TransCAD (in green) and Python (in blue) along with the interface options: TransCAD's GUI, a Python API, or through a terminal or command prompt (CMD).

Figure 3
TDM23 Software Structure



Init = Initialization. API = application programming interface. CMD = command prompt. EMAT = exploratory modeling and analysis tool. GUI = graphical user interface.

2.3.2 File and Folder Structure

TDM23 is self-contained with all inputs, parameters, scripts, and outputs organized in a single folder structure. Path references within all scripts are relative to model root folder such that the model can be installed anywhere on the computer and multiple copies can be installed on the same computer.

Code Structure

The GISDK and Python scripts are organized by model functionality to simplify debugging, understanding operations, and future enhancements. All parameters are stored in separate input tables (i.e., there are no hard-coded parameters in scripts).

³ <https://tmip-emat.github.io/>

Input and Output File Management

Input files are stored in the Inputs folder of the model. Outputs are written to the Outputs folder under the scenario name. Files in the Inputs folder will not be changed in the course of a model run. Pre-processors run as part of TDM23 and write their outputs within the scenario under the Outputs folder.

Specific file naming conventions are adopted for input and output files.

- Input files are versioned by name of the file, and the specific file is specified in the model parameters. Input files are not hard coded into the model software, and any changes to an input file are recorded as a new file name.
- Output files are written to a unique output folder associated with the scenario name (see Section 2.8.1 under the Scenario Management header for more information). Output files have standardized names and locations. The names and locations of the most commonly used outputs are defined by parameters. Less commonly used outputs have their names and locations recorded in the TDM23 code.

Roadway and Transit Networks

Roadway and transit networks are stored in TransCAD's geodatabase files. Each geodatabase contains a unique scenario. Therefore, representation of different scenarios requires a copy of the geodatabase to be first created and then the edits applied to the copied geodatabase. The TDM23 file naming convention prescribes the copied geodatabase to be created with a different name as the original geodatabase.

In application, it may be most efficient to create a combined geodatabase that includes all scenario versions. The modeler can then generate specific scenario geodatabases by using the link, route, and stop "available" attribute.

2.4 ZONAL DATA

The zonal data input is data that are organized by TAZ or census block. These data include socioeconomic data (persons, households, and jobs), school enrollment, representations of walk/bike conditions, parking costs, and direct travel demand inputs.

2.4.1 Socioeconomic Data

Socioeconomic data are generated by two different models. MAPC's Urban Sim model produces data for Massachusetts organized by census block. For New Hampshire and Rhode Island, the data are generated by PopulationSim and

organized by TAZ. Population, household, and employment data are from the census.

Massachusetts Socioeconomic Inputs

The socioeconomic inputs for Massachusetts are estimated by MAPC's UrbanSim land use forecasting model. The UrbanSim model was estimated using 2010 Census data and corresponding Public Use Microdata Sample (PUMS) data and calibrated to a 2019 base year. The model produces land use estimates for every year from 2010 through 2050 for the Boston Region MPO. Another UrbanSim model allocates households and employment for every census block in the entire state of Massachusetts. MAPC merges the outputs of the two models.

New Hampshire and Rhode Island Socioeconomic Inputs

PopulationSim, an open-source synthetic population generator, is used to produce the disaggregate demographic data for New Hampshire and Rhode Island using TAZ-level control totals with a similar structure developed for TDM19.

Population and Household Data

The population inputs are a disaggregate table of persons, associated with a household and location (census block or TAZ). The persons table attributes are shown in Table 6.

Table 6
Persons Table Attributes

| Field | Description |
|--------------|-----------------------------------|
| hid | Household ID |
| block_id | 2010 Census Block FIPS or TAZ ID |
| hh_inc | Annual Household Income in 2010\$ |
| persons | Number of persons in household |
| workers | Number of workers in household |
| children | Number of children in household |
| person_num | Person ID |
| age | Person age in years |
| is_worker | Person is employed |
| wage_inc | Annual Worker Income in 2010\$ |

FIPS = Federal Information Processing Series. ID = identification. TAZ =travel analysis zone.

Employment Data

Employment inputs are total jobs by super sector associated with a location (census block or TAZ). The employment super sectors, their associated North American Industry Classification System (NAICS) codes, and the closest TDM19 employment sector are shown in Table 7.

Table 7
NAICS Codes and TDM Employment Sectors

| ID | Description | NAICS | NAICS Description | TDM19 Employment Sector |
|-----------|------------------------------------|--------------|--|--------------------------------|
| 1 | Construction | 23 | Construction | BASIC |
| 2 | Education and Health Services | 61 | Educational Services | SERVICE |
| 2 | Education and Health Services | 62 | Health Care and Social Assistance | SERVICE |
| 3 | Financial Activities | 52 | Finance and Insurance | SERVICE |
| 3 | Financial Activities | 53 | Real Estate and Rental and Leasing | SERVICE |
| 4 | Public Administration | 92 | Public Administration | SERVICE |
| 5 | Information | 51 | Information | SERVICE |
| 6 | Retail, Leisure, and Hospitality | 44 | Retail Trade | RETAIL |
| 6 | Retail, Leisure, and Hospitality | 45 | Retail Trade | RETAIL |
| 6 | Retail, Leisure, and Hospitality | 71 | Arts, Entertainment, and Recreation | SERVICE |
| 6 | Retail, Leisure, and Hospitality | 72 | Accommodation and Food Services | SERVICE |
| 7 | Manufacturing | 31 | Manufacturing | BASIC |
| 7 | Manufacturing | 32 | Manufacturing | BASIC |
| 7 | Manufacturing | 33 | Manufacturing | BASIC |
| 8 | Other Services | 11 | Agriculture, Forestry, Fishing, and Hunting | BASIC |
| 8 | Other Services | 21 | Mining, Quarrying, and Oil and Gas Extraction | BASIC |
| 8 | Other Services | 81 | Other Services (except Public Administration) | SERVICE |
| 8 | Other Services | 99 | NA | NA |
| 9 | Professional and Business Services | 54 | Professional, Scientific, and Technical Services | SERVICE |

| | | | | TDM19 Employment Sector |
|-----------|--------------------------------------|--------------|--|--|
| ID | Description | NAICS | NAICS Description | |
| 9 | Professional and Business Services | 55 | Management of Companies and Enterprises | SERVICE |
| 9 | Professional and Business Services | 56 | Administrative and Support and Waste Management and Remediation Services | SERVICE |
| 10 | Trade, Transportation, and Utilities | 22 | Utilities | BASIC |
| 10 | Trade, Transportation, and Utilities | 42 | Wholesale Trade | BASIC |
| 10 | Trade, Transportation, and Utilities | 48 | Transportation and Warehousing | BASIC |
| 10 | Trade, Transportation, and Utilities | 49 | Transportation and Warehousing | BASIC |

TDM = travel demand model. NA = not applicable. NAICS = North American Industry Classification System.

2.4.2 School Enrollment

The two enrollment inputs to TDM23 are K-12 enrollment and college commuter enrollment. Both inputs are TAZ based.

K-12 enrollment for public, private, and charter schools is associated with the TAZ containing the school parcel.

College commuter enrollment is distributed for universities spanning multiple TAZs.

2.4.3 Intersection Density

The nonmotorized network, derived from Open Street Map (OSM), is processed outside of TDM23 to calculate the density of intersections that would support walking and biking activities. The density of intersections is assumed to be a proxy for ease of walking and biking due to shorter blocks and denser development.

Intersections are identified as a node with more than two links connected to it. Intersection density is the number of intersections per square mile, calculated using the land area of a TAZ.

Due to inconsistencies in how the OSM network is coded, intersection density has been capped at 1,000 intersections per square mile for any TAZ. Specifically, within the model area, some TAZs include roads with sidewalks, while neighboring TAZs may only include roads or sidewalks. Although the true levels of walkability and bikeability are similar between these TAZs, the sidewalk coding discrepancy creates variation in the intersection density. The maximum density threshold mitigates these discrepancies.

2.4.4 Parking Costs

TAZ hourly, daily, and monthly parking costs are input. The multiple time period costs are useful to distinguish parking rates by trip purpose and expected duration. The relationship between trip purpose and parking cost input is shown in Table 8.

Table 8
Activity Durations and Parking Cost Derivations

| Purpose | Observed Activity Duration (hours) | Parking Cost Input |
|------------------------------|---|--|
| Home-Based Work | 6.58 | Monthly / 21.67: amortize monthly costs by average weekdays in a month |
| Home-Based Personal Business | 0.88 | Hourly * 1 |
| Home-Based Social Recreation | 2.02 | Hourly * 2 |
| Home-Based School | 6.47 | Daily: assume limited parking at schools so higher price as proxy |
| Non-Home Based Work | 1.77 | Hourly * 2 |
| Non-Home Based Non-Work | 1.61 | Hourly * 2 |

Work trips are the only trips assumed to be regular enough to take advantage of a monthly rate. School trips are also regular, but schools are more likely to have constrained parking; thus, the daily rate is used. Note, these values only apply in zones that have non-zero parking costs.

Parking costs were collected from publicly reported parking prices at lots in Boston, Cambridge, and Somerville for weekdays in spring 2022. The individual prices were converted to zonal averages through a spatial averaging of nearest lots to each zone.

2.4.5 Direct Travel Demand Inputs

Direct trip inputs are used in travel demand modeling to represent nonresident and/or non-regular travel. In TDM23, this includes nonresident travel to/from areas outside of the model area (external trips) and non-regular trips to/from airports and casinos (special generators).

Externals

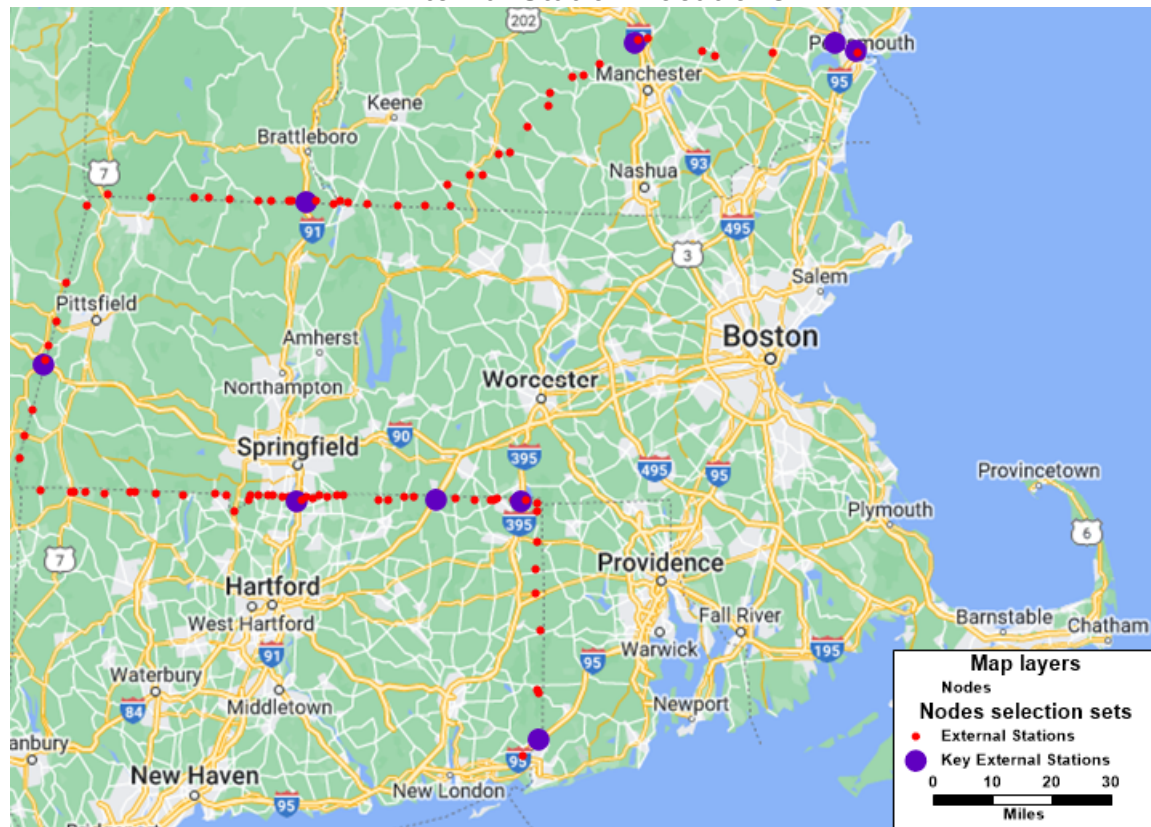
External-external trips (starting and ending outside the model region) and external-internal trips (one end is outside and the other one is within the model region) are input for the nine key external stations that generate a substantial number of auto and/or truck trips within or traveling through the Boston region.

External trips at each external station are categorized as follows:

- Vehicle type (auto, medium truck, or heavy truck)
- Share of external-external and external-internal trips

The external-external trip distribution is estimated based on an input pattern segmented by vehicle type. The vehicle distribution pattern was developed from daily vehicle flows between key external stations using Streetlight data. The key external stations and all stations are shown in Figure 4.

Figure 4
External Station Locations



The external inputs developed from MassDOT counts include segments by auto and truck as shown in Table 9.

Table 9
Key External Stations

| Location | 2019 AADT | External | Auto Share | Truck Share | Medium Truck | Heavy Truck |
|--------------------------------------|--------------|----------|---------------|----------------|-----------------|----------------|
| I-95 over Piscataqua River NH | 82,937 | 0.176 | 0.941 | 0.059 | 0.312 | 0.688 |
| NH 4 and NH 16 NH | 60,141 | 0.156 | 0.951 | 0.049 | 0.548 | 0.452 |
| I-93 Everett Turnpike Hooksett NH | 81,968 | 0.026 | 0.941 | 0.059 | 0.563 | 0.437 |
| I-91 MA/VT Border | 15,458 | 0.382 | 0.911 | 0.089 | 0.274 | 0.726 |
| I-90 MA/NY Border | 24,835 | 0.180 | 0.735 | 0.265 | 0.122 | 0.878 |
| I-91 MA/CT Border | 103,875 | 0.056 | 0.944 | 0.056 | 0.324 | 0.676 |
| I-84 MA/CT Border | 63,865 | 0.062 | 0.929 | 0.071 | 0.136 | 0.864 |
| I-395 MA/CT Border | 24,464 | 0.040 | 0.958 | 0.042 | 0.374 | 0.626 |
| I-95 CT/RI Border | 40,732 | 0.003 | 0.947 | 0.053 | 0.357 | 0.643 |

AADT = average annual daily traffic. CT = Connecticut. MA = Massachusetts. NH = New Hampshire. RI = Rhode Island. VT = Vermont.

The most active external station is Interstate 91 (I-91) at the Massachusetts and Connecticut border. I-90 has the highest truck share. As mentioned above, the external-external patterns are input through a seed matrix and capture travel such as through trips on I-91 or I-95.

Airport Ground Access Trips

Daily enplanements and deplanements, net of transferring passengers, at Logan airport are input along with the segmentation by residency (resident or visitor) and purpose (leisure or business). The share of airport ground access trips traveling outside the region is also an input to TDM23.

Special Generators

Special generators are input as trips by purpose (social recreational or personal business) and peak or non-peak time period.

Special Generators for TDM23 currently include trips associated with casinos in the region.

2.5 NETWORKS

The roadway, transit, and nonmotorized networks are all represented in TransCAD geodatabase files.

Each geodatabase file represents a unique scenario.

2.5.1 Roadway

The roadway network represents the alignment, capacity, and potential of roadway links for vehicular travel across the four model time periods. Not all roadways are represented in the model to simplify maintenance and network routing. Essentially, only roadways used for regional travel are included, i.e., collectors, arterials, and highways with some significant local roads.

Roadway alignments are derived from the TDM19 networks.

The roadway network is made up of a link layer and node layer. The link and node attributes are listed in Tables 10 and 11, respectively. These tables indicate whether the field is required and must be set for any scenario definitions.

Table 10
Roadway Link Attributes

| Field | Required | Notes |
|--------------|-----------------|--|
| ID | * | Unique ID maintained by TransCAD |
| Length | * | Length in miles maintained by TransCAD |
| street_name | | Roadway name or descriptive text of link |
| route_number | | Route number |
| taz_id | * | TAZ ID |
| dir | * | Link direction 0 = Two-way travel 1 = A to B travel only -1 = B to A travel only |
| func_class | * | Functional Class 1 = Interstate 2 = Limited Access Arterial 3 = Principal Arterial 5 = Minor Arterial 6 = Collector 10 = Local Road 20, 21 = Nonmotorized 30, 41, 42 = Transit Walk 50-56 = HOV 60 = Truck Only 70 = PNR Auto Only 71 = Bus Only 72-84 = Ramps 90,99 = Centroid Connector 100, 101, 102 = Transit |

| Field | Required | Notes |
|----------------|----------|--|
| fac_type | * | Facility Type 1 = Freeway 2 = Expressway 3 = Major Arterial 4 = Minor Arterial 5 = Collector 6 = Local Road 7 = Freeway-Freeway Connector 8 = Expressway Ramp 9 = Centroid Connector 10 = Transit 11 = Nonmotorized |
| AB/BA_lanes | * | Number of directional lanes |
| available | * | Link availability 1 = enabled 0 = disabled |
| shoulder_use | * | Permitted use of shoulder for travel 0 = none 1 = AM period only 2 = PM period only |
| peak_link | * | Zipper lane 0 = NA 1 = lane increase/decrease in AM/PM 2 = lane decrease/increase in AM/PM |
| peak_hov | * | Restricted to HOV use for peak periods 0 = none 1 = AM period only 2 = PM period only 3 = Both AM and PM periods |
| bus_lane | * | Bus lane attributes - directionality - time of day - impact on general purpose lanes |
| max_truck_size | * | Restrictions for medium or heavy trucks 1 = No trucks 2 = No medium trucks or heavy trucks 3 = No heavy trucks |
| toll_auto | * | Toll for autos |
| toll_lt_trk | * | Toll for 4-tire commercial vehicles |

| Field | Required | Notes |
|--------------------|----------|--|
| toll_md_trk | * | Toll for single unit 6-tire trucks |
| toll_hv_trk | * | Toll for combination trucks |
| posted_speed | | Speed limit |
| alpha_input | | Override value of alpha for VDF |
| beta_input | | Override value of beta for VDF |
| ff_speed_input | | Override value of speed for VDF |
| capacity_input | | Override value of capacity for VDF |
| auto_time_input | | Override value of travel time |
| transit_time_input | | Override input of travel time (all transit routes using link and all time periods) |
| walk_time_input | | Override input of walk time |
| pnr_parking_cost | | PnR parking cost in dollars |
| pnr_penalty | | Calibration parameter for PnR use |
| project_key | | Short name reference to roadway project |
| count_id | | Count station ID |

HOV = high-occupancy vehicle. ID = identification. NA = not applicable. PnR = park and ride. TAZ = travel analysis zone. VDF = volume delay function.

Table 11
Roadway Node Attributes

| Field | Required | Notes |
|--------------|----------|----------------------------------|
| ID | * | Unique ID maintained by TransCAD |
| Longitude | * | Longitude maintained by TransCAD |
| Latitude | * | Latitude maintained by TransCAD |
| Elevation | | Elevation maintained by TransCAD |
| int_zone | * | Internal TAZ |
| ext_zone | * | External TAZ |
| pnr_lot | * | PnR Lot |
| station_name | | Transit station name |
| parking | * | Parking capacity |
| project_key | | Short name reference to project |

ID = Identification. PnR = park and ride. TAZ = travel analysis zone.

Facility Type Definitions

TDM23 uses facility types consistent with those defined in National Cooperative Highway Research Program (NCHRP) Report 716, as shown in Table 12.

Table 12
TDM23 Facility Types

| Facility Type | Definition |
|----------------------|---|
| Freeways | Grade separated, high speed, high capacity, and limited access |
| Expressways | Very few signals, high speed connections between major points |
| Major Arterials | Roadways connecting major points with frequency traffic signals |
| Minor Arterials | Roadways connecting local points and major arterials with frequency traffic signals |
| Collectors | Connecting to neighborhoods and arterials |
| Local Roads | Lower speed connectors |
| Ramps | Connecting freeways and expressways to other roads |

For reference, Table 13 and Figures 5 and 6 give examples of freeways, expressways, and major arterials in TDM23.

Table 13
Facility Type Examples

| Facility Type | Example Roadway |
|----------------------|---|
| Freeways | All Interstates |
| | Route 128 |
| | Route 3 North of I-95 and South of I-93 |
| Expressways | Route 1 (in part) |
| | Route 2 (in part) |
| | Route 9 (in part) |
| Major Arterials | Commonwealth Avenue |
| | Route 28 |

Figure 5
Boston Area Roadways

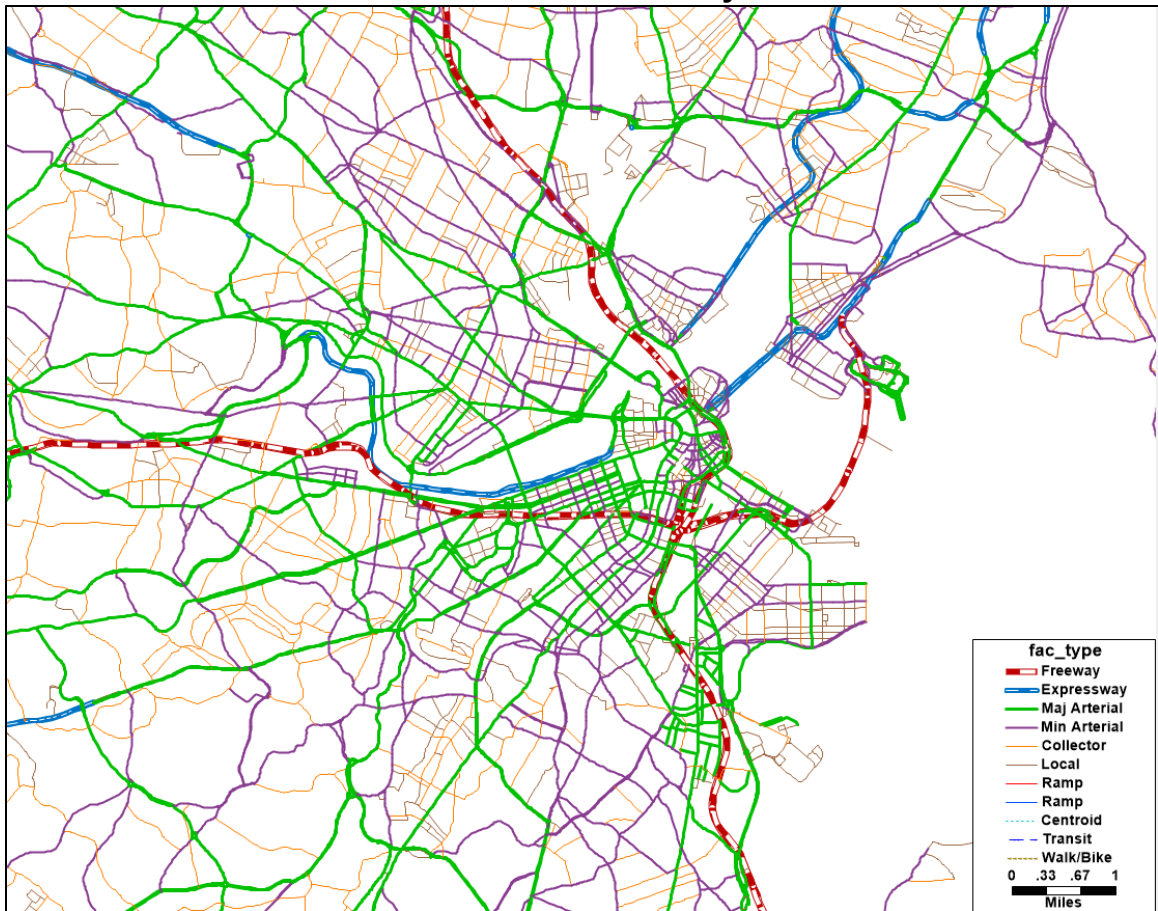
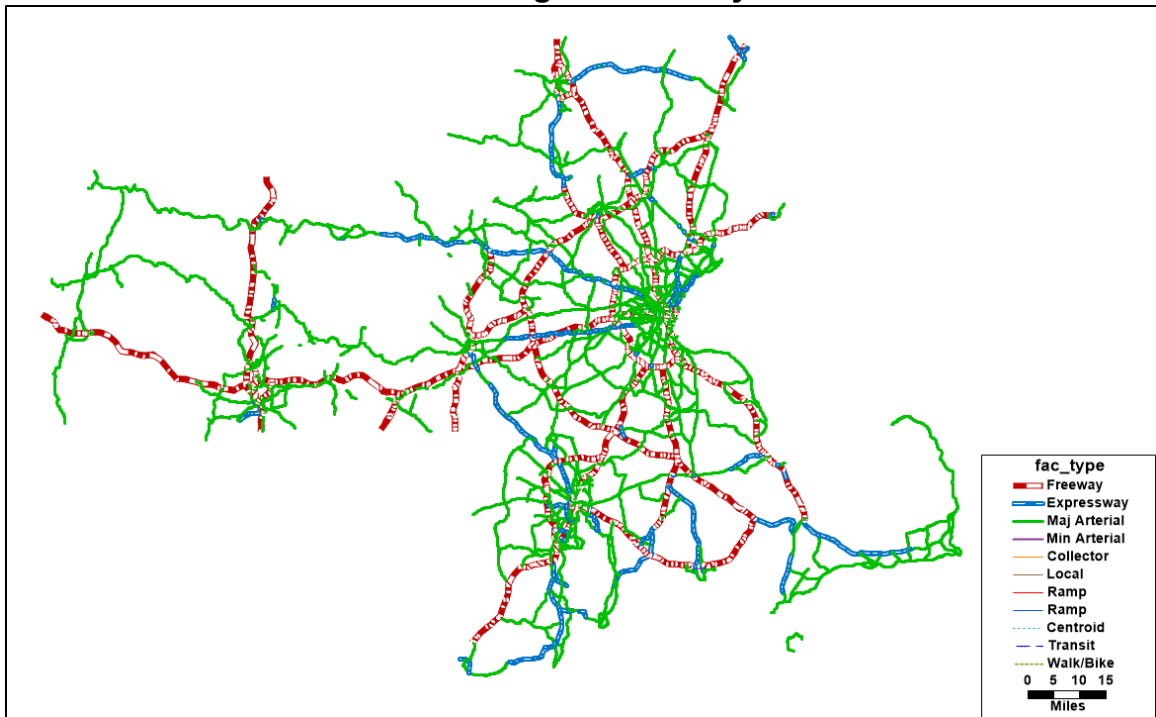


Figure 6
Model Region Roadways



Turn Prohibitions

Turn prohibitions are set on specific link sequences where the network coding would allow a prohibited turn. Global turn prohibitions are also set between freeways and expressways as these facilities are always connected by ramp facilities.

2.5.2 Transit

The transit network represents the alignment, stop locations, headways, travel times, and fares for transit service aggregated to the four model time periods.

The transit network is derived from the TDM19 networks. However, due to the substantial changes in the planned Bus Network Redesign and a need to ensure consistency in the model base year, transit service for several operators were redeveloped using the General Transit Feed Specification (GTFS). GTFS-defined service plans include occasional route patterns, for example school trips, that are combined into the common pattern following the heuristic that routes with fewer than three trips per time period are combined. This process reduces the number of distinct routes in the model network, simplifying the network maintenance with little reduction to model precision.

The GTFS source and operators are listed in Table 14.

Table 14
Transit Modes

| Transit Operator | Service Plan Source |
|-------------------------|---|
| MBTA | https://mbta-massdot.opendata.arcgis.com/datasets/MassDOT::gtfs-recap-fall-2018/about |
| Cape Ann | https://transitfeeds.com/p/massdot/95/20180831 |
| Brockton | https://transitfeeds.com/p/massdot/94/20180902 |
| Metro West | https://transitfeeds.com/p/massdot/101/20181004 |
| Pioneer Valley | https://transitfeeds.com/p/massdot/104/20181001 |
| Worcester | https://transitfeeds.com/p/massdot/108/20181005 |

MBTA = Massachusetts Bay Transportation Authority.

Note that the fall 2018 GTFS was used for MBTA services to avoid the partial roll out of the Better Bus Project in 2019, which risked creating a biased response in the model.

Transit service is aggregated into sub-modes to better represent different fare, dwell times, transfer propensity, reliability, and rider experience by transit type as shown in Table 15.

Table 15
Transit Sub-Modes

| Transit Mode | Description |
|---------------------|---|
| Local Bus | MBTA bus service |
| Express Bus | MBTA express bus service (higher fare, express service) |
| Bus Rapid | Silver Line - all routes |
| Light Rail | Green Line and Mattapan High Speed |
| Heavy Rail | Red, Blue, and Orange Lines |
| Commuter Rail | All commuter rail lines |
| Ferry | All commuter boat services |
| Shuttle | Point-to-point service, potentially restricted access |
| RTA Local Bus | Bus services supplied by non-MBTA operators |
| Regional Bus | Bus services with longer distance routes |

MBTA = Massachusetts Bay Transportation Authority. RTA = regional transit authority.

Transit service that is included in TDM23 is shown in Table 16.

Table 16
TDM23 Transit Service

| Operator | Transit Mode(s) |
|--|--------------------------------|
| Bedford Local Transit | RTA (local bus) |
| Bloom Tours | Regional Bus |
| Boston Express | Regional Bus |
| Brockton Area Transit Authority (BAT) | RTA (local bus) |
| Burlington | RTA (local bus) |
| C&J | Regional Bus |
| Cape Ann Transportation Authority (CATA) | RTA (local bus) |
| Concord Coach | Regional Bus |
| DATTCO Motorcoach | Regional Bus |
| Dedham | RTA (local bus) |
| Greater Attleboro-Taunton RTA (GATRA) | RTA (local bus) |
| Joseph's/JBL | Shuttle |
| Lexpress | RTA (local bus) |
| Lowell RTA (LRTA) | RTA (local bus) |
| Massport (Logan Express, Shuttle) | Regional Bus, Shuttle |
| MBTA | Local Bus, BRT, LRT, CR, Ferry |
| Merrimack Valley RTA (MVRTA) | RTA (local bus) |
| Metrowest RTA (MWRTA) | RTA (local bus) |
| MGH | Shuttle |
| Mission Hill | Shuttle |
| Peter Pan | Regional Bus |
| Pioneer Valley Transit Authority (PVRTA) | RTA (local bus) |
| Plymouth & Brockton | Regional Bus |
| Southeastern RTA (SRTA) | RTA (local bus) |
| Worcester RTA (WRTA) | RTA (local bus) |
| Yankee Line | Regional Bus |

BRT = bus rapid transit. CR = commuter rail. LRT = light rail transit. Massport = Massachusetts Port Authority. RTA = regional transit authority.

Transit Model Attributes

The transit network is made up of a routes layer and stops layer. The route and stop attributes are listed in Tables 17 and 18, respectively. These tables indicate whether the field is required and must be set for any scenario definitions.

Table 17
Transit Route Attributes

| Field | Required | Notes |
|----------------|-----------------|---|
| route_id | * | Unique ID maintained by TransCAD |
| route_name | * | Route name text |
| dir | * | Route direction text |
| mode | * | Transit submode 1 = Local Bus 2 = Express Bus 3 = Bus Rapid 4 = Light Rail 5 = Heavy Rail 6 = Commuter Rail 7 = Ferry 8 = Shuttle 9 = RTA Local Bus 10 = Regional Bus |
| operator | | Operator name |
| primary_route | | Primary route name |
| trip_head_sign | | Destination and routing |
| desc | | Route description |
| fare_type | | Fare type 1 = flat fare 2 = zonal fare |
| fare | | fare value in dollars |
| fare_core | | zonal fare reference |
| fuel_type* | | Type of fuel used by vehicle |
| available | * | Route availability 1 = enabled 0 = disabled |
| headway_%TOD% | * | Route headway by time of day (AM, MD, PM, NT) |
| project_key | | Short name reference to project |

* The transit route fuel attribute is not consistently maintained and is not used in modeling or emissions calculations.

ID = identification. MD = midday. NT =nighttime. RTA = regional transit authority.

Table 18
Transit Stop Attributes

| Field | Required | Notes |
|--------------------|-----------------|---|
| ID | * | Unique ID maintained by TransCAD |
| Longitude | * | Longitude maintained by TransCAD |
| Latitude | * | Latitude maintained by TransCAD |
| Route_ID | * | Unique ID maintained by TransCAD |
| Pass_Count | * | Maintained by TransCAD |
| Milepost | * | Maintained by TransCAD |
| DistanceToNextStop | * | Maintained by TransCAD |
| stop_id | * | Maintained by TransCAD |
| near_node | | Node ID associated with stop for walk/auto access |
| stop_name | | Stop name |
| fare_zone | | Fare zone |
| available | * | Stop availability 1 = enabled 0 = disabled |
| time_next | | Override of travel time to next stop |

ID = identification.

Transit Fares

Trips are not segmented by fare type (single ride, pass, reduced fare, etc.), therefore a weighted average fare is calculated based on the observed distribution of fares paid on each transit mode. The fare inputs to TDM23 are by mode for Massachusetts Bay Transportation Authority (MBTA) services (local bus, bus rapid transit, light rail, heavy rail, commuter rail, and ferry) and by route of regional transit authority (RTA), shuttle, and regional bus services.

Fare values are specific to the scenario to represent contemporary levels, but with constant 2010 dollars. For example, express bus services changed from a zonal fare (inner and outer) to a single fare category in July 2021.

Bus Lanes

Bus lanes are configured at the link level. A bus lane is defined by the direction, available time, and impact on general purpose lanes. For example, a bus lane that only operates in the peak periods and is otherwise dedicated to parking versus a bus lane that operates all day and takes a lane from general purpose traffic can each be identified.

To define a bus lane, the modeler needs to specify the following:

1. The travel direction with a bus lane
2. Whether the bus lane will reduce the general purpose lanes or not
3. The time of day when the bus lane is in operation
4. (Optional) The travel speed on the bus lane (default is free-flow speed)

Where bus lanes are defined, all transit routes on that link are assumed to use the bus lane. Routes using the bus lane will traverse the link at the input transit speed or the link free-flow speed.

2.5.3 Nonmotorized

Walk, bike, and micromobility modes would take advantage of local roads and multiuse paths that are not necessarily maintained in the model roadway network.

The nonmotorized network is created from Open Street Map with the following edits:

- Remove all links with the “foot” attribute equal to no, including cycleways, motorways, and private ways with no walking permitted.
- Remove all service roads including links such as parking lot lanes, alleys, etc., that do not explicitly prohibit pedestrians but are not intended to enhance pedestrian travel.

The only network attribute retained from OpenStreetMap (OSM) is the link length.

2.6 PROCESS

This section describes each step or component of TDM23. Starting from the pre-processors through the demand components and assignment and ending with the post-processors.

2.6.1 Pre-Processors

Pre-processors are components that derive attributes based on the input data that are used by the model components. These include household and zonal attributes.

Household Classification

Households in the synthetic population have a household income. A size-based household income category is defined to distinguish travel behavior between

small households and large households with the same income. Three categories of income are defined as low, mid, and high income.

Low income households are identified as being below 200 percent of the federal poverty level guidelines, which are based on the total household income and number of household members. The thresholds are set as follows in Table 19 (2010 dollars):

Table 19
Household Size Income Thresholds

| Household Size | Low Income Threshold | High Income Threshold |
|-----------------------|-----------------------------|------------------------------|
| 1 | \$22,688.49 | \$100,000.00 |
| 2 | \$30,059.79 | \$123,214.90 |
| 3 | \$35,136.87 | \$133,944.04 |
| 4 | \$45,718.21 | \$162,081.12 |
| 5 | \$55,035.74 | \$181,455.88 |
| 6 | \$62,641.26 | \$192,074.47 |
| 7 | \$72,239.36 | \$205,999.43 |
| 8+ | \$81,001.68 | \$214,817.20 |

Middle income households are those that are neither low nor high. The threshold between middle and high income households was updated from a fixed value in previous versions.

Employment Accessibility

Employment accessibility is the share of employment accessible within

- 10 minutes by auto,
- 30 minutes by transit, or
- 30 minutes by auto.

Travel time for the employment accessibility calculations is derived using AM peak congestion and walk-transit paths.

Transit Access Density

Transit access density is effectively the area type category for TDM23. Area type calculations can be problematic because of the following challenges:

- Densities are susceptible to zone sizes. Small zones may have very high densities.

- TAZs with urban parks have low or no density and might be naively categorized as rural without a smoothing process.
- Manual smoothing processes hinder dynamic recalculation of area types.

Leveraging transit service walk access along with population and employment density resolves these challenges effectively because the transit system acts as a smoothing agent and the presence of transit, especially high frequency and/or rapid transit, are good proxies for dense land uses.

The population and employment density ([population + employment] / buildable area in square miles) level thresholds are defined in Table 20.

Table 20
Socioeconomic Density Levels

| Level | Density Range |
|--------------|---|
| High | ≥ 10,000 persons and/or jobs per square mile |
| Medium-High | ≥ 7,500; < 10,000 persons and/or jobs per square mile |
| Medium-Low | ≥ 5,000; < 7,500 persons and/or jobs per square mile |
| Low | < 5,000 persons and/or jobs per square mile |

Access to transit service is identified at the stop location. The transit services are grouped as follows:

- Heavy rail rapid (red, orange, and blue)
- Green Line trunk (sections with service on all four lines)
- Any rapid transit (heavy or light rail)
- Any Silver Line
- Commuter rail
- High-frequency bus (less than 5 minute headway)
- Mid-frequency bus (less than 15 minute headway)
- All local service (any transit service except commuter rail or regional bus)

The transit access density area type categorization is divided into six segments: central business district (CBD), dense urban, urban, fringe urban, suburban, and rural. The intersection of transit service and densities is shown in Table 21. Note that any of the identified transit service levels are sufficient, i.e., only one condition needs to be met.

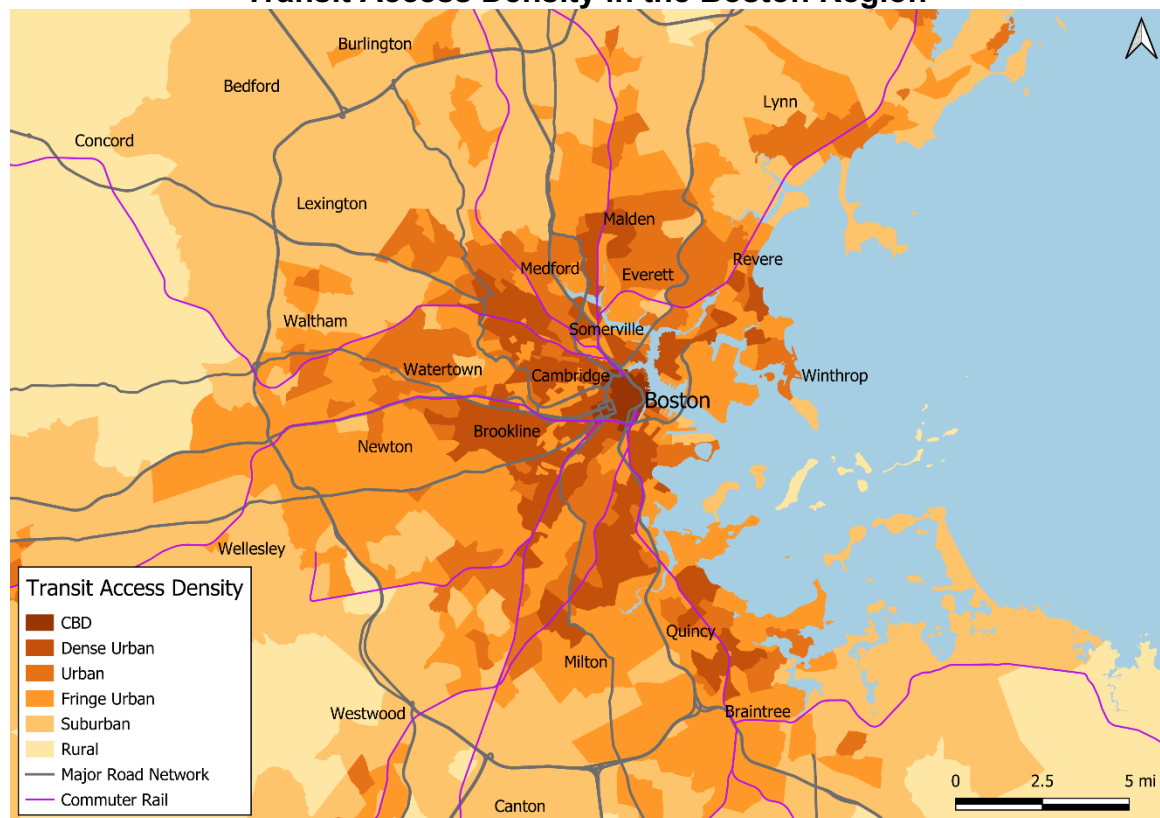
Table 21
Transit Access Density Definitions

| Access Density | Multiple Heavy Rail Stations | Core Green Line | Any Rail Rapid Transit | Commuter Rail | < 5 Minute Headway | < 15 Minute Headway | Any Local Bus | SE Density |
|-----------------------|-------------------------------------|------------------------|-------------------------------|----------------------|------------------------------|-------------------------------|----------------------|-------------------|
| CBD | 1/2 mile | 1/4 mile | | | | | | ANY |
| Dense Urban | | | 1/2 mile | | | | | > 10,000 |
| Urban | | | 1 mile | 1/2 mile | 1/2 mile | | | > 7,500 |
| Fringe Urban | | | 1 mile | | | | | ANY |
| Fringe Urban | | | | 1/2 mile | | 1/2 mile | | > 5,000 |
| Suburban | | | | | | | 1/2 mile | ANY |

CBD = central business district. SE = Socioeconomic.

The base year transit access density is summarized in Figure 7.

Figure 7
Transit Access Density in the Boston Region



The transit access density is associated with other categorizations as shown in Table 22.

Table 22
Access Density and Area Type Comparison

| Transit Access Density | ITE Setting/Location* | TDM19 Area Types |
|-------------------------------|------------------------------|---------------------------------------|
| Central Business District | Center City Core | CBD (set manually, general alignment) |
| Dense Urban | Center City Core | Urban |
| Urban | Dense Multi-Use Urban | Urban |
| Fringe Urban | General Urban/ Suburban | Suburban |
| Suburban | General Urban/ Suburban | Suburban |
| Rural | Rural | Rural |

* ITE Trip Generation Manual, 10th Edition, Definition of Terms, pages 7-8.

Terminal Times

TDM23 sets the terminal times according to the transit access density and distinguishes the production and attraction end times to reflect the availability of parking for residences in dense areas. The longest terminal times are in dense areas where it is likely that parking is not available in the same parcel as the production or attraction end of the trip.

Table 23
Terminal Time by Access Density

| Transit Accessible Density | Production End | Attraction End |
|-----------------------------------|-----------------------|-----------------------|
| CBD | 5 minutes | 6 minutes |
| Dense Urban | 4 minutes | 5 minutes |
| Urban | 4 minutes | 5 minutes |
| Fringe Urban | 2 minutes | 2 minutes |
| Suburban | 1 minute | 1 minute |
| Rural | 1 minute | 1 minute |

2.6.2 Roadway Path Building and Skimming

Warm Start Speeds

The default travel time values for roadway links are the free-flow speeds input or derived on each link. However, free-flow speeds can be quite different from congested speeds. The larger the difference, the more iterations TDM23 will require to converge the demand response and supply conditions. In order to reduce the iterations, a set of warm start speeds can be input. These speeds are generated by a previous model run. Note that newly coded network links will not have a warm start speed and will use the free-flow default for the initial speeds.

Roadway Skims

Roadway skims are done in the initialization step as well as in each speed feedback iteration for trip distribution and mode choice. The times of day skimmed are AM Peak and Midday. Travel times are segmented by roadways available to drive alone (single-occupancy vehicles [SOV]) and shared ride (high-occupancy vehicles [HOV]). A single distance skim is produced based on drive-alone network distances.

Intrazonal interchanges are derived from half the average distances and times to the three nearest neighbor values.

Turn Penalties

Turn penalties that reflect the delay for turning movements are set globally. These are set as shown in Table 24.

Table 24
Global Turn Penalties

| Parameter | Value |
|------------------|--------------|
| Left | 0.09 |
| Right | 0.03 |
| Through | 0.05 |
| U-turn | -1 |

These settings show that U-turns are prohibited in the network. Left turns have three times the penalty of right turns. There is some delay for through movements to reflect signal delays and turning conflicts.

Volume-delay Function (VDF)

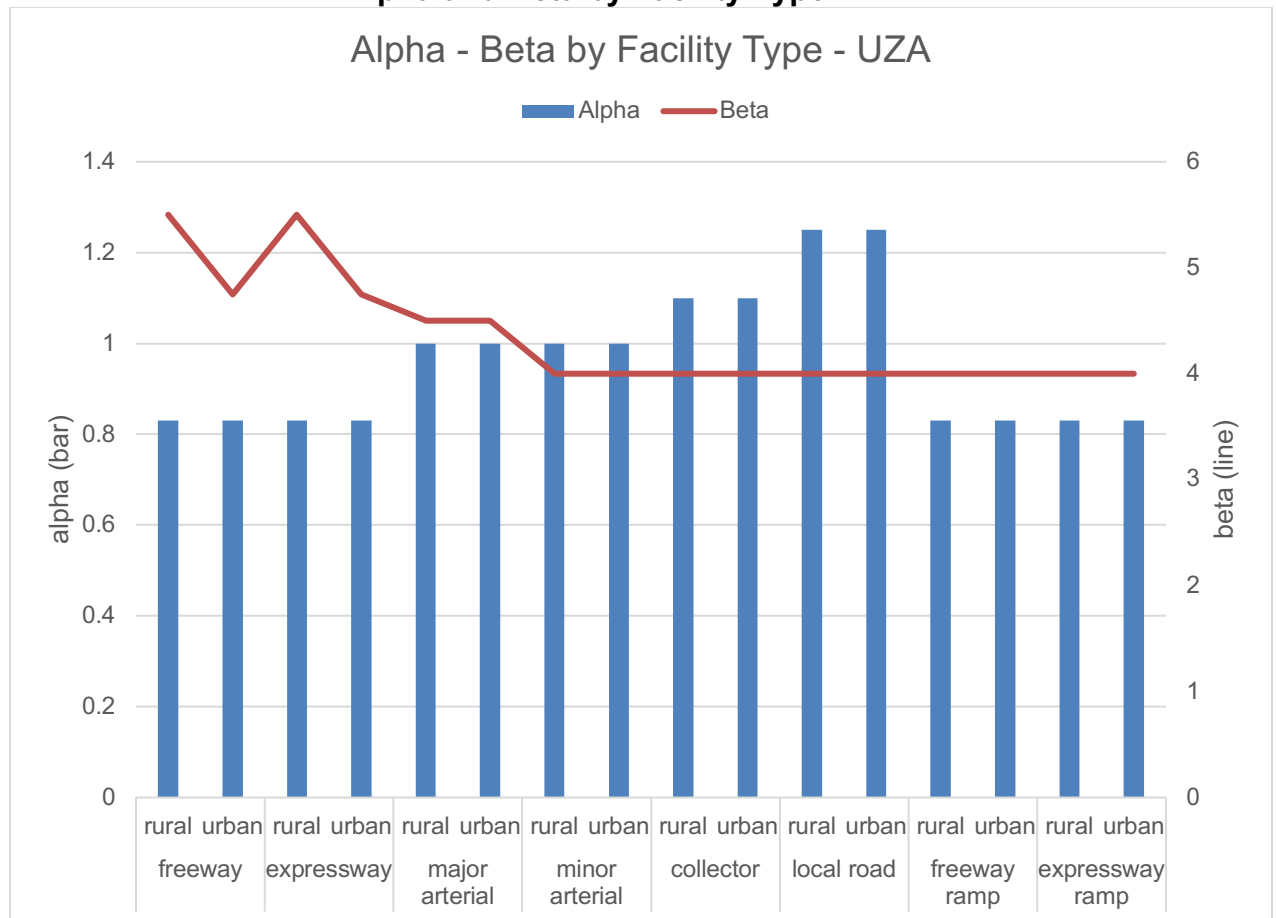
TDM23 uses a standard BPR volume-delay function, with the formulation:

$$\text{Travel Time} = \text{Free Flow Time} * (1 + \alpha * [\text{Volume/Capacity}] ^ \beta)$$

VDF Parameters

The alpha and beta values are segmented by facility type and urbanized areas as shown in Figure 8, based on the 2020 Census Urbanized Area definitions.

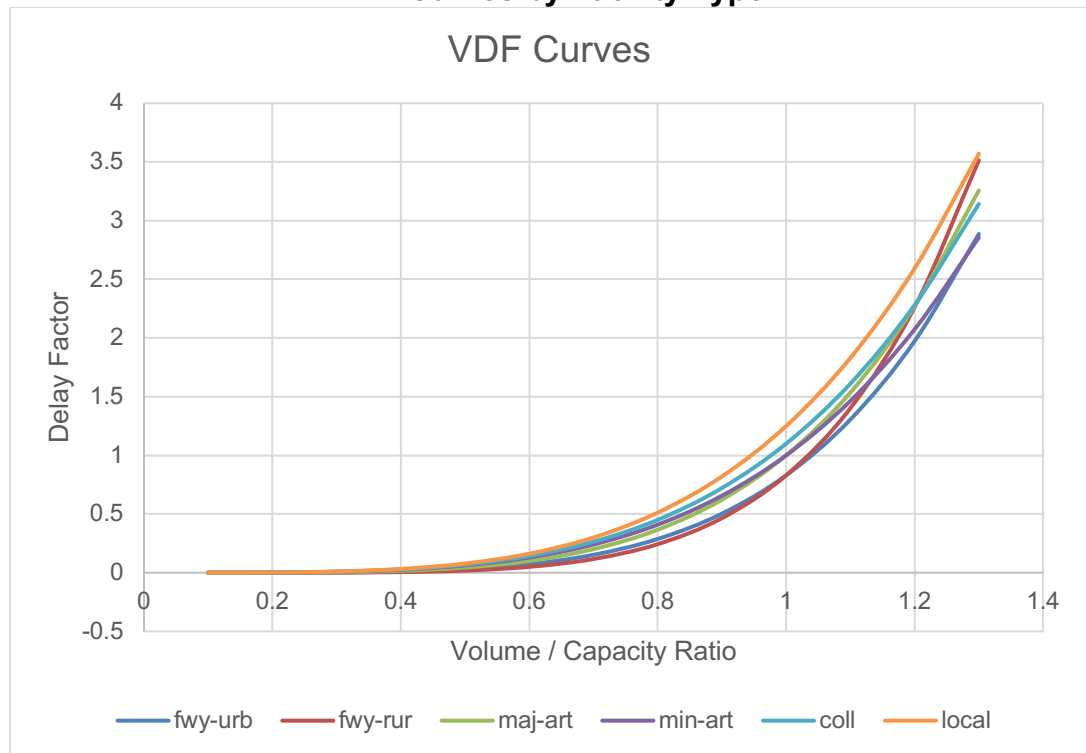
Figure 8
Alpha and Beta by Facility Type



UZA = urbanized area.

Freeways and expressways have slightly different beta values between urban and rural roadways. This reflects the closer spacing of ramps and intersections in urban areas. The resulting decay curves are shown in Figure 9. The lower design roadways have a delay response to increasing congestion at a lower volume to capacity ratio.

Figure 9
VDF Curves by Facility Type

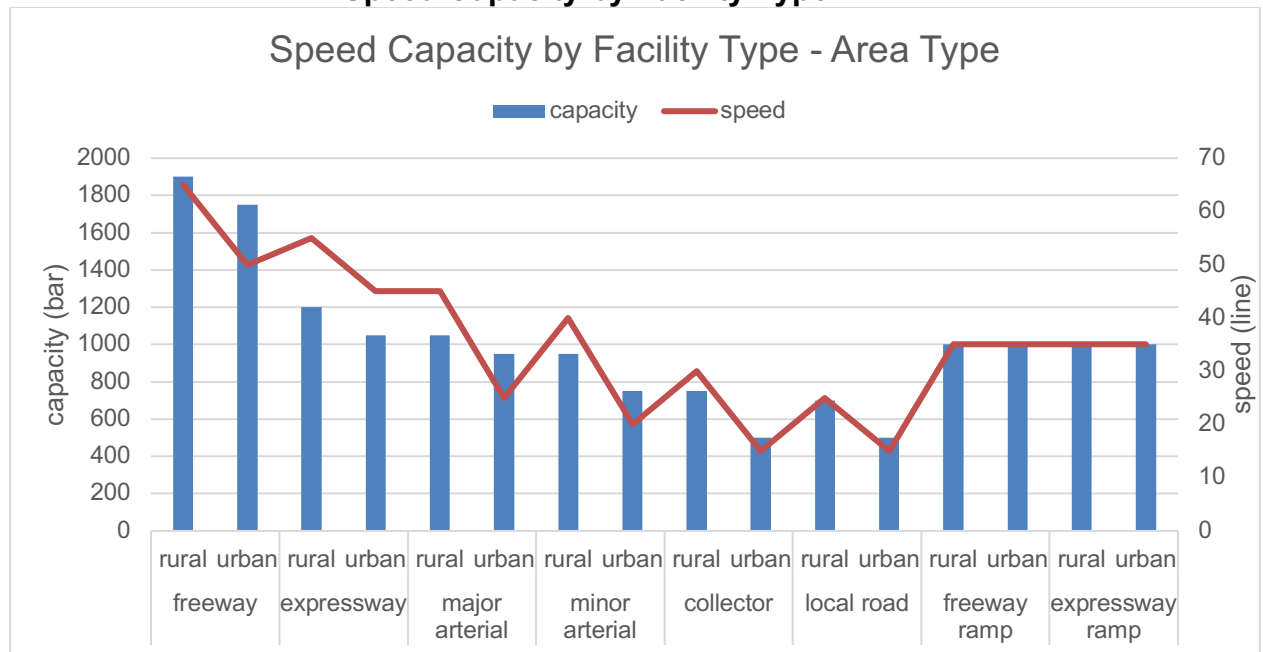


fwy-urb= Freeway Urban. fwy-rur = Freeway Rural. maj-art = Major Arterial. min-art = Minor Arterial. coll = Collector. Local = Local Roads. VDF = volume-delay function.

Speed and Capacity

The frequency of intersections and driveways as well as turning and weaving behavior is captured through the roadway capacity and free-flow speed. Default values for capacity and free-flow speed are shown in Figure 10.

Figure 10
Speed Capacity by Facility Type



Default free-flow speeds are used where an input speed is not set in the network. In TDM23, free-flow speeds are set for most roadways in the model. The source of these speeds is derived from the Replica observed free-flow speeds and checked against INRIX for speeds on interstates and previously set modeled speeds for other roadways.⁴

There are no override capacity values on any links in TDM23. The capability to set override capacity, alpha, and beta values are retained to support focus area calibration, for example when using TDM23 for a specific project analysis.

2.6.3 Transit Path Building and Skimming

Transit paths are built by time period and access/egress mode. The segments are the following:

- All time periods (AM, midday [MD], PM, nighttime [NT])
- Transit-walk (walk access and egress)
- Transit-auto-access with walk egress
- Transit-auto-egress with walk access

There are core assumptions in TDM23 that underpin the transit path building process:

⁴ <https://documentation.replicahq.com/docs/free-flow-speed-per-network-link>

- There are maximum times that travelers will walk or drive to access transit services.
- There is a maximum number of transfers that travelers will make, even if an additional transfer reduces the total travel time.
- All transit travelers have a similar sensitivity to fares and parking fees. In other words, all travelers would make a similar choice to reduce travel time by using a mode with a higher fare.
- Travelers perceive time spent driving to a park-and-ride (PnR), walking to/from/between stations, waiting (initially or for transfer), and traveling in a transit vehicle differently. For example, the time waiting may be two times more onerous than traveling in a transit vehicle; thus, a path with the same total time but more in-vehicle time would be preferred.

These assumptions are converted into transit path thresholds and parameters based on an analysis of the 2015–17 MBTA Transit Rider survey and a comparison of observed and modeled paths.

Transit Path Thresholds

Transit paths are built within defined threshold limits for each path component (total time traveling, time waiting, walk and drive access and egress times, etc.). The thresholds encourage reasonable paths and simplify the computational burden of the model.

The thresholds set for TDM23 are shown in Table 25.

Table 25
Global Transit Path Thresholds

| Parameter | Value |
|--------------------|--------------|
| MaxTripCost | 180 |
| MaxModalTotal | 180 |
| MaxTransfers | 6 |
| MaxInitialWait | 60 |
| MaxTransferWait | 45 |
| MaxAccessWalk | 25 |
| MaxEgressWalk | 25 |
| MaxDriveTime | 60 |
| MaxParkToStopTime | 10 |
| MinParkingCapacity | 25 |

Transfers between transit modes include an additional penalty time to represent the reliability and inconvenience of transferring. Transit-auto paths have fewer transfers, reflecting the preference of travelers to avoid transferring if possible. Accordingly, transit-auto paths have a higher penalty for transfers. Transfer penalties by mode and time of day are shown in Table 26.

Table 26
Transfer Penalties

| Mode | Time Period | Penalty |
|--------------|--------------------|----------------|
| Transit Walk | Peak | 12 |
| Transit Walk | Non-peak | 8 |
| Transit Auto | Peak | 24 |
| Transit Auto | Non-peak | 24 |

Transit Waiting Time

Initial and transfer wait times are assumed to be half the headway up to the maximum global times. Overlapping route frequencies are combined to calculate an effective wait time across multiple routes.

Transit Travel Time

Transit travel times are derived from the roadway conditions but may be overridden on a route-specific and/or stop-specific level. The total in-vehicle time is the sum of the travel time and dwell time. Dwell times are set by transit mode and are uniform across all routes, stops, and time periods.

If the link is only used by transit, i.e., a dedicated right-of-way, then the transit travel time input or default speed on the link will determine the transit time. If non-transit vehicles can also use the link, the transit travel time is the congested travel time on the link, unless the transit travel time override value is set.

Transit Time and Cost Weights

The transit path is built by minimizing the generalized cost. Generalized cost consists of the total costs (fare, toll, and parking) and time (walking, waiting, transferring, and traveling).

Translation of time to cost uses a constant value of time of \$0.25 per minute or \$15 per hour.

- Walking time is weighted as two times in-vehicle time.
- Driving time is weighted as 10 times in-vehicle time. Note that this value is not based on the assumption that driving is much more onerous compared

to using transit. Instead, this value represents the unobserved constraints on an auto if used to connect to transit (e.g., being dropped off, using a transportation network company (TNC), or wanting to maximize useful time on board transit).

TDM23 supports setting time weights by sub-mode. For example, traveling on commuter rail is more pleasant than local bus due to the comfort of the seats and smoothness of the ride. Also, it can be less pleasant to wait for a local bus than a heavy rail train because of station amenities and protection from the elements.

The sub-mode adjustments implemented are as follows:

- In vehicle travel time weight:
 - commuter rail time is 5 percent less onerous than other transit modes, and
 - ferry time is 10 percent less onerous than other transit modes.
- Initial or transfer weight time:
 - wait time is weighted as two times in-vehicle time for heavy rail, commuter rail and ferry. For the rest of the transit modes, the wait time is weighted three times the in-vehicle time.

Park-and-Ride Lot Capacity

The parking capacity at park-and-ride (PnR) lots is represented in TDM23 through a shadow cost. The shadow cost is estimated during the capacity constrained transit assignment (see Section 2.6.17). This cost is then incorporated into the auto path generalized cost and effectively reduces demand to over-capacity parking lots. As with the roadway initial speeds, warm start PnR demand may also be input to reduce the iterations needed to converge the demand and supply components.

Transit Skims

Transit skims are done in the initialization step as well as in each speed feedback iteration for trip distribution and mode choice. The times of day skimmed are AM Peak and Midday. Travel times and costs are segmented by access mode (walk and auto). The skims include the breakdown of time and cost components and can optionally include travel times by each transit sub-mode.

Intrazonal interchanges are asserted to not have a viable transit path.

2.6.4 Nonmotorized Path Building and Skimming

A single set of skims is built for both walk and bike modes. The distance is the only impedance factor in the path building.

Intrazonal interchanges are derived from half the average distances to the three nearest neighbor values.

2.6.5 Vehicle Availability

This component will estimate vehicles available to the household, not necessarily *owned* vehicles. The vehicles available are those that could be accessed for average weekday travel. These might include

- vehicles shared among friends in the same building, but not necessarily the same household;
- company vehicles with de-minimis personal use; and
- motorcycles.

Vehicles available through a subscription car-share service (e.g., ZipCar or Turo) are not explicitly represented through the vehicle availability model.

The vehicle availability component actually estimates the household segment based on the vehicles available relative to the number of drivers. The segments are defined as follows:

- **Zero Vehicles (ZV)**—Households with no vehicles
- **Insufficient Vehicles (IV)**—Households with fewer vehicles than drivers (persons older than 16 years)
- **Sufficient Vehicles (SV)**—Households with at least as many vehicles as drivers (persons older than 16 years)

The number of vehicles available in a household is derived by the household segment with insufficient vehicle households having one fewer vehicle than drivers and sufficient vehicle households having the same number of vehicles as drivers.

Table 27 shows the parameters for the component. These parameters were initially estimated using the 2011 Massachusetts Travel Survey and calibrated as described in Chapter 3.

Table 27
Vehicle Availability Parameters

| Variable | Value |
|---|--------------|
| Zero Vehicle Coefficients | |
| ASC | -3.0 |
| Workers in HH | -0.475 |
| Children in HH | -0.371 |
| CBD or Dense Urban | 2.5 |
| Intersection Density | 1.2 |
| Low Income HH | 2.75 |
| Suburban or Rural | -0.95 |
| Transit Accessibility/Highway Accessibility | 0.758 |
| Insufficient Vehicle Coefficients | |
| ASC | -0.289 |
| CBD or Dense Urban | 1.25 |
| Intersection Density | 0.928 |
| Low Income HH | 0.6 |
| Seniors in HH | 0.315 |
| Suburban or Rural | -0.537 |
| Number of Drivers above 2 | 0 |
| Presence of Drivers above 2 | 1.75 |
| Sufficient Vehicle Coefficients | |
| ASC | 0.7 |
| All drivers are workers | 0.955 |
| High Income HH | 0.292 |

ASC = Alternative Specific Constant. CBD = central business district. HH = household.

These coefficients imply

- ZV households are most prevalent for smaller households, without children, in urban areas, and with low income;
- IV households are most prevalent for larger households with seniors and in urban areas; and
- SV households are most prevalent for households consisting entirely of workers and that are high income.

Limitations

Limitations to the vehicle availability component include the following:

- Does not directly estimate number of vehicles, therefore comparison to other data sources may not be consistent.

- Does not represent vehicles available through a purely on-demand service, such as TNCs and taxis. These are represented through the ride-source mode alternative.
- Does not estimate vehicle fuel technology (internal combustion engine, hybrid, full electric, etc.). Different fuel technology assumptions would impact the emissions rates input to the air quality post processor, which are generated by the MOVES model process. (MOVES is the US Environmental Protection Agency's Motor Vehicle Emission Simulator model.)
- Does not estimate vehicle driving technology (drive assist, automation). Vehicle automation could impact the vehicle operating cost, perceived travel time, and traffic efficiency.

2.6.6 Work From Home

The work-from-home (WFH) component estimates the level of work-related trips that are not taken on the average weekday. The 2019 base year is the baseline level of work from home, i.e., the estimates of commuting and work from home are relative to the levels of remote work in 2019, rather than a scenario where every worker commutes.

In TDM23, WFH rates are estimated and used from two perspectives: workers and jobs. A worker who does not commute to work is assumed to make fewer work-related trips in the model. Thus, the WFH rate applied to a worker effectively reduces the work trips produced by that worker. Conversely, a job that is performed remotely is assumed to attract fewer trips, both work related and otherwise. Thus, the WFH rate applied to employment reduces the work and other trips attracted by the employment. For testing, TDM23 provides the ability to apply WFH rates on either end of the trip generation process, or both.

There are four modes for WFH:

- No WFH
- WFH for workers only
- WFH for employment only
- WFH for both workers and employment

By default, TDM23 operates with No WFH, i.e., with the 2019 remote work levels. To support scenario analysis with WFH behavior, a series of preset levels by state and MPO are estimated and saved in TDM23.

Calculation of Preset Values

The WFH rates for workers and employment are calculated using either the preset values calculated from 2023 observations or through custom values based on local surveys or studies. This section outlines the procedure used to establish these preset values, serving as a guide for users who wish to generate their own inputs based on specific data.

WFH rates are the differential rates from 2019. Therefore both 2019 and 2023 rates are calculated from the common data to determine the differential value. Replica data was used to calculate these rates.⁵

The key attributes from the Replica People dataset are “person id,” “TAZ id,” “employment status,” “WFH status,” and “industry (job sector).” By aggregating these data to the TAZ level, we obtain Worker WFH rates specific to each TAZ. Further, by applying the relationships between TAZ and MPO, as well as TAZ and State, we can extrapolate these rates to broader geographic levels, yielding Worker WFH rates at both the MPO and State levels.

In addition, by aggregating the data based on the industry to job sector relationships, we can determine Employment WFH rates by job sector. Tables 28, 29, and 30 present the WFH rates for workers (categorized by state and MPO) and employments (categorized by sector) for both the years 2019 and 2023, highlighting the differences to be used as TDM23 inputs. Note, rounding errors may be present in these tables.

Table 28
State-Level WFH Rates

| State | 2019 WFH Rate | 2023 WFH Rate | Difference |
|---------------|----------------------|----------------------|-------------------|
| Massachusetts | 0.05 | 0.27 | 0.22 |
| New Hampshire | 0.07 | 0.28 | 0.22 |
| Rhode Island | 0.04 | 0.2 | 0.16 |

WFH = work from home.

⁵ <https://www.replicahq.com/>

Table 29
MPO-Level WFH Rates

| MPO | 2019 WFH Rate | 2023 WFH Rate | Difference |
|--|--------------------------|--------------------------|-------------------|
| Boston Region Metropolitan Planning Organization | 0.05 | 0.3 | 0.25 |
| Berkshire Regional Planning Council | 0.06 | 0.11 | 0.05 |
| Cape Cod Commission | 0.07 | 0.16 | 0.1 |
| Central Massachusetts Regional Planning Council | 0.05 | 0.27 | 0.22 |
| Franklin Region Council of Governments | 0.08 | 0.21 | 0.13 |
| Montachusett Regional Planning Commission | 0.05 | 0.25 | 0.21 |
| Martha's Vineyard Commission | 0.12 | 0.21 | 0.1 |
| Merrimack Valley Planning Commission | 0.05 | 0.25 | 0.21 |
| Northern Middlesex Council of Governments | 0.04 | 0.26 | 0.22 |
| Nantucket Planning & Economic Development Commission | 0.06 | 0.08 | 0.02 |
| Old Colony Planning Council | 0.04 | 0.27 | 0.24 |
| Pioneer Valley Planning Commission | 0.04 | 0.26 | 0.21 |
| Southeastern Regional Planning & Economic Development District | 0.03 | 0.24 | 0.21 |

WFH = work from home.

Table 30
Employment WFH Rates

| Job Sector | 2019 WFH Rate | 2023 WFH Rate | Difference |
|--------------------------------------|--------------------------|--------------------------|-------------------|
| Construction | 0.04 | 0.12 | 0.08 |
| Education and Health Services | 0.04 | 0.22 | 0.18 |
| Financial Activities | 0.08 | 0.47 | 0.39 |
| Public Administration | 0.02 | 0.34 | 0.32 |
| Information | 0.1 | 0.53 | 0.43 |
| Retail, Leisure, and Hospitality | 0.03 | 0.14 | 0.1 |
| Manufacturing | 0.03 | 0.24 | 0.2 |
| Other Services | 0.08 | 0.16 | 0.08 |
| Professional and Business Services | 0.11 | 0.47 | 0.35 |
| Trade, Transportation, and Utilities | 0.03 | 0.15 | 0.12 |

WFH = work from home.

Of the Worker WFH rates at the State and MPO levels, 0.21 emerges as the most common difference in WFH rates. Consequently, 0.21 is designated as the default WFH rate for the Model Regional level for year 2023 in TDM23. In instances where the WFH rate difference is 0.22, which is very close to the default of 0.21, the default value will still be applied to maintain consistency and simplicity in the model.

For Employment WFH rates, the differences in WFH rates by sector are used directly as inputs.

The preset inputs for both Worker and Employment WFH rates are outlined below. While the preset Worker WFH rates primarily focus on the State and MPO levels, rather than extending to the Town/City level, users who require Town/City level analysis can adapt the same methodology to achieve this finer level of detail.

Worker WFH Rates

Worker WFH rates are calculated in geographic levels (Model Regional, State, MPO, Town/City levels), and use default values and different values from the default values.

In setting the geographic Worker WFH rates within the TDM23 model, we employ a method that uses default WFH rates alongside specific, differing values for certain areas, rather than relying on average WFH rates. This method entails setting a standard, or default, WFH rate for a larger geographic area (such as a state) and then applying different WFH rates for specific subregions within that area (such as individual MPOs) where the WFH trends are known to vary from the norm. For instance, if most parts of a state have a consistent WFH rate, this rate is set as the default for the entire state. However, for any MPO within the state that demonstrates a distinctively different WFH rate, this unique rate is applied specifically to that MPO. As a result, the overall WFH rate for the state does not simply mirror the average of all its MPOs, but rather reflects a more nuanced combination of the default rate and these individual variations, providing a more accurate and representative picture of WFH trends across different geographic levels.

For general analysis, the model recommends using the Model Regional, State, and MPO levels. At these levels, a default WFH rate is established for each category. This rate is typically reflective of the most common WFH rate within that category. However, for specific areas within these categories, such as individual MPOs or states that exhibit unique WFH trends, distinct WFH rates are

applied. These rates are inputted through tables in the user interface, providing an efficient and user-friendly means of data management.

On a more detailed scale, the Town/City level is available. This level is particularly useful for in-depth analysis of localized WFH trends. For towns and cities, WFH rates are inputted via a CSV file, consisting of two fields: “town” and “wfh_rate”. This method ensures that detailed data for each locality is accurately represented in the model.

Preset Worker WFH Rates are shown in Figure 11.

Figure 11
Worker WFH Rates Set in TDM23

Workers

Regional Default WFH Rate

0.21

WFH Rate by State

| State | Different from Regional Default | WFH Rate |
|-------|-------------------------------------|----------|
| MA | <input type="checkbox"/> | |
| NH | <input type="checkbox"/> | |
| RI | <input checked="" type="checkbox"/> | 0.16 |

WFH Rate by MPO

| MPO | Different from Regional and State Defaults | WFH Rate |
|--------|--|----------|
| BRMPO | <input checked="" type="checkbox"/> | 0.25 |
| BRPC | <input checked="" type="checkbox"/> | 0.05 |
| CCC | <input checked="" type="checkbox"/> | 0.1 |
| CMRPC | <input type="checkbox"/> | |
| FRCOG | <input checked="" type="checkbox"/> | 0.13 |
| MRPC | <input type="checkbox"/> | |
| MVC | <input checked="" type="checkbox"/> | 0.1 |
| MVPC | <input type="checkbox"/> | |
| NMCOG | <input type="checkbox"/> | |
| NPEDC | <input checked="" type="checkbox"/> | 0.02 |
| OCPC | <input checked="" type="checkbox"/> | 0.24 |
| PVPC | <input type="checkbox"/> | |
| SRPEDD | <input type="checkbox"/> | |

☐ Some towns/cities have different WFH rates from the regional/state/MPO defaults.

WFH Rates of these Towns/Cities:

WFH = work from home.

Employment WFH Rates

Worker WFH Rates are calculated by job sectors, regardless of geographies. Preset Employment WFH Rates are shown in Figure 12.

Figure 12
Employment WFH Rates Set in TDM23

| Employment | |
|-----------------------------|----------|
| Remote Level by Job Sectors | |
| Code | WFH Rate |
| 1_constr | 0.08 |
| 2_eduhlth | 0.18 |
| 3_finance | 0.39 |
| 4_public | 0.32 |
| 5_info | 0.43 |
| 6_ret_leis | 0.1 |
| 7_manu | 0.2 |
| 8_other | 0.08 |
| 9_profbus | 0.35 |
| 10_ttu | 0.12 |

WFH = work from home.

Limitations

The key limitations of this approach are summarized below:

- The WFH component does not adjust times of day of trips. For example, it would not account for commuting travel behavior if the travel was only for one-half day or for personal business trips conducted during the day by remote workers.
- The only change in household trips produced is from home-based work (HBW) and non-home-based work (NHBW) trips. Non-work-related trips that may increase with work-from-home behavior, e.g., shopping in the middle of the day, are not represented.

2.6.7 Trip Generation

The trip purposes for TDM23 are defined by the production end (home, work, non-home, or work) and attraction end purpose.⁶

Trip productions are estimated at the worker and household level. Trip attractions are estimated at the block and TAZ level. Following trip generation, the

⁶ For an explanation of trip generation approaches and the production and attraction components of a trip, please see https://tfresource.org/topics/Trip_Generation.html.

production end of non-home-based trips are allocated and trips are segmented into peak and non-peak trips.

Trip Productions

The trip production models are segmented by purpose and the production end location (home or non-home). Trips with the production end at the home are shown in Table 31.

Table 31
Home-based Trip Purpose Definitions

| Trip Purpose | Attraction End Activity |
|---------------------------------------|---|
| Home-based work (HBW) | Work/job, all other activities at work, volunteer work/activities, and work business related |
| Home-based personal business (HBPB) | Service private vehicle (gas, oil lube, etc.), routine shopping (groceries, clothing, convenience store, household maintenance), shopping for major purchases or specialty items (appliance, electronics, new vehicle, major household repairs), household errands (bank, dry cleaning, etc.), personal business (visit government office, attorney, accountant), and health care (doctor, dentist) |
| Home-based social-recreational (HBSR) | Eat meal outside of home, civic/religious activities, outdoor recreation/entertainment, indoor recreation/entertainment, and visit friends/relatives |
| Home-based school (HBSC) | Attending class, and all other school activities for persons who have not completed high school (Grade 12 or lower grades) and are younger than age 21 |
| Home-based university (HBU) | Attending class, and all other school activities for persons who have completed high school or are older than 20 |

Trips with a production end at work (non-home-based work) or a production end at neither home nor work are listed in Table 32.

Table 32
Non-home-based Trip Purpose Definitions

| Trip Purpose | Attraction End Activity |
|--------------------------------|---|
| Non-home-based work (NHBW) | Any |
| Non-home-based non-work (NHBW) | Any except work/job, all other activities at work, volunteer work/activities, and work business related |

Work-related trip productions (HBW and NHBW) are estimated at the individual worker level. All other trip purposes are estimated at the household level.

Worker Trip Productions

The worker trip generation rates are shown in Table 33. These parameters were initially estimated using the 2011 Massachusetts Travel Survey and calibrated as described in Chapter 3.

Table 33
Worker Trip Generation Rates

| Variable | Home-based Work | Non-home-based Work |
|------------------------------|------------------------|----------------------------|
| Constant | 1.414 | 0.100 |
| 65 or Older | -0.149 | |
| Workers | -0.025 | |
| Zero Vehicle Household | -0.093 | |
| Sufficient Vehicle Household | | 0.053 |
| Middle Income | 0.062 | 0.048 |
| High Income | 0.062 | 0.048 |

Home-based work (HBW): This model is applied at the worker level; therefore, the constant establishes the average work trips by worker. This average is assumed to vary based on whether the person is a part- or full-time worker. The terms imply that workers in households with higher income, fewer workers, and no seniors are more likely to be full-time workers.

Non-home-based work (NHBW): NHBW trips are more likely to be made by workers with autos. Higher income workers also have more NHBW trips as these people are more likely to work full time.

Household Trip Productions

The household based trip rates are shown in Table 34. These parameters were initially estimated using the 2011 Massachusetts Travel Survey and calibrated as described in Chapter 3.

Table 34
Household Trip Generation Rates

| Variable | Home-based Personal Business | Home-based School | Home-based Social Recreation | Non-home-based Non-work |
|--------------------------|---|------------------------------|---|------------------------------------|
| Constant | 1.031 | 0.023 | 0.550 | 1.371 |
| Persons | | | | 0.218 |
| Workers | 0.249 | | 0.300 | 0.315 |
| Non-Working Adults | 1.330 | -0.028 | 0.739 | 0.302 |
| Seniors | 0.915 | | 0.575 | 0.194 |
| Children | 0.509 | 1.174 | 0.974 | 0.243 |
| Zero Vehicle Household | -0.107 | | -0.405 | -0.221 |
| Middle Income | | | 0.333 | 0.091 |
| High Income | | | 0.458 | 0.189 |
| Employment Accessibility | | | 0.528 | |

Home-based personal business (HBPB): Personal business trips increase by household member, while non-working adults add the most and children and workers add the least. Having a vehicle is also correlated with more personal business trips.

Home-based social recreation (HBSR): Similar to personal business, the number of people in the household is correlated with the number of social-recreational trips. Children in the household increase trips the most of any person type. Higher income households, households with vehicles, and households with access to more employment within 30 minutes by auto make more social-recreational trips.

Non-home-based non-working (NHBNW): This model has a similar structure as HBSR, although workers, children, and non-working adults all have similar impacts on NHBNW trips with seniors producing slightly fewer trips.

Home-based school (HBSC): Reasonably, households with more children produce more school trips. However, the number of non-working adults makes it

more likely that the children can be cared for and schooled in the home. This is expected as school trips for children aged 0–18 are included, and pre-school and daycare trips occur at a lower rate in households with non-working adults than households with working adults only. While this model is applied at the household level, it is only applied to households with children. Note that adults who work remotely are still considered to be workers; thus, changes to the work-from-home rate does not impact the school trips.

Trip Attractions

The trip attraction model is a linear regression model that estimates the total trips attracted to an area. Note that several of the distribution models are destination choice models; therefore, the trip attractions are not necessarily equal to the number of trips attracted by zone.

These parameters were initially estimated using the 2011 Massachusetts Travel Survey with trips aggregated to a district level. Adjustments were made to the total job and total household trip attraction rates to scale the trips attracted to be generally consistent with the trips produced without biasing any particular job sector. This produced more reasonable trip distribution results.

Table 35
Trip Attraction Rates

| Variable | Access Density | HBW | HBPB | HBSR | NHBW | NHBNW |
|--------------------------|-----------------------|------------|-------------|-------------|-------------|--------------|
| Total Jobs | | 0.712 | 0.1 | 0.1 | 0.2 | 0.25 |
| Construction | | | | | | |
| Education/Health | | 1.134 | 0.659 | 0.232 | 0.127 | 0.272 |
| Finance | | 0.713 | | | | |
| Public | | | | | 0.227 | |
| Information | | | | 1.128 | | 0.582 |
| Retail/Leisure | | 0.401 | 2.084 | 0.586 | 0.148 | 1.563 |
| Retail/Leisure | Dense Urban | | | | | |
| Retail/Leisure | Dense Urban / Urban | | | | | |
| Manufacturing | | 0.816 | | | | |
| Other | | | | | | |
| Professional Services | | 1.147 | | 0.340 | 0.172 | 0.580 |
| Transportation/Utilities | | 0.667 | | | | |
| Households | | 0.01 | 1.176 | 1.054 | 0.111 | 1.015 |
| Households | Suburb | | 0.406 | 0.713 | | 0.875 |

HBPB = home-based personal business. HBSR = home-based social recreation. HBW = home-based work. NHBNW = non-home-based non work. NHBW = non-home-based work.

Home-based work trips are attracted to the total jobs at a baseline rate. Certain sectors attract higher levels of work trips. Retail/leisure jobs are segmented by density. This means that dense areas may have a smaller footprint, but conduct a higher level of business per employee.

The other trip purposes are attracted to households as well as work locations. Retail/leisure jobs are the among highest attractor of trips. Note that non-home-based trips are attracted to the widest variety of socioeconomic inputs as they cover all non-work activities.

Worker Income Attraction Segmentation

Home-based work attractions are segmented by worker income. The distribution of income by employment sector is shown in Table 36. This was derived from the

CTPP A202205 table (Industry [15] by Earnings in the past 12 months [in 2010 inflation adjusted dollars] [11] [Workers 16 years and over]). ⁷

Table 36
Employment Segments by Income

| Employment Sector | \$1 to \$34,999 | \$35,000 to \$64,999 | \$65,000 to \$99,999 | \$100,000+ |
|---|----------------------------|---------------------------------|---------------------------------|-------------------|
| Construction | 37% | 36% | 18% | 9% |
| Education and Health Services | 45% | 32% | 15% | 8% |
| Financial Activities | 27% | 34% | 18% | 21% |
| Public Administration | 20% | 40% | 29% | 11% |
| Information | 30% | 31% | 21% | 17% |
| Retail, Leisure, and Hospitality | 64% | 23% | 8% | 5% |
| Manufacturing | 31% | 33% | 19% | 18% |
| Other Services | 59% | 26% | 10% | 5% |
| Professional and Business Services | 32% | 27% | 19% | 22% |
| Trade, Transportation, and Utilities | 32% | 36% | 17% | 15% |

Home-Based School Attractions

School attractions can use a consistent set of enrollment for the base and forecast year; the important factor is the relative magnitude of the school enrollment (school attractions to productions). TDM23 has inputs on children by age and can estimate school trips directly and balance productions to attractions. Therefore, the attraction rate for school will be 1.0 applied to grade school enrollment.

Non-Home-Based Trip Allocation

Non-home-based trips are generated at the home end but, by definition, are actually produced away from the home end. These trips are aggregated and the productions allocated according to the following process:

- The production end is allocated according to the attractions of home-based-work trips (i.e., non-home-based-work trips are assumed to be produced at the work activity location).
- The production end is allocated by the non-home-based-non-work trip attractions.

⁷ U.S. Census Bureau, 2006-2010 American Community Survey 5-Year Estimates, Special Tabulation: Census Transportation Planning Products Program.

Note that the non-home-based trips are aggregated before the allocation. Therefore, there is no connection between the home- and non-home-based trip. This means that non-home-based trips cannot be segmented by vehicle availability.

Work-From-Home Trip Generation Impacts

The estimated share of workdays that a worker works remotely is applied to the trip generation productions for workers. For example, if a worker is estimated to work from home 50 percent of the time, the estimated home-based-work and non-home-based-work trips are multiplied by 0.5.

The estimated share of workdays that a job is conducted remotely is applied to the number of jobs prior to estimation of trip attractions.

Peak and Non-Peak Segmentation

Trip purpose specific factors are applied to segment trip purposes as shown in Table 37.

Table 37
Peak and Non-Peak Rates

| Period | HBW | HBPB | HBSR | HBSC | HBU | NHBW | NHBNW |
|---------------|------------|-------------|-------------|-------------|------------|-------------|--------------|
| Peak | 0.692 | 0.486 | 0.509 | 0.746 | 0.348 | 0.446 | 0.398 |
| Non-Peak | 0.308 | 0.514 | 0.491 | 0.254 | 0.652 | 0.554 | 0.602 |

HBPB = home-based personal business. HBSC = home-based school. HBSR = home-based social recreation. HBU = home-based university. HBW = home-based work. NHBNW = non-home-based non work. NHBW = non-home-based work.

Note that the majority of home-based work and home-based-social-recreation trips occur in the peak periods, which is reasonable. Non-home-based and home-based-university trips primarily occur in the non-peak periods.

Limitations

The key limitations of this approach are summarized below.

- Trip rates are independent by purpose.
- If trip-making changes purpose, there would be no direct impact on the other purpose categories. For example, if work trips are reduced due to remote working no increase would be seen in non-work travel.
- Assumed or expected changes across multiple trip purpose categories would require exogenous changes in multiple trip purpose rates.

2.6.8 Trip Distribution

This section describes the process to distribute trips generated by households. Distribution of trips generated through direct input (externals, special generators, airport ground access, and trucks) are described in later sections.

TDM23 distributes trips by multiplying the trips produced by zone, purpose, and segment to an estimated probability of the trips being attracted to every zone. The probabilities are estimated either through a destination-choice formulation or a gravity formulation. The destination-choice formulations take in the logsum from mode choice such that changes in utility by any mode will impact the destination zone probability. The gravity formulations use different singular impedance inputs and are not necessarily sensitive to changes in mode utility.

TDM23 trip distribution model formulations are listed in Table 38. Note that the home-based models are segmented by household vehicle levels (zero vehicles, insufficient vehicles, and sufficient vehicles). These segments are identical to those used in mode choice, therefore the utilities and logsums from mode choice are calculated once and used for both distribution and mode choice.

Home-based work is segmented by worker income. However, the only difference in that segmentation is the number of attractions that are calculated from factored employment segments, and the segmentation is not carried into mode choice.

Table 38
Trip Distribution Formulation and Segments

| Trip Purpose | Distribution Formulation Segments |
|---------------------|---|
| HBW | Destination choice worker income, household vehicles |
| HBSC | Singly constrained (production end) gravity (roadway time impedance) household vehicles |
| HBPB | Destination choice household vehicles |
| HBSR | Destination choice household vehicles |
| NHBW | Destination choice none |
| NHBO | Destination choice none |

HBPB = home-based personal business. HBSC = home-based school. HBSR = home-based social recreation. HBW = home-based work. NHBO = non-home-based other. NHBW = non-home-based work.

The destination-choice parameters are listed in Table 39. These parameters were initially estimated using the 2011 Massachusetts Travel Survey and calibrated as described in Chapter 3.

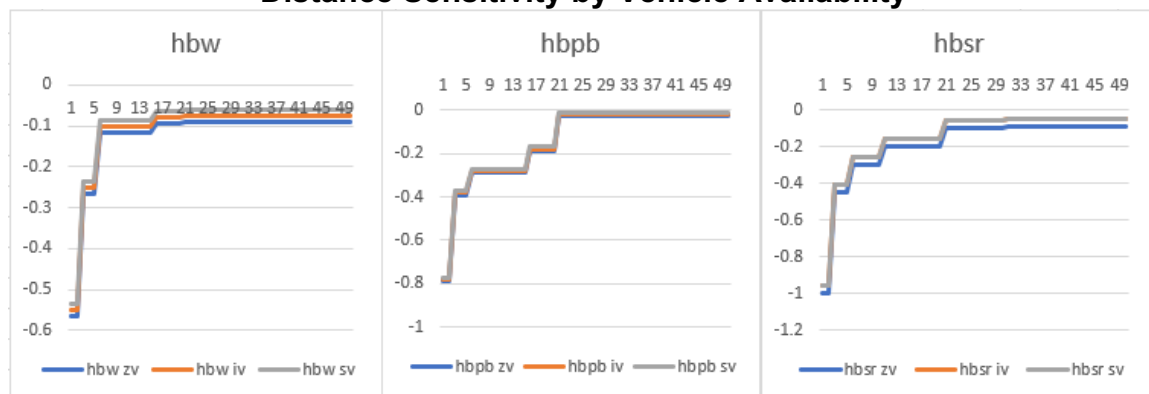
Table 39
Destination-Choice Parameters

| Variable | Vehicles | HBW | HBPB | HBSR | NHBW | NHBNW |
|-----------------------|-----------------|------------|-------------|-------------|-------------|--------------|
| Mode Choice | | | | | | |
| Logsum | ALL | 0.4 | 0.7 | 0.8 | 0.7 | 0.7 |
| Distance (miles) | ALL | 0 | 0 | 0 | -0.51 | -0.54 |
| Distance (miles) | ZV | -0.645 | -1.05 | -0.81 | 0 | 0 |
| Distance (miles) | IV | -0.59 | -0.995 | -0.8 | 0 | 0 |
| Distance (miles) | SV | -0.57 | -0.995 | -0.79 | 0 | 0 |
| Distance > 2.5 miles | ALL | 0.3 | 0.55 | 0.4 | 0 | 0 |
| Distance > 5.0 miles | ALL | 0.15 | 0.15 | 0.1 | 0.36 | 0.25 |
| Distance > 10.0 miles | ALL | 0 | 0.1 | 0 | 0.042 | 0.15 |
| Distance > 15.0 miles | ALL | 0.02 | 0 | 0.1 | 0.038 | 0.01 |
| Distance > 20.0 miles | ALL | 0.005 | 0.1 | 0.16 | -0.02 | 0.04 |
| Distance > 30.0 miles | ALL | 0 | 0.01 | 0 | 0 | 0 |
| Distance > 40.0 miles | ALL | 0 | 0 | 0 | 0 | 0 |
| Intrazonal | ALL | 0 | 0 | 0 | 0.7 | 0.2 |
| Intrazonal | ZV | 0.65 | -0.15 | 0.03 | 0 | 0 |
| Intrazonal | IV | 0.5 | -0.2 | 0 | 0 | 0 |
| Intrazonal | SV | 0.3 | -0.4 | -0.15 | 0 | 0 |
| Transit Accessible | ALL | 0.263 | 0 | 0 | 0 | 0 |
| Attractions | ALL | 1 | 1 | 1 | 1 | 1 |

HBPB = home-based personal business. HBSR = home-based social recreation. HBW = home-based work. NHBNW = non-home-based non-work. NHBW = non-home-based work IV = insufficient vehicles. SV = sufficient vehicles. ZV = zero vehicles.

The distance coefficient varies by distance. Figure 13 shows how this term changes by purpose and vehicle availability segment. Note that the zero vehicle segment is the most sensitive to distance (with the most negative coefficient). But, for all purposes, the marginal sensitivity to distance decreases at higher distances.

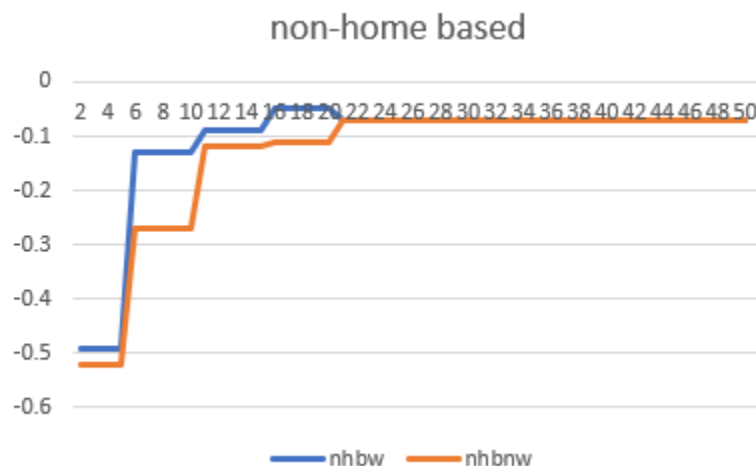
Figure 13
Distance Sensitivity by Vehicle Availability



HBPB = home-based personal business. HBSR = home-based social-recreational. HBW =home-based work. IV = insufficient vehicles. SV = sufficient vehicles. ZV = zero vehicles.

Non-home based trips are not segmented by vehicle availability. They have a similar pattern of sensitivity to distance, although the non-home-based-work trips have a slightly lower sensitivity at an intermediate distance (between 15 and 20 miles) than at a longer distance (more than 20 miles).

Figure 14
Non-home-based Distance Sensitivity



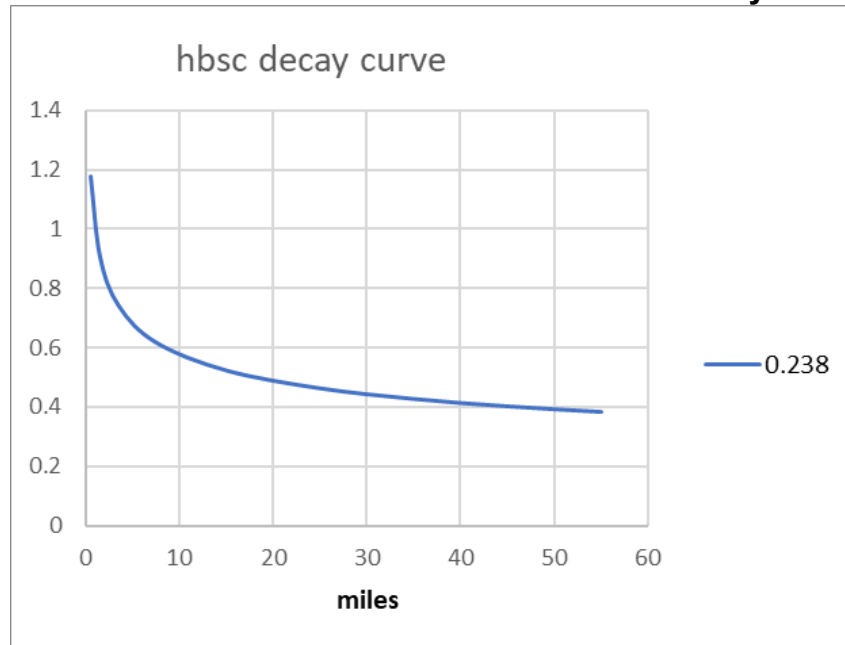
NHBNW = non-home-based non-work. NHBW = non-home-based work.

Home-Based School

School trips are modeled using a singly constrained gravity model with sensitivity to shared ride roadway times matching productions at home locations. Home-based-school trips are segmented by vehicle level for input into mode choice, although the parameters for trip distribution are the same across the vehicle levels; i.e., the distribution model can be applied to all home-based-school trips and split proportionally by vehicle level.

The school gravity model uses an exponential decay function. The calibrated parameter is 0.238, which produces a decay curve as shown in Figure 15.

Figure 15
Home-based School Distribution Sensitivity



HBSC = home-based school.

Limitations

The key limitations of this approach are that all zones are assumed to be available for distribution from all other zones, creating a highly fractionalized trip table with a very small number of trips for some origin-destination (OD) interchanges. The very small trip numbers increase the model runtime and do not provide value for analysis.

2.6.9 Mode Choice

TDM23 mode choice is estimated using nested logit formulations with auto, transit, and nonmotorized nests. Mode choice probabilities are applied to the production-attraction trip tables estimated by trip distribution to produce production-attraction trip tables by purpose, vehicle segment (where available), and mode.

The transit alternatives are segmented by access mode (walk or auto). Routing choices between transit sub-modes (e.g., local bus vs. heavy rail) is estimated in transit assignment.

Alternatives and Nests

The mode choice alternatives and availability by purpose are shown in Table 40.

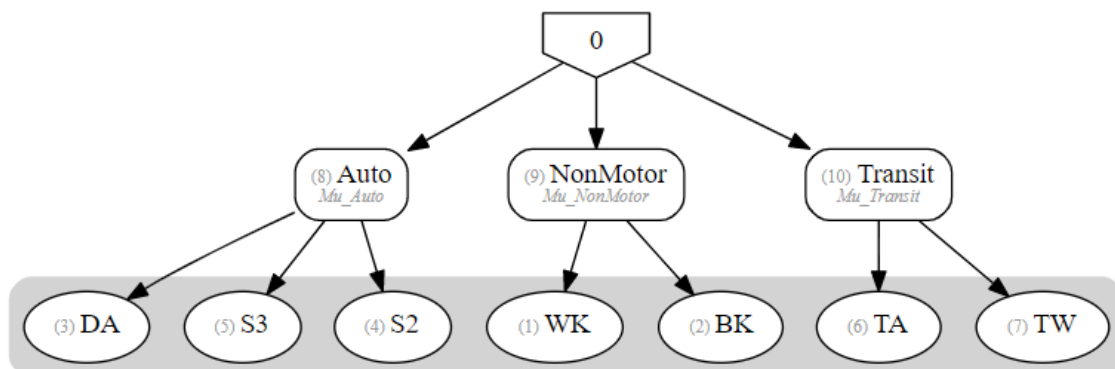
Table 40
Mode Availability

| Mode | Model Abbreviation | Home-Based Trips (Except School) | Home-Based School | Non-Home-Based | Airport |
|-------------------------------|--------------------|----------------------------------|-------------------|----------------|---------|
| Drive Alone (SOV) | DA | x | x | x | |
| 2 Person Shared Ride (HOV2) | S2 | x | x | x | |
| 3+ Person Shared Ride (HOV3+) | S3 | x | x | x | |
| Walk | WK | x | x | x | |
| Bike | BK | x | x | x | |
| Auto Access to Transit | TA | x | x | | x |
| Walk Access to Transit | TW | x | x | x | x |
| Ride-sourcing | RS | x | x | x | x |
| School Bus | SB | | x | | |
| Drive and Park | DP | | | | x |
| Pickup or Drop-off | PU | | | | x |
| Logan Express | LX | | | | x |
| Rental Car | RC | | | | x |

HOV = high-occupancy vehicle. SOV = single-occupancy vehicle.

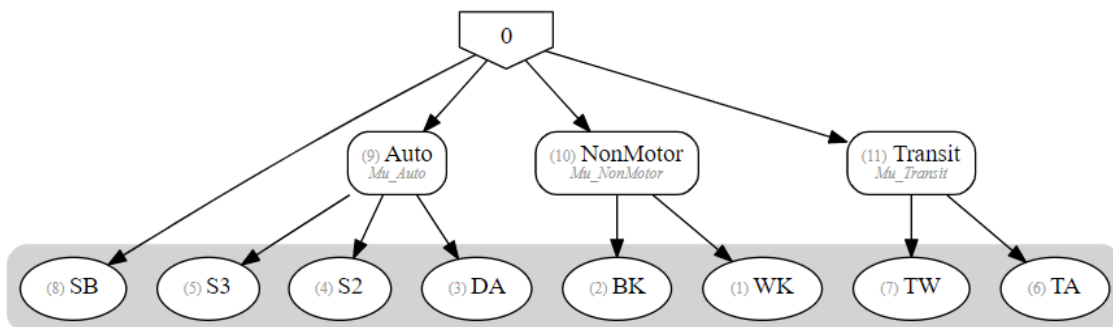
The estimated mode nests are shown in Figures 16, 17, and 18. Note that there was insufficient data to estimate parameters for ride sourcing. This alternative is asserted in the model and identified as its own nest.

Figure 16
Home-based Work, Social-recreation, and Personal Business Trips



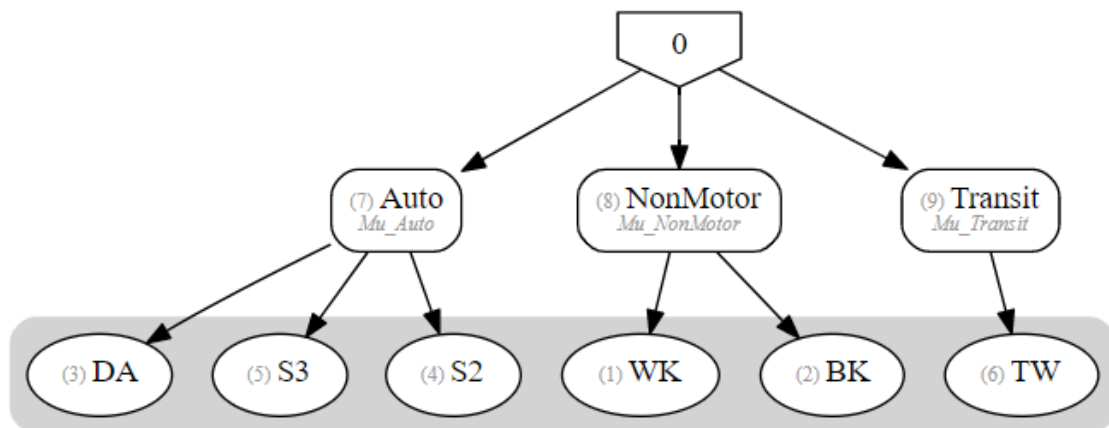
BK = bike. DA = drive alone. S2 = 2 person shared ride. S3 = 3+ person shared ride. TA = auto access to transit. WK = walk. TW = walk access to transit.

Figure 17
School—Including School Bus (SB) Mode



BK = bike. DA = drive alone. S2 = 2 person shared ride. S3 = 3+ person shared ride. TA = auto access to transit. TW = walk access to transit. WK = walk.

Figure 18
Non-home Based Trips



BK = bike. DA = drive alone. S2 = 2 person shared ride. S3 = 3+ person shared ride. TW = walk access to transit. WK = walk.

Key Assumptions

This section describes the mode-specific assumptions required to calculate mode utilities.

Table 41
Mode Choice Parameters

| Parameter | Value |
|-----------------------|------------------|
| Auto operating costs | \$0.244 per mile |
| Maximum walk distance | 3 miles |
| Maximum bike distance | 12 miles |
| Walk speed | 3 miles / hour |
| Bike speed | 12 miles / hour |

The walk/bike maximum distance and speeds imply a maximum trip duration of one hour.

Shared Ride Mode Cost Sensitivity

The estimated formulation factored the shared-ride mode costs by occupancy, which implies that costs are born equally amongst all passengers. This formulation led to an artifact such that shared ride 2 and 3 modes steadily increased in mode share as the trip distance increased because auto operating costs are a function of trip distance. This phenomenon was not seen in the observations. Therefore, the cost formulation was changed such that operating costs are not factored by occupancy, although tolls and parking costs are still factored by occupancy. This approach is used because operating costs (e.g., gas) are not necessarily paid during travel, while toll and parking costs are and thus are more likely to be split amongst the traveling party. Therefore, the model will estimate some mode shift between drive-alone and shared-ride travel as tolls and parking costs change.

Ride-Source Wait and Fare Parameters

The ride-source mode initial waiting time is defined according to the transit access density. In denser areas, a shorter wait is assumed to reflect the higher demand for ride-source services and thus a better supply of drivers. In lower density areas, the lower demand and fewer drivers equate to a longer wait time. Ride-source wait time also serves as a proxy for the need to schedule trips in advance where there is less service (see Table 42).

Table 42
Ride-Source Calibrated Waiting Times

| Transit Access Density | Calibrated TDM23 Ride-source Waiting Time Values |
|-------------------------------|---|
| CBD, Dense Urban | 5 minutes |
| Urban | 10 minutes |
| Fringe Urban | 30 minutes |
| Suburban | 60 minutes |
| Rural | 90 minutes |

CBD = central business district.

Ride-source fares are calculated by travel time and distance along with minimum fares as shown in the following equation:

$$\text{Fare} = \text{Max (minimum fare OR} \\ \text{base fare + service fee +} \\ \text{time * fare per minute +} \\ \text{distance * fare per mile)}$$

The fare parameters (in 2010 dollars) are shown in Figure 19.

Figure 19
Ride-Source Fare Parameters

| | |
|-------------------------------|------|
| Minimum Ride Sourcing Fare | 3.39 |
| Ride Sourcing Base Fare | 3.44 |
| Ride Sourcing Fare per Mile | 0.51 |
| Ride Sourcing Fare per Minute | 0.2 |

Coefficients

Mode choice utility coefficients are listed in Tables 43, 44, and 45 along with the implied value of time by purpose. These coefficients were initially estimated using the 2011 Massachusetts Travel Survey and calibrated as described in Chapter 3. Work trips are asserted to have the highest value of time and social-recreational trips the lowest. Values of time are derived from the median household income.

Table 43
Trip Value of Time

| Trip Purpose | Share of Median Household Income |
|-----------------------|---|
| HBW, HBSC, NHBW | 60% |
| HBSR, HBPB, HBU, NHBW | 35% |
| Airport – Leisure | 75% |
| Airport – Business | 100% |

HBPB = home-based personal business. HBSC = home-based school.
 HBSR = home-based social recreation. HBU = home-based university.
 HBW = home-based work. NHBW = non-home-based non-work.
 NHBW = non-home-based work.

The path impedance terms include in-vehicle travel time (IVTT), out-of-vehicle travel time (OVTT), cost, and distance as well as path-shaping terms for transit modes. IVTT represents travel time within the alternative mode (i.e., it does not include personal auto time for transit auto). OVTT includes all walking, biking, and waiting time. The terminal times are used to derive OVTT for the drive-alone, 2-person-shared-ride, and 3+-person-shared-ride modes. The costs include tolls, operating costs, parking costs for autos, fares for ride source and transit, and parking costs for autos to access transit.

The Drive Access Path parameter reduces the use for transit-auto paths that require a longer auto-access travel distance than an auto-only path. This, for example, would apply where there are circuitous paths to use transit, such as those that would require driving away from the destination to access a park-and-ride lot or driving most of the way before using transit. The term is derived as follows:

$$\text{Drive Access Path} = \text{Maximum} [(\text{Drive access to transit distance} / \text{Direct auto distance}) - 0.5, 0]$$

- If the transit-auto access distance is less than or equal to 50 percent of the auto distance, then this term is zero.
- If the transit-auto access distance is equal to the auto distance, then this term is 0.5.
- As the transit-auto access distance increases beyond the auto distance, the term increases in magnitude.

The short distance variables begin at 1.0 with a distance of zero and decrease as the distance increases. The variables are equal to zero when the distance is

equal to or beyond the threshold (3 miles for transit-walk, 20 miles for transit-auto).

Table 44
Mode Choice Utilities—Part 1

| | mode \ trip | HBW | HBSC | HBPB | HBSR | NHBW | NHBNW | HBU |
|--------------------------|-------------|----------|----------|----------|----------|----------|----------|----------|
| Travel Impedance | | | | | | | | |
| IVTT | All | -0.0201 | -0.02 | -0.0162 | -0.0125 | -0.02 | -0.02 | -0.02 |
| OVT | All | -0.0431 | -0.06 | -0.0485 | -0.0376 | -0.06 | -0.06 | -0.0563 |
| Cost | All | -0.0613 | -0.061 | -0.0846 | -0.0655 | -0.061 | -0.061 | -0.105 |
| Distance | SB | | -0.0453 | | | | | |
| Value of Time (2010 \$) | | \$ 19.67 | \$ 19.67 | \$ 11.49 | \$ 11.45 | \$ 23.43 | \$ 19.67 | \$ 11.43 |
| Path Variables | | | | | | | | |
| Auto Dist Ratio | TA | -3 | -7.38 | -3 | -3 | | | -3 |
| Max(3 - dist, 0) | WK | 0.748 | 0.910 | 1.02 | 1.07 | 0.897 | 0.772 | |
| Max(3 - dist, 0) | BK | 0.207 | 1.1 | 0.452 | 0.64 | 0.001 | 0.482 | |
| Max(3 - dist, 0) | TW | -1.05 | -0.952 | -0.867 | -0.704 | -1.35 | -1.01 | -1 |
| Max(20- dist, 0) | TA | -0.0668 | -0.18 | -0.125 | -0.129 | | | -0.1 |
| Vehicle Ownership | | | | | | | | |
| Sufficient Vehicles | DA | 0.617 | | 0.663 | 0.501 | | | |
| Sufficient Vehicles | S2 | -0.264 | | | | | | |
| Sufficient Vehicles | S3 | -0.264 | | | | | | |
| InSufficient Vehicles | WK, BK | 0.545 | 0.534 | 0.158 | 0.296 | | | |
| InSufficient Vehicles | TW | 0.717 | 0.781 | | | | | |
| Zero Vehicles | TW | 3.87 | 3.09 | 4.31 | 3.41 | | | |
| Zero Vehicles | WK, BK | 2.59 | 1.51 | 2.27 | 2.02 | | | |
| Zero Vehicles | RS | 4 | | 2.5 | 2.5 | | | |
| Zero Vehicles | SB | | 2.14 | | | | | |

HBPB = home-based personal business. HBSC = home-based school. HBSR = home-based social recreation. HBU = home-based university. HBW = home-based work. NHBNW = non-home-based non-work. NHBW = non-home-based work. Max = maximum.

Table 45
Mode Choice Utilities—Part 2

| | mode \ trip | HBW | HBSC | HBPB | HBSR | NHBW | NHBNW | HBU |
|---------------------------------------|-------------|--------|--------|--------|--------|--------|--------|---------|
| Land Use | | | | | | | | |
| Intersection Density (Production End) | TW | 0.228 | | | | | | |
| Intersection Density (Production End) | TA | | | | | | | -0.5 |
| Intersection Density (Attraction End) | TW, TA | 1.28 | 0.476 | 1.06 | 1.02 | | | |
| Intersection Density | TW | | | | | 2.28 | 0.753 | 0.75 |
| Intersection Density | WK, BK | 0.848 | | 0.542 | 0.311 | 0.865 | 0.987 | |
| Intersection Density | SB | | -1.68 | | | | | |
| Intersection Density | BK | | 0.322 | | | | | |
| CBD, Dense Urban (Attraction End) | TA | 1.328 | | 1.498 | 1.427 | | | 1.114 |
| CBD, Dense Urban (Attraction End) | TW | 0.999 | | 1.146 | 1.24 | | | 0.75 |
| CBD, Dense Urban | BK, WK | | 0.0548 | | | | | 1.15 |
| CBD, Dense Urban | TW | | | | | | | 0.876 |
| CBD (Attraction End) | TW | | | | | | | 0.5 |
| CBD (Attraction End) | TA | | | | | | | 1 |
| Suburban, Rural - Production End | TA | 0.265 | | | | | | |
| Constants | | | | | | | | |
| DA | | | | | | | | 0.427 |
| S2 | | -0.388 | 1.134 | 0.228 | 0.283 | -0.988 | -0.3 | -0.187 |
| S3 | | -0.892 | 1.32 | -0.14 | 0.286 | -1.482 | -0.61 | -0.72 |
| TA | | -1.452 | 1.227 | -2.643 | -2.136 | | | -1.905 |
| TW | | -2.218 | 0.4092 | -2.55 | -3.071 | -5.415 | -1.832 | -1.79 |
| BK | | -3.649 | -2.17 | -3.82 | -3.15 | -4.81 | -4.41 | -3.952 |
| WK | | -2.72 | 0.296 | -2.457 | -1.935 | -3.465 | -1.867 | -0.7248 |
| SB | | | 1.5 | | | | | |
| RS | | -2.5 | -5 | -3.5 | -2.5 | -2.25 | -2.5 | -1.5 |

BK = bike. CBD = central business district. DA = drive alone. HBPB = home-based personal business. HBSC = home-based school. HBSR = home-based social recreation. HBU = home-based university. HBW = home-based work. NHBNW = non-home-based non-work. NHBW = non-home-based work. RS = ride source. S2 = 2 person shared ride. S3 = 3+ person shared ride. SB = school bus. TA = transit auto. TW = transit walk. WK = walk.

Limitations

The key limitation of this approach is that mode choice is made at the production-attraction level and, thus, can be considered a tour-level choice (for outbound and return trip). The AM peak and Midday skims are used for Peak and Non-Peak conditions. Therefore, the mode choice is not sensitive to asymmetrical service changes or roadway features, such as improved transit service only in the PM Peak.

2.6.10 Time of Day (Production-Attraction to Origin-Destination)

This section describes both the conversion of production-attraction (PA) to origin-destination (OD) trips as well as the conversion from person to vehicle trips.

Time Period to Time of Day

The TDM23 times of day are as follows:

- AM Peak: 6:30 AM – 9:30 AM
- Midday: 9:30 AM – 3:00 PM
- PM Peak: 3:00 PM – 7:00 PM
- Nighttime: 7:00 PM – 6:30 AM

The factors to segment trips into time of day and direction (production to attraction or attraction to production) on the peak and non-peak trips are shown in Tables 46 and 47. These factors were initially estimated using the 2011 Massachusetts Travel Survey and calibrated as described in Chapter 3.

Table 46
Peak PA to OD Factors

| Peak Trips | HBW | HBPB | HBSR | HBSC | HBU | NHBW | NHBNW |
|-------------------|------------|-------------|-------------|-------------|------------|-------------|--------------|
| AM-AP | 0.014 | 0.076 | 0.073 | 0.002 | 0.38 | 0.249 | 0.004 |
| PM-AP | 0.432 | 0.406 | 0.298 | 0.299 | 0.62 | 0.751 | 0.288 |
| AM-PA | 0.512 | 0.294 | 0.266 | 0.679 | 0.38 | 0.249 | 0.596 |
| PM-PA | 0.042 | 0.224 | 0.363 | 0.02 | 0.62 | 0.751 | 0.112 |

| Peak Trips | HBW | HBPB | HBSR | HBSC | HBU | NHBW | NHBNW |
|-------------------|------------|-------------|-------------|-------------|------------|-------------|--------------|
| AM-AP | 0.014 | 0.076 | 0.073 | 0.002 | 0.005 | 0.190 | 0.125 |
| AM-PA | 0.512 | 0.294 | 0.266 | 0.679 | 0.595 | 0.190 | 0.125 |
| PM-AP | 0.432 | 0.406 | 0.298 | 0.299 | 0.288 | 0.310 | 0.375 |
| PM-PA | 0.042 | 0.224 | 0.363 | 0.02 | 0.112 | 0.310 | 0.375 |

AM-AP = AM peak attraction-production. AM-PA = AM Peak production attraction. HBPB = home-based personal business. HBSC = home-based school. HBSR = home-based social recreation. HBU = home-based university. HBW = home-based work. NHBNW = non-home-based non-work. NHBW = non-home-based work. OD = origin-destination. PA = production to attraction. PM-AP = PM peak attraction-production. PM-PA = PM Peak production attraction.

Table 47
Non-Peak PA to OD Factors

| Non-Peak Trips | HBW | HBPB | HBSR | HBSC | HBU | NHBW | NHBNW |
|-----------------------|------------|-------------|-------------|-------------|------------|-------------|--------------|
| MD-AP | 0.222 | 0.375 | 0.187 | 0.886 | 0.97 | 0.824 | 0.477 |
| NT-AP | 0.286 | 0.167 | 0.453 | 0.054 | 0.03 | 0.176 | 0.246 |
| MD-PA | 0.268 | 0.394 | 0.218 | 0.052 | 0.97 | 0.824 | 0.265 |
| NT-PA | 0.225 | 0.063 | 0.142 | 0.008 | 0.03 | 0.176 | 0.012 |

| Non-Peak Trips | HBW | HBPB | HBSR | HBSC | HBU | NHBW | NHBNW |
|-----------------------|------------|-------------|-------------|-------------|------------|-------------|--------------|
| MD-PA | 0.268 | 0.395 | 0.218 | 0.052 | 0.264 | 0.485 | 0.412 |
| MD-AP | 0.222 | 0.375 | 0.187 | 0.886 | 0.478 | 0.484 | 0.412 |
| NT-PA | 0.225 | 0.063 | 0.142 | 0.008 | 0.012 | 0.015 | 0.088 |
| NT-AP | 0.285 | 0.167 | 0.453 | 0.054 | 0.246 | 0.015 | 0.088 |

HBPB = home-based personal business. HBSC = home-based school. HBSR = home-based social recreation. HBU = home-based university. HBW = home-based work. MD-AP = midday attraction production. MD-PA = midday production attraction. NHBNW = non-home-based non-work. NHBW = non-home-based work. NT-AP = night attraction production. NT-PA = nighttime production attraction. OD = origin-destination. PA = production to attraction.

As expected, most home-based-work and home-based-school trips travel from production (home) to attraction (work or school) in the AM peak and the reverse in the PM peak. The majority of home-based-school trips in the non-peak periods are trips returning home midday. Most home-based-university trips are in the non-peak, traveling to school in the midday period and returning in the midday and night.

The non-home-based trips do not have a production or attraction end and thus are evenly distributed by direction per time period. However, the directionality of the home-based purposes reflects the tendency for stops to be made on the return trip home (AP direction) from work and school and that these trips are for personal business or social-recreational purposes. Table 47 shows a slight majority of work and school tours make a stop on the return home, which is revealed by the share of PA trips being greater than 50 percent.

Table 48
Production-Attraction Trip Share

| Purpose | HBW | HBPB | HBSR | HBSC | HBU |
|-------------------|------------|-------------|-------------|-------------|------------|
| Share of PA Trips | 0.535 | 0.463 | 0.472 | 0.537 | 0.448 |

HBPB = home-based personal business. HBSC = home-based school. HBSR = home-based social recreation. HBU = home-based university. HBW = home-based work. PA = production attraction.

Person to Vehicle Trips

TDM23 uses an average occupancy to convert from person to vehicle trips. The occupancies by mode alternative are shown in Table 49.

Table 49
Vehicle Occupancy Rates

| Purpose | SR2 Occupancy | SR3p Occupancy | RS Occupancy |
|---------|---------------|----------------|--------------|
| hbw | 2 | 3.627 | 1.21 |
| hbse | 1 | 2.49 | 1.6 |
| hbsr | 2 | 3.627 | 1.6 |
| hbp | 2 | 3.627 | 1.6 |
| nhbw | 2 | 3.627 | 1.21 |
| nhbnw | 2 | 3.627 | 1.6 |
| hbu | 2 | 3.627 | 1.6 |

HBPB = home-based personal business. HBSC = home-based school. HBSR = home-based social recreation. HBU = home-based university. HBW = home-based work. NHBNW = non-home-based non-work. NHBW = non-home-based work. RS = ride-source. S2 = 2 person shared ride. S3p = 3+ person shared ride.

Note that the home-based-school trip purpose is assigned a smaller occupancy rate for the 2 and 3+ person shared ride purpose than the other trip purposes. This implies that most of the home-based-school trips with a shared ride are actually pickup and drop-off trips. So, if there are two people in the vehicle for a home-based-school trip, only one of them has a home-based-school person trip. The generation of the outbound/return pickup/drop-off trip (without the student) is described in the following section.

Ride source occupancies are segmented by work and non-work purposes.

Pickup/Drop-off Vehicle Trips

Pickup and drop-off trips generate two vehicle trips for each person trip. One vehicle trip is the share ride (S2 or S3) mode and the other is a drive-alone mode in the opposite direction.

An associated drive-alone trip is generated for the following trip purposes and modes:

- Home-Based School: 2 person shared ride (S2) and 3 + person shared ride (S3)
- Airport: pickup/drop-off (PD)

Ride-source Non-Revenue Vehicle Trips

TDM23 leverages the ride-sourcing person trip origin and destination to estimate non-revenue trips within each time of day. The non-revenue model sequence is as follows:

- Convert ride-source trips from production-attraction by time period into origin-destination by time of day.
- Calculate total ride-source origins and ride-source destinations for each TAZ and time of day.
- Apply a gravity distribution model with the ride-sourcing origins and destinations as attractions and productions respectively, i.e., passenger trips begin when a deadhead trip ends and vice versa.

The gravity distribution model uses an exponential decay curve with a value of 0.18. This value was calibrated to produce non-revenue vehicle-miles traveled (VMT) in proportion with the revenue VMT.

Limitations

- A key limitation of this approach are that time-of-day rates are fixed input and are not sensitive to changes in travel conditions. Representing phenomena such as peak spreading would require changes to the time-of-day rates as well as the capacity factors (see Highway Assignment).
- As discussed in Chapter 3, observations suggest that time-of-day and mode are correlated, particularly for ride-source and transit modes. Mode-generic time-of-day factors assert a purpose and direction-specific, fixed-trip time distribution across all modes.

2.6.11 Trucks and Commercial Vehicles

The TDM23 truck component estimates medium and heavy truck trips through the following process:

- Daily TAZ level trip generation
- Distribution of trips between TAZs
- Distribution of trips by time of day
- Routing and congested conditions of vehicles on the roadway network (as part of the highway assignment)

Only medium and heavy truck trips are modeled in TDM23 because the available truck data for OD flows and counts could only distinguish medium and heavy trucks. Light-duty commercial vehicle trips cannot be observed separately from

personal trips. Therefore, light truck/commercial vehicle trips are effectively represented through the non-home-based trip purposes.

TDM23 uses the terminology *medium* and *heavy trucks*, but these would be more accurately defined as *single unit* and *combination unit* respectively. A comparison of TDM23 truck classes, Federal Highway Administration classes, and gross vehicle weight classes are described in Table 50.

Table 50
Vehicle Classifications

| | FHWA Class Description Average Vehicle Weight | Observed GVW Range (lbs.) | GVW Classes | TDM23 Trucks |
|----|--|--------------------------------------|------------------------|-------------------------|
| 1 | Motorcycles | 8,000–25,000 | 1 | |
| 2 | Passenger vehicles | 4,500–9,000 | 1 and 2 | Light Duty |
| 3 | Two-axle, four-tire single-unit trucks | 7,000–9,000 | 2 and 3 | Light Duty |
| 4 | Buses | 25,000–29,000 | 6 and 7 | |
| 5 | Six-tire, two-axle single-unit vehicles | 12,000–14,000 | 4 and 5 | Medium Truck |
| 6 | Three-axle single-unit vehicles | 24,000–30,000 | 6 and 7 | Medium Truck |
| 7 | Four or more axle single-unit vehicles | 41,000–58,000 | 8 | Medium Truck |
| 8 | Three or four axle single-trailer vehicles | 26,000–31,000 | 7 | Heavy Truck |
| 9 | Five-axle single-trailer vehicles | 48,000–58,000 | 8 | Heavy Truck |
| 10 | Six-axle single-trailer vehicles | 60,000–65,000 | 8 | Heavy Truck |
| 11 | Five or less axle multi-trailer vehicles | 50,000–61,000 | 8 | Heavy Truck |
| 12 | Six-axle multi-trailer vehicles | 56,000–63,000 | 8 | Heavy Truck |
| 13 | Seven or more axle multi-trailer vehicles | 72,000–92,000 | 8 | Heavy Truck |

FHWA = Federal Highway Administration. GVW = Gross Vehicle Weight. lbs. = pounds.

Truck Trip Generation

The generated trips represent both the production and attraction end. This produces a balanced trip table with every TAZ having an equal number of trips destined to it as originating from it.

Table 51 shows the parameters for the component. The truck model parameters were estimated from Streetlight truck data calibrated to classified counts and using the 2019 estimates for household and employment. The parameters were calibrated as described in Chapter 3.

Table 51
Truck Trip Generation Rates

| TAZ Households/Jobs | Access Density | Medium Trucks | Heavy Trucks |
|--------------------------------------|-----------------------|----------------------|---------------------|
| Households | | 0.030 | |
| Construction | | 0.546 | 0.093 |
| Construction | Suburban/Rural | | 0.111 |
| Education and Health Services | | | |
| Financial Activities | | | |
| Public Administration | | | |
| Information | | | |
| Retail, Leisure, and Hospitality | | 0.099 | 0.025 |
| Manufacturing | | 0.081 | 0.051 |
| Other Services | Suburban/Rural | 0.264 | 0.111 |
| Professional and Business Services | | | |
| Trade, Transportation, and Utilities | | 0.081 | 0.051 |

TAZ = travel analysis zone.

For reference, all employment sectors are listed, including those that do not impact the truck trips generated.

Fewer heavy truck trips are generated than medium trucks, so the average coefficient magnitude is smaller. The Construction and Other Services sectors produce the most truck trips for either class.

Truck Trip Distribution

A gravity distribution distributes the trips with distinct parameters to produce different average trip lengths by vehicle size. The distribution impedance is distance in roadway miles. Trips are distributed at the daily level.

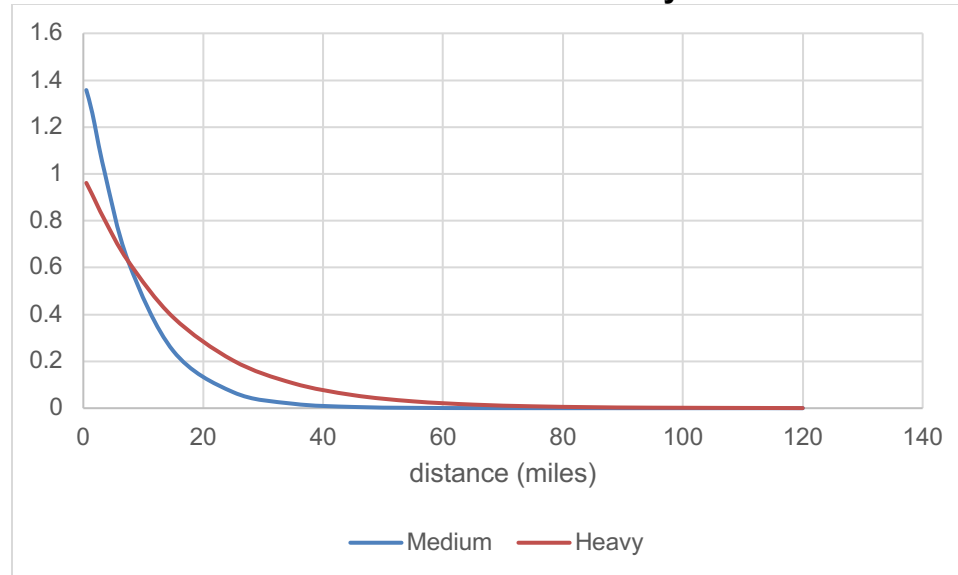
The decay function follows a gamma distribution with parameters.

Table 52
Truck Distribution Parameters

| Parameter | Medium | Heavy |
|------------------|---------------|--------------|
| a | 1.5 | 1 |
| b | -0.05 | -0.01 |
| c | 0.13 | 0.065 |

These parameters produce a distribution with shorter trips by medium trucks and longer trips by heavy trucks.

Figure 20
Truck Distribution Decay

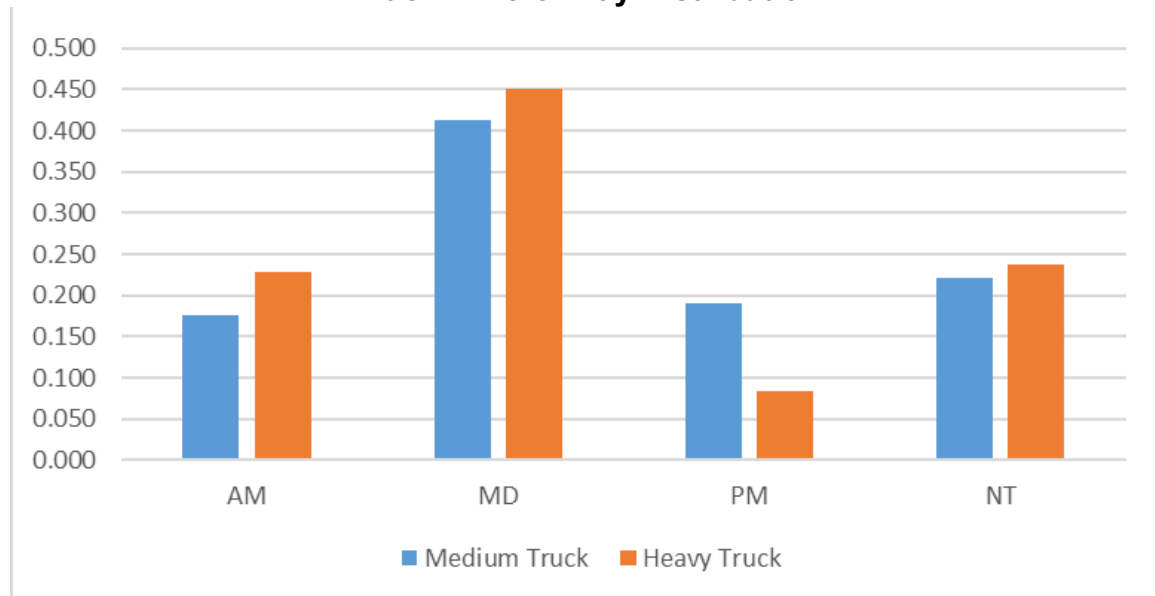


Truck Trip Time of Day

Time-of-day factors by vehicle size are applied to the daily trips to produce time-of-day trip tables. Therefore, the truck distribution pattern is consistent across the times of day, and only the number of trips to and from each zone will vary by time of day.

The splits by TDM23 time of day are shown in Figure 21.

Figure 21
Truck Time-of-Day Distribution



Most truck trips take place in the midday period. Heavy truck trips are more skewed towards the AM period and medium truck trips to the PM period.

Truck Assignment

Medium and heavy trucks are assigned as distinct user classes to distinguish their value of time, tolls, and roadway availability. Trucks of different sizes are restricted from several roadways in the region (e.g., Storrow Drive in Boston).

Specifics on the truck values of time are included in the highway assignment section.

Limitations

The key limitations of this approach are summarized below.

- An explicit representation of e-commerce trips is not included. Instead, TDM23 implicitly includes these trips as home-based-social-recreation and non-home-based-non-work trips as a proxy for goods purchased on the internet and delivered.
- Freight and service trucks are not distinguished. Changes in freight mode, for example, from truck to rail, would require direct changes to truck trip rates and distribution parameters.

2.6.12 Airport Ground Access

Trips to and from Logan Airport to serve air travelers are represented through the *airport ground access* component. Logan Airport is the only airport modeled in TDM23.

TDM23 takes as input non-transferring enplanements and deplanements and the share of trips by four market segments, organized by residency and travel purpose:

- Resident business
- Resident leisure
- Visitor business
- Visitor leisure

The TDM23 airport ground access component estimates the following (by market segment):

- Distribution of trips to and from the airport
- Trip mode
- Trip time of day
- Routing and congested conditions of vehicles on the roadway network and travelers through the transit network (as part of the highway and transit assignments respectively)

Trip Generation and Distribution

To be consistent in terminology, airports are treated as the attraction end of the trip. In this context, TDM23 effectively balances to trip attractions, i.e., trips produced at the home and work end are scaled to the input non-transferring enplanements and deplanements at Logan Airport.

The share of airport trips that originate from outside the model region is a direct input. Trip productions are estimated from household and employment characteristics to distribute trips within the model region.

The trip production parameters are shown in Table 53. These and all airport-ground-access model parameters were initially estimated using the 2018 ground access survey conducted by the Massachusetts Port Authority (Massport) and calibrated as described in Chapter 3. Note that some variables are segmented by geographic ring, which is a proxy for distance to Logan Airport.

Table 53
Airport-Ground-Access Trip Generation Rates

| Variable | Ring | Resident Business | Resident Leisure | Visitor Business | Visitor Leisure |
|------------------------------|-------------|--------------------------|-------------------------|-------------------------|------------------------|
| Households | | 0.070 | 0.150 | | |
| Households | 0,1,2 | 0.005 | | | |
| Households | 0,1,2,3 | | 0.010 | | |
| College Enrollment | | | 0.062 | | |
| Construction | | | | | |
| Education/Health | | | | 0.054 | |
| Finance | | | | 0.054 | |
| Public | | | | 0.054 | |
| Office Service | | | | 0.900 | |
| Information | | | | | |
| Retail / Leisure (all rings) | | | | 0.220 | 0.420 |
| Retail / Leisure | 0, 1 | 0.100 | 0.293 | 0.100 | 0.700 |
| Manufacturing | | | | | |
| Other Services | | | | | |
| Professional Services | | | | 0.054 | |
| Transportation / Utilities | | | | | |
| Total Employment | 0,1,2,3 | 0.030 | 0.020 | | |

Residents trip productions are generated primarily by households, but also employment and retail/leisure purposes. This represents that some travelers go straight between work and the airport or stay at a hotel before or after their flight. Visitor business trips are mostly produced by office/service employment, which may have a higher rate of business travel than other employment types.

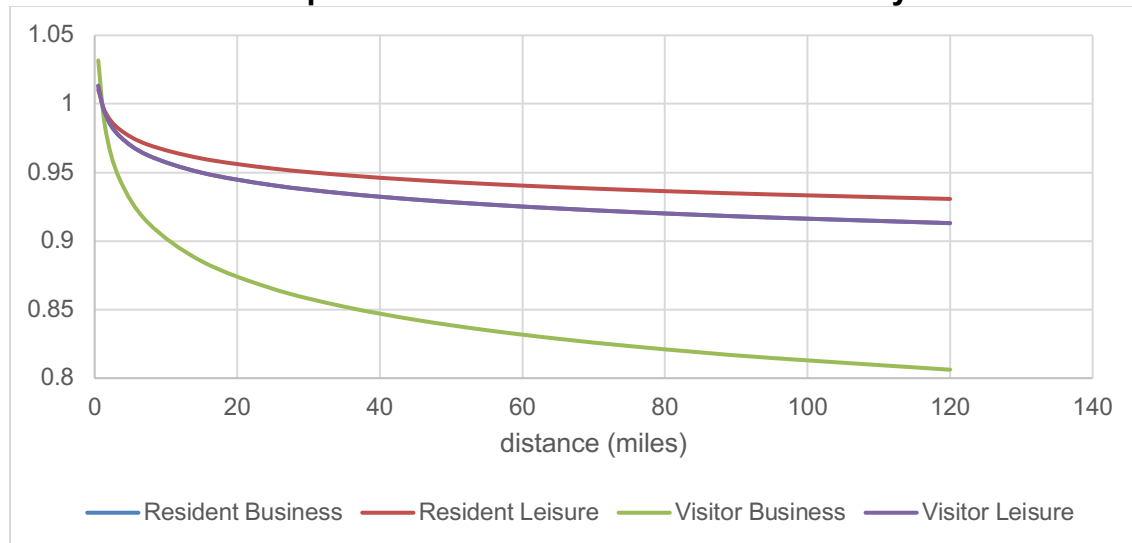
Trips are distributed according to an exponential decay function with the parameters shown in Table 54.

Table 54
Airport-Ground-Access Distribution Parameters

| Segment | Distribution |
|-------------------|---------------------|
| Resident business | 0.019 |
| Resident leisure | 0.015 |
| Visitor business | 0.045 |
| Visitor leisure | 0.019 |

As shown in the figure below, *visitor business* travelers are the most sensitive to distance (productions decay the fastest). *Resident leisure* travelers are the least sensitive to distance. The *resident business* and *visitor leisure* segments follow the same curve as shown in Figure 22.

Figure 22
Airport-Ground-Access Distribution Decay



Trips are segmented into peak and non-peak time periods according to the following rates. Most airport-ground-access trips occur in the non-peak periods.

Table 55
Airport-Ground-Access Time Period Parameters

| Time Period | Resident Business | Resident Leisure | Visitor Business | Visitor Leisure |
|-------------|-------------------|------------------|------------------|-----------------|
| Peak | 0.39 | 0.4 | 0.46 | 0.42 |
| Non-peak | 0.61 | 0.6 | 0.54 | 0.58 |

Mode Choice

Airport ground access trips have a unique set of modes. The mode alternatives and availability by market segment are listed in Table 56.

Table 56
Airport-Ground-Access Modes

| Mode | Description | Resident Business | Resident Leisure | Visitor Business | Visitor Leisure |
|-------------|--------------------------|--------------------------|-------------------------|-------------------------|------------------------|
| dp | Drive and Park | x | x | | |
| rc | Rental Car | | | x | x |
| pu | Personal Pickup/Drop-off | x | x | x | x |
| tw | Transit Walk | x | x | x | x |
| ta | Transit Auto | x | x | x | x |
| lx | Logan Express | x | x | x | x |
| rs | Ride Source | x | x | x | x |

Mode Specific Parameters

Drive-and-park mode parking costs are segmented by market segments. The rates vary by air-trip purpose because of different trip durations and cost sensitivity (economy vs. central parking). These rates, converted to 2010 dollars are shown in Table 57.

Table 57
Airport-Ground-Access Values of Time

| Resident Business | Resident Leisure |
|--------------------------|-------------------------|
| \$26.60 | \$24.60 |

Massport charges a fee for ride source trips to and from the airport. This fee converted to 2010 dollars is \$2.77 and is included in the ride-source mode choice utility.

The out-of-vehicle time between the end of the vehicle trip and the terminal varies by mode as some modes end at central parking, the rental car facility, or directly at the terminal. The time values by mode are shown in Table 58.

Table 58
Airport-Ground-Access Mode Attributes

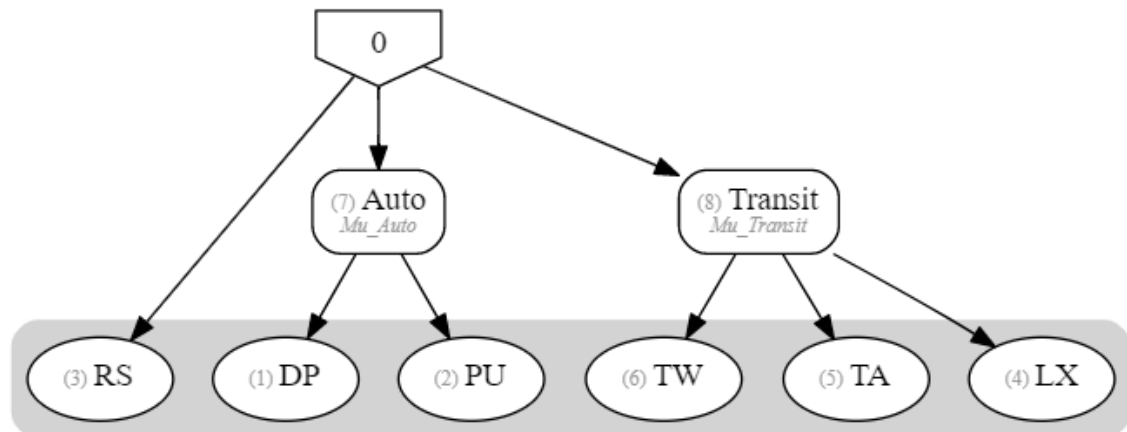
| Mode | Terminal Time (minutes) |
|--------------------------|--------------------------------|
| Drive and Park | 10 |
| Rental Car | 18 |
| Personal Pickup/Drop-off | 0 |
| Transit Walk | 0 |
| Transit Auto | 0 |
| Logan Express | 0 |
| Ride Source | 10 |

Note that rental car costs are not included in the mode choice utility.

Model Structure and Coefficients

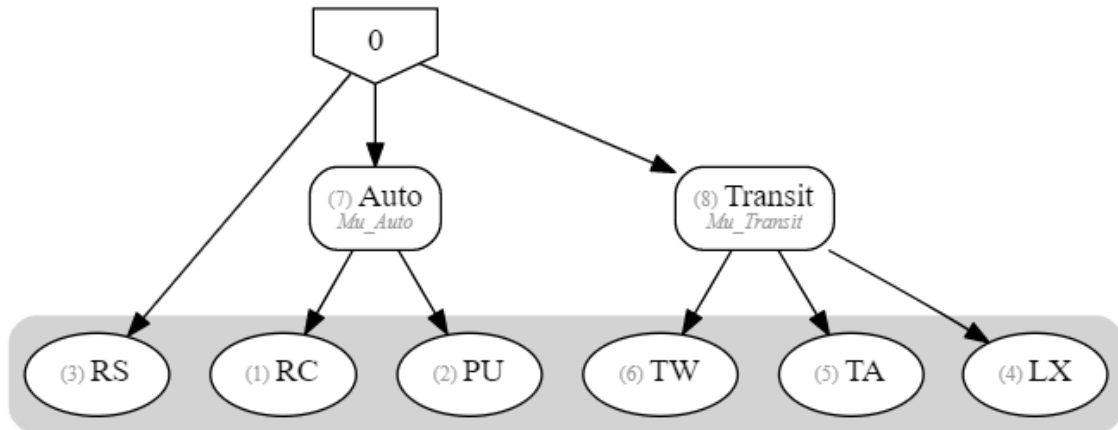
The trip mode alternatives are grouped into private modes, public modes, and ride sourcing and differ between residents and visitors only by the modes available.

Figure 23
Resident Air-Ground-Access Mode Choice Nest Structure



DP = drive and park. LX = Logan Express. PU = pickup. RS = ride source. TA = transit auto. TW = transit walk.

Figure 24
Visitor Air-Ground-Access-Mode Choice Nest Structure



LX = Logan Express. PU = pick-up. RC = rental car. RS = ride source. TA = transit auto. TW = transit walk.

Distinct models were estimated for each of the airport market segments. Values of time were segmented by business and leisure purposes. As in the household-trip mode choice formulation, a drive-access path parameter is included to deter transit-auto paths that have a large share of driving distance.

Table 59
Airport-Ground-Access Mode Choice Parameters

| | | Airport | | | |
|-------------------------|-------------|----------|----------|----------|----------|
| | mode \ trip | RESB | RESL | VISB | VISL |
| Travel Impedance | | | | | |
| IVTT | All | -0.02 | -0.02 | -0.03 | -0.02 |
| OVTT | All | -0.04 | -0.04 | -0.0636 | -0.04 |
| Cost | All | -0.021 | -0.0323 | -0.0315 | -0.0323 |
| Value of Time (2010 \$) | | \$ 57.14 | \$ 37.15 | \$ 57.14 | \$ 37.15 |
| Drive Access Path | TA,LX | -3 | -3 | -3 | -3 |
| Distance | PU | -0.0095 | -0.0089 | -0.0127 | -0.0049 |
| | | | | | |
| Land Use | | | | | |
| CBD Dense Urban | RS | -0.021 | 0.602 | 1.29 | 0.528 |
| CBD Dense Urban | TW | | 0.587 | | |
| | | | | | |
| Constants | | | | | |
| DP / RC | | | | | |
| PU | | -1.0019 | -0.74 | -1.7981 | -0.6982 |
| TW | | -0.2694 | 0.1439 | 0.7576 | 0.2855 |
| TA | | -3.6875 | -1.4771 | -2.6027 | -2.3313 |
| LX | | -1.8277 | -0.8035 | -1.5134 | -1.2434 |
| RS | | 1.082 | 1.0945 | 2.8113 | 1.3753 |

CBD = central business district. DP = drive and park. IVTT = in-vehicle travel time. LX = Logan Express. OVTT = out-of-vehicle travel time. PU = pickup. RESB = Resident Business. RESL = Resident Leisure. RS = ride source. TA = transit auto. TW = transit walk. VISB = Visitor Business. VISL = Visitor Leisure.

Time of Day

The factors to segment trips into time of day and direction (production to attraction or attraction to production) operate on the peak and non-peak trips are shown in Tables 60 and 61.

Table 60
Airport-Ground-Access Peak Time of Day Factors

| Peak Trips | Resident Business | Resident Leisure | Visitor Business | Visitor Leisure |
|------------|-------------------|------------------|------------------|-----------------|
| AM-AP | 0.07 | 0.1 | 0.13 | 0.12 |
| PM-AP | 0.34 | 0.32 | 0.28 | 0.28 |
| AM-PA | 0.35 | 0.26 | 0.22 | 0.31 |
| PM-PA | 0.24 | 0.32 | 0.37 | 0.29 |

AM-AP = AM peak attraction-production. AM-PA = AM peak production-attraction. PM-AP = PM peak attraction-production. PM-PA = PM peak production-attraction.

Table 61
Airport-Ground-Access Non-Peak Time-of-Day Factors

| Non-Peak Trips | Resident Business | Resident Leisure | Visitor Business | Visitor Leisure |
|-----------------------|--------------------------|-------------------------|-------------------------|------------------------|
| MD-AP | 0.14 | 0.16 | 0.31 | 0.30 |
| NT-AP | 0.36 | 0.29 | 0.23 | 0.21 |
| MD-PA | 0.21 | 0.21 | 0.31 | 0.28 |
| NT-PA | 0.30 | 0.34 | 0.15 | 0.21 |

MD-AP = midday attraction-production. MD-PA = midday production-attraction. NT-AP = night attraction-production. NT-PA = nighttime production-attraction.

Most trips to the airport (PA) occur in the AM peak or later in the day. There are the fewest trips from the airport (AP) in the AM peak, which is reasonable as fewer flights have arrived by that time in the morning.

Person to Vehicle Trips

The vehicle occupancy varies by market segment to reflect different air travel party sizes by market segment and their correlated mode choices. Business trips have the lowest occupancies. (See Table 62.)

Table 62
Airport-Ground-Access Average Party Sizes

| Vehicle Occupancy | Resident Business | Resident Leisure | Visitor Business | Visitor Leisure |
|--------------------------|--------------------------|-------------------------|-------------------------|------------------------|
| Drive and Park | 1.3 | 2.5 | - | - |
| Rental Car | 1.9 | 2.5 | 1.9 | 3.3 |
| Personal Pickup/Drop-off | 1.7 | 2.5 | 3.2 | 2.6 |
| Ride Source | 1.9 | 2.3 | 2.2 | 2.9 |

2.6.13 University

The university component of TDM23 represents trips for students living off-campus. Off-campus home-based university (HBU) trips are modeled as a single-market segment. The model takes as input the number of off-campus students per college and university (i.e., enrollment by TAZ). With these inputs, TDM23 estimates the following:

- HBU trip production (household) end and number of trips attracted by campus
- HBU distribution from home productions to university attractions
- HBU trip mode

Trip Generation

Trip generation is estimated at the TAZ level with totals segmented by household income and vehicle availability.

Table 63 shows the parameters for the component. These parameters were initially estimated using the 2011 Massachusetts Travel Survey and calibrated as described in Chapter 3.

Table 63
HBU Trip Generation Rates

| Variable | HBU Trip Productions |
|------------------------------|-----------------------------|
| Constant | -0.114 |
| Workers | 0.109 |
| Non-Working Adults | 0.156 |
| Seniors | 0.121 |
| Sufficient Vehicle Household | -0.058 |
| High Income | -0.028 |
| CBD/Dense Urban | 0.026 |

CBD = central business district. HBU= home-based university,

Note that the intercept reduces the impact of the person-specific coefficients. For example, a one-worker household would have effectively zero HBU trips because the constant has a greater magnitude than the worker coefficient. The model estimates imply that non-working adults make the most HBU trips. Higher income and households with sufficient vehicles make fewer HBU trips. Households in the central business districts and dense urban areas make more HBU trips.

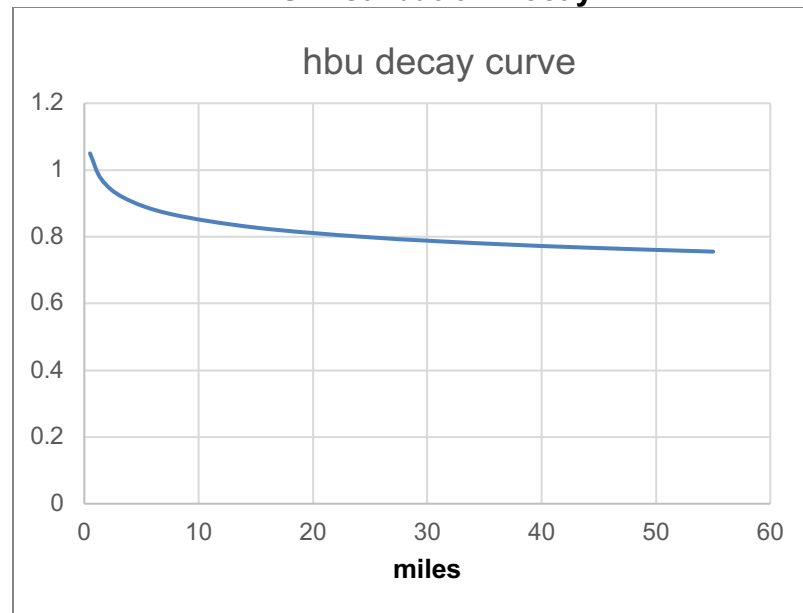
A trip attraction rate of 1.76 trips attracted per enrollment is used to calculate the HBU trips attracted by campus.

Trip Distribution

University trips are modeled using a singly constrained gravity model with sensitivity to shared-ride roadway times matching attractions at university locations.

The university gravity model uses an exponential decay function. The calibrated parameter is 0.07, which produces a decay curve as shown in Figure 25.

Figure 25
HBU Distribution Decay

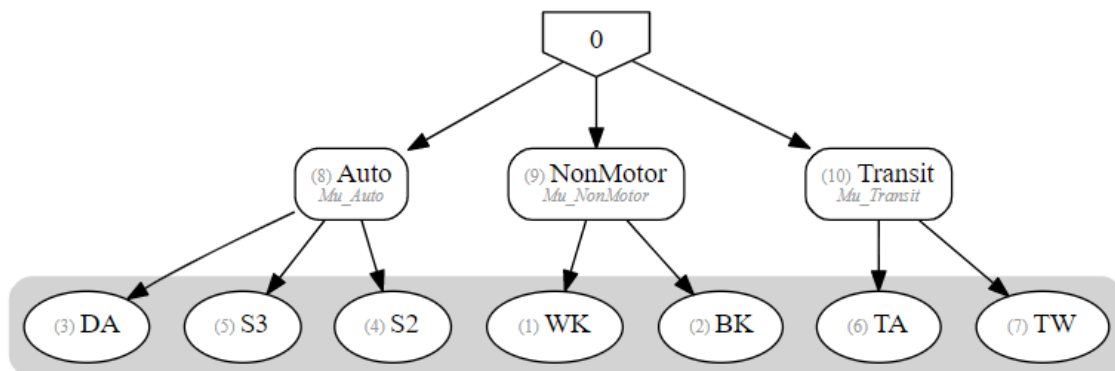


HBU = home-based university trip.

Mode Choice

The home-based-university trip purpose has the same nest and mode alternative available structure as the home-based-work trip purpose. Note that ride source is represented as an alternative in its own nest.

Figure 26
HBU Mode Choice Nest Structure



BK = bike. DA = drive alone. HBU = home-based university. . S2 = 2 person shared ride. S3 = 3+ person shared ride.. TA = transit auto. TW = transit walk. WK = walk.

The mode choice parameters show a higher likelihood of using transit and nonmotorized modes when the university and student's home are in the central business district or a dense urban or urban area. Transit auto modes are more likely when the university is in a central business district or dense urban area.

Table 64
HBU Mode Choice Parameters

| Variable | Alternative | Coefficients |
|----------------------------------|--------------------|---------------------|
| IVTT | All | -0.020 |
| OVT | All | -0.054 |
| Cost | All | -0.105 |
| Value of Time (2010 \$) | | \$ 11.43 |
| Drive Access Path | TA | -3.000 |
| Short Distance (< 3) | TW | -1.000 |
| Short Distance (< 20) | TA | -0.100 |
| CBD Dense Urban (Production End) | TA | -0.500 |
| CBD Dense Urban (Attraction End) | TA | 1.114 |
| CBD Dense Urban (Attraction End) | TW | 0.750 |
| CBD Dense Urban | WK, BK | 1.150 |
| CBD, Dense Urban, Urban | TW | 0.876 |
| CBD | TW | 0.500 |
| CBD | TA | 1.000 |
| Constants | DA | 0.427 |
| | S2 | -0.187 |
| | S3 | -0.720 |
| | WK | -0.725 |
| | BK | -3.952 |
| | TW | -1.790 |
| | TA | -1.905 |
| | RS | -1.500 |

BK = bike. CBD = central business district. DA = drive alone. HBU = home-based university. IVTT = in-vehicle travel time. OVT = out-of-vehicle travel time. RS = ride source. S2 = 2 person shared ride. S3 = 3+ person shared ride. TA = transit auto. TW = transit walk. WK = walk.

Limitations

The key limitation is that travel by on-campus students is not represented in TDM23.

2.6.14 Externals

As described in Section 2.4.5, on Direct Travel Demand Inputs, vehicle trip volumes are input by station along with the auto, medium truck, and heavy truck shares for each external station. The external to external trip distribution pattern is also input.

External-internal trips are modeled using a singly constrained gravity model with sensitivity to network distance matching attractions at external stations. Auto trips

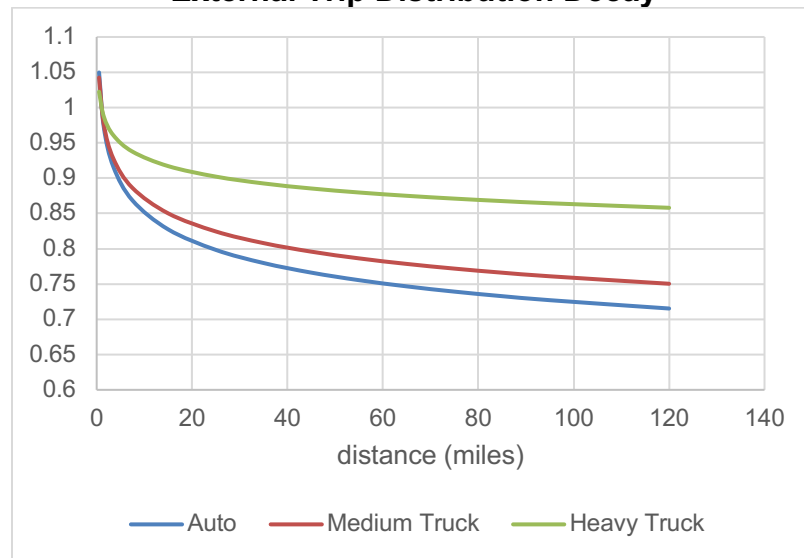
are attracted by the sum of all home-based purpose attractions. Truck trips are attracted by the estimated truck attractions from the truck-trip generation model.

The External-internal gravity model uses an exponential decay function. The parameters are shown in Table 65, which produce decay curves as shown in Figure 27.

Table 65
External Trip Distribution Parameters

| Segment | Distribution |
|----------------|---------------------|
| Autos | 0.07 |
| Medium Trucks | 0.06 |
| Heavy Trucks | 0.032 |

Figure 27
External Trip Distribution Decay



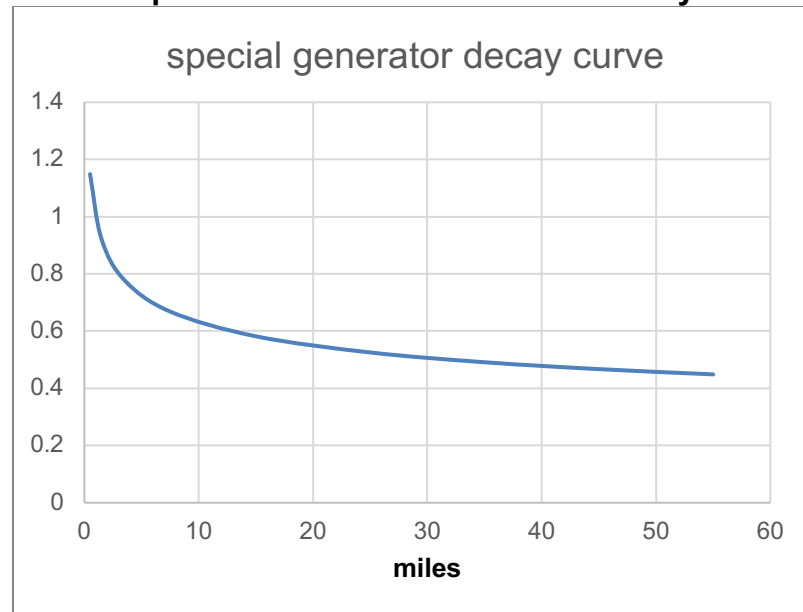
Auto and medium truck trips are more sensitive to distance and thus have shorter trips. Heavy truck trips are longer.

2.6.15 Special Generators

Special generator trips are input at the attraction TAZ and segmented by home-based-social-recreation and home-based-personal-business trip purposes. Trip distribution is modeled by a singly constrained gravity model with sensitivity to network distance matching attractions at the special generator TAZs. The estimated trip productions for the associated trip purpose (HBSR or HBPB) are used to distribute these trips to the home end.

The special generator gravity model uses an exponential decay function. A standard 0.2 parameter is asserted for the special generator distributions, which produce decay curves as shown in Figure 28.

Figure 28
Special Generator Distribution Decay



2.6.16 Highway Assignment

TDM23 employs a static user equilibrium assignment to estimate roadway link volumes.⁸ A static user equilibrium assignment implies the following assumptions:

- No queuing or spill-back behavior
- Steady-state network condition across multi-hour periods
- Temporal conditions (changes in network operation or demand) within the multi-hour period are not represented
- Full knowledge of alternative routes
- No crashes, weather, construction impacts
- Conflicting and opposing traffic impacts at signalized and unsignalized intersections are not represented; therefore, traffic signal priority is also not represented

⁸ https://tfresource.org/topics/User_Equilibrium.html

Within each speed-feedback loop, the AM peak and midday period highway assignments are run. The conditions from these assignments represent the peak and non-peak conditions respectively and are fed back to trip distribution.

User Classes

The highway assignment simultaneously routes vehicles from different user classes. The user class values of time, passenger car equivalents, and roadway restrictions are shown in Table 66.

Table 66
Highway Assignment User Classes

| User Class | Values of Time (\$/hour) | PCE | Restrictions |
|--------------------|-------------------------------------|------------|--------------------------|
| SOV | \$15.81 | 1 | No HOV or Truck-Only |
| HOV | \$15.81 | 1 | No Truck-Only |
| Commercial Vehicle | \$33.33 | 1 | No HOV or Truck-Only |
| Medium Truck | \$42.74 | 1.67 | No HOV, Truck Restricted |
| Heavy Truck | \$64.10 | 3.75 | No HOV, Truck Restricted |

HOV = high-occupancy vehicle. PCE = passenger car equivalents. SOV = single-occupancy vehicle.

Note the following regarding user classes:

- Personal travel is approximately 50 percent of the median income, which reflects the mix of trip purposes.
- The commercial vehicles (light duty trucks) user class is a placeholder for future enhancements and is currently not used in TDM23.

Capacity Factors

The AM, midday, and PM periods are all relatively consistent with little variation between the peak hour and other times within each period, so their capacity factors are expected to be close to the number of hours in the periods (3, 5.5, and 4 respectively). Most of the demand in the nighttime period is concentrated in the evening times of 19:00 to 23:30, therefore the NT capacity factor is expected to be substantially less than the 11.5 hour period.

Table 67
Highway Capacity Factors

| Period | Hours | Peak Hour | Peak Hour Factor | Capacity Factor |
|---------------|--------------|------------------|-------------------------|------------------------|
| AM | 3 | 7:15 AM–8:15 AM | 0.353 | 2.835 |
| MD | 5.5 | 2:00 PM–3:00 PM | 0.208 | 4.809 |
| PM | 4 | 4:15 PM–5:15 PM | 0.265 | 3.774 |
| NT | 11.5 | 7:00 PM–8:00 PM | 0.181 | 5.518 |

MD = midday. NT = nighttime.

Convergence

By default, roadway assignment is configured to run up to 200 iterations to attain a relative gap threshold of e^{-4} .

Limitations

The key limitation is that trip purposes with different values of time are combined into a single value of time.

2.6.17 Transit Assignment

Transit assignment, routing the estimated transit person-trips onto the transit network, is done for the following segments:

- Time of day period
- Walk-access and walk-egress trips
- Auto-access and walk-egress trips (i.e., transit-auto production-attraction)
- Walk access and auto egress (i.e., transit-auto attraction-production)
- Logan Express auto access

The optional representation of parking capacity at park-and-ride (PnR) lots through an AM peak auto-access trip assignment within the feedback loop is described in the following section.

Transit Capacity Constrained Assignment

TDM23 represents parking capacity constraints at PnR lots but does not represent vehicle or station platform capacity constraints. Within TDM23, all transit travelers are assumed to be able to access stations and platforms without delay and board the first vehicle that arrives. Where this is not a reasonable assumption, transit vehicle and station platform capacity constraints are best handled in post-processing or through microsimulation. Within TDM23, the time-of-day assignments assume a uniform distribution of travel demand and service.

Parking demand is easier to represent in a model with multi-hour time periods because the number of spaces is constant regardless of time of day, and the parking space use can be reasonably assumed to not turn over within an assignment period.

However, transit auto demand includes travelers who drive and park their vehicle as well as those who share a ride, are dropped off (KnR), or use a ride-source mode. Therefore, the parking lot capacity and the relationship between the person-trip demand and parking spaces include the level of high-occupancy vehicle (HOV), KnR, and ride-source usage. A PnR occupancy factor essentially defines the level of non-drive-alone demand at PnR lots.

The PnR lot constraint is estimated by calculating the ratio of transit auto trips and the available parking capacity by station. This ratio is then used in a volume-delay type function to calculate the “shadow cost” for use of each PnR lot.⁹ The demand and capacity are equilibrated through an iterative loop and converged with a means of successive averaging process.

The converged shadow cost is stored on the network and used in skimming as part of the impedance for paths to use a given PnR lot.

The parameters to calculate the shadow cost are summarized in Table 68.

Table 68
Transit PnR Capacity Parameters

| Parameter | Description | Value |
|------------------|---|--------------|
| Alpha | Alpha term of the function to calculate shadow cost | 1.5 |
| Beta | Beta term of the function to calculate shadow cost | 2 |
| MaxFactor | Maximum value of shadow cost | 25 |
| PnROccupancy | Factor to convert person to vehicle trips | 1.2 |
| RMSE_Threshold | Convergence threshold | 10 |
| Max Iterations | Maximum iterations for convergence | 16 |

The AM peak and midday periods are the only cases where parking constraints have an impact on path choice due to the directionality of demand. This is the case because most transit-auto trips are production to attraction the AM and midday periods, and parking spaces are freed up as travelers return to their vehicles later in the day.

⁹ $\alpha * (\text{Volume/Capacity})^\beta$

Auto Egress Path Constraint (PnR Symmetry)

Maintaining PnR symmetry means that transit-auto egress trips match transit-auto access trips for each PnR lot. Asymmetrical travel is an issue for the Boston region because of the overlapping rapid transit and commuter rail paths, particularly where the Orange Line runs on the north side and where the Red Line runs on the south side.

The PnR lots used in the AM transit-auto access assignment are used for all transit-auto egress assignments. There may be some discrepancies as the transit-auto access assignments in the other time periods may use different PnR lots but the vast majority of transit auto access trips occur in the AM period.

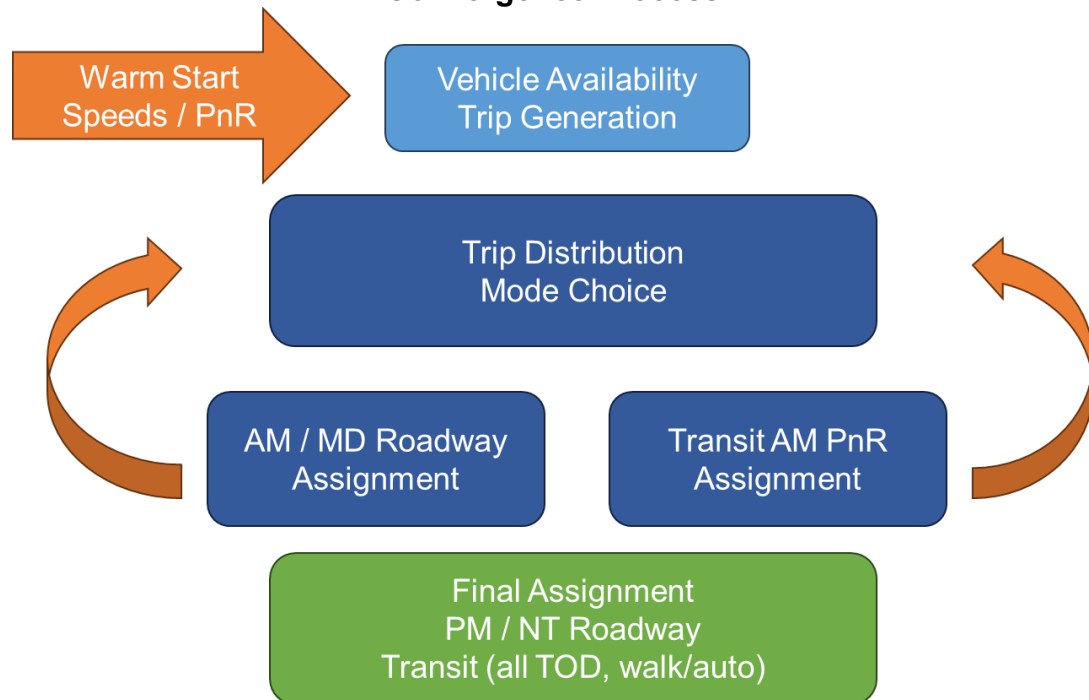
Logan Express

For simplicity, airport-ground-access travel demand on Logan Express service is only assigned in the production-attraction format with auto access. Therefore, only total boardings by route can be analyzed as roughly 50 percent of the assigned trips are actually from the airport (attraction to production).

2.6.18 Convergence

TDM23 converges the estimated trip distribution and mode choice with the highway congestion and transit PnR constrained parking through a feedback loop between the AM peak and midday highway assignment and AM peak transit auto-access assignment to trip distribution. (See Figure 29.)

Figure 29
Convergence Process



AM = morning. MD = midday. NT = nighttime. PnR = park-and-ride. TOD = time of day.

Convergence between successive speed-feedback is determined by the change in assigned volumes on roadway links. In each iteration, the root mean squared error (RMSE) between the previous and current assigned volumes for the AM and midday periods are calculated. If the RMSE is below a set threshold (e.g., 1.0), the supply and demand components of the model are in equilibrium and the model is converged.

To hasten convergence, the assigned volumes are successively averaged through a Method of successive Averaging (MSA) process with each iteration contributing $1/N$ to the rolling average. The link travel time fed back to distribution is calculated from the volumes resulting from the MSA. An MSA process is helpful to achieve convergence when there are parallel paths and highly congested roadways, as is present in the Boston region.

2.6.19 Post Processors

There are two post processors built into TDM23: a process to generate air quality metrics and a process to generate equity metrics.

Air Quality

TDM23 takes as input the outputs of the US Environmental Protection Agency's (EPA) Motor Vehicle Emission Simulator (MOVES) model.¹⁰ The MOVES model takes the vehicle fleet as input and produces emissions rates by distance segmented by speed bin, roadway type, time of day, season, and vehicle type (passenger/commercial).

Using the rates from MOVES, TDM23 estimates the following air quality metrics at the link level:

- Carbon dioxide
- Carbon monoxide
- Oxides of nitrogen
- Sulfur dioxide
- Volatile organic compounds

It is important to highlight that the air quality model utilizes the Bureau of Public Roads (BPR) function to calculate congested speed, which considers the dynamic volume-to-capacity (VC) ratio at different times of the day. However, while TDM23 estimates an average speed across a multi-hour time period, the hourly speed may vary with some hours having higher congestion and lower speeds. To correct this aggregation, the air quality post-processor applies an hourly distribution of trips to the estimated period level total volumes. Then, the congested speed is recalculated for each hour and the resulting speed used in the air quality calculations.

TDM23 also takes as input rates by transit vehicle. These rates are applied to the effective transit service miles by vehicle type in the transit network.

Equity

The Equity Post Processor calculates equity-related metric values by TAZ, including destination access metrics, travel time metrics, and environmental metrics. These metrics are the weighted average across all TAZs in the Boston Region MPO area and weighted by the share of minority and low-income populations in each TAZ.

To calculate destination-access-metric values by TAZ, all TAZs accessible within the specified mode travel time are identified and accessible TAZ attributes are summed.

¹⁰ <https://www.mass.gov/info-details/mobile-source-emission-factors#:~:text=Emission%20Factor%20Outputs%20from%20the%20MOVES%20model,-A%20detailed%20explanation&text=Rates%20per%20Distance%20provides%20kilograms,w hen%20vehicles%20are%20on%20roads>

The destination-access type and time by highway or transit are listed in Table 69.

Table 69
Equity Accessibility Metric Thresholds

| TAZ Attributes | Highway Time | Transit Time |
|-----------------------|---------------------|---------------------|
| Employment | 45 | 45 |
| Healthcare | 25 | 25 |
| Parks | 45 | 45 |
| Essential Places | 25 | 25 |
| Higher Education | 25 | 25 |

TAZ = travel analysis zone.

To calculate the travel time metrics, the travel time of specified mode and time of day are weighted by trips. The travel time metrics are calculated as the average travel time by highway and transit to all other Boston Region MPO TAZs.

The environmental metrics are the total emissions on all links within a TAZ.

2.7 OUTPUTS

TDM23 outputs are written to a folder specific to each model scenario (more details are provided in Section 2.8.1 under the Scenario Management header). Outputs from each model component, including those that are used as inputs to successive components, are stored in the scenario output folder. Along with the model outputs, TDM23 copies the full set of model parameters, generates summaries and reports, and writes all run logs to the scenario output folder.

TDM23 outputs are mainly stored

- in an SQLite database;
- as tables indexed to the highway or transit networks;
- as tables indexed to TAZ; and
- as matrices.

In addition, the input highway and transit networks are copied to the scenario folder and the tables are extended with derived attributes and a selection of the assignment results.

The outputs and format by component are listed in Table 70.

Table 70
Outputs By Component

For placement only

2.7.1 Aggregation areas

Aggregate areas are defined to aid in the data summaries. The areas are organized into concentric rings with downtown Boston as the center and corridors radiating out from Boston. The intersection of the rings and corridors are defined as districts.

Rings

Downtown Boston is Ring 0, the outlying ring in Berkshire County is Ring 7.

Figure 30
Model Analysis Rings, A

FOR PLACEMENT ONLY

Figure 31
Model Analysis Rings, B
For Placement Only

Corridors

Downtown Boston is both Corridor and Ring 0. Corridors are numbered as shown in Figure 32.

Figure 32
Model Analysis Corridors, A
For Placement Only

Figure 33
Model Analysis Corridors, B

FOR PLACEMENT ONLY

Districts

The districts are the intersection of the rings and corridors.

Figure 34
Model Analysis Districts, A
For Placement Only

Figure 35
Model Analysis Districts, B
For Placement Only

2.7.2 Summaries and Reports

High level summaries are written to CSV files from most components to support overall model reports and facilitate analysis.

TransCAD automatically generates a summary report with high level statistics along with a detailed report and error log.

2.8 USABILITY

TDM23 was designed to be a useful and transparent tool, therefore special attention was paid to

- leverage TransCAD's user interface to present the model parameters in a clear, structured manner and to simplify scenario management;
- support various run modes; and
- enable retention of intermediate results and debug outputs.

2.8.1 User Interface

The primary interface to set up and run TDM23 is through TransCAD. TDM23 can also be set up and run programmatically using TransCAD's python API, as is done using TMIP-EMAT. Model components implemented in Python may be run directly using Jupyter notebooks or a Python terminal.

Model Parameters

The parameters in the TDM23 user interface are organized such that frequently changed inputs are grouped in a "Primary Inputs" section to guide the modeler through the values that are likely to change scenario by scenario, for example, highway and transit networks and socioeconomic data.

Less frequently changed inputs, such as parameter values are arranged by Demand and Supply components. This structure helps avoid accidental or missed settings while maintaining full functionality.

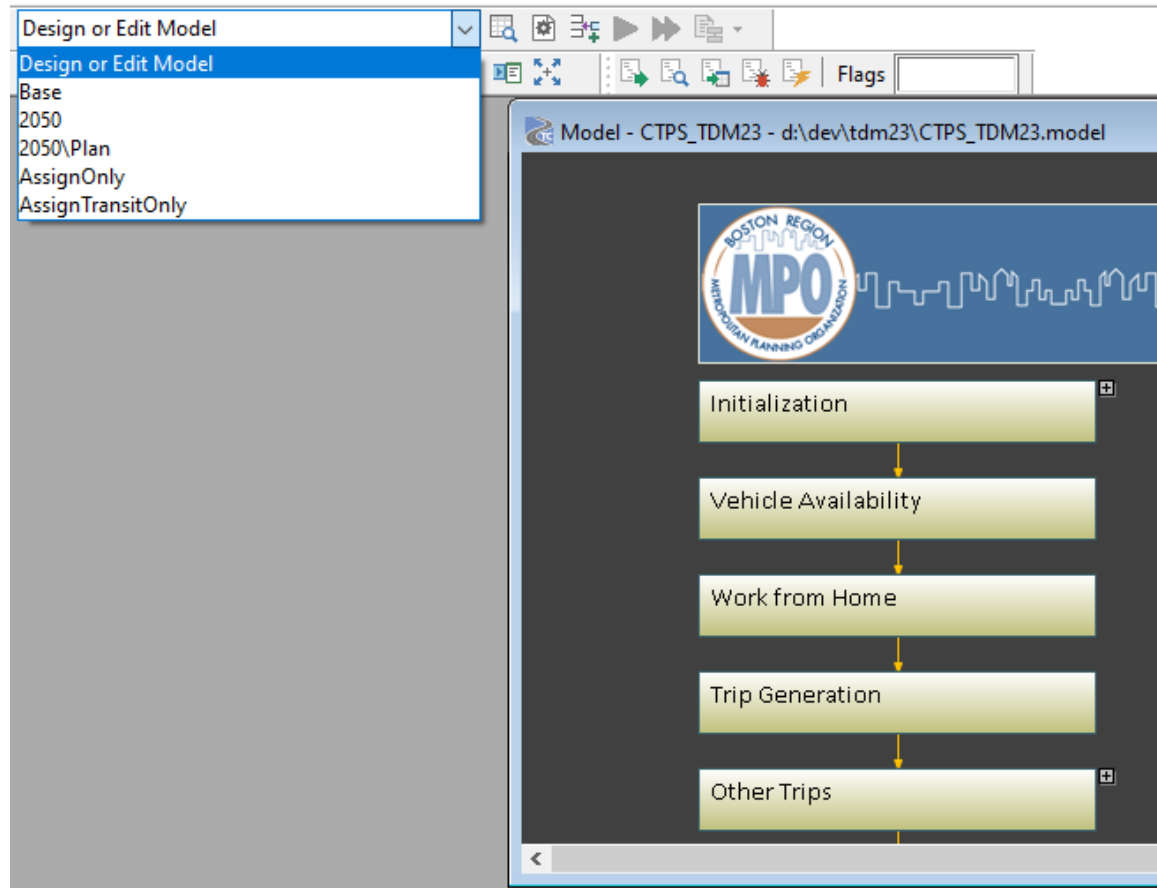
Scenario Management

TDM23 uses the TransCAD model scenario interface to organize scenarios in a generational format, i.e., with inheritance, and records the differences by scenario in a text file. The TransCAD scenario manager is configured to create separate output folders for each scenario and all output files specific to that scenario are stored in an output folder with the same name. Therefore, each scenario creates a similar set of output files that, with a few exceptions, have the same name, but are stored in a specific scenario. This simplifies post-processors

that take the model outputs as input but requires that the folder structure be maintained to understand what scenario generated the output files.

An example of the scenario hierarchy is shown in Figure 36.

Figure 36
TDM23 Scenario Interface



The default scenarios are as follows:

- **Base** (2019)—full model run with feedback using 2019 networks and socioeconomic data
- **2050**—full model run with feedback using 2050 SE data and user defined networks (not a functional scenario)
- **2050\Plan**—Inherits settings from 2050 scenario and sets the network inputs to files that include the Long-Range Transportation Plan projects
- **AssignOnly**—User defined demand inputs and networks, runs highway and transit assignment steps only

- **AssignTransitOnly**—User defined demand inputs and networks, runs transit assignment steps only

Input File Organization

As described in Section 2.3 on the Platform, input file versions are maintained through a unique file name. This facilitates the identification of any changes defined in a scenario.

2.8.2 Run Modes

TDM23 has a variety of run modes ranging from individual components and subsets of components to full model runs with feedback between the TDM supply and demand components to convergence. Table 71 shows the model applications relevant to each run mode. Note that all run modes except the feedback to land use can be executed through the TransCAD interface. The feedback to land use requires a manual exchange of TDM and UrbanSim outputs and convergence determination.

Table 71
Model Application by Run Mode

| Application | Run Individual Components | Run Subset of Components | Full Run with Internal TDM Feedback | Full Run with Feedback to Land Use |
|------------------------|----------------------------------|---------------------------------|--|---|
| Validation | X | | X | X |
| Exploratory | | X | X | |
| Scenario Planning | | X | X | X |
| LRTP Plan | | | X | X |
| Application | | X | X | |
| Inputs to Other Models | X | X | X | |

LRTP = Long-Range Transportation Plan. TDM = Travel Demand Model.

2.8.3 Intermediate Results and Debugging

TransCAD automatically generates a detailed report and error log that can be useful when there is an error. Users may also activate the debug mode in TransCAD to receive more specific information as to where the error occurred.

Intermediate files are written to the output folder and deleted by default, with an option to save for debugging purposes.

TDM23 supports retaining the intermediate results from each feedback loop and a more complete set of intermediate files. A review of the intermediate files can help modelers understand how TDM23 is processing the scenario inputs. These options require more storage (more than 100GB per scenario).

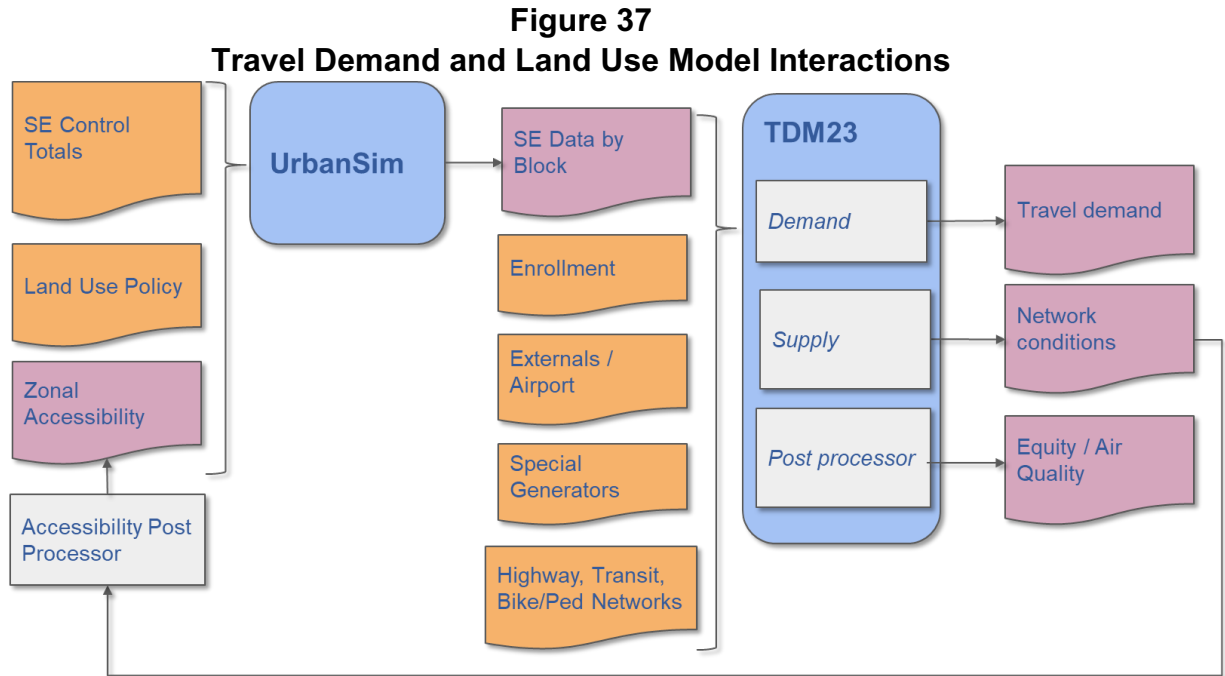
The speed feedback and transit parking convergence iterations are recorded into an associated log file.

2.9 TRANSPORTATION AND LAND USE MODEL CONNECTION

TDM23 uses socioeconomic data produced by MAPC's newly developed UrbanSim land use model.

There is a feedback loop from the TDM back to the land use model through the accessibility derived from roadway and transit network conditions. Ideally, these models would be in equilibrium such that the resulting network conditions are consistent with the distribution of demographic and employment distributions.

In Figure 37, modeled data is shown in red, input data shown in orange. The model components are gray boxes.



Chapter 3—Performance

3.1 OVERVIEW

This chapter summarizes the performance of TDM23 compared to observed data for the base year and presents results of sensitivity tests.

Evaluation of TDM23 was conducted and summarized through a series of validation reports. The validation reports can be run interactively as Jupyter notebooks and published as HTML files. This section includes links to all of the published validation reports for the current model version. Select outputs from the validation reports are included inline.

TDM23 was calibrated with a focus on the Boston Region Metropolitan Planning Organization. Most of the results and summary reports in this chapter are for Boston Region MPO areas.

Thresholds and Targets

Where applicable, reference thresholds are included in the validation summaries. However, as the Travel Model Improvement Program's (TMIP) validation manual strongly advocates, matching specified standards is neither necessary nor sufficient to prove model validity.¹¹ The manual avoids the specification of validation standards for this reason. Nevertheless, it is recognized that past standards may have been set by agencies regarding model validation statistics and failure to match those standards will cast doubts on model's validity and usability. Thus, from a practical standpoint, it's important to match, and where possible, exceed the standards. Such standards are acknowledged and the necessary model statistics calculated for reference.

3.2 VALIDATION DATA

This section summarizes the data used to calibrate and validate TDM23.

3.2.1 2011 Household Survey

The 2011 Massachusetts Travel Survey (2011 MTS) was a traditional household travel survey with GPS subsample conducted between June and October 2011. The survey data is for a 24-hour travel period on weekdays. Statewide, 15,281 observations were collected, with approximately 10,000 within the 164 communities in and around the Boston Region MPO area.

¹¹ Federal Highway Administration, "Travel Model Validation and Reasonableness Checking Manual" Second Edition (prepared by Cambridge Systematics, Inc., 2010).

3.2.2 American Community Survey

The Census Transportation Planning Products (CTPP) are a special set of data tables produced by the US Census Bureau from American Community Survey (ACS) responses, funded by states and MPOs, and organized by the American Association of State Highway and Transportation Officials. At the time of TDM23 development, the most recent CTPP release was from the 2012–16 ACS.

CTPP data, like all special sets of tables, are subject to greater privacy protection procedures than standard Census/ACS products. For the CTPP, this includes the rounding of table data after production: values between one and seven are rounded to four, all other values greater than seven are rounded to the nearest multiple of five. In addition, data in individual cells of a cross tabulation may be suppressed. The net result is that the value in the “Total” column of a table will rarely equal the sum of the remaining columns. However, the tables corresponding to the two potential uses cited above do not appear to be subject to any suppression. Due to the small sample size, margins of error may be quite high, but aggregation to districts lessens this effect.

The Public Use Microdata Sample (PUMS) data from the ACS is also used as another source of comparison for vehicle availability.

3.2.3 Transit Passenger Survey

At the time of TDM23 development, the most recent transit passenger survey collected data between October 2015 through May 2017. Data collected contains the following kinds of information:

- Demographic characteristics, including minority status, English proficiency, gender, age, and household income
- Preferred language for receiving Massachusetts Bay Transportation Authority (MBTA) information
- Possession of a valid driver’s license, number of usable vehicles in household, and vehicles per capita in household
- Trip purpose
- Origin and destination locations
- Modes of access and egress
- Fare and fare payment method
- Frequency of making the reported trip using the MBTA

The data were expanded based on travel volumes, rather than demographics. Therefore, these data could not be used to validate travel behavior between

market segments, e.g. male vs. female transit preference, but could be used to validate travel behavior within market segments, e.g. transit access mode given auto ownership.

3.2.4 TNC Trip Data and Passenger Survey

In 2019, rideshare companies—also called transportation network companies (TNC)—provided 91.1 million rides in Massachusetts, approximately 12.0 percent more than in 2018 and 40.6 percent more than in 2017. Massachusetts law requires rideshare companies to share data and the Department of Public Utilities (DPU) publishes the total annual TNC trip start, end, and duration at the community level.¹² Additional information will be forthcoming, but this information is not yet available for analysis. (The requirement to provide additional information was removed from Massachusetts House Bill 5248, but a subsequent bill restored the requirement.)

MAPC surveyed nearly 1,000 ride-hailing passengers in late 2017 and asked about their demographics, the nature of their trip, and why they chose ride-hailing over other modes of transportation.¹³

Ride-sourcing deadheading trips are also calibrated in the model to match reported levels of between 40 and 47 percent of total ride-source vehicle-miles traveled (VMT).¹⁴

3.2.5 Logan Airport Ground Access Survey

The Massachusetts Port Authority (Massport) has conducted a triannual ground-access survey. Data used in development and calibration of TDM23 is from the survey conducted in 2019. In total 252 flights were surveyed over a two-week period, achieving a final sample of 8,763 responses.

3.2.6 Roadway Counts

Roadway counts for validation are sourced directly from the Massachusetts Department of Transportation (MassDOT) count program or Replica or, for limited access roadways, processed by Central Transportation Planning Staff (CTPS) to be balanced and consistent.¹⁵

¹² Mass.gov., 2019 Data Report: Rideshare in Massachusetts. <https://tnc.sites.digital.mass.gov/>

¹³ Steven R. Gehrke, Alison Felix, and Timothy Reardon. Fare Choices: A survey of Ride-Hailing Passengers in Metro Boston, Report #1, (2018). <https://www.mapc.org/farechoices/>

¹⁴ Union of Concerned Scientists, Are Uber and Lyft Rides Bad for the Climate? <https://www.ucsusa.org/resources/uber-and-lyft-rides-bad-climate>

¹⁵ Massachusetts Department of Transportation. Traffic Volume and Classification in Massachusetts (2024). <https://www.mass.gov/traffic-volume-and-classification-in-massachusetts>

CTPS Balanced Counts

CTPS processed raw count data from MassDOT for limited access roadways to be consistent with ramp ons and offs.

The balancing process is operationally straightforward: adjustments are made to nearby round numbers such that the closed system of traffic is consistent.

However, data inconsistencies are expected as counts are taken in different years and/or different times of year. Other inconsistencies could be from count equipment failing, which may require going back to an older count for useful values or extrapolating from partial counts.

Balanced counts were developed for the following roadways in Massachusetts:

- Interstate 90 (I-90)
- I-93
- I-95
- I-495
- US Route 1 North of the Tobin Bridge
- Route 24
- Route 128
- US Route 3 North of I-95
- US Route 3 South of I-93

3.2.7 Origin-Destination (OD) Travel Data

OD travel data were gathered from both Streetlight and Replica over the course of the TDM23 calibration.^{16,17} Both platforms provide similar Big Data-derived metrics of OD flows, segmented by vehicle. Data was aggregated to the TDM23 districts (intersections of rings and corridors described in Section 2.7.1) to improve reliability.

The available Streetlight dataset did not extend to the full model region. Parts of New Hampshire and Rhode Island were not covered. Therefore, the data summaries are not expected to match between the platforms.

3.2.8 Roadway Speeds

Through the I-95 Corridor Coalition, CTPS has access to INRIX data through the RITIS platform. The relevant data for roadway speed validation is available

¹⁶ <https://www.streetlightdata.com/>

¹⁷ <https://www.replicahq.com/>

through the RITIS NPMRDS Analytics features, which can be used to provide the average and 95th percentile speed by NPMRDS INRIX TMC segment and vehicle class (passenger vehicles vs. trucks).

3.2.9 Transit Boardings

Commuter Rail

The MBTA Open Data portal provides detailed boarding, alighting, and load data for commuter rail. It contains the averages per trip, season, route or line, direction, stop, day type, and time period. Data is sourced from manual counts and is available for spring 2018. TDM23 validation leverages the more detailed version of the data available to CTPS.

Ferry

The MBTA Open Data portal provides boarding, alighting, and load data for the commuter ferry service. It contains data for the full calendar year for past years and up to the most recent month for the current year. Data is sourced from manual counts; however, due to other data issues, data is not guaranteed to be complete for any line or date.

Local and Express Bus

The MBTA Open Data portal provides average boardings, alightings, and loading per trip, season, route or line, direction, stop, day type, and time period. These data are sourced from automated passenger counters (APCs) and are available for the fall 2019 period.

Rapid Transit

The MBTA Open Data portal provides detailed ridership and flow data for heavy rail and light rail. It contains the average ridership per season, route or line, direction, stop, day type, and time period. Data is sourced from automated fare collection (AFC) and a modeled derivation of trip OD and is available for fall 2019.¹⁸

3.2.10 Park-and-Ride Lot Utilization

In the spring and fall seasons between April 2017 and November 2018, CTPS inventoried MBTA, private, and town-operated parking facilities at 152 locations comprising 121 commuter rail stations, 27 rapid transit stations, two ferry terminals, and two express bus origin locations.

¹⁸ <https://www.massdottracker.com/wp/>

The park-and-ride lots were inventoried by performing a one-time observation during the morning peak period of a typical weekday from April 2017 to November 2018. The data collectors were instructed to visit each lot immediately after the last inbound, peak-period trip. The time of the last inbound train, express bus, or ferry varied by station.¹⁹

3.3 COMPONENT VALIDATION

This section presents a selection of validation comparisons for each of the model demand components. The overall OD flow and assignment validation comparisons are presented in the following section.

3.3.1 Vehicle Availability

A challenge in the Vehicle Availability calibration is that the household survey and synthetic population had different distributions and weighting by household attributes. This results in some illogical comparisons where the overall shares of zero vehicles are high compared to the household survey, but low compared by income segment. Adjustments were made to parameters to improve model fit at the segment level.

The calibration examined both the average number of vehicles as well as the share of vehicle sufficiency (zero, insufficient, and sufficient). Most attention was paid to the vehicle sufficiency as those are the market segments for the downstream model components.

The [Vehicle Availability validation report](#) shows comparisons between the model results and the 2011 MTS for households in the Boston Region MPO area. Overall, the vehicle sufficiency share is within a few percentage points for each segment, except for the very largest households. The average vehicles are typically underestimated, which is expected given the heuristic to convert vehicle sufficiency to mean exactly as many vehicles as drivers.

The model reproduces vehicle availability trends across size, workers, drivers, income, and access density.

3.3.2 Trip Generation

To calibrate the trip productions, the rates are adjusted when they are clearly different from the national averages as that indicates an undercounting in the

¹⁹ Ryan Hicks, 2017–18 Inventory of Park-and-Ride Lots at MBTA Facilities (2020).
<https://www.ctps.org/data/html/programs/cmp/park-and-ride/park-and-ride-memo-2017-2018.html>

household survey. Undercounting is a known problem, especially with shorter trips such as brief shopping trips and non-home-based trips.

The need to adjust the trip rates is motivated and guided by the highway and transit assignments and how the estimated volumes and transit boardings align with observations. Low volumes and transit boardings imply that the trip rates could be low (as well as potential implications on distribution and mode choice). Following an iterative, systems level calibration process, trip rates and results were developed. Note that no changes were made to the home-based work (HBW) or non-home-based work (NHBW) trip production rates. The calibrated trip rates are shown in Section 2.6.7.

Trip Rate References

Trip rates in TDM23 were adjusted in consideration with the following published rates.²⁰

²⁰ National Cooperative Highway Research Program (NCHRP) Report 716, Travel Demand Forecasting: Parameters and Techniques.
<https://nap.nationalacademies.org/catalog/14665/travel-demand-forecasting-parameters-and-techniques>

Table 72
NCHRP Trip Generation Rates

Home-Based Work Trips (Table C.5. – NCHRP 716)

Number of Workers by Number of Autos

| Autos | Workers | | | | |
|---------|---------|-----|-----|-----|---------|
| | 0 | 1 | 2 | 3+ | Average |
| 0 | 0.0 | 1.0 | 2.4 | 5.1 | 0.5 |
| 1 | 0.0 | 1.0 | 2.6 | 5.1 | 0.8 |
| 2 | 0.0 | 1.3 | 2.6 | 5.1 | 1.6 |
| 3+ | 0.0 | 1.3 | 2.6 | 5.1 | 2.3 |
| Average | 0.0 | 1.2 | 2.6 | 5.1 | 1.4 |

Home-Based School Trips (Table C.8. – NCHRP 716)

Number of Persons by Number of Children

| Children | Household Size | | | | | |
|----------|----------------|-----|-----|-----|-----|---------|
| | 1 | 2 | 3 | 4 | 5+ | Average |
| 0 | 0.0 | 0.0 | 0.5 | 1.0 | 1.1 | 0.1 |
| 1 | 0.0 | 1.0 | 1.0 | 1.7 | 1.8 | 1.1 |
| 2 | | | 1.6 | 1.8 | 2.6 | 1.9 |
| 3+ | | | | 2.7 | 2.7 | 2.7 |
| Average | 0.0 | 0.1 | 0.8 | 1.7 | 2.5 | 0.6 |

Home-Based Non-Work Trips (Table C.9. – NCHRP 716)

Number of Persons by Number of Vehicles, Urban Area Greater Than 500,000 Population

| Vehicles | Household Size | | | | | |
|----------|----------------|-----|-----|-----|------|---------|
| | 1 | 2 | 3 | 4 | 5+ | Average |
| 0 | 1.4 | 3.5 | 5.0 | 5.9 | 8.6 | 2.9 |
| 1 | 1.9 | 3.8 | 5.6 | 7.1 | 9.2 | 3.4 |
| 2 | 2.4 | 4.0 | 5.7 | 9.2 | 11.1 | 6.0 |
| 3+ | 2.5 | 4.0 | 6.4 | 9.2 | 12.2 | 7.5 |
| Average | 1.8 | 3.9 | 5.8 | 8.7 | 10.9 | 4.9 |

Non-Home-Based Non-Work Trips (Table C.7. – NCHRP 716)

Number of Persons by Number of Vehicles

| Vehicles | Household Size | | | | | |
|----------|----------------|-----|-----|-----|-----|---------|
| | 1 | 2 | 3 | 4 | 5+ | Average |
| 0 | 0.7 | 1.7 | 2.0 | 3.7 | 3.9 | 1.3 |
| 1 | 1.4 | 2.3 | 3.5 | 3.9 | 3.9 | 2.0 |
| 2 | 1.6 | 2.6 | 3.9 | 5.5 | 5.6 | 3.5 |
| 3+ | 1.6 | 2.7 | 4.5 | 5.8 | 7.1 | 4.4 |
| Average | 1.3 | 2.5 | 3.8 | 5.3 | 5.7 | 3.0 |

Table 73
TMIP Trip Generation Rates

| Source: Table 5.2, MPO areas larger than 3 Million (estimated from 2001 NHTS) | Average HH Rate |
|---|-----------------|
| Home-Based Work | 1.54 |
| Home-Based Nonwork | 5.84 |
| Non-Home Based | 3.27 |

TMIP = Travel Model Improvement Program.

Source: Travel Model Validation and Reasonableness Checking Manual – Second Edition (Cambridge Systematics, Inc., 2010)

Trip Rate Comparison

The TDM23 summary report presents summary statistics on the trip production rates per household, person, and worker. These are helpful to check the rates at an aggregate level across purposes. That report is excerpted in Table 74 to show the production rates by household, person, and worker.

Table 74
Effective Trip Production Rates

| Trip Production Rates | | | | | | | | | |
|-----------------------|--------|--------|---------|---------|---------|----------|---------|---------|----------|
| [productions per] | hh_max | hh_min | hh_mean | per_max | per_min | per_mean | wrk_max | wrk_min | wrk_mean |
| hbw_p | 15.82 | 0 | 1.90 | 1.45 | 0 | 0.80 | 1.45 | 1.07 | 1.41 |
| hbsc_p | 11.76 | 0 | 0.59 | 1.20 | 0 | 0.15 | 11.73 | 0 | 0.48 |
| hbsr_p | 11.73 | 0.45 | 2.19 | 2 | 0.33 | 0.98 | 11.39 | 0.33 | 1.55 |
| hbpb_p | 13 | 1.17 | 2.38 | 2.36 | 0.32 | 1.17 | 10.59 | 0.32 | 1.59 |
| nhbw_p | 5.60 | 0 | 0.51 | 0.40 | 0 | 0.22 | 0.40 | 0.30 | 0.38 |
| nhbnw_p | 9.19 | 1.56 | 2.69 | 2.29 | 0.57 | 1.31 | 7.04 | 0.65 | 1.89 |
| all_trips | 42.44 | 4.12 | 10.25 | 8.72 | 2.44 | 4.62 | 39.58 | 2.82 | 7.30 |

Source: Boston Region MPO.

The non-home-based trips per household (hh_mean column) are $0.51 + 2.69 = 3.2$, which is similar to the 3.0 and 3.27 average rates from NCHRP and TMIP, respectively. The home-based non-mandatory trip rates per household (HBSR + HBPB) add up to 4.57 ($2.19 + 2.38 = 4.57$), which is still less than the 4.9 NCHRP rate. The 1.90 home-based work (HBW) trip rates are slightly higher than the average work trips from the national data, but could reflect the higher share of workers in the Boston region. Note that no calibration adjustments were made to the estimated HBW or NHBW trip production rates.

Effective Trip Rates

The effective rates by purpose and household/worker type for average weekday trips, exclusive of home-based university, are visualized in the [Trip Generation validation report](#).

These summaries show a consistent trend by household size, income, and vehicle ownership. Note that smaller households make more trips per person.

3.3.3 Trip Distribution

The [Trip Distribution validation report](#) compares the metrics listed below to the 2011 MTS data. Each metric is segmented by purpose and vehicle availability market segment:

- Average trip length
- Trip length distribution (time and distance) and coincidence ratio
- Intrazonal share
- Geographic flows by MPO, Boston Region MPO subregion, and ring

Where trip purposes are segmented by vehicle availability, TDM23 reproduces the trend observed in the household survey with zero- and insufficient-vehicle households having shorter average trip lengths.

The coincidence ratios of trip length distribution are all greater than the 0.70 guidelines with only school trips less than 0.8.

3.3.4 Mode Choice

Mode choice calibration has several steps:

1. Fit mode shares to the observed shares from MTS 2011.
2. Introduce the ride-source alternative and calibrate to match ride-sourcing targets.
3. Run through the full model and calibrate mode choice parameters to better fit transit and roadway observations.

The [Mode Choice validation report](#) compares mode share by purpose and vehicle ownership. The mode shares will not match perfectly because the modeled mode share includes ride-source, which was not reported in MTS 2011. The report also includes a comparison of mode share by distance and transit versus auto flows for the MPO subregions.

The 91,082,437 total annual TNC rides for 2019 in Massachusetts (sourced from the DPU) were allocated to weekdays using the trip purpose and vehicle splits based on the MAPC rider survey data.²¹

²¹ Mass.gov, 2019 Data Report: Rideshare in Massachusetts. <https://tnc.sites.digital.mass.gov/>

Table 75 shows the impact that introducing ride-source modes has on mode choice by trip purpose. With the ride source mode enabled, all modes see a decrease in mode share. Transit and nonmotorized modes have the largest percentage change within each purpose category, with the greatest changes related to the non-home-based purposes. This is expected as ride-source modes are most popular for shorter trips in dense areas.

Table 75
Ride-Source Impact on Mode Share (Percent Change in Mode Share)

| Purpose/Mode | DA | S2 | S3 | WK | BK | TW | TA |
|--------------|------|------|------|------|------|------|------|
| HBW | -0.8 | -1.3 | -1.3 | -3.2 | -2.5 | -3.7 | -0.9 |
| HBPB | -0.1 | -0.1 | -0.1 | -0.5 | -0.2 | -0.8 | -0.3 |
| HBSR | -0.2 | -0.3 | -0.3 | -1.1 | -0.6 | -2.1 | -0.6 |
| NHBW | -1.6 | -2.0 | -2.2 | -5.3 | -5.1 | -6.4 | - |
| NHBNW | -0.7 | -0.8 | -0.8 | -1.5 | -1.7 | -2.5 | - |

BK = bike. DA = drive alone. HBPB = home-based personal business. HBSC = home-based school. HBSR = home-based social recreation. HBW = home-based work. NHBNW = non-home-based non work. NHBW = non-home-based work. S2 = 2 person shared ride. S3 = 3+ person shared ride. TA = auto access to transit. TW = walk access to transit. WK = Walk.

The [Ride Source validation report](#) compares ride-source results to the available data, including total daily ride-source trips, ride-source trips by purpose, vehicle sufficiency, and time of day as well as the distribution of ride-source usage by municipality and the average share of deadheading VMT.

TDM23 underpredicts ride-source usage during the night period and overpredicts in the midday period. This is expected given that ride-source usage is higher in the evening when travelers could be more sensitive to waiting times, more likely to not be able to operate a vehicle, and/or traveling while transit is not operational. However, the ride-source observations are from all days of the week and weekday trips may not show as high a share in night period trips. In any case, mode-specific time-of-day factors are not included in TDM23 so this variation in travel behavior cannot be represented accurately.

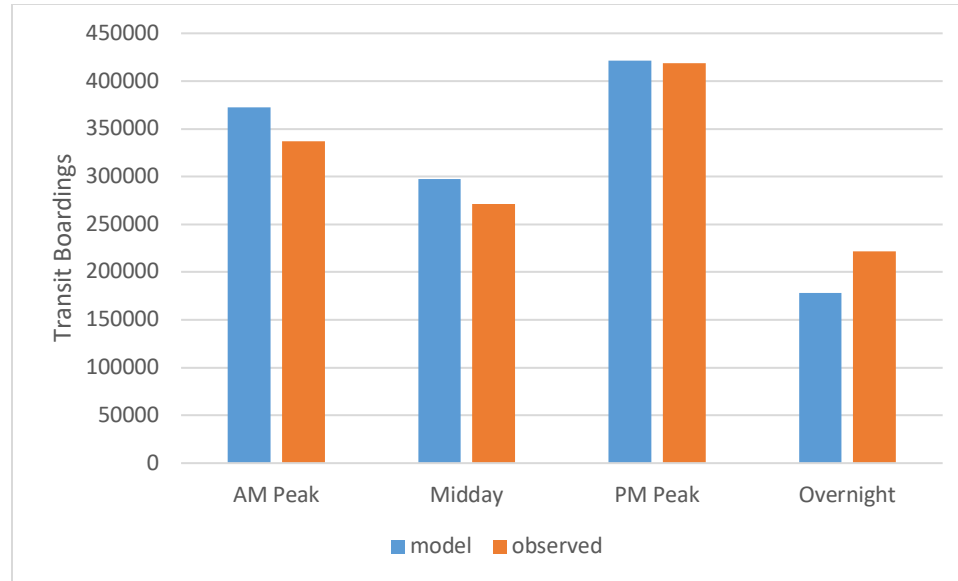
3.3.5 Time of Day

The time of day factors are calibrated to the total trip distributions by time of day for person and vehicle trips compared to the 2011 MTS, Modern Traffic Analytics (MS2) count data, and Replica estimated vehicle trips. These comparisons are shown in the [Time of Day validation report](#).

Some adjustments in time-of-day factors were necessary due to the change in trip generation rates and to better fit the more recent MS2 and Replica data, where the time-of-day factors were initially derived from the 2011 MTS.

The transit validation report (excerpted in Figure 38) includes a summary of transit travel by time of day. Transit observations also show a stronger night share than is modeled. There may be a relationship between nonmotorized and transit mode use by time of day where nonmotorized trips are preferred in daytime and transit is preferred in the evening.

Figure 38
Transit Time-of-Day Comparison



3.3.6 Trucks and Commercial Vehicles

Truck calibration is limited to an evaluation of the trip distribution. The average trip lengths and coincidence ratios are shown in the [Commercial Vehicle validation report](#). Note that the truck distribution does not quite meet the 0.70 threshold for a coincidence ratio. Long-distance truck trips would be best estimated as part of a freight model with shorter distance service and distribution handled through the trip distribution.

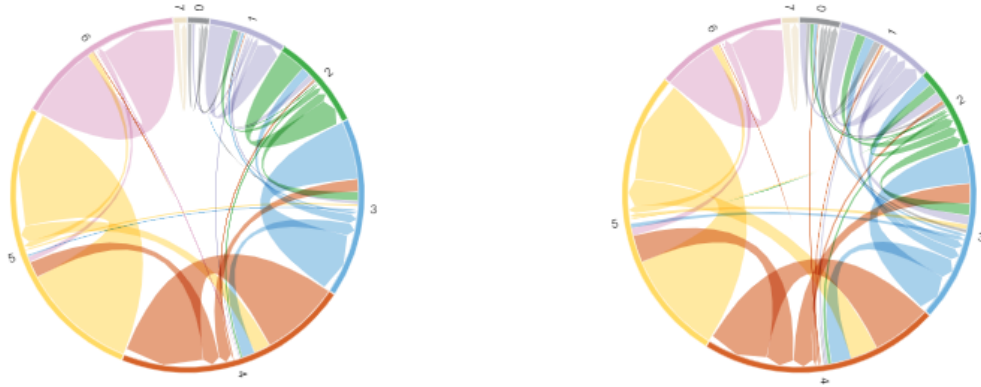
Truck flows by area are compared to both Replica data in the [OD Replica validation report](#) and Streetlight data in the [OD Streetlight validation report](#).

Overall truck flows are relatively consistent between TDM23 and observations. Figure 39 shows the flows by ring.

Figure 39
Truck Flows by Ring Compared to Replica

Observe:

Model:

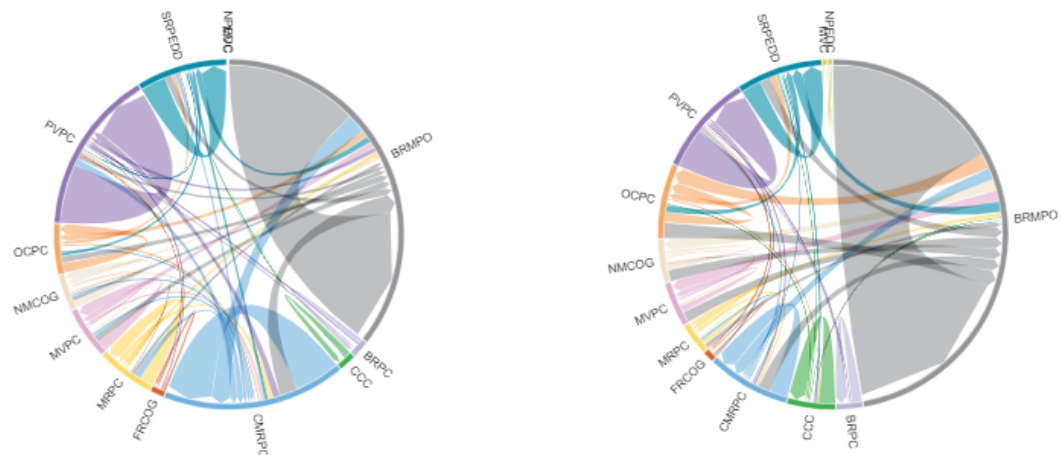


However, there is a discrepancy in the heavy truck flows that are available from Streetlight. Figure 40 shows that TDM23 has fewer heavy trucks in central and western Massachusetts, consistent with the truck assignment report (discussed in Highway Assignment, below).

Figure 40
Heavy Truck Flows by MPO Compared to Streetlight

Observe:

Model:



BRMPO = Boston Region Metropolitan Planning Organization. BRPC = Berkshire Regional Planning Council. CCC = Cape Cod Commission. CMRPC = Central Massachusetts Regional Planning Council. FRCOG = Franklin Regional Council of Governments. MRPC = Montachusett Regional Planning Council. MVPC = Merrimack Valley Planning Commission. NMCOG = Northern Middlesex Council of Governments. NPEDC = Nantucket Planning & Economic Development Commission. OCPC = Old Colony Planning Council. PVPC = Pioneer Valley Planning Council. SRPEDD = Southeastern Regional Planning & Economic Development District.

3.3.7 Airport Ground Access

Calibration of airport-ground-access trip distribution is done by adjusting both the distribution gravity parameters and calibrating the trip generation rates. The [Airport Ground Access validation report](#) presents the trip distribution and mode choice fit to the Massport Triennial survey data. TDM23 matches the distinct patterns by each of the resident/visitor and business/leisure market segments.

3.3.8 University

The university trip model is calibrated to the MTS 2011 survey summaries for trip length distribution and mode share. The [University Trip Distribution validation report](#) shows the average trip length and coincidence ratios for university trips.

The [University Trip Mode Choice validation report](#) compares the mode share. TDM23 tracks the observed pattern showing a higher level of transit and nonmotorized modes for home-based university (HBU) trips.

3.3.9 External Trips

External trips were calibrated by adjusting the distribution gravity parameters according to the observed distribution to districts, rings, and corridors in Streetlight OD data.

The [External Trip validation report](#) presents the comparisons to Streetlight OD data for auto, medium trucks, and heavy trucks. TDM23 generally follows the relative magnitude of the observed data, although the estimated trips to Ring 5 are substantially lower than observed.

3.4 SYSTEM VALIDATION

This section presents the validation checks at the system level, resulting from the entire sequence of models.

3.4.1 Travel Flows

The examination of travel flows is conducted by first examining the reasonableness of the generation and distribution component outputs and then comparing flows by mode.

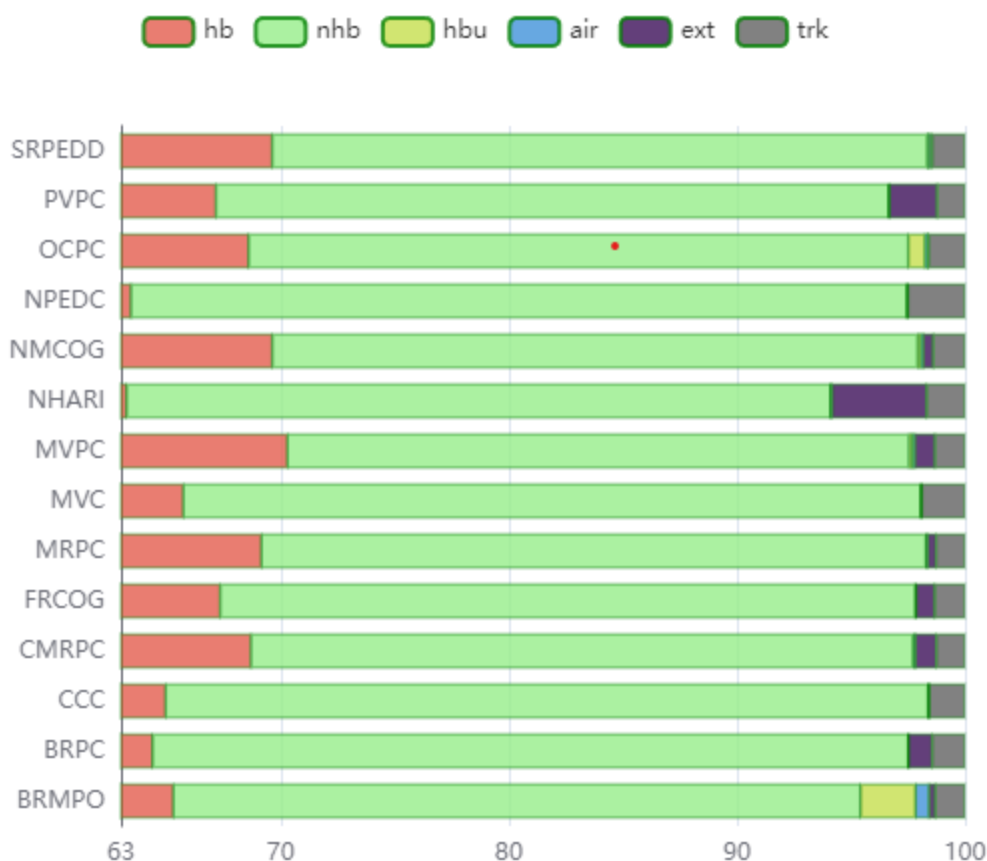
Trip Generation and Distribution

Travel flows were examined for reasonableness based on the distribution of trips by production and attraction end. The [Travel Flow validation report](#) provides

interactive figures to examine the share of trips by purpose and type for transit access density, MPO, Boston Region MPO subregion, ring, and corridor.

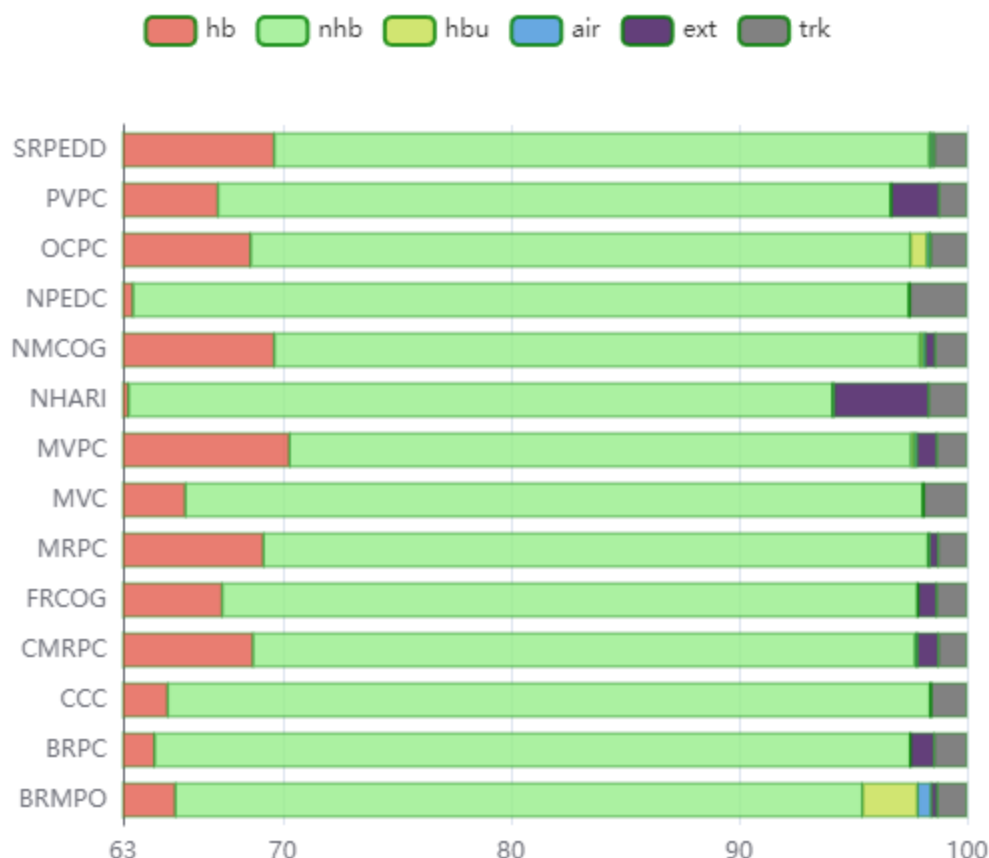
The validation report is previewed below in Figures 41 and 42 that show the marginal distributions of trip ends by MPO. Note that New Hampshire and Rhode Island (NHARI) have the highest share of external trips. The Boston Region MPO has the highest share of university trips.

Figure 41
MPO Trip Distribution—Production End



Air = airport ground access. BRMPO = Boston Region Metropolitan Planning Organization. BRPC = Berkshire Regional Planning Council. CCC = Cape Cod Commission. CMRPC = Central Massachusetts Regional Planning Council. Ext = external trips. FRCOG = Franklin Regional Council of Governments. HB = home-based. HBU = home-based university. MRPC = Montachusett Regional Planning Council. MVC = Martha's Vineyard Commission. MVPC = Merrimack Valley Planning Commission. NHARI = New Hampshire and Rhode Island. NMCOG = Northern Middlesex Council of Governments. NHB = non-home based. NPEDC = Nantucket Planning & Economic Development Commission. OCPC = Old Colony Planning Council. PVPC = Pioneer Valley Planning Council. SRPEDD = Southeastern Regional Planning & Economic Development District. Trk = truck trips.

Figure 42
MPO Trip Distribution—Attraction End



Air = airport ground access. BRMPO = Boston Region Metropolitan Planning Organization. BRPC = Berkshire Regional Planning Council. CCC = Cape Cod Commission. CMRPC = Central Massachusetts Regional Planning Council. Ext = external trips. FRCOG = Franklin Regional Council of Governments. HB = home-based. HBU = home-based university. MRPC = Montachusett Regional Planning Council. MVC = Martha's Vineyard Commission. MVPC = Merrimack Valley Planning Commission. NHARI = New Hampshire and Rhode Island. NMCOG = Northern Middlesex Council of Governments. NHB = non-home based. NPEDC = Nantucket Planning & Economic Development Commission. OCPC = Old Colony Planning Council. PVPC = Pioneer Valley Planning Council. SRPEDD = Southeastern Regional Planning & Economic Development District. Trk = truck trips.

Mode Choice

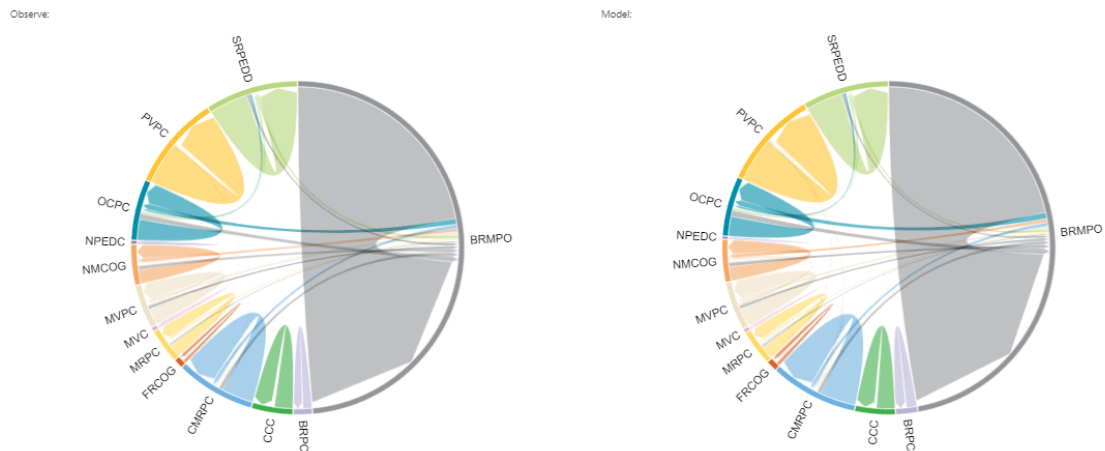
TDM23 flows by mode were compared to both Replica data in the [OD Replica validation report](#) and Streetlight data in the [OD Streetlight validation report](#). Streetlight produced data by vehicle (auto, medium truck, and heavy truck). Replica produced data by vehicle as well as transit and nonmotorized trips.

Auto Flows

The TDM23 auto flows by MPO match the Streetlight MPO flows within 1 percent for each interchange. Figure 43 shows a chord diagram of auto flows between

MPOs compared to Streetlight data. An interactive tabular comparison with percentages is available through the report linked above.

Figure 43
MPO Auto Trip Flows



BRMPO = Boston Region Metropolitan Planning Organization. BRPC = Berkshire Regional Planning Council. CCC = Cape Cod Commission. CMRPC = Central Massachusetts Regional Planning Council. FRCOG = Franklin Regional Council of Governments. MRPC = Montachusett Regional Planning Council. MVC = Martha's Vineyard Commission. MVPC = Merrimack Valley Planning Commission. NMCOG = Northern Middlesex Council of Governments. NPEDC = Nantucket Planning & Economic Development Commission. OCPC = Old Colony Planning Council. PVPC = Pioneer Valley Planning Council. SRPEDD = Southeastern Regional Planning & Economic Development District.

Auto flows are consistent between the model and Streetlight and Replica data at both the district and ring geographies as well.

Person Flows

Only Replica estimates person flows by mode. The person-level auto flow comparisons are similar to the vehicle-level flows and are consistent between the model and observations.

The transit and nonmotorized flows, however, show distinct differences. For trips within the central business district (CBD), TDM23 estimates 7 percentage points more than Replica and shows a greater number of trips between the CBD and surrounding districts. (See Figure 44.) The relatively small share of downtown nonmotorized trips estimated by Replica is suspect and warrants further analysis.

Figure 44
District Nonmotorized Trip Flows—CBD (District 0) Highlighted



CBD = central business district.

Transit flows also show a discrepancy between TDM23 and Replica. Figure 45 shows the trip flows from the CBD (Ring 0) and outlying rings. TDM23 estimates that most of the transit trips are between the CBD and connect more transit to outlying rings than Replica. TDM23 produces results more consistent with expectations on transit travel in the region. This discrepancy could be due to Replica not including auto-transit as a modal option.

Figure 45
Ring Transit Trip Flows—CBD (District 0) Highlighted



CBD = central business district.

3.4.2 Highway Assignment

Assignment calibration is an iterative process, requiring adjustments to trip generation rates, distribution, time of day, and mode choice. This section presents the vehicle-miles traveled (VMT) comparisons after adjustments were made across the demand components.

The [Highway validation report](#) includes volume and VMT comparisons segmented by facility type, volume group, and area type.

HPMS Comparison

A comparison with the Highway Performance Monitoring System (HPMS) Interstate VMT shows a strong correlation between the model and observed data by MPO. The modeled VMT for the Boston Region MPO and statewide are about 3 percent less of the HPMS 2019 estimates. Note that there are larger differences in the modeled and HPMS VMT across other facility types and overall. The modeled VMT for all roads is approximately 15 percent lower than the HPMS-estimated total VMT.

Roadway Count Comparison

The following tables show the model results, observation summaries, percent root-mean squared error (RMSE %), and the peak hour RMSE for the Boston Region MPO roadways.

Table 76 presents a comparison by volume group. The lowest volume roadways are at or over the target percent difference, however these counts are the least reliable. A project to investigate and potentially incorporate more comprehensive count data from Replica is underway and could give better insight into the model performance for small roadways. The validation report tables include the target percent differences and RMSE thresholds.

Table 76
Highway Comparisons by Volume Group

| Volume Group | Model | Observed | Percent Difference | RMSE % | Peak Hour RMSE |
|--------------|-------|----------|--------------------|--------|----------------|
| 1-999 | 1212 | 716 | 70.01 | 136.5 | 77.7 |
| 1000-2499 | 2760 | 1739 | 58.79 | 173.2 | 240.1 |
| 2500-4999 | 4542 | 3699 | 22.72 | 68.2 | 201.5 |
| 5000-9999 | 7325 | 7160 | 2.36 | 39.2 | 224.5 |
| 10000-24999 | 14560 | 15478 | -5.92 | 32.6 | 403.7 |

| | | | | | |
|-------------|-------|-------|-------|------|-------|
| 25000-49999 | 36081 | 37323 | -3.22 | 18.6 | 555.4 |
| 50000-74999 | 58936 | 60228 | -2.01 | 12.8 | 621.6 |
| 75000+ | 91572 | 91885 | -0.26 | 9.1 | 676.3 |

RMSE = root mean squared error.

Table 77 groups the highway assignment comparisons by facility type. Across facility types, the average difference is well within the target. The RMSE differences for arterials and local roads are higher than target, but do not translate into a substantial difference in the peak hour.

Table 77
Highway Comparisons by Facility Type

| Volume Group | Model | Observed | Percent Difference | RMSE % | Peak Hour RMSE |
|---------------------------|-------|----------|--------------------|--------|----------------|
| Freeway | 70964 | 71727 | -1.06 | 11.1 | 636.9 |
| Expressway | 35678 | 34921 | 2.17 | 21.2 | 592.3 |
| Major Arterial | 17773 | 17923 | -0.84 | 33.2 | 476 |
| Minor Arterial | 9939 | 10540 | -5.7 | 40 | 337.3 |
| Collector | 5159 | 5064 | 1.88 | 54.3 | 220 |
| Local Road | 3524 | 4149 | -15.05 | 91.2 | 302.7 |
| Freeway-Freeway Connector | 23124 | 23294 | -0.73 | 20.3 | 378.3 |
| Ramp | 8083 | 8309 | -2.72 | 37.2 | 247.3 |

RMSE = root mean squared error.

Truck Assignment

There were very few classified counts available for comparison. The [Truck validation report](#) shows that TDM23 underestimates both medium and heavy trucks across the state, and particularly in the Central and Pioneer Valley regions. Due to the sparse data, no calibration adjustments were made to try to better fit the observations. When available, the Replica data will be leveraged to verify existing counts and attempt to better understand and improve the model representation of medium and heavy trucks.

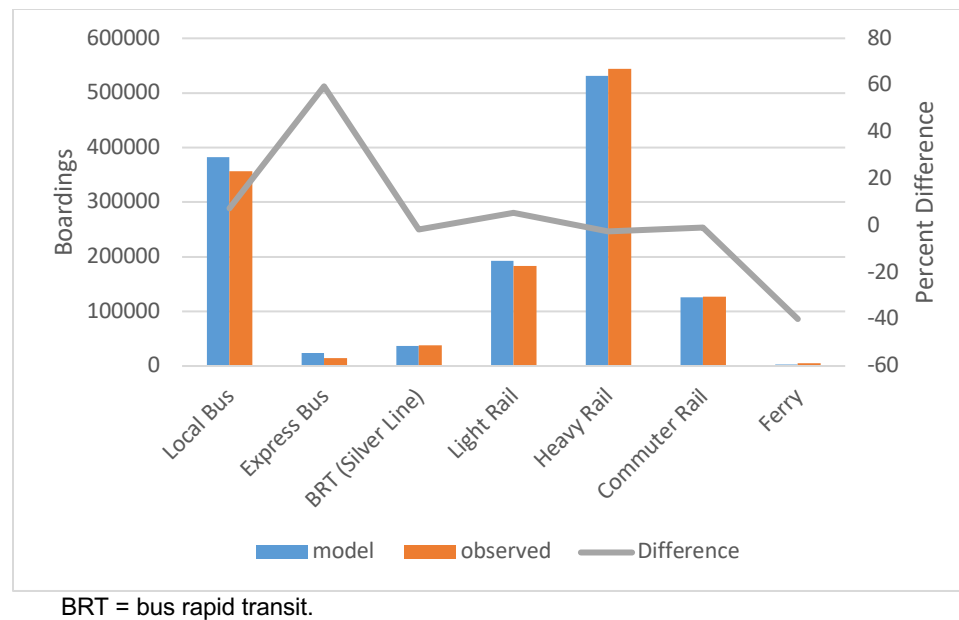
3.4.3 Transit Assignment

The calibration proceeded iteratively from higher to lower levels of comparisons. The [Transit validation report](#) contains a more complete set of comparisons.

Overall Boardings

Boardings were first checked at the mode level for MBTA routes where boarding data were available. Every mode except express bus and ferry are within 10 percent of the observed boardings.

Figure 46
Transit Boardings Comparison



Express buses may be overestimated due to a lack of vehicle capacity constraint in the model. If a traveler cannot board the first express bus, they could wait for the next one; but then the headway is higher than represented in the schedule. The magnitude of express bus boardings relative to other modes reduces the negative impact of this inaccuracy in the model.

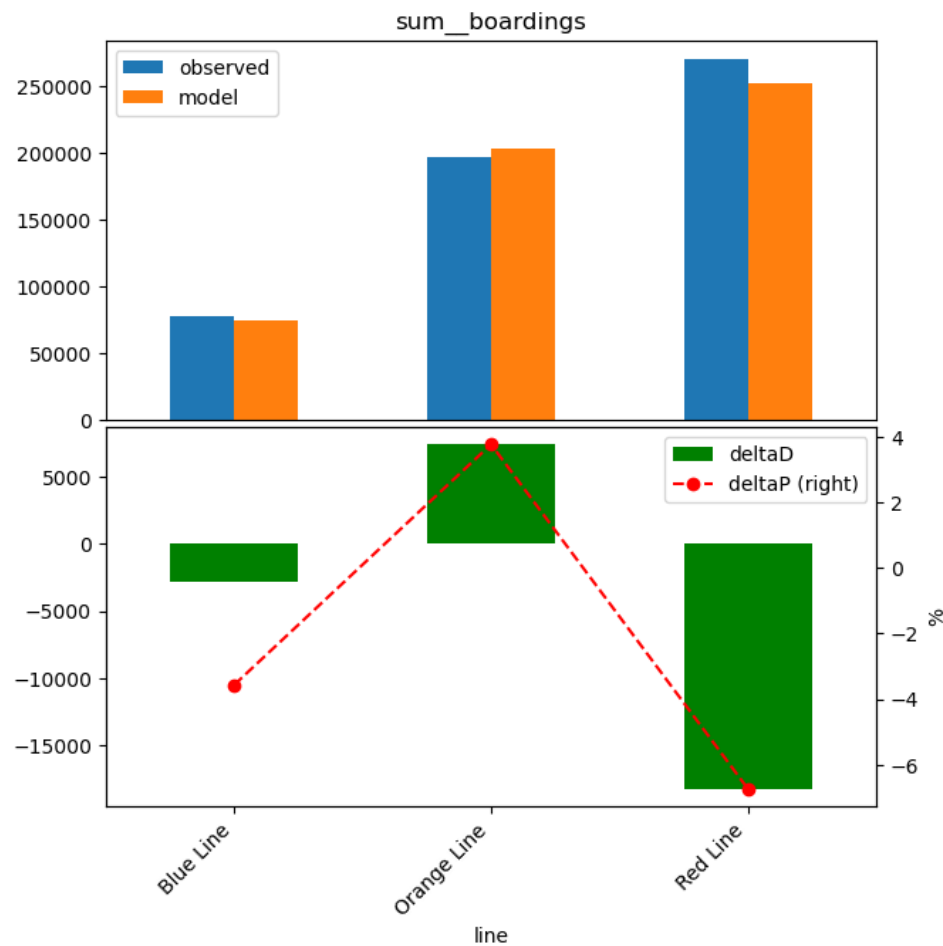
Ferry boardings may be underestimated since the model does not include estimates of boardings by people traveling by ferry for pleasure.

Transfers

The path-building parameters were refined to better fit the observed transfer rates with the full model assignment.

Transfers using MBTA routes in the model are compared to the onboard survey data by access mode and time period in Figure 47. Transfers across all transit operators are presented in the [Transfer validation report](#).

Figure 47
Heavy Rail Boardings Comparison



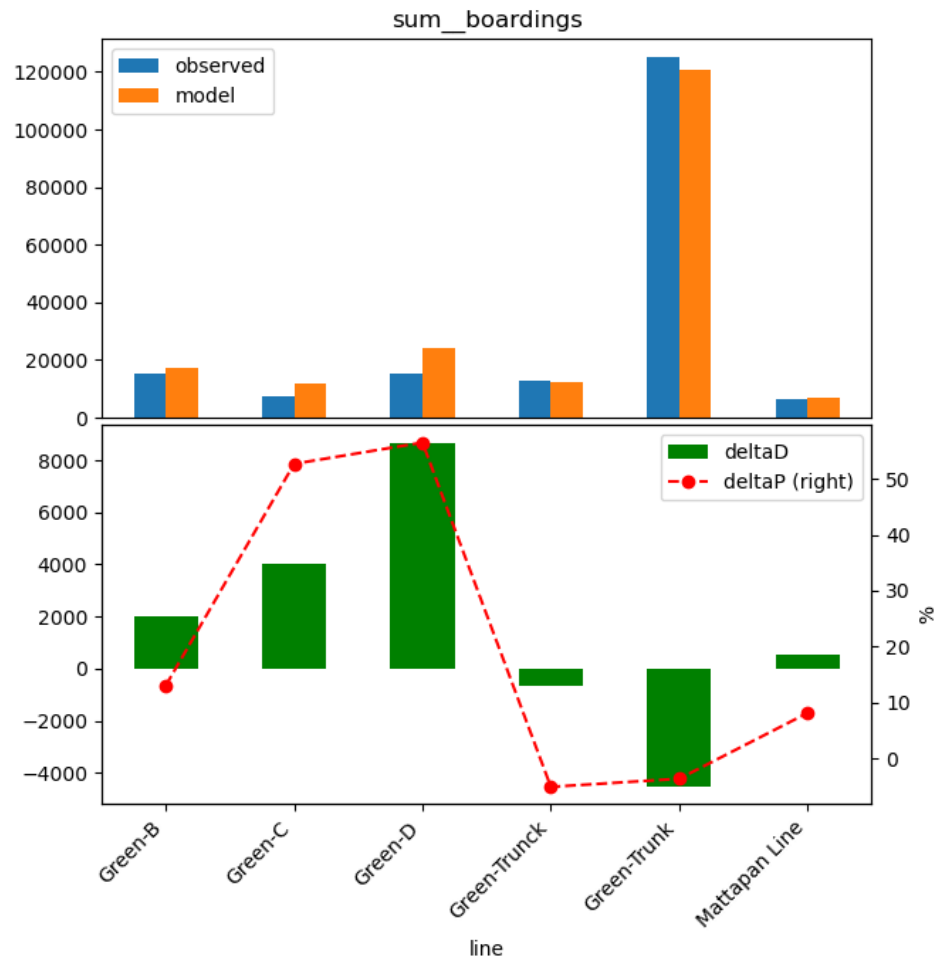
Route Level

Route level checks confirm network coding, representation of supporting transit services, and OD flows.

Heavy rail boarding estimates are all very close to observed boardings, with less than a 10 percent difference.

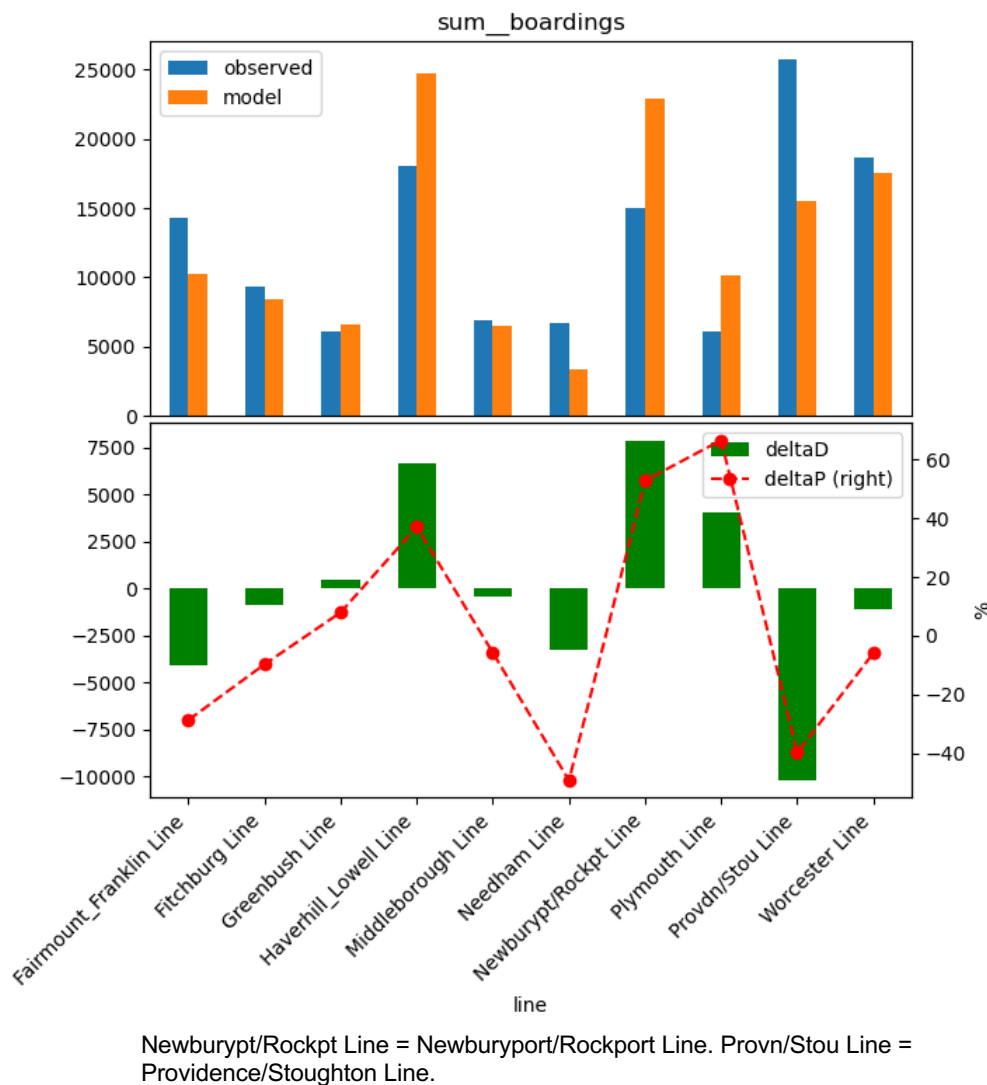
Light rail boardings are good on the trunk section, but the C and D Branches of the Green Line are overestimated. (See Figure 48.)

Figure 48
Light Rail Boardings Comparison



Several commuter rail lines are overestimated. The Plymouth, Haverhill/Lowell, and Newburyport/Rockport Lines are all overestimated by more than 20 percent. The Providence Line is underestimated, but the Rhode Island Public Transit Authority services are not represented in the model and this restricts some transit paths between zones. The Needham and Fairmount/Franklin Lines, which serve urban neighborhoods, are underestimated, indicating a lack of representation of short distance walk-transit trips.

Figure 49
Commuter Rail Boardings Comparison



3.5 SENSITIVITY TESTS

A series of sensitivity tests are run where a single parameter is adjusted and a set of metrics compiled to gauge the model response. The [Sensitivity Test report](#) compiles the test metrics compared to the baseline scenario for travel in the Boston region. The report is also useful to reveal which aspects of TDM23 are sensitive to changes in a particular parameter. This section describes how each sensitivity test is implemented and the response in the model as shown in the Sensitivity Test report.

3.5.1 Work From Home

An increase in remote work is represented by enabling the work-from-home preset spring 2023 values for worker and employment sector remote levels. This component reduces work-related trips (home-based work and non-home-based work). Attractions for all trip purposes are calculated against the reduced employment. As explained in the Work From Home component description in Section 2.6.6, the component only reduces work trips; it does not increase non-work trips that may be completed by the remote worker (e.g., grocery shopping).

Work-related trips are reduced by 25 percent, consistent with the Boston Region MPO input rate. Overall, trips are reduced by 6.7 percent. Transit trips are reduced at a higher rate than auto and non-motorized trips because transit mode share is highest for work trips. School bus mode share effectively increases, but that is due to the overall trip number in the denominator decreasing and school trips not changing.

The change in VMT is higher than the change in trips (8.1 percent) reflecting that home-based-work trips are more likely to be drive-alone trips and longer distance and thus have a higher impact on VMT. The change in vehicle-hours traveled (VHT) is higher still (14.3 percent), indicating that congestion is reduced. This is borne out in the reduction of congested VMT (19.8 percent).

Commuter rail and ferry transit boardings decrease the most of any transit mode. This is reasonable as these services are designed to serve travelers commuting to work.

3.5.2 Ride-Source Availability

To represent the increased availability of ride-source services, for example through automation of ride-source vehicles, the initial waiting time and fares are reduced by 50 percent. Trip mode choice and distribution will utilize the new parameters in calculating ride-source utilities.

Trips shift equally from transit and nonmotorized trips to ride-source trips. Across transit modes, there is less of a decrease in rail trips than bus trips due to the advantage of rail service in congested areas.

Increased ride-source availability also increases congestion and slightly decreases average speed.

3.5.3 Electric Bikes

To represent the electrification and proliferation of e-bikes, an adjustment is made to the existing bike mode. To represent that biking may be done with an electric bike, the average speed and maximum range are increased by 25 percent: from 12 miles per hour (mph) and 12 miles to 15 mph and 15 miles.

This change is applied to the bike speed inputs and availability thresholds. Trip mode choice and distribution will utilize the new parameters in calculating bike utilities and availability.

This scenario produced a large increase in nonmotorized trips, shifting mostly from transit and, to a lesser extent, from auto and school bus modes.

All transit modes except regional bus had a decrease in boardings. This implies that the longer biking range presents an alternative even to the longer haul transit modes of commuter rail and ferry.

3.5.4 Highway Toll Increase

Highway tolls currently coded in the model network are doubled. Tolls are coded along I-90, the Callahan and Sumner Tunnels, and on the Tobin Bridge. Trip distribution and mode choice for household trips and highway assignment for all trips are sensitive to this change.

Highway tolls are present where there are few alternative routes with similar travel times. Therefore, the response in the model is to shift destinations more so than mode. Thus, the highway toll has a small impact on mode share. Auto mode shares and trips are reduced, but so are transit mode shares and overall boardings. Transit boardings are reduced as fewer trips are distributed along paths with an increased highway toll. Express bus and regional bus transit boardings both increase by 6 percent and 3 percent, respectively, as highway congestion is slightly reduced.

Overall, VMT is reduced by about 1 percent, primarily on freeways, expressways, and ramps.

3.5.5 Transit Fare Decrease

For simplicity, transit fares are decreased by applying a factor of 0.7 to the transit fare table in the transit skims. Trip distribution and mode choice use the reduced fare, but there are no changes in the path building and changes such as shorter walk distances and higher transfers will be underestimated.

Trip mode shifts to transit mostly from auto, but some from nonmotorized modes. The shift has a negligible impact on roadway congestion metrics.

Transit linked trips increase by 2.6 percent and boardings by 3 percent. The modes with the largest increases are those that are more expensive: commuter rail, ferry, and regional bus. The percentage increase in boardings implies a fare elasticity of negative 0.1 [-0.03 / 0.30]. This is smaller in magnitude than the negative 0.21 overall elasticity implied in a study CTPS conducted in 2017 to study a planned MBTA fare increase. The smaller magnitude may be due to not incorporating the fare change into the path-builder inputs. It may also imply that the \$15 per hour transit traveler value of time is too high. Studies of transit fare changes should review this sensitivity and potentially account for an underestimated response in the model outputs.

3.5.6 LRTP Highway and Transit Projects

The additional highway and transit projects defined as part of the Long-Range Transportation Plan (LRTP) are described in Appendix A. The projects coded into this network are those defined in the LRTP as well as any projects completed since the model base year (2019) and those programmed in an MPO or State Transportation Improvement Program or Capital Investment Plan. The networks with these projects coded are run with the base-year socioeconomic and other inputs.

The increased transit accessibility decreases the share of sufficient vehicle households slightly (~0.4 percent) and increases the insufficient and zero vehicle households. This change has a negligible impact on the trips generated. There is a substantial mode shift due to the change in network conditions. This scenario sees the largest increase in transit ridership, largely due to the Green Line Extension, which opened in 2019, as well as the service improvements from the Bus Network Redesign and Commuter Rail Transformation projects.

This scenario results in a decrease in emissions and improvement across all equity metrics.

3.5.7 Disable Bus Lanes

Bus lanes are defined by a link attribute. (See Section 2.5.2.) To test the model response to bus lanes, a special parameter was created to override bus lane settings, effectively disabling the link attribute.

Removing bus lanes shifts trips from transit and nonmotorized modes to auto modes. The nonmotorized mode shift is due to the increased auto speed making auto modes more attractive. VMT and VHT both increase slightly along with

emissions, these being regional values, it is expected that a local analysis would show a larger change.

APPENDICES

Appendix A—Scenario Definitions

Appendix A describes the preset parameter inputs:

- 2019 base year
- 2050 horizon year with Long-Range Transportation Plan (LRTP) projects

A.1 NETWORKS

A.1.1 Highway Network

The 2019 base-year highway network is coded to be consistent with highway projects that were complete for the majority of 2019.

Table A-1 lists the projects that are added to represent the 2050 horizon year including the LRTP projects.

Table A-1
2050 Plan Scenario Highway Projects

| | Project Name | MassDOT Project ID |
|----|--|---------------------------|
| 1 | Middlesex Turnpike Improvements Phase III | 29492 |
| 2 | Route 18 Capacity Improvements (Weymouth) | 601630 |
| 3 | Reconstruction on Route 20 from Richardson's Corner easterly to Route 12 | 602659 |
| 4 | Reconstruction of East Street (Route 9) | 604003 |
| 5 | New Boston Street bridge replacement at MBTA Lowell Line | 604996 |
| 6 | Route 9 widening from Middle Street to Maple Street from one lane in each direction to two lanes in each direction | 605032 |
| 7 | Gateway East on Route 9 in Brookline: Realign Walnut Street to the intersection of Route 9 opposite Pearl Street forming a four-way intersection | 605110 |
| 8 | Route 27 Bridge Replacement over Route 9 (Natick) | 605313 |
| 9 | Intersection improvements at Route 1 and University Avenue/Everett Street (Norwood) | 605857 |
| 10 | Route 146 (northbound and southbound) bridge replacement over West Main Street and improvements on Route 146 at Elm Street, Elmwood Street, and West Main Street | 605964 |
| 11 | Route 126/Route 135 Grade Separation (Framingham) | 606109 |
| 12 | I-95/Dedham Street Interchange Reconstruction | 606146 |

| | Project Name | MassDOT Project ID |
|----|--|---------------------------|
| 13 | Rutherford Avenue/Sullivan Square (Boston) | 606226 |
| 14 | Intersection and signal improvements at First Street and North Street near Berkshire Medical Center | 606233 |
| 15 | I-90 Allston Interchange and West Station | 606475 |
| 16 | Quincy Burgin Parkway-Cliveden Street Bridge | 606518 |
| 17 | Reconstruction of Highland Avenue, Needham Street, and Charles River Bridge, from Webster Street to Route 9 | 606635 |
| 18 | Improvements on Route 9 at I-495 Interchange | 607701 |
| 19 | Rehabilitation of Mount Auburn Street (Route 16) | 607777 |
| 20 | Reconstruction of Boston Road (Route 20) | 607869 |
| 21 | Realignment of Tucker Road to Route 6 and Hathaway Road | 607871 |
| 22 | Rourke Bridge Replacement: two travel lanes in each direction | 607887 |
| 23 | I-495 and I-90 Interchange Redesign | 607977 |
| 24 | McGrath Boulevard: remove the existing McCarthy Viaduct and replace it with an at-grade boulevard (Somerville) | 607981 |
| 25 | Route 79 (Western Expressway) conversion from a limited access highway to an at-grade urban arterial (Fall River) | 608049 |
| 26 | Improvements at Route 44/28/18 (Rotary) | 608124 |
| 27 | Roundabout construction at the intersection of Patriots Road, South Main Street, North Main Street, and Gardner Road | 608784 |
| 28 | Worcester Kelley Square Improvement Project | 609226 |
| 29 | Ramp Improvements at I-495 southbound to I-290 westbound (Marlborough and Hudson) | 610552 |
| 30 | Conley Haul Road: new terminal access road | |
| 31 | I-495 Route 1A Ramps | |
| 32 | I-495 NB Route 140 Ramp | |
| 33 | I-91 Viaduct Study - Only Agawam Rotary (Springfield) | |
| 34 | Route 2 at South Athol Road: New interchange design and Route 2 expansion to four lanes | |
| 35 | Route 4/225 (Bedford Street/Hartwell Avenue): Reconstruction of major intersections as multi-lane roundabouts. (Lexington) | |
| 36 | I-91 Interchange 19 at Route 9: Construction of a two-lane roundabout at the intersection of Route 9 and Damon Road/I-91 NB off ramp | 604597 |

MassDOT = Massachusetts Department of Transportation. MBTA = Massachusetts Bay Transportation Authority.

A.1.2 Transit Network

TDM23 includes all MBTA fixed-route services and most of the fixed-route services provided by regional transit authorities (RTAs), as well as regional bus service and shuttle service.

RTA services are included where they have a substantial ridership, and the ridership is consistent throughout the year. For example, transit service on Cape Cod and Martha's Vineyard are not included because their ridership is seasonal.

Tables A-2, A-3, and A-4 show the regional transit, regional bus, and shuttle services represented in TDM23.

Table A-2
Regional Transit Authority Service Included in TDM23

| Regional Transit Agency |
|--|
| Brockton Area Transit Authority (BAT) |
| Burlington |
| Cape Ann Transportation Authority (CATA) |
| Greater-Attleboro-Taunton RTA (GATRA) |
| Lexpress (Lexington) |
| Lowell RTA (LRTA) |
| Merrimack Valley RTA (MVRTA) |
| MetroWest RTA (MWRTA) |
| Pioneer Valley Transit Authority (PVRTA) |
| Southeastern RTA (SRTA) |
| Worcester RTA (WRTA) |
| RTA = regional transit authority. |

Table A-3
Regional Bus Service Included in TDM23

| Regional Bus Service/Operator |
|--|
| Bloom |
| Boston Express |
| C&J |
| Concord Coach |
| DATTCO Motorcoach |
| Peter Pan |
| Plymouth & Brockton Street Railway Co. |
| Yankee Line |
| Logan Express/Massport |

Table A-4
Shuttle Service Included in TDM23

| Shuttle Operator |
|--------------------------------------|
| Bedford Local Transit |
| Joseph's/JBL |
| Massachusetts General Hospital (MGH) |
| Massport |
| Mission Hill |
| Dedham |

2019 Transit Service

In 2019, the MBTA started implementing service changes related to the Better Bus Project.²² To avoid a mixed implementation and lagging ridership response to service changes, the 2019 scenario has implemented the fall 2018 service definition and utilizes ridership data from that period for the validation reports.

Transit route alignment, station location, and headways for the following transit operators were updated based on service plans defined in General Transit Feed Specification (GTFS). The GTFS sources are listed in Table A-5.

Table A-5
Transit Service Plan Source

| Transit Operator | Service Plan Source |
|-------------------------|---|
| MBTA | https://mbta-massdot.opendata.arcgis.com/datasets/MassDOT::gtfs-recap-fall-2018/about |
| Cape Ann | https://transitfeeds.com/p/massdot/95/20180831 |
| Brockton | https://transitfeeds.com/p/massdot/94/20180902 |
| MetroWest | https://transitfeeds.com/p/massdot/101/20181004 |
| Pioneer Valley | https://transitfeeds.com/p/massdot/104/20181001 |
| Worcester | https://transitfeeds.com/p/massdot/108/20181005 |

MBTA = Massachusetts Bay Transportation Authority.

2050 Transit Service

The 2050 transit service replaces the MBTA bus, express bus, bus rapid transit, light rail, and heavy rail as defined in the MBTA bus network redesign service plan.²³ The commuter rail service is as defined by the commuter rail transformation service plan.²⁴

²² <https://www.mbtta.com/projects/better-bus-project>

²³ The Service Plan was received from the MBTA as GTFS file on November 2022.

²⁴ The Service Patterns for Power Study was received from MassDOT Rail and Transit in February 2023.

Discrete transit projects included in the 2050 transit network are listed in Table A-6.

Table A-6
2050 Plan Scenario Transit Projects

| | |
|----|---|
| 1 | Clockface commuter rail schedules |
| 2 | Green Line Branch northern termini changes |
| 3 | Green Line Extension - Medford |
| 4 | Green Line Extension - Union Square |
| 5 | MBTA Bus Network Redesign |
| 6 | MBTA Commuter Rail - Vision |
| 7 | South Coast Rail, Phase 1 |
| 8 | New Red Line Cars – reduced headway |
| 9 | New Orange Line Cars – reduced headway |
| 10 | I-90 Allston Interchange and West Station including shuttles |
| 11 | Bus Lanes (MBTA Project ID) |
| | Broadway (Project CHE-20-1P-01, CHE-20-1P-02) |
| | Broadway AM IB Peak (REV-BRO-20-1-01, REV-BRO-20-1-02, REV-BRO-20-1-03) |
| | Columbus Ave, Seaver to Ruggles (BOS-COL-20-1-01, BOS-COL-20-1-02, BOS-COL-21-1-01, BOS-COL-21-1-02, BOS-COL-21-1-03, BOS-COL-21-1-04, BOS-COL-21-1-05) |
| | Florence St – MAL-FLO-20-1-01 |
| | Main St – West/Oakes to Sweetser Circle (DOT-SWE-20-1-02, DOT-SWE-20-1-03) |
| | North Common St – LYN-COM-20-1 |
| | Sweetser Circle (DOT-SWE-20-1-01, DOT-SWE-20-1-04, DOT-SWE-20-1-05) |
| | Washington St (Gateway East) – both directions (Project BRO-WAS-20-1-01) |
| | Washington St Queue Jumps – SOM-WAS-20-1, SOM-WAS-20-2 |
| | Washington St, Roslindale – BOS-WAS-20-1-01, BOS-WAS-20-1-01, BOS-WAS-20-1-02, BOS-WAS-20-1-03, BOS-WAS-20-1-04, BOS-WAS-20-1-05, BOS-WAS-18-1-06 |
| | Western Ave – LYN-WES-20-1-01, LYN-WES-20-2-02 |
| | Mass Ave North CAM-MASS-XX-X |
| 12 | Green Line Stop Consolidations/Relocations (B and C Branches) |

MBTA = Massachusetts Bay Transportation Authority.

Transit Fare

Trips are not segmented by fare type (single ride, pass, reduced fare, etc.), therefore a weighted average fare is calculated based on the observed distribution of fares paid on each transit mode. The fare inputs to TDM23 are by mode for Massachusetts Bay Transportation Authority (MBTA) services (local bus, bus rapid transit, light rail, heavy rail, commuter rail, and ferry) and by route for RTA, shuttle, and regional bus services.

Fare values are specific to the scenario to represent contemporary levels, but with constant 2010 dollars. For example, express bus services changed from a zonal fare (inner and outer) to a single fare category in July 2021.

State Fiscal Year 2019 average fare is implemented for the 2019 base year to be the most similar to the service plan.

The 2050 scenario incorporates the fare change for express bus services changing from a zonal fare (inner and outer) to a single fare category in July 2021. Fare increases are assumed to track inflation; therefore, the 2050 scenario has the same fare rate.

The average fares (in 2019 dollars and converted to 2010 dollars) by MBTA mode are shown in Table A-7. Tables A-8 and A-9 show the commuter rail fare inputs (in 2010 dollars) and the transfer fare rates.

Table A-7
Transit Mode Fare

| Mode Fares | 2019\$ | 2010\$ |
|---------------------|---------------|---------------|
| Local Bus | \$ 1.02 | \$ 0.86 |
| Bus Rapid | \$ 1.28 | \$ 1.08 |
| Light Rail | \$ 1.47 | \$ 1.25 |
| Heavy Rail | \$ 1.47 | \$ 1.25 |
| Express Bus (inner) | \$ 3.33 | \$ 2.82 |
| Express Bus (outer) | \$ 4.58 | \$ 3.88 |
| Ferry (inner) | \$ 2.86 | \$ 2.42 |
| Ferry (outer) | \$ 7.87 | \$ 6.67 |

Table A-8
Commuter Rail Zonal Fare Inputs

| Commuter Rail Zone | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
|--------------------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|
| 1 | \$ 1.64 | \$ 4.60 | \$ 4.92 | \$ 5.20 | \$ 5.70 | \$ 6.58 | \$ 7.03 | \$ 7.29 | \$ 8.13 | \$ 8.42 | \$ 8.76 |
| 2 | \$ 4.60 | \$ 2.36 | \$ 2.47 | \$ 2.75 | \$ 2.97 | \$ 3.69 | \$ 4.06 | \$ 4.34 | \$ 4.75 | \$ 5.14 | \$ 5.54 |
| 3 | \$ 4.92 | \$ 2.47 | \$ 2.36 | \$ 2.47 | \$ 2.75 | \$ 2.97 | \$ 3.69 | \$ 4.06 | \$ 4.34 | \$ 4.75 | \$ 5.14 |
| 4 | \$ 5.20 | \$ 2.75 | \$ 2.47 | \$ 2.36 | \$ 2.47 | \$ 2.75 | \$ 2.97 | \$ 3.69 | \$ 4.06 | \$ 4.34 | \$ 4.75 |
| 5 | \$ 5.70 | \$ 2.97 | \$ 2.75 | \$ 2.47 | \$ 2.36 | \$ 2.47 | \$ 2.75 | \$ 2.97 | \$ 3.69 | \$ 4.06 | \$ 4.34 |
| 6 | \$ 6.58 | \$ 3.69 | \$ 2.97 | \$ 2.75 | \$ 2.47 | \$ 2.36 | \$ 2.47 | \$ 2.75 | \$ 2.97 | \$ 3.69 | \$ 4.06 |
| 7 | \$ 7.03 | \$ 4.06 | \$ 3.69 | \$ 2.97 | \$ 2.75 | \$ 2.47 | \$ 2.36 | \$ 2.47 | \$ 2.75 | \$ 2.97 | \$ 3.69 |
| 8 | \$ 7.29 | \$ 4.34 | \$ 4.06 | \$ 3.69 | \$ 2.97 | \$ 2.75 | \$ 2.47 | \$ 2.36 | \$ 2.47 | \$ 2.75 | \$ 2.97 |
| 9 | \$ 8.13 | \$ 4.75 | \$ 4.34 | \$ 4.06 | \$ 3.69 | \$ 2.97 | \$ 2.75 | \$ 2.47 | \$ 2.36 | \$ 2.47 | \$ 2.75 |
| 10 | \$ 8.42 | \$ 5.14 | \$ 4.75 | \$ 4.34 | \$ 4.06 | \$ 3.69 | \$ 2.97 | \$ 2.75 | \$ 2.47 | \$ 2.36 | \$ 2.47 |
| 11 | \$ 8.76 | \$ 5.54 | \$ 5.14 | \$ 4.75 | \$ 4.34 | \$ 4.06 | \$ 3.69 | \$ 2.97 | \$ 2.75 | \$ 2.47 | \$ 2.36 |

Table A-9
Transfer Fare from Local Bus

| Local Bus Transfer | 2019\$ | 2010\$ |
|--------------------|---------|---------|
| Bus Rapid | \$ 0.26 | \$ 0.22 |
| Light Rail | \$ 0.45 | \$ 0.38 |
| Heavy Rail | \$ 0.45 | \$ 0.38 |

A.1.3 Nonmotorized Network

The base year and 2050 plan scenarios have distinct nonmotorized networks. The 2050 scenario includes the pedestrian facilities included in the I-90 Allston Interchange and West Station project.

A.2 ZONAL DATA

A.2.1 Socioeconomic Data

Socioeconomic inputs are segmented by state with Massachusetts inputs sourced from the UrbanSim models maintained by Metropolitan Area Planning Council (MAPC) and New Hampshire and Rhode Island inputs synthesized from control totals.

Population and household totals for both scenarios are available by model region, state, and metropolitan planning organization through the Socio-Economic (SE) Data tab of the [Model Summary Report](#).

New Hampshire

New Hampshire has developed population projections at the municipal level to 2050.²⁵ The 2016 and 2040 populations in TDM19 were scaled to the projected

²⁵ <https://www.nheconomy.com/office-of-planning-and-development>

2020 and 2050 populations, respectively. Therefore, the 2020 and 2050 distributions by income, size, and workers are consistent with the reference data (2016 and 2040).

For employment, the overall change in workers from 2016 to 2020 and from 2040 to 2050 was applied to the reference data with consistent proportions across employment sectors.

Rhode Island

Rhode Island has not updated its population and employment forecasts since the previous LRTP that forecast to 2040. The Massachusetts population forecasts show a slight decline in population from 2040 to 2050, therefore the 2040 Rhode Island forecasts were assumed to be a reasonable estimate for 2050 as well.

A.2.2 Enrollment

K-12 and college enrollment are consistent from the base- to forecast-year scenarios.

Note that home-based school (K-12 trips) are balanced to the home-end trip productions. Therefore, using the same enrollment inputs assumes that school locations and relative sizes are consistent between the base and forecast year.

College enrollment, however, determines the number of home-based-university trips. Therefore, the base- and future-year scenarios have the same number of home-based-university trips.

A.2.3 Parking Costs

Parking costs are consistent from the base- to forecast-year scenarios.

TDM23 uses constant 2010 dollars, so parking costs do not need to be changed to reflect inflation. However, parking costs may change due to changing demand for vehicle trips or due to changes in modal options and/or land use.

Costs by travel analysis zones can be visualized in the [interactive parking explorer](#).

A.2.4 Direct Trip Inputs

Direct trip inputs are defined by the zone of production or attraction. The direct trips input are for airport ground access, external trips, and special generators.

Airport Ground Access

Total airport passengers arriving and departing from Logan Airport in 2019 was 42,522,411.²⁶ Based on the analysis from the 2019 air passenger survey and inputs from the Massachusetts Port Authority (Massport), the average weekday airport passengers in May 2019 is estimated to be 125,883. Ten percent of passengers are assumed to transfer, therefore the estimated number of passengers using ground access transportation is 113,295. These passengers are assumed to be evenly split between enplanements and deplanements.

The 2050 scenario leverages Massport projections to its horizon year (2035) and the Federal Aviation Administration (FAA) forecast growth rate from 2035 to 2050. Massport projects the total airport passengers in 2035 to be 53 million, representing an approximate 1.39 percent annualized growth rate. FAA forecasts a higher growth rate (~2.4 percent). The application of these two growth rates produces a 2050 average weekday airport-ground-access passenger estimate of 200,415.

External Trips

External trips are assumed to change consistently with the population change. The most reliable population forecasts are the University of Massachusetts Donahue Institute-generated forecasts for the state of Massachusetts, summarized in Table A-10.

| Table A-10 | | |
|---|-------------------|-------------------------|
| Massachusetts Population Projections | | |
| Year | Population | Growth from 2020 |
| 2020 | 7,029,917 | 0.00% |
| 2025 | 7,106,597 | 1.09% |
| 2030 | 7,195,346 | 2.35% |
| 2035 | 7,242,935 | 3.03% |
| 2040 | 7,263,082 | 3.32% |
| 2045 | 7,271,709 | 3.44% |
| 2050 | 7,267,961 | 3.39% |

The 2050 scenario has a 3.39 percent growth rate applied to the base year external trip inputs. The distribution of external trips and splits between auto and truck trips are consistent between the base and future year.

²⁶ <https://www.massport.com/sites/default/files/2023-10/1219-avstats-airport-traffic-summary.pdf>

Special Generators

Non-work trips to and from major casinos in the region are input as special generators. Trip amounts were derived from traffic impact studies conducted in advance of the casino openings.

The 2019 scenario includes the Everett Encore casino only. The 2050 scenario includes the Encore, MGM Springfield, and Plainville Plainridge Park casinos. Table A-11 shows the input trips by purpose and casino.

Table A-11
Special Generator Input Daily Trips

| Scenario | Special Generator | Social-Recreational Trips | Personal Business Trips |
|-----------------|----------------------------|----------------------------------|--------------------------------|
| 2019 | Everett Encore | 25,000 | 21,295 |
| 2050 | Everett Encore | 29,000 | 24,735 |
| | Springfield MGM | 9,720 | 8,280 |
| | Plainville Plainridge Park | 2,160 | 1,840 |

Appendix B—Model Versions

This appendix describes the changes implemented between successive releases of TDM23. TDM23.0.1 was the initial release version of TDM23, used for the Boston Region Metropolitan Planning Organization's Long-Range Transportation Plan (LRTP) *Destination 2050*. TDM23.1.0 was the first version to be publicly released and was made available in February 2024. The current version of the model is TDM23.2.0.

B.1 TDM23.1.0

This section describes the changes between TDM23.0.1 and TDM23.1.0. Enhancements to the model scripts are first described, followed by changes to the parameters and input data.

B.1.1 Model Scripts

The following enhancements were made in the model scripts:

- The capability to run a highway and transit select query analysis was added through a menu option.
- Interstate 93 zipper lane functionality was improved to decrease the available lanes on the general purpose links in the non-peak direction.
- The work-from-home component was revised to operate at a geographic-specific level. Work-from-home rates for workers could be input at the model region, state, metropolitan planning organization, or town level.
- Walk and bike trip tables were recorded separately.
- An input data check was added for the warm start speed inputs.
- The user interface was restructured to organize the inputs in a more logical way. Output files were also restructured to be named and stored in a more logical way.

There were two changes to the scripts to correct functionality:

- Transit initial wait-time calculations were modified to be consistent between mode choice and route choice.
- Mode choice for home-based-university trips was corrected to assign trips to the shared-ride modes.

B.1.2 Parameters

TDM23.1.0 was recalibrated to improve the model fit with the updated scripts and input data. The calibration focused on adjustments to the mode choice and distribution parameters. Also, as part of the calibration, a park-and-ride (PnR) penalty was added to the Lynn parking lot to reduce the transit-auto trips using that facility.

B.1.3 Input Data

Input data make up the preset scenarios. Refer to Appendix A for a complete list of scenario inputs.

Input data changes were organized by network inputs (transit and highway, socioeconomic data inputs, and other inputs).

Transit Network

Continued review of the transit network revealed routes and PnR lots that were unused. These were removed for clarity.

Routes that showed a discontinuity due to changes in the highway network were fixed.

Roadway links with missing or incorrect bus lane codes were fixed.

Transit fares were updated across all modes to be in 2010 dollars, consistent with other model cost inputs.

Heavy Rail

Blue Line coding was updated to remove a solitary run and combine with a frequent pattern.

Red Line headways in the 2050 scenario were updated to 6 minutes in the peak periods and 7.5 minutes in the off-peak periods.

Commuter Rail

Updates to the Needham Line were applied to correct for long travel times and missing walk connectors.

Waltham PnR lot parking costs were updated.

Highway Network

The 2050 highway network was updated with two projects:

- **Rourke Bridge replacement in Lowell** (MassDOT Project ID 607887). The number of lanes on Rourke Bridge was updated in the model network.
- **Reconstruction of East Street (Route 9) in Pittsfield** (MassDOT Project ID 604003). The number of lanes on East Street, from the intersection of East Street and Lyman Street to the intersection of East Street with Merrill Road, was increased in the model network.

Corrections and enhancements to the highway network are categorized as changes to the network alignment (e.g., where roadways were missing or incorrect) or changes to the network attributes (e.g., where the roadway definitions were incorrect).

Network Alignment

Network alignment changes were as follows:

- Removed flyover link cutting across the rotary (at Routes 18, 28, and 44) in Middleborough
- Added roundabout on Route 6 eastbound at Route 149 (Exit 65)
- Added I-495 northbound frontage road
- Reviewed the network and removed duplicate links
- Reconfigured ramps as the following locations:
 - Route 12 and Route 2
 - Route 24 in Tiverton, Rhode Island
 - I-90 westbound in Boston
 - I-90 Exit 125 (Route 16 West Newton)
 - I-95 Exit 43 A-B (Winter Street/Totten Pond Road)
 - Route 3 Exit 3
 - Route 2 in Devens, Massachusetts
 - I-90 westbound interchange with I-95
 - I-90 Exit 3 (Route 41) in West Stockbridge

Network Attributes

Network attribute changes include the following:

- Updated free flow speeds on all facilities with estimated free flow speeds from Replica
- Converted tolls and PnR costs to 2010 dollars

- Distinguished freeway-to-freeway ramps from other ramps in the facility type designation
- Corrected roadway lanes and directionality in the west Boston area as reported in the Red/Blue Connector Study
- Corrected functional class and facility type on Pleasant Street in Lee
- Corrected the number of lanes on Route 18
- Corrected the facility type on Route 3 south between Braintree and Cape Cod
- Corrected facility type for an Everett roadway

Socioeconomic Inputs

The Metropolitan Area Planning Council (MAPC) updated the Massachusetts and Boston Region UrbanSim models with corrected block definitions and the latest MassBuilds data. The produced run is versioned: Statewide – 97, MAPC Region – 176. Note that population and employment control totals are unchanged.

Other Inputs

The 2050 estimate of Logan Airport passengers was updated to be consistent with Massachusetts Port Authority (Massport) and Federal Aviation Administration forecasts.

B.2 TDM23.2.0

This section describes the changes between TDM23.1.0 and TDM23.2.0. Modifications to the model scripts are first described, followed by changes to the parameters and input data.

B.2.1 Model Scripts

The following enhancements were made in the model scripts:

- The python environment (tdm23_env_1) was updated to support new utilities, including TMIP-EMAT, and the utility platform.
- Non-home-based non-work (NHBNW) trip productions were distributed according to the attractions of NHBNW. Previous versions were distributed using both NHBNW and non-home-based work (NHBW) attractions that skewed trip activity around employment centers.

There were several changes to the scripts to correct functionality:

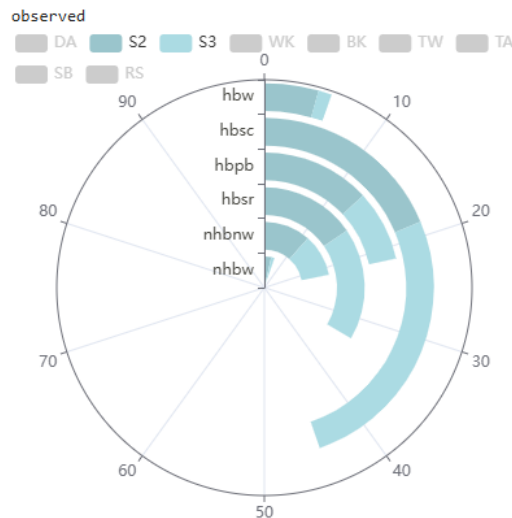
- **Transit Access Density** calculations were updated to use employment and population density. Previous versions used worker and population density. This change produces higher access density values for employment centers and some reduced values for mid-level population centers.
- **Household Size-Income Categories** were updated to have a variable high-income threshold. Previous versions had a fixed high-income threshold that resulted in fewer large households with medium-income.
- **PM Peak and Night Transit Congested Times** were corrected to use the congested speed from the highway network, as is done for AM peak and midday periods. Previous versions used free-flow speeds for PM peak and nighttime periods that increased use of transit services in mixed traffic, such as local and express buses.
- **PnR Link Availability** was restricted to only transit-auto paths. These links were available in the highway assignment in previous versions causing some unreasonable routing.
- **Assignment Only** run mode issues in setting output paths and running summaries were fixed.

B.2.2 Parameters

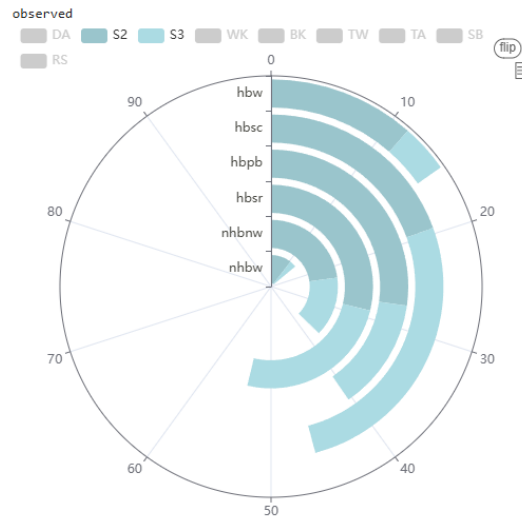
The changes in intersection density inputs described in Section B.2.3 and the script changes in access density both significantly impact model results. Additionally, an error was discovered in the household survey processing that led to an underestimation of the shared-ride modes. (See Figure B-1.)

Figure B-1
Mode Share Target Comparison

TDM23.1.0 Targets



TDM23.2.0 Targets



In addition to these changes, sensitivity tests of a localized area showed a stronger response to parking cost changes in trip distribution than mode choice. This response implies the logsum parameter overstates the impact of change in mode utility on the attractiveness of a destination. Reducing this value shows a stronger response in mode choice while still connecting distribution to changing utilities. This is reasonable for trip purposes, such as work, where travelers are more likely to switch mode than destination. Trip purposes such as social recreation may be more sensitive to parking costs or transit service changes and thus shift destination. Table B-1 shows the calibrated logsum parameter values.

Table B-1
Logsum Parameter Values

| Purpose | Logsum Parameter Value |
|-------------------|------------------------|
| Work | 0.4 |
| Personal Business | 0.7 |
| Social Recreation | 0.8 |
| Non-Home Based | 0.7 |

These values are confirmed with a sensitivity test that changed parking costs in the Seaport district of Boston. Tables B-2 and B-3 present the two testing scenarios.

Table B-2 illustrates the changes in the number trips and mode shifts when parking costs are decreased, and Table B-3 shows results based on an increase

in parking costs. TDM23.2.0 exhibits lower sensitivity to parking cost changes in the trip distribution step.

Table B-2
Parking Cost Decreased

| | TDM23.1.0 Base | | | TDM23.2.0 Base | | |
|--------------------|----------------|--------------|----------------|----------------|--------------|----------------|
| Daily Person Trips | \$20 Parking | \$10 Parking | Percent Change | \$20 Parking | \$10 Parking | Percent Change |
| Auto | 59063 | 80587 | 36.4% | 71849.5 | 85669 | 19.2% |
| Non motorized | 60940 | 60285 | -1.1% | 49168 | 47913 | -2.6% |
| Transit | 12589 | 12546 | -0.3% | 19106 | 17643 | -7.7% |
| School bus | 23 | 23 | 0.0% | 24 | 24 | 0.0% |
| All | 132615 | 153441 | 15.7% | 140148 | 151249 | 7.9% |

Table B-3
Parking Cost Increased

| | TDM23.1.0 Base | | | TDM23.2.0 Base | | |
|--------------------|----------------|--------------|----------------|----------------|--------------|----------------|
| Daily Person Trips | \$20 Parking | \$30 Parking | Percent Change | \$20 Parking | \$30 Parking | Percent Change |
| Auto | 59063 | 48255 | -18.3% | 71849.5 | 63402 | -11.8% |
| Non motorized | 60940 | 61321 | 0.6% | 49168 | 49975 | 1.6% |
| Transit | 12589 | 12610 | 0.2% | 19106 | 20004 | 4.7% |
| School bus | 23 | 23 | 0.0% | 24 | 24 | 0.0% |
| All | 132615 | 122209 | -7.8% | 140148 | 133404 | -4.8% |

With these changes, the following components were recalibrated:

- **Vehicle Availability:** Corrected for updated transit-access density and intersection-density travel analysis zone (TAZ) values
- **Trip Generation:** Corrected trip-production rates with new shared-ride mode choice targets, and increased trip-attraction rates to better match productions
- **Trip Distribution:** Correct for updated logsum values and mode choice utilities

- **Mode Choice:** Corrected for updated transit-access density and intersection density TAZ values and to fit new shared-ride mode choice targets

B.2.3 Input Data

Input data make up the preset scenarios. Refer to Appendix A for a complete list of scenario inputs.

Input data changes are organized by network inputs (transit and highway, socioeconomic data inputs, and other inputs).

Transit Network

Bus/Shuttles:

- Three shuttles serving West Station were added to the 2050 network.
- Ruggles Shuttle was updated.

Heavy Rail/Light Rail

- Green Line Stop Consolidations/Relocations on the B Branch for 2050:
 - Chestnut Hill Avenue and South Street stations were consolidated into a single, new station on the west side of the Chestnut Hill Avenue and Commonwealth Avenue intersection.
 - Boston College station was relocated to the median of Commonwealth Avenue.
- Green Line Stop Consolidations/Relocations on the C Branch for 2050:
 - Brandon Hall and Fairbanks Street stations were consolidated into a single, new station located between the two current stations.
 - Summit Avenue station was shifted to the east side of Summit Avenue.
 - Kent Street station was closed.

Commuter Rail

- Worcester Line headways and time to next stops were updated based on more recent information on the Allston Project.

Highway Network

The 2050 highway network was updated with four projects:

- **I-91 Interchange 19 at Route 9:** Construction of a two-lane roundabout at the intersection of Route 9 and Damon Road/I-91 northbound off-ramp
- **Clark Road at the Route 3 Northbound and Southbound Ramps:** Adding a slip ramp from Clark Road to Route 3
- **Route 128/Exit 19 at Brimbal Avenue:** Interchange reconstruction at Route 128/Exit 19 at Brimbal Avenue (Phase II) involves building a bridge from Brimbal Avenue over Route 128 to Dunham Road, two rotaries, and new ramps on and off the highway
- **Route 116 in the City of Chicopee:** Reduction from two lanes of travel to one lane of travel in each direction along Route 116 (Chicopee Street) in the City of Chicopee from Meadow Street to Springfield Street (Davitt Bridge)

Corrections and enhancements to the highway network are categorized as changes to the network alignment (e.g., where roadways were missing or incorrect) or changes to the network attributes (e.g., where the roadway definitions were incorrect).

Network alignment

- Add roundabout on Route 6 EB at Route 149 (exit 65) in Barnstable
- Add roundabout on Route 128 NB at Route 22 in Beverly
- Add roundabout on Route 146 at Elm Street in Milbury
- Add roundabout on I-190 at Route 12 in Sterling

Network attribute

- Reviewed the network and updated the directionality, number of lanes, or facility type.

Nonmotorized Network

A separate 2050 nonmotorized network was developed to represent the planned changes in the I-90 Allston Interchange and West Station project that include the new street grid and Malvern Street transit bridge.

Socioeconomic Inputs

The Metropolitan Area Planning Council (MAPC) updated the Massachusetts and Boston Region socioeconomic projections as follows:

- A zoning constraint was applied to avoid over-assigning employment in denser areas.

- Mass Build assumptions were consistent with the 2050 Long-Range Transportation Plan assumptions.
- The land use around West Station was based on changes completed for the Allston Multimodal Project/West Station work.
- Accessibilities are updated to use TDM23.1.0 estimates.

The produced run is versioned: Statewide – 113, MAPC Region – 198. Note that the changes primarily apply to the allocation of population and employment and there are only negligible changes in the statewide totals.

Other Inputs

Intersection Density

Due to inconsistencies in how the OSM network is coded, intersection density has been capped at 1,000 intersections per square mile for any TAZ. Specifically, within the model area, some TAZs include roads with sidewalks, while neighboring TAZs may only include roads or sidewalks. Although the true levels of walkability and bikeability are similar between these TAZs, the sidewalk coding discrepancy creates variation in the intersection density. The maximum density threshold mitigates these discrepancies.

Enrollment

Redistribution of Harvard College enrollment was based on suggested enrollments in two zones (TAZ 244 and 245) in the Allston Multimodal Project area. To keep the total enrollment in the model region constant, the extra Harvard enrollment removed from the Allston campus was redistributed among other Harvard campuses.

Table B-4
University Enrollment Updates

| TAZ | Default Enrollment | Updated Enrollment | Change |
|------------|---------------------------|---------------------------|---------------|
| 244 | 4,358 | 780 | -3,578 |
| 245 | 0 | 470 | 470 |

TAZ = travel analysis zone.