TDM23: Structures and Performance

TDM23 Version 1.0

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directed by the Boston Region Metropolitan
Planning Organization (MPO). The MPO is composed of
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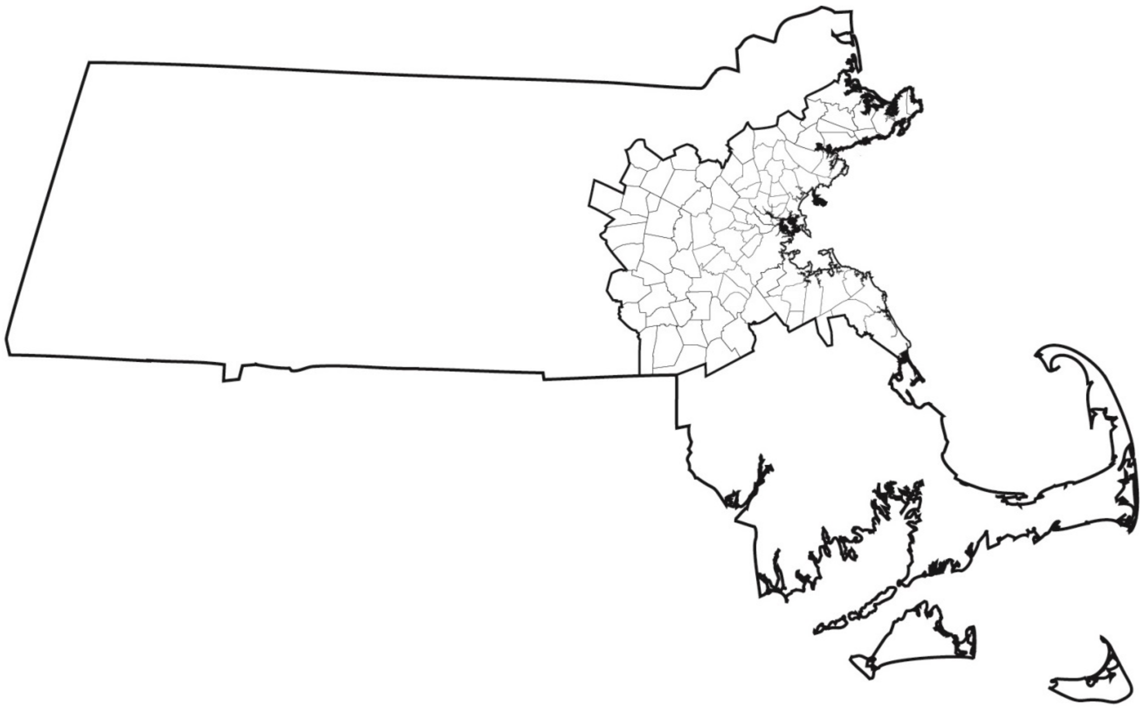
June 2024



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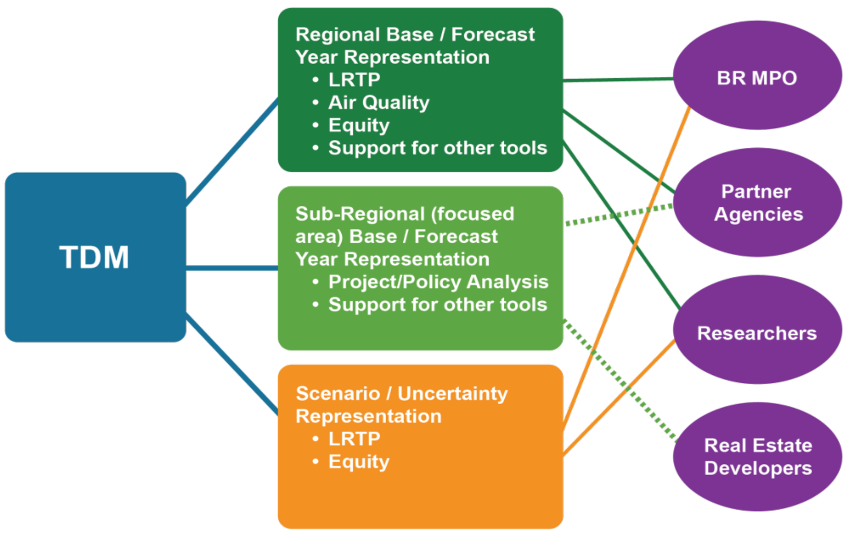
Executive Summary

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 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, 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 is 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 and, thus, are more difficult to evaluate many scenarios. Given the need to evaluate uncertainty, the Boston Region MPO has a first requirement for a model that can evaluate a broader set of scenarios and may adopt other tools to produce finer detail in the demand representation now that this need is better met with TDM23.

The geography covers the entire state of Massachusetts, but limited areas of the surrounding states located away from the Boston Region MPO (see Figure E-2). TDM23 is primarily implemented in [Caliper's TransCAD](https://www.caliper.com/tcovu.htm) Version 9 travel demand software and uses Python for several demand components and post-processors.[1]

Figure E-2
Model Area

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[1] https://www.caliper.com/tcovu.htm

Table E-1 summarizes the demand components of TDM23 followed by Table E-2 that 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)	• Household size, income, workers, children • Transit access density
Work from Home	Share of commute vs. work at home days	• Regionally specific inputs of work-from-home levels
Trip Generation	Resident average daily trips within region by purpose produced and attracted by zone	• Person type • Household size, income, vehicles • Household children, seniors, non-workers • Employment by category
Peak/Off-peak	Segmentation of trips into peak period (AM or PM) and off-peak (MD or NT)	• Trips by zone, purpose and market segment
Trip Distribution	Flow of trips between zones	• Trip productions and attractions by peak/off-peak • Path impedances • Mode choice utilities
Mode Choice	Mode shares and flow of trips by mode	• 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	• Commuter enrollment • Household population

Truck Trips	Generation, distribution, and time of day of medium, and heavy truck trips	• Employment • Path distances
Airport Ground Access	Distribution, time of day, and mode of airport traveler trips	• Airport non-transferring enplanements and deplanements
Special Generator, Externals	Non-average daily trips (airport) and non-resident/outside of region trips (through trips)	• Trips produced/attracted by zone
Time of Day	Outbound and inbound trip time of day period	• 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	• Population and employment density • Transit location by mode
Highway Assignment	Congested speed and volumes by roadway segment	• 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, transfer) by line segment	• Trip tables by transit access mode, market segment, and time of day • Transit network

Table E-3
Model post processors

Component	Estimates	Sensitive To
Equity Analysis	Metrics by equity population	• Impedances and Transit level of service between zones • Demographic data • Trip tables by market segment
Air Quality Analysis	Air quality metrics	• Roadway network with volumes, 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 skewing later results. After the component sequence was calibrated, a series of system-level checks was 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 to identify 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 Table 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

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

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	Matches vehicle sufficiency and number of vehicle trends across household and TAZ attributes Lower fit for larger households with multiple drivers, overestimating sufficient vehicle households and underestimating insufficient vehicle households
Trip Generation	Calibrated trip rates by worker and household are consistent with national averages, adjustments implied underreporting of trips in previous household survey
Trip Distribution	Average trip distances and trip length distributions are calibrated to vehicle availability market segment by purpose. Geographic distributions aggregated to MPO, district, ring, and corridor are consistent with observations.
Mode Choice	Calibrated mode share included a multi-step introduction of ride-source mode that is not present in previous household survey data.
Time of Day	Mode-specific time of day trends are not captured in the model, particularly higher transit and ride-source use in the nighttime period.
University Travel	Calibrated with relaxed thresholds due to limited observations of student travel and data on student home locations
Truck Trips	Calibrated with relaxed thresholds due to limited observations. Assignment and distribution comparisons indicate underestimates of long-distance heavy truck trips.

Airport Ground Access	Consistent distribution and mode patterns with observations by resident / visitor and business / leisure market segments.

Table E-8
System-Level Performance

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

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 not applications or policy recommendations but are run to analyze and understand model sensitivities to potential project and policy applications. The sensitivity tests conducted and key result 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.	Transit has the largest percentage change in trips by mode, commuter rail and ferry have the largest percentage decrease. Has largest reduction in VMT and emissions, but auto mode share increases slightly as congestion is reduced.
Increased Ride-Source Availability	Ride-source waiting time and fares reduced by 50%	Increase in ride-source trips mostly shifts from transit. Added congestion leads to negative impacts on VMT, air quality, and equity metrics. Equity populations have a larger negative impact.
Micro-Mobility	Walk and bike modes are 33% faster and can travel 33% farther	Large increase in nonmotorized trips, shifting from auto and school bus use. Increase in linked transit trips as well because micro-mobility improves transit access and egress. Faster access and egress also reduces transfers. Transit mode increases on higher service level modes (rail and express bus) with decreases on local bus and shuttle routes. Has largest impact on emissions reductions besides work from home. Emission reductions benefit equity populations at a higher rate.
Highway Toll Increase	All highway tolls increased by 100%	Has the smallest impact on mode share of any sensitivity test. In addition to auto trips, transit boardings also decrease presumably due to changed destinations due to tolls.

Transit Fare Decrease	Transit fares decreased by 30%	Increases transit linked trips by 3.5% and boardings by 4%. Largest increases are on more expensive modes (commuter rail, ferry, regional bus).
LRTP Highway and Transit Projects	2050 LRTP Plan scenario highway and transit	
Disable bus lanes	2050 LRTP Plan scenario highway and transit with all bus lanes disabled	

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 MPO involved with the MPO activities and client-directed applications of the model. The steering committee includes representatives from the Metropolitan Area Planning Council's (MAPC) data services group, the Massachusetts Department of Transportation's (MassDOT) Office of Transportation Planning, and the Chair of the Regional Transportation Advisory Council (RTAC) and an MPO board member. 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 program 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 TDM 23 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 Boston region MPO. 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 is 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 broader 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; and
- 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 across 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.

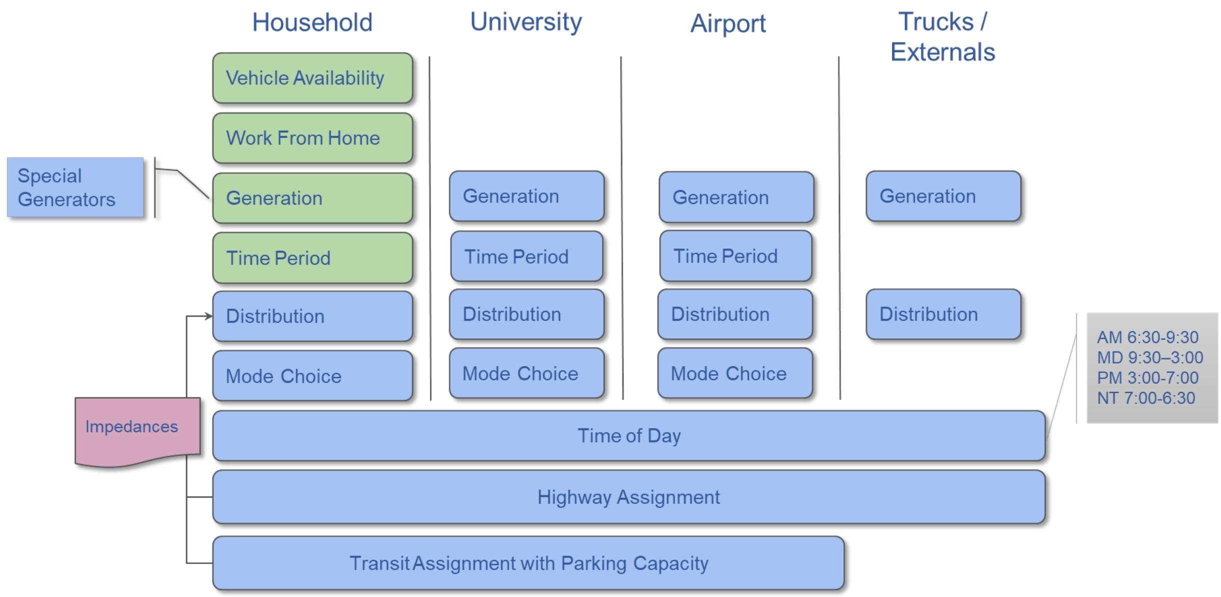
TDM23 is a regional model with a statewide extent. The geography covers the entire states of Massachusetts and Rhode Island and southeastern New Hampshire. The model includes a higher resolution of transit representation than typical statewide models but includes neither a freight model component nor 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.

Figure 1
TDM23 Component Structure



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

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

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 Transit route/stop	Vehicle volume by time of day Congested speeds 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

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 and 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 Statewide	4,497
External Stations	100
Key External Stations	9

TAZ = travel analysis zone.

2.2.2 Temporal

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

- 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 of day to time period roadway and transit conditions are

- 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

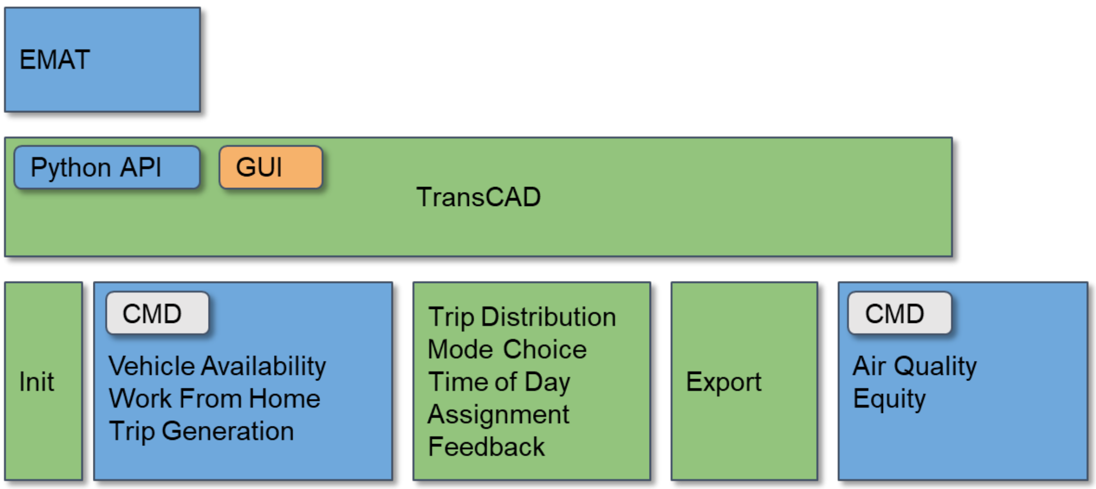
TDM23 is primarily implemented in Caliper’s TransCAD Version 9 travel demand software and is controllable through graphical and programmatic interfaces (graphical user interface [GUI], application programming interface [API]).[2] The GUI is through TransCAD’s flowchart interface that presents major components 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



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 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 Usability-Scenario Management section 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, jobs), school enrollment, representations of walk/bike conditions, parking costs, and direct travel demand inputs

2.4.1 Socioeconomic

Socioeconomic data are generated by UrbanSim or PopulationSim and are organized by Census Block or TAZ for Massachusetts and New Hampshire/Rhode Island respectively.

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 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
TAZ Distribution

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$

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
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

ID	Description	NAICS	NAICS Description	TDM19 employment sector
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 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.

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 and 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

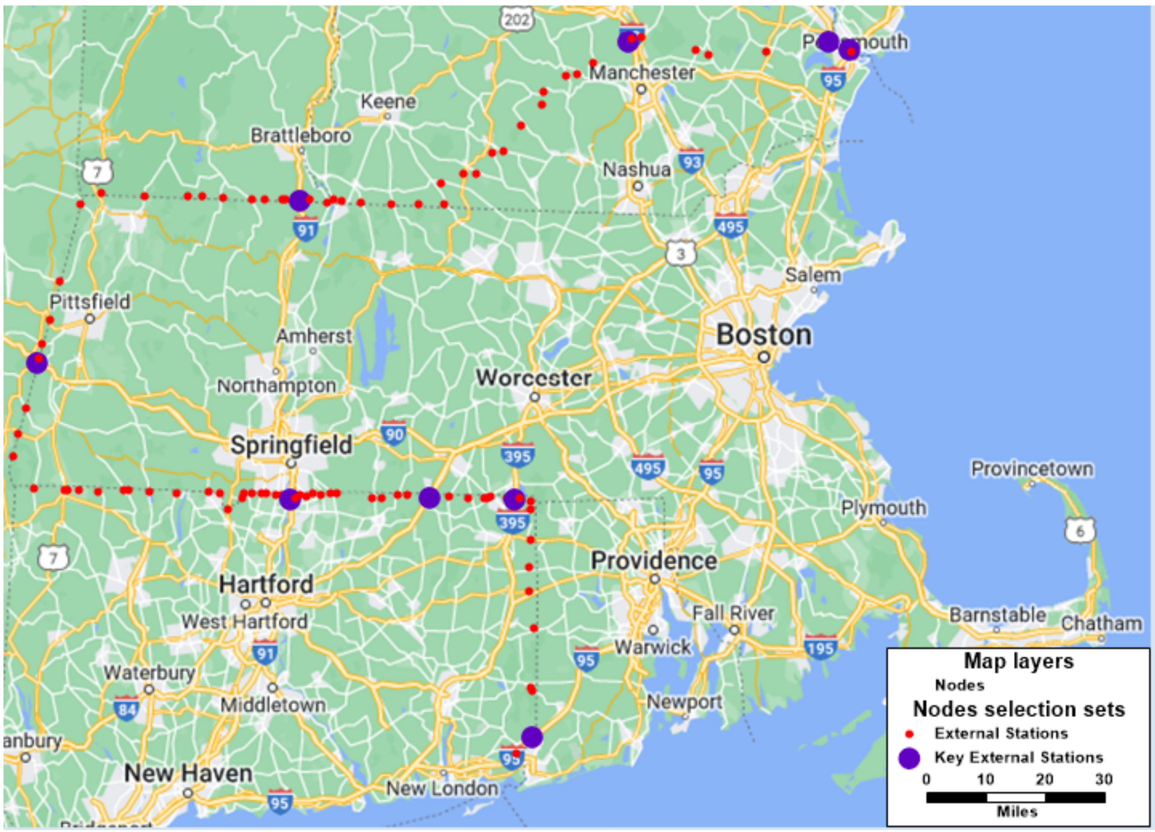
External-external and external-internal trips are input for the nine key external stations that generate a substantial number of auto and/or truck trips in or through the Boston region.

External trips at each external station are categorized as

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

The external to 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 Tpke 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.

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 to 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 and above 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 include a flag 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
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

Field	Required	Notes
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
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

Field	Required	Notes
pnr_penalty		Calibration parameter for PnR use
project_key		Shortname reference to roadway project
count_id		Count station ID

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		Shortname reference to project

TAZ = travel analysis zone.

Facility type definitions

TDM23 uses facility types consistent with those defined in NCHRP 716, as shown in Table 12.

Table 12
TDM23 Facility Types

Facility Type	Definition
Freeways	Grade separated, high speed, high capacity, 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 Ave Route 28

Figure 5
Boston Area Roadways

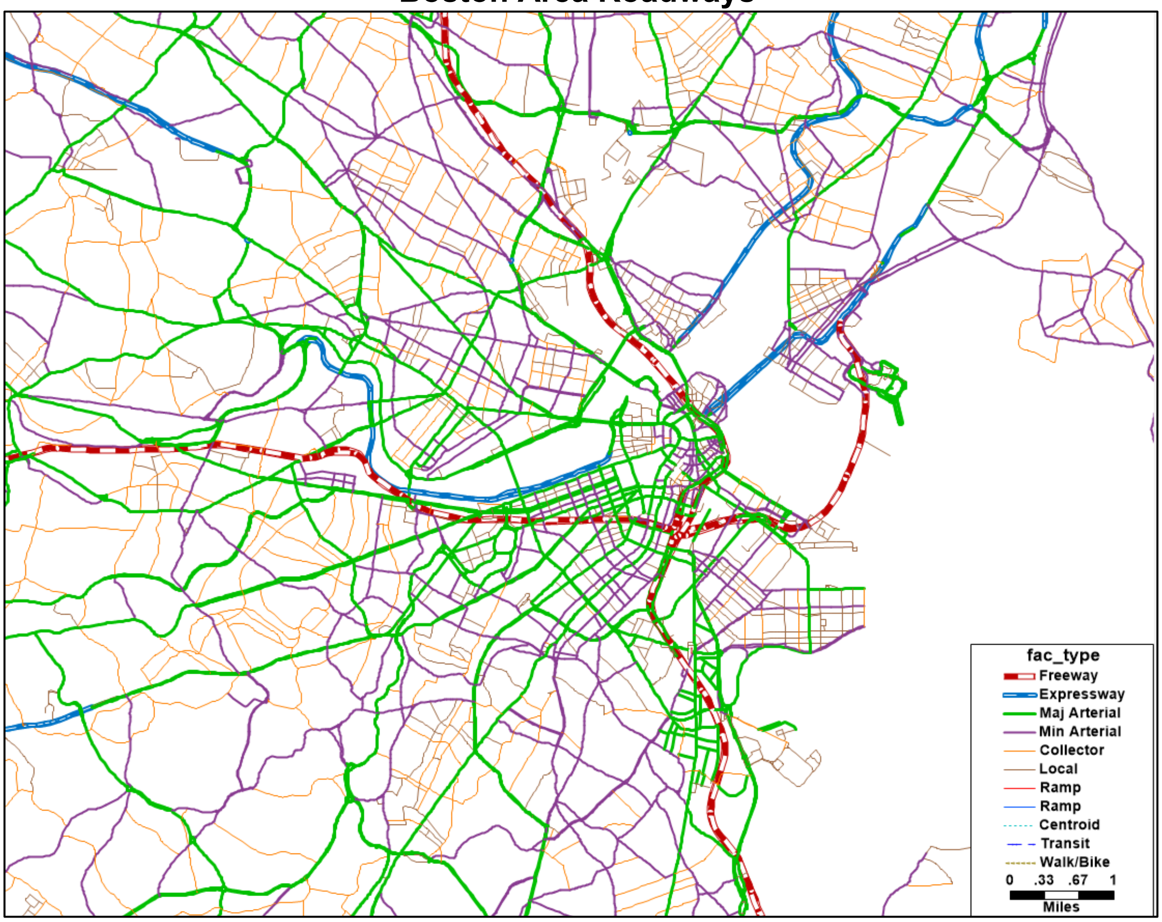
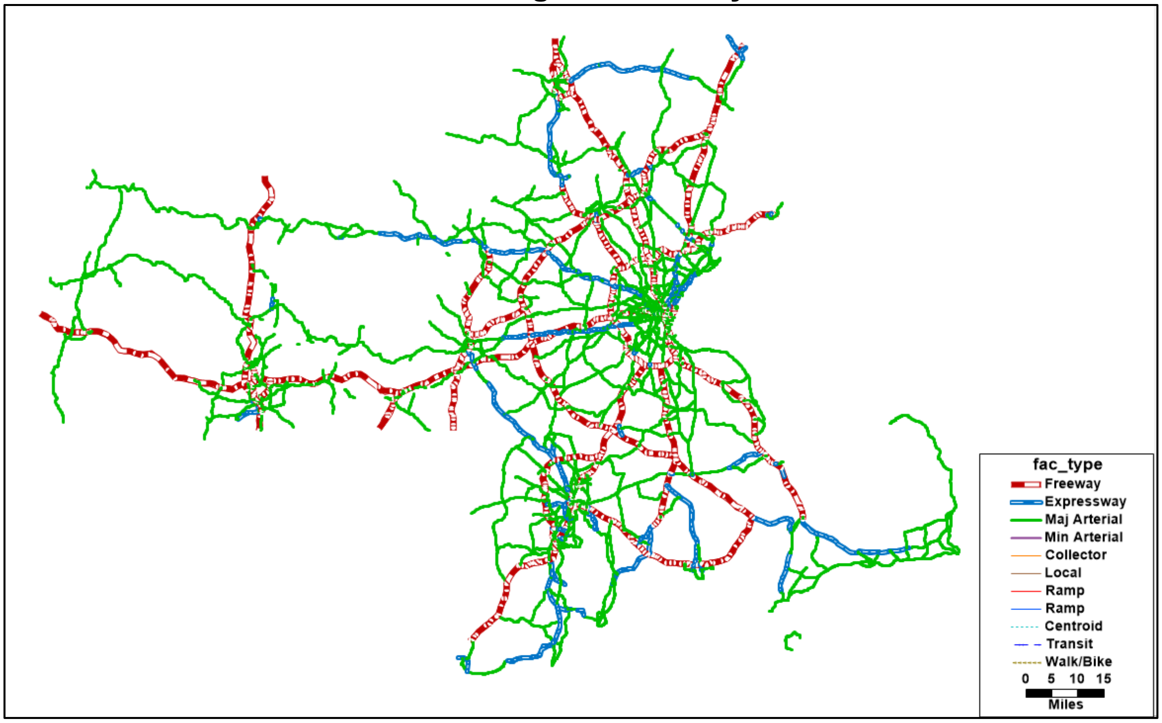


Figure 6
Model Region Roadways



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 operator 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

Operator	Transit Mode(s)
Boston Express	Regional Bus
Brockton Area Transit Authority (BAT)	RTA (local bus)
Burlington	RTA (local bus)
C&J	Regional Bus
Cape Ann Transit 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 RTA (PVTA)	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. 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 include a flag 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		Shortname reference to project

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

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

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

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: 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 (2010 dollars):

- One-person households with income below $22,688
- Two-person households with income below $30,060
- Three-person households with income below $35,137
- Four-person households with income below $45,718
- Five-person households with income below $55,036
- Six-person households with income below $62,641
- Seven-person households with income below $72,239
- Eight or more person households with income below $81,002

High-income households are defined as those that have an income greater than $100,000, regardless of household size. Mid income households are those that are neither low nor high.

The fixed threshold between Mid- and high-income households has been found to be problematic in later testing and will be updated in later versions of TDM23.

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 19.

Table 19
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, 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 (< 5 minute headway) bus
- Mid frequency (< 15 minute headway) bus
- All local service (any transit 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 20. Note that any of the identified transit service levels are sufficient, i.e., only one condition needs to be met.

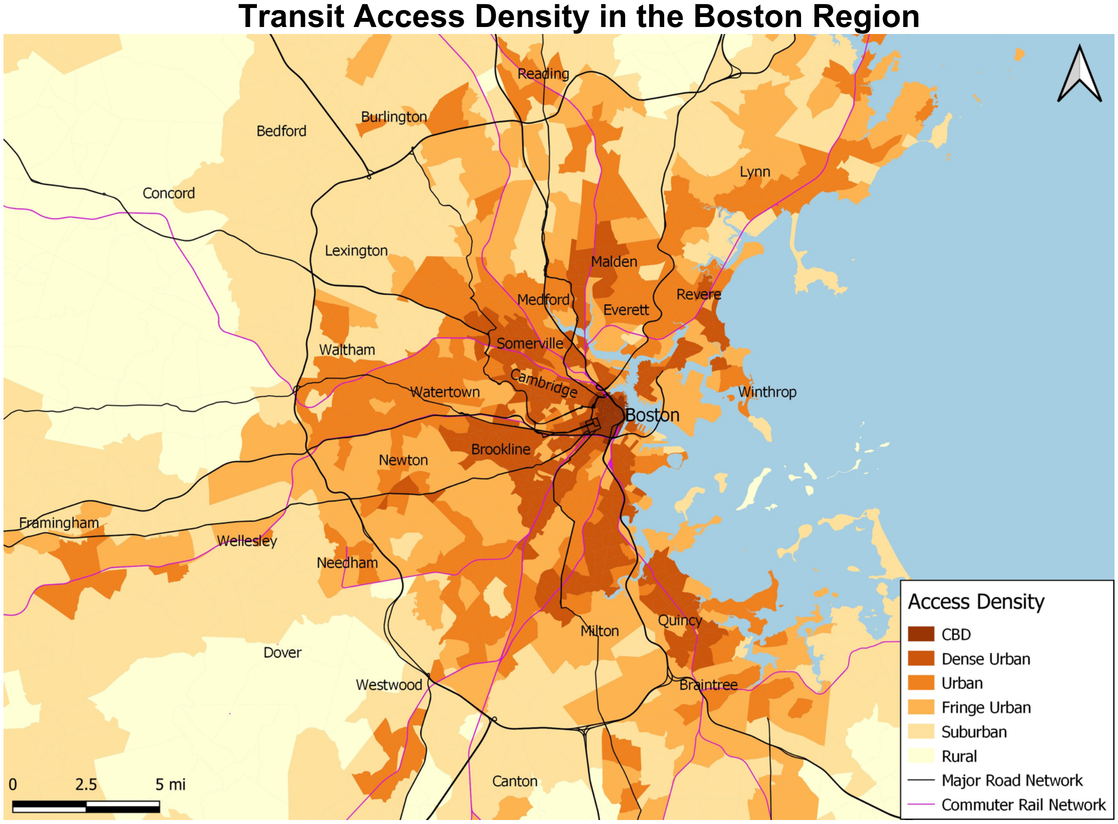
Table 20
Transit Access Density Definitions

Access Density	*Multiple Heavy Rail Stations*	*Core Green Line*	*Any Rail Rapid Transit*	*Commuter Rail*	*< 5 min hdwy*	*< 15 min hdwy*	*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. hdwy = headway, 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 21.

Table 21
Access Density and Area Type Comparison

Transit Access Density	ITE Setting/Location[a]	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

a. 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 22
Terminal Time by Access Density

Transit Accessible Density	Production end	Attraction end
CBD	5 min	6 min
Dense Urban	4 min	5 min
Urban	4 min	5 min
Fringe Urban	2 min	2 min
Suburban	1 min	1 min
Rural	1 min	1 min

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 23.

Table 23
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)

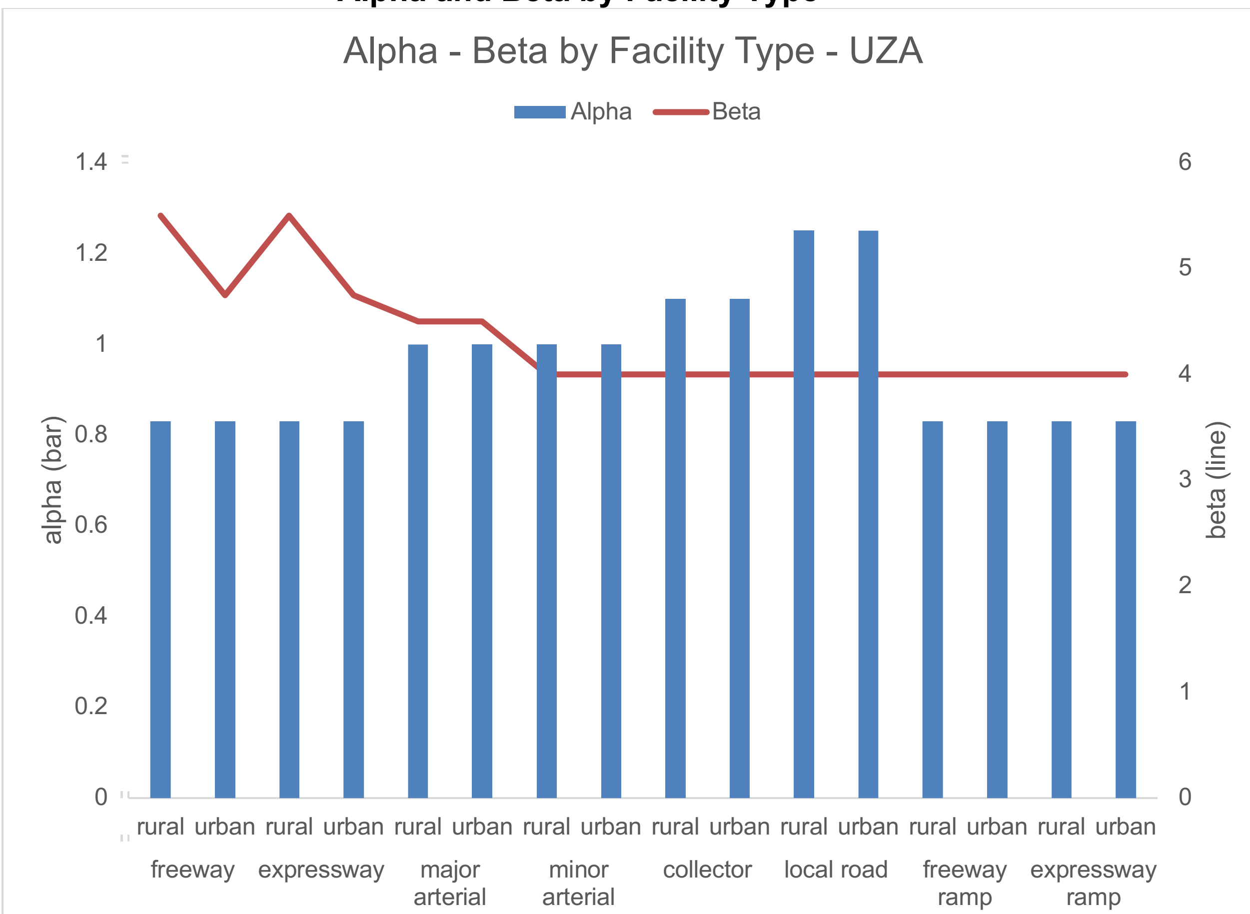
TDM23 uses a standard BPR volume-delay function, with the formulation:

Travel Time = Free Flow Time * (1 + *alpha* * [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.

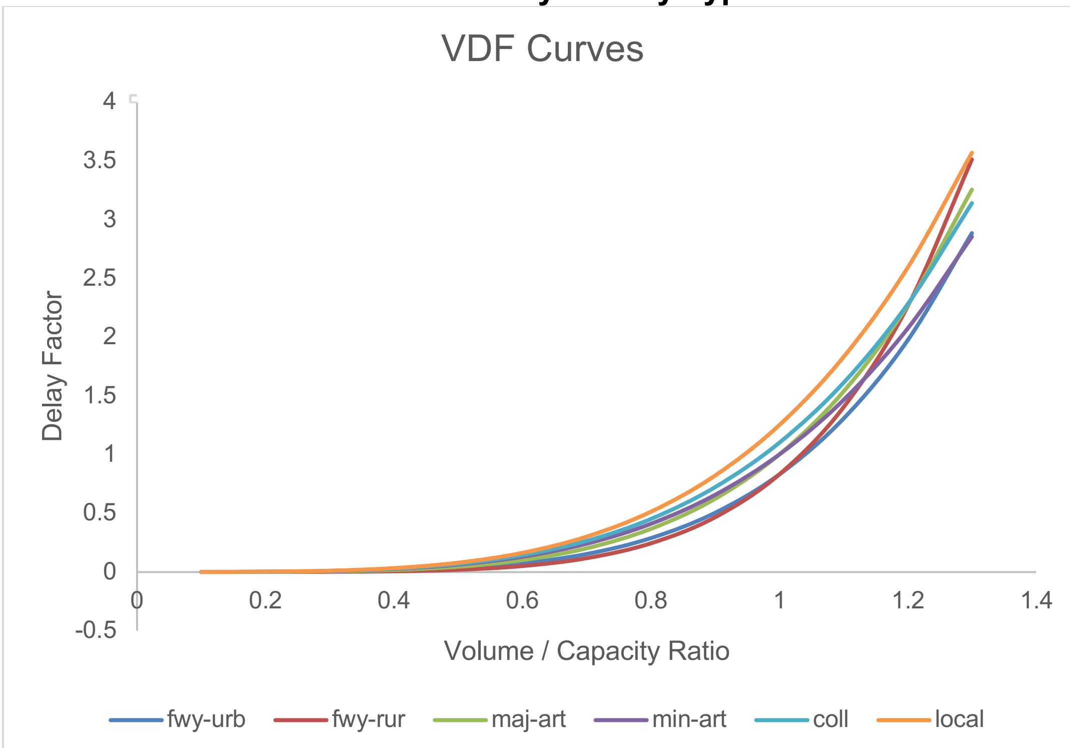
Figure 8
Alpha and Beta by Facility Type



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

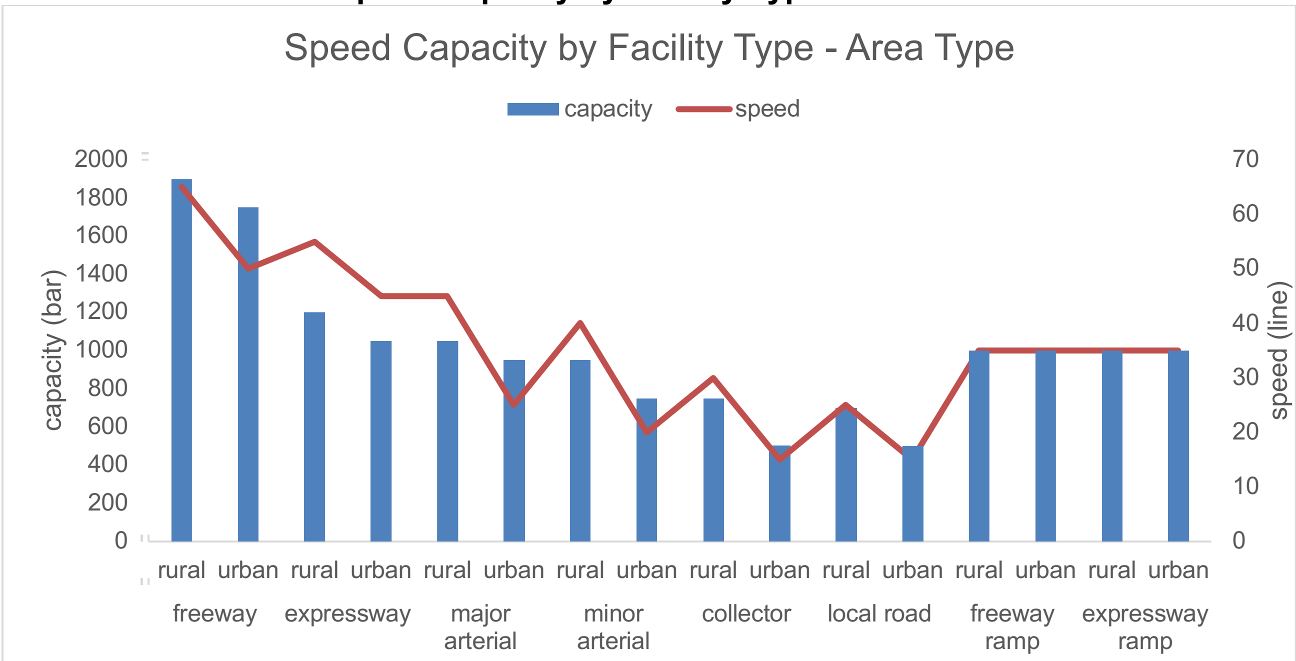


VDF = volume-delay function.

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 following 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 an 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, MD, PM, 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 24.

Table 24
Global Transit Path Thresholds

Parameter	Value
MaxTripCost	180
MaxModalTotat	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 25.

Table 25
Transfer Penalties

Mode	Time Period	Penalty
Transit Walk	Peak	12
Transit Walk	Non-peak	10
Transit Auto	Peak	18
Transit Auto	Non-peak	20

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, parking) and time (walking, waiting, transferring, traveling).

Translation of time to cost uses a constant value of time of $0.20/minute or $12/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 isn’t based on the assumption that driving is much more onerous to using transit. Instead, this represents the unobserved constraints on an auto if used to connect to transit (e.g., being dropped off, using a TNC, or wanting to maximize useful time on board transit).
- Transfer time is weighted as three times in-vehicle time.

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. Alternatively, 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

- commuter rail time is 5 percent less onerous than other transit modes, and
- ferry time is 10 percent less onerous than other transit modes.

PnR Lot Capacity

The parking capacity at 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 vehicle with de-minimis personal use; and
- motorcycle.

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 their vehicles available relative to the number of drivers. The segments are defined as the following:

- **Zero Vehicle Households (ZV)**
- Fewer Vehicles than Drivers (persons older than 16 years)—**Insufficient Vehicles (IV)**
- At least as many vehicles as drivers (persons older than 16 years)—**Sufficient Vehicles (SV)**

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 26 shows the parameters for the component. These parameters were initially estimated using the 2011 Massachusetts Travel Survey and calibrated as described in the Performance chapter.

Table 26
Vehicle Availability Parameters

Variable	Value
Zero Vehicle Coefficients	
ASC	-3.05
Workers in HH	-0.475
Children in HH	-0.371
CBD or Dense Urban	0.5
Intersection Density	1.2
Low Income HH	3.5
Suburban or Rural	-0.95
Transit Accessibility / Highway Accessibility	0.758
Insufficient Vehicle Coefficients	
ASC	-0.289
CBD or Dense Urban	0.768
Intersection Density	0.928
Low Income HH	0.6

Seniors in HH	0.315
Suburban or Rural	-0.537
Number of Drivers above 2	0.45
Presence of Drivers above 2	0.85
Sufficient Vehicle Coefficients	
ASC	1
All drivers are workers	0.955
High Income HH	0.292

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

These coefficients imply

- ZV 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 more urban areas; and
- SV households are most prevalent for households consisting entirely of workers and 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.
- 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.

[5] https://www.replicahq.com/

Tables X, X, and X 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 Tables 27, 28, and 29.

Table 27
State-Level WFH Rates

State	2019 WFH Rate	2023 WFH Rate	Difference
MA	0.05	0.27	0.22
NH	0.07	0.28	0.22
RI	0.04	0.2	0.16

MA = Massachusetts. NH = New Hampshire. RI = Rhode Island.

Table 28
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

Table 29
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	☐	
NH	☐	
RI	☑	0.16

WFH Rate by MPO

MPO	Different from Regional and State Defaults	WFH Rate
BRMPO	☑	0.25
BRPC	☑	0.05
CCC	☑	0.1
CMRPC	☐	
FRCOG	☑	0.13
MRPC	☐	
MVC	☑	0.1
MVPC	☐	
NMCOG	☐	
NPEDC	☑	0.02
OCPC	☑	0.24
PVPC	☐	
SRPEDD	☐	

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

WFH Rates of these Towns/Cities:

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

Limitations

The key limitations of this approach are summarized below.

- The WFH component does not adjust times of day of trips. For example, if travel behavior was to commute, but only for one-half day or for personal business trips to be conducted more during the day by remote workers.
- The only change in household trips produced is 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 production end of non-home-based trips are allocated and trips are segmented into peak and non-peak.

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 30.

[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.

Table 30
Home-based Trip Purpose Definitions

Trip Purpose	Attraction End Activity
home-based work (HBW)	Work/Job, All other activities at work, Volunteer Work/Activities, Work Business Related
home-based personal business (HBPB)	Service private vehicle (gas, oil lube, etc.), Routine shopping (groceries, clothing, convenience store, HH maintenance), Shopping for major purchases or specialty items (appliance, electronics, new vehicle, major HH repairs), Household errands (bank, dry cleaning, etc.), Personal business (visit government office, attorney, accountant), Health care (doctor, dentist)
home-based social-recreational (HBSR)	Eat meal outside of home, Civic/Religious activities, Outdoor recreation/entertainment, Indoor recreation/entertainment, Visit friends/relatives
home-based school (HBSC)	Attending Class, All other School Activities—persons who have not completed high school (12^{th} grade or less) and are younger than age 21
Home-based university (HBU)	Attending Class, All other School Activities—persons who have completed high school or are older than 20

HH = household.

Trips with a production end at work (non-home-based work) or a production end at neither home nor work are listed in Table 31.

Table 31
Non-home-based Trip Purpose Definitions

Trip Purpose	Attraction End Activity
non-home-based work (NHBW)	Any
non-home-based non-work (NHBNW)	Any except: Work/Job, All other activities at work, Volunteer Work/Activities, 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 32. These parameters were initially estimated using the 2011 Massachusetts Travel Survey and calibrated as described in the Performance chapter.

Table 32
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

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 worker is part or full time. The terms imply that workers in households with higher income, fewer workers, without seniors are more likely to be full-time workers.

NHBW: NHBW trips are more likely to be made by workers with autos. Higher income workers also have more NHBW trips as these workers are more likely to be full time.

Household Trip Productions

The household based trip rates are shown in Table 33. These parameters were initially estimated using the 2011 Massachusetts Travel Survey and calibrated as described in the Performance chapter.

Table 33
Household Trip Generation Rates

Variable	home-based personal business	home-based school	home-based social recreation	non-home-based non-work
Constant	0.791	0.023	0.120	0.996
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, more people in the household are correlated with more 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 remote working adults are still considered to be workers and 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.

Table 34
Trip Attraction Rates

Variable	Access Density	HBW	HBPB	HBSR	NHBW	NHBNW
Total Jobs		0.512				
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	1.466				0.572
Retail/Leisure	Dense Urban / Urban			0.577	0.089	
Manufacturing		0.816				
Other						
Professional Services		1.147		0.340	0.172	0.580
Transportation/ Utilities		0.667				
Households			0.872	0.792	0.061	0.360
Households	Suburb			0.363		

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 35. 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 35
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 base and forecast year, the important thing is the relative magnitude of the school enrollment (scale 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

NHB 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:

- NHBW: production end is allocated according to the attractions of HBW trips (i.e., NHBW trips are assumed to be produced at the work activity location)
- NHBNW: production end is allocated by the attractions of NHBW and NHBNW trips

[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 HBW and NHBW 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 36.

Table 36
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 HBW and HBSC trips occur in the peak periods, which is reasonable. Non-home based and HBU trips primarily occur in the non-peak periods.

Limitations

The key limitations of this approach are summarized below.

- Trip rates are independent by purpose. Changes in trip making in one purpose, for example, work trips reduced due to remote work behavior, do not directly impact changes in other trips, for example, increased non-work travel. Assumed or expected changes across multiple trip purposes 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 37. 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.

HBW 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 37
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 38. These parameters were initially estimated using the 2011 Massachusetts Travel Survey and calibrated as described in the Performance chapter.

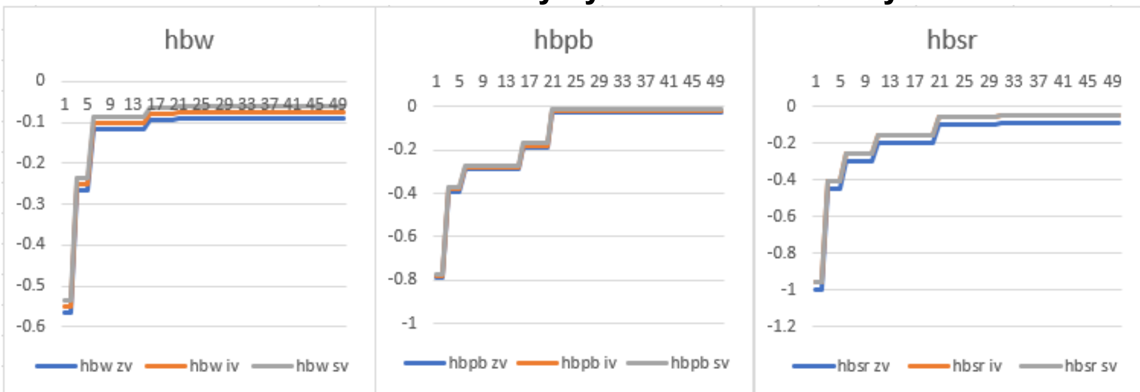
Table 38
Mode Choice Parameters

Variable	Vehicles	hbw	hbsr	hbpb	nhbw	nhbnw
Mode Choice Logsum	all	1	1	1	1	1
Distance (miles)	all	0	0	0	-0.49	-0.52
Distance (miles)	zv	-0.565	-1	-0.79	0	0
Distance (miles)	iv	-0.55	-0.955	-0.78	0	0
Distance (miles)	sv	-0.535	-0.955	-0.77	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	0.55	0.45
Intrazonal	zv	0.5	-0.15	0.1	0	0
Intrazonal	iv	0.4	-0.2	0	0	0
Intrazonal	sv	0.29	-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.

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 (most negative coefficient). But, for all purposes, the marginal sensitivity to distance decreases at higher distances.

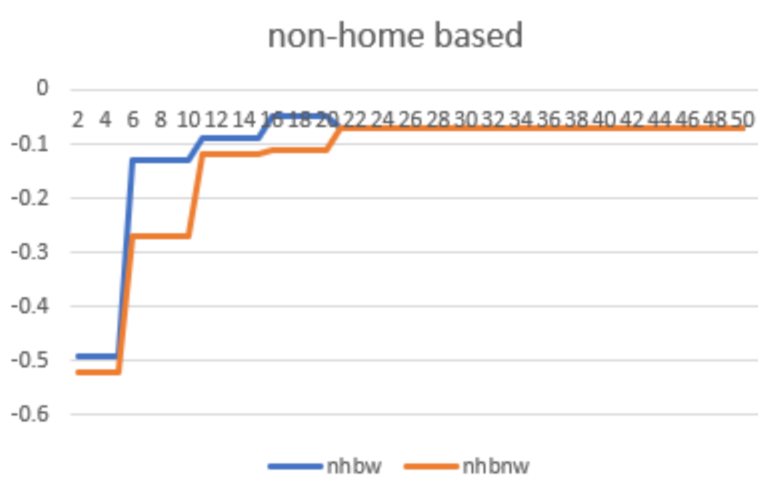
Figure 13
Distance Sensitivity by Vehicle Availability



hbpb = home-based personal business. Hbpb iv = home-based personal business insufficient vehicles. Hbpb sv = home-based personal business sufficient vehicles. Hbpb zv = home-based personal business zero vehicle households. Hbsr = home-based social-recreational. Hbsr iv = home-based social-recreational insufficient vehicles. Hbsr sv = home-based social-recreational sufficient vehicles. Hbsr zv = home-based social-recreational zero vehicle households. Hbw = home-based work. Hbw iv = home-based work insufficient vehicles. Hbw sv = home-based work sufficient vehicles. Hbw zv = home-based work zero vehicle households.

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

Figure 14
Non-home-based Distance Sensitivity



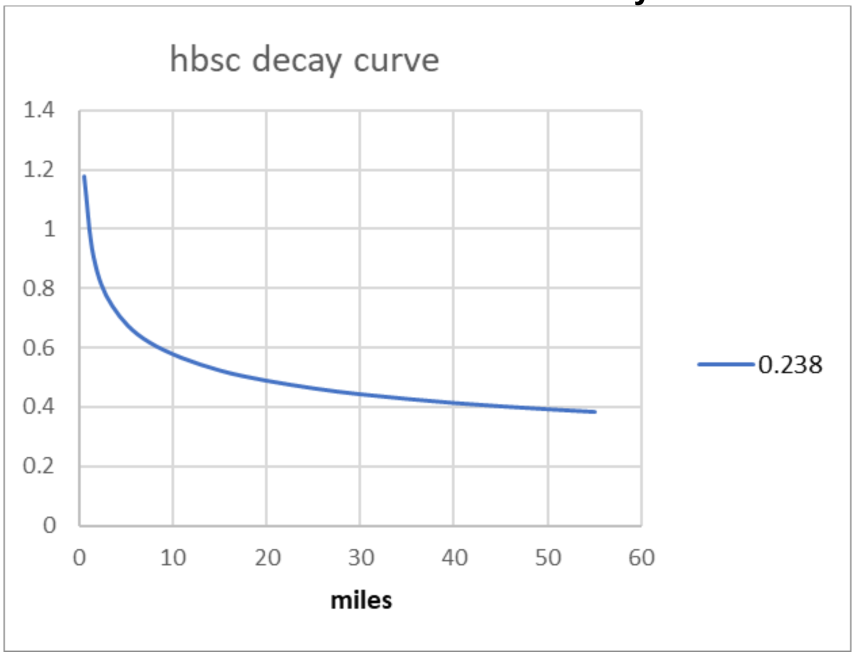
NHBNW = non-home-based non-work. NHBW = non-home-based work.

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. HBSC trips are segmented by vehicle level for input into mode choice, although the parameters for trip distribution are the same across the vehicle levels, that is, the distribution model can be applied to all HBSC 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
HBSC Distribution Sensitivity



HBSC = home-based school.

Limitations

The key limitations of this approach is 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

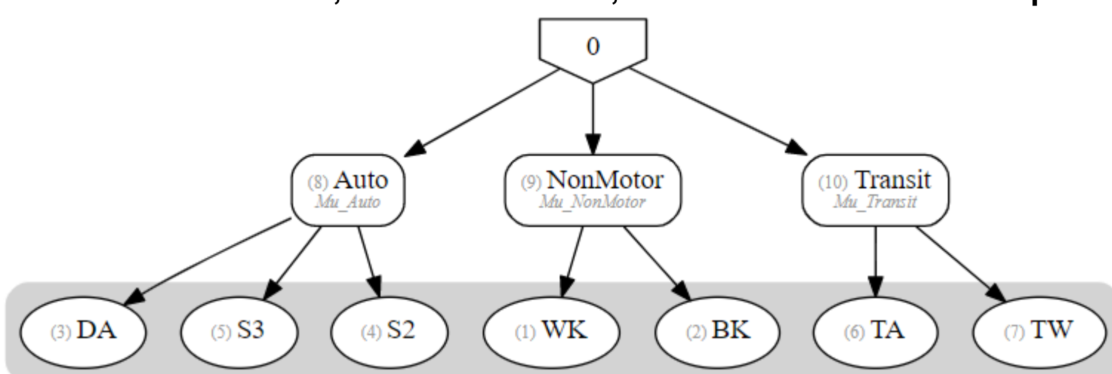
The mode choice alternatives and availability by purpose are shown in Table 39.

Table 39
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

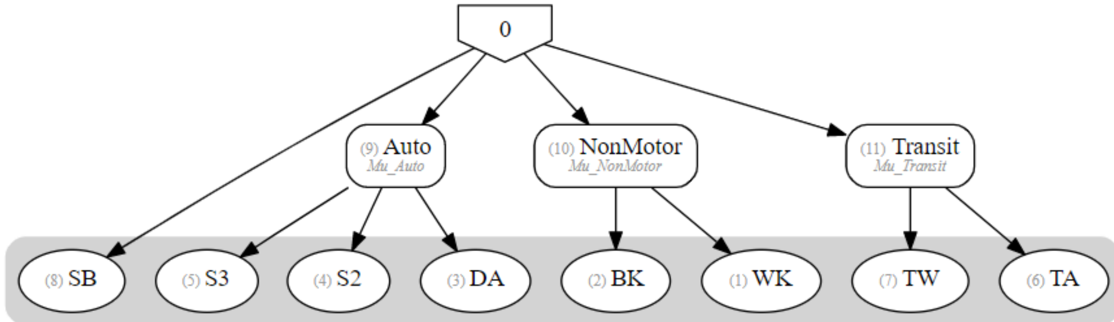
The estimated mode nests are shown in Figures 16, 17, and 18. Note that there was insufficient data to estimate parameters for ride sourcing. This alternative is asserted in the model and identified as its own nest.

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



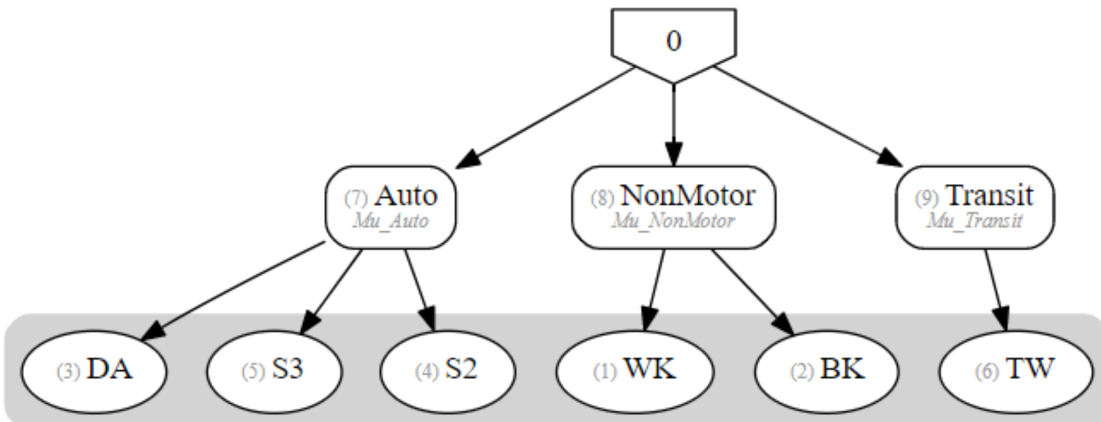
BK = bike. DA = drive alone. S2 = 2 Person shared ride. S3 = 3 Person shared ride. TA = Auto access to transit. WK = walk. TW = Walk access to transit.

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 40
Mode Choice Parameters

Parameter	Value
Auto Operating Costs	$0.244 per mile
Max walk distance	3 miles
Max 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 41).

Table 41
Ride-source Calibrated Waiting Times

Transit Access Density	Calibrated TDM23 RS 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:

Fare = Max (minimum fare OR
base fare + service fee +
time * fare per minute +
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 42, 43, and 44 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 the Performance chapter. Work trips are asserted to have the highest value of time with social-recreational trips the lowest. Values of time are derived from the median household income.

Table 42
Trip Value of Time

Trip Purpose	Share of Median Household Income
HBW, HBSC, NHBW	60%
HBSR, HBPB, HBU, NHBNW	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. NHBNW = non-home-based non-work.
NHBW = non-home-based work.

The path impedance terms include in-vehicle time (IVTT), out of vehicle time (OVTT), cost, and distance as well as path-shaping terms for transit modes. IVTT represents travel time within the alternative mode (i.e., 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 da, s2, and s3 modes. The costs include tolls, operating costs, parking costs for autos, fares for ride source and transit, and parking costs for transit auto.

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, that is, where there are circuitous paths to use transit such as driving away from the destination to access a PnR lot or driving most of the way before using transit. The term is derived as

Drive Access Path = Maximum [
(Drive access to transit distance / 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 (three miles for transit-walk, 20 miles for transit auto).

Table 43
Mode Choice Utilities

	mode \ trip	HBW	HBPB	HBSR	HBSch	NHBW	NHBNW	HBU
Travel Impedance								
IVTT	All	-0.0223	-0.02	-0.0172	-0.0257	-0.0258	-0.0204	-0.02
OVTT	All	-0.0546	-0.0599	-0.0517	-0.0772	-0.0774	-0.0605	-0.0536
Cost	All	-0.0681	-0.104	-0.104	-0.0784	-0.0787	-0.0618	-0.105
Value of Time (2010 $)		$19.65	$ 11.54	$ 9.92	$ 19.67	$19.67	$ 19.81	$11.43
Drive Access Path	TA	-3	-3	-3	-3			-3
Short Distance (< 3)	WK	0.75	0.75	0.75				
Short Distance (< 3)	BK	0.1	0.1	0.1				
Short Distance (< 3)	TW	-1	-1	-1	-1	-1	-1	-1
Short Distance (< 20)	TA	-0.1	-0.1	-0.1	-0.1			-0.1
Vehicle Ownership								
Sufficient vehicles	DA	0.265		0.341				
Sufficient vehicles	S2	-1.36						
Sufficient vehicles	S3	-1.72						
Sufficient vehicles	TW	-0.8155	-0.58208	-0.57572				
Insufficient vehicles	WK, BK	0.825	0.0654	0.215	0.508			
Insufficient vehicles	TW	0.5095	0.019685	0.220024	0.723			
Insufficient vehicles	TA	0.35						
Zero vehicles	DA	-2.35		-2.1				
Zero vehicles	WK	3.19		2.06	1.61			
Zero vehicles	BK	2.44		1.31	0.86			
Zero vehicles	TW	3.81		3.76	3.32			
Zero vehicles	TA	0.25		1.17				
Zero vehicles	RS	3		3				
Zero vehicles	SB				1.87			

Table 44
Mode Choice Utilities

	mode \ trip	HBW	HBPB	HBSR	HBSch	NHBW	NHBNW	HBU
Land Use								
IntersectionDensity (Production End)	TW	0.053	0.347					
IntersectionDensity (Production End)	TA		0.347					
IntersectionDensity (Attraction End)	TW, TA	0.662		0.383	0.187			
IntersectionDensity	WK	0.353	0.271	0.121		0.379	0.644	
IntersectionDensity	BK	0.353	0.271	0.121	0.373	0.379	0.644	
IntersectionDensity	TW					0.459	0.384	
IntersectionDensity	SB				-1.13			
Rural	SB				1			
CBD Dense Urban (Production End)	TA	-0.5	-0.5	-0.5	-0.5			-0.5
Suburban Rural (Production End)	TA	0.75						
CBD Dense Urban (Attraction End)	TA	1.542	1.228	1.524				0.364
CBD Dense Urban (Attraction End)	TW	0.55	1.098	1.394				
CBD Dense Urban	WK	0.89	0.599	0.89	0.255			1.15
CBD Dense Urban	BK	0.64	0.349	0.64	0.255			1.15
CBD Dense Urban	TW	0.111			0.25			0
CBD	TW, TA	0.6				0.5	0.5	0.5
Urban	TW	0.375						
Constants								
DA								0.427
S2		-1.4	-0.872	-0.717	0.884	-2.238	-1.25	-0.837
S3		-2.042	-1.24	-0.664	1.07	-2.732	-1.36	-1.47
WK		-3.12	-2.457	-1.935	2.246	-1.415	-0.827	-0.2948
BK		-3.649	-3.82	-2.85	-1.97	-4.56	-3.96	-3.952
TW		-2.268	-2.5	-2.971	0.1092	-3.665	-2.052	-1.44
TA		-2.462	-2.593	-2.286	0.727			-1.555
RS		-2.25	-4.5	-3.5	-5	-2.25	-2.5	-1.5
SB					0.8			

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, for example, improved transit service only in the PM Peak.

2.6.10 Time of Day (PA to OD)

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

Time Period to Time of Day

The TDM23 times of day are

- 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 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 45 and 46. These factors were initially estimated using the 2011 Massachusetts Travel Survey and calibrated as described in the Performance chapter.

Table 45
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

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. PM-AP = PM peak attraction-production, PM-PA = PM Peak production attraction.

Table 46
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

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.

As expected, most HBW and HBSC trips travel from production (home) to attraction (work or school) in the AM peak and the reverse in the PM peak. The majority of HBSC trips in the non-peak periods are trips returning home midday. Most HBU 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 47
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 48.

Table 48
Vehicle Occupancy Rates

Purpose	SR2 Occupancy	SR3p Occupancy	RS Occupancy
hbw	2	3.627	1.21
hbsc	1	2.49	1.6
hbsr	2	3.627	1.6
hbpb	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. SR = shared ride.

Note that home-based school has a smaller occupancy for shared ride 2 or 3-plus 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 S2 trip, but 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: shared ride 2 (S2) and shared ride 3 (S3)
- Airport: pickup/drop off (PD)

RideSource 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 the Performance chapter, 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 would more accurately define these 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 49.

Table 49
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.

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 50 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 the Performance chapter.

Table 50
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. Construction and Other Services 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.

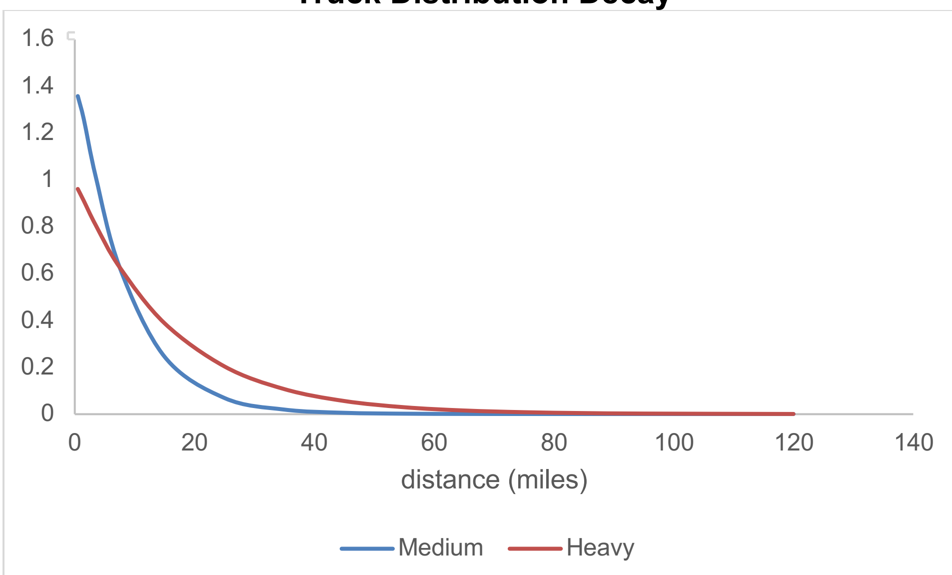
The decay function follows a gamma distribution with parameters.

Table 51
Truck Distribution Parameters

param	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

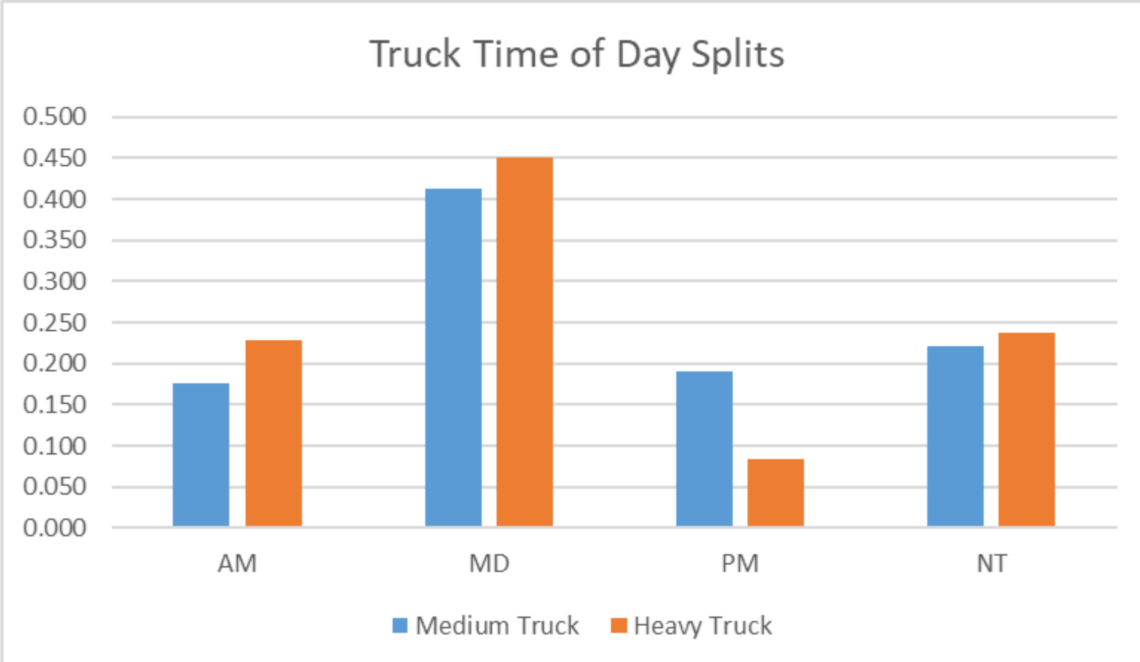


Truck trip time of day

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 trucks are more skewed towards the AM period and medium trucks 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).

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 HBSR and NHBNW 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 (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.

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 52. These and all airport ground access model parameters were initially estimated using the 2018 Massport ground access survey and calibrated as described in the Performance chapter. Note that some variables are segmented by geographic ring, which is a proxy for distance to Logan airport.

Table 52
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. 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.

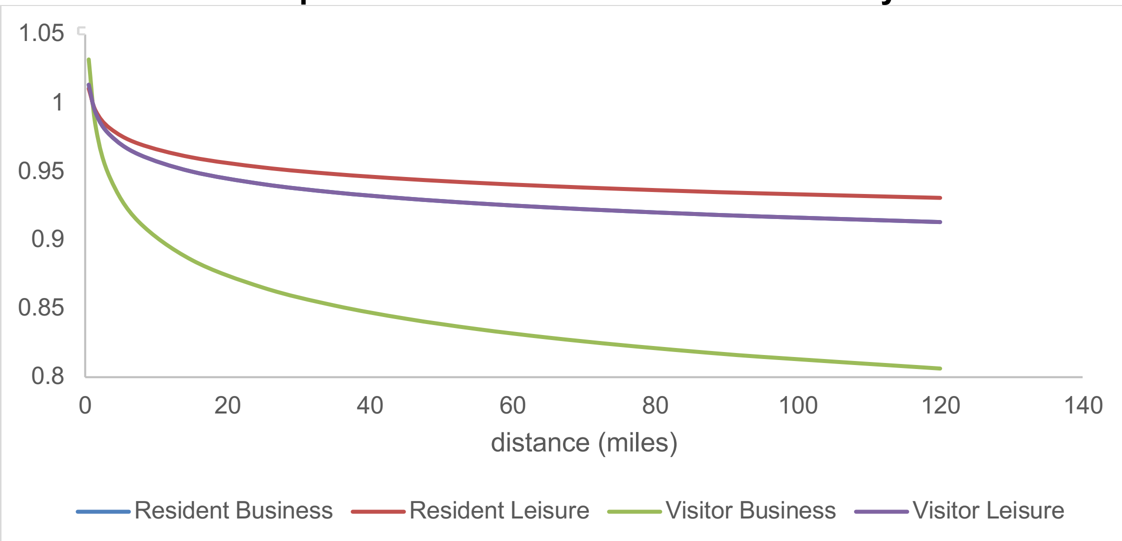
Trips are distributed according to an exponential decay function with the parameters shown in Table 53.

Table 53
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. Resident Business and Visitor Leisure 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 54
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 55.

Table 55
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 pick up / 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 56.

Table 56
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 57.

Table 57
Airport Ground Access Mode Attributes

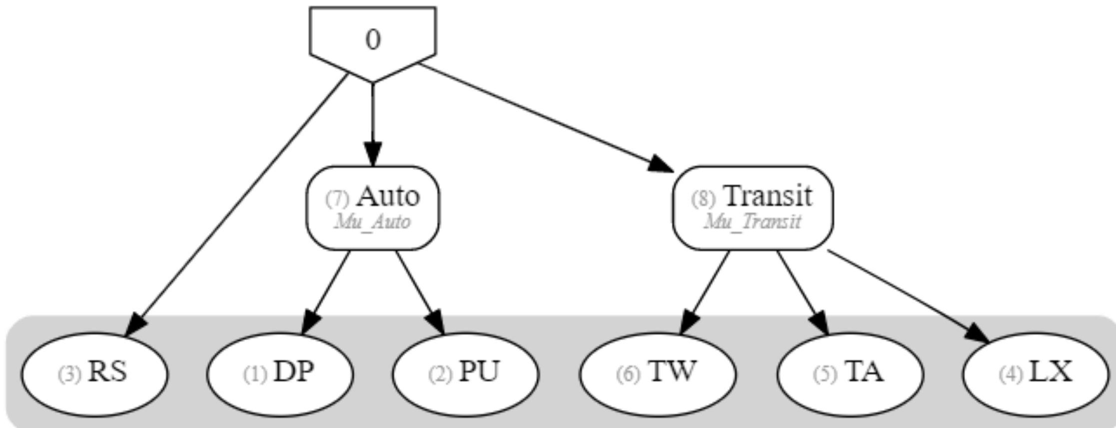
Mode	Terminal Time (minutes)
Drive and park	10
Rental Car	18
Personal pick up / drop off	0
Transit Walk	0
Transit Auto	0
Logan Express	0
Ride Source	10

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

Model structure and coefficients

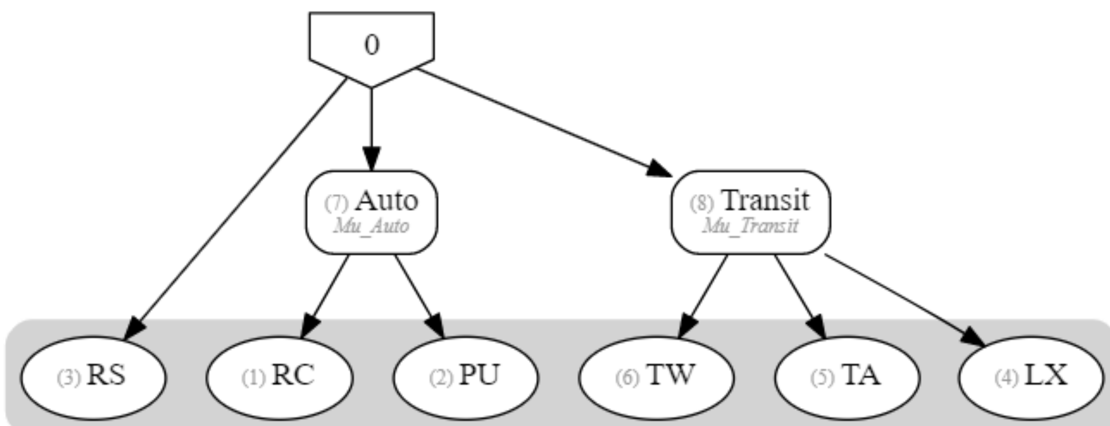
The trip mode alternatives are grouped into private modes, public modes, and ride sourcing and differ between residents and visitors only by the modes available.

Figure 23
Resident Air Ground Access Mode Choice Nest Structure



DP = drive and park. LX = Logan Express. PU = pick up. 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 58
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 time. LX = Logan Express. OVTT = out of vehicle time. PU = pick up. RESB = Resident Business. RESL = Resident Leisure. RS = ride source. TA = transit auto. TW = transit walk.

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 59 and 60.

Table 59
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 = morning production attraction. PM-AP = PM peak attraction-production, PM-PA = PM Peak production attraction.

Table 60
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 61.)

Table 61
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 pick up / 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

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

Trip Generation

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

Table 62 shows the parameters for the component. These parameters were initially estimated using the 2011 Massachusetts Travel Survey and calibrated as described in the Performance chapter.

Table 62
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.

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 CBD and in dense urban areas make more HBU trips.

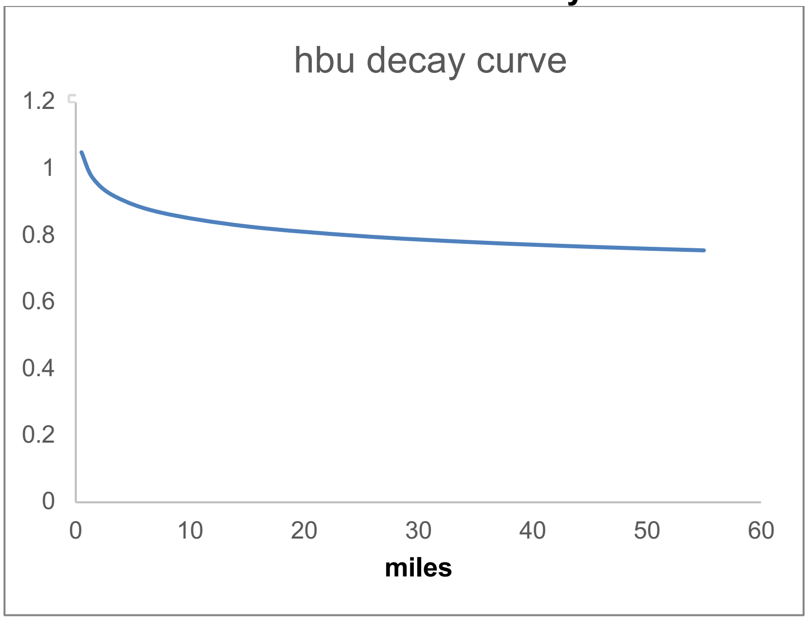
A trip attraction rate of 1.76 trips attracted per enrollment is used to calculate the HBU trips attracted by campus.

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.

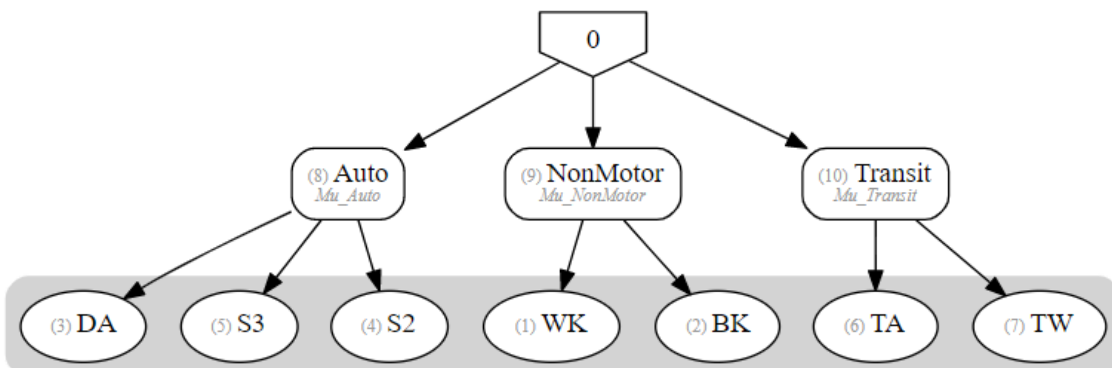
Figure 25
HBU Distribution Decay



Mode Choice

HBU has the same nest and mode alternative available structure as HBW. Note that RS is represented as an alternative in its own nest.

Figure 26
HBU Mode Choice Nest Structure



BK = bike. DA = drive alone. WK = walk. TA = transit auto. TW = transit walk.

The mode choice parameters show a higher likelihood of using transit and nonmotorized modes when the university and student’s home are in CBD, Dense Urban, or Urban Areas. Transit auto modes are more likely when the university is in a CBD or Dense Urban area.

Table 63
HBU Mode Choice Parameters

Variable	Alternative	Coefficients
IVTT	All	-0.020
OVTT	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	0.364
CBD Dense Urban	WK,BK	1.150
CBD Dense Urban	TW	0.876
CBD	TW, TA	0.500
Constants	DA	0.427
	S2	-0.837
	S3	-1.470
	WK	-0.295
	BK	-3.952
	TW	-1.440
	TA	-1.555
	RS	-1.500

BK = bike. DA = drive alone. RS =ride source. S2/S3 = shared ride 2/3+. 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 the Direct Travel Demand Inputs section, 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.

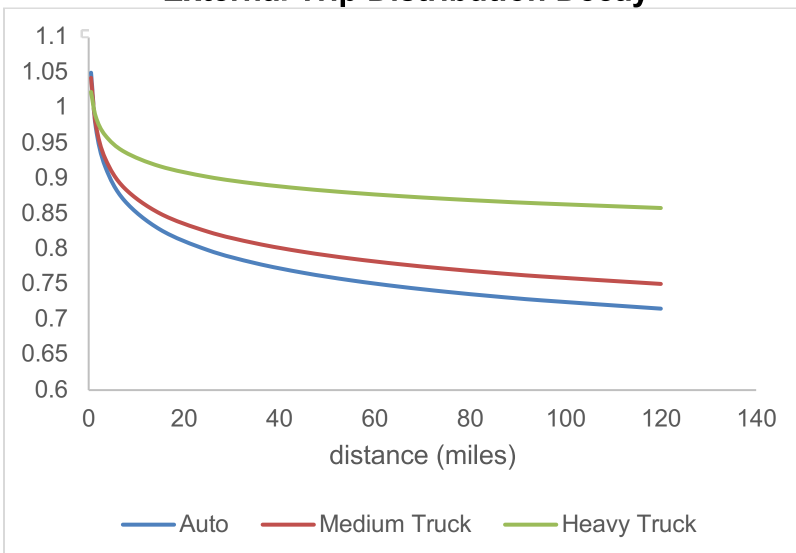
External-Internal trips are modeled using a singly constrained gravity model with sensitivity to network distance matching attractions at external stations. Auto trips are attracted by the sum of all home-based purpose attractions. Truck trips are attracted by the estimated truck attractions from the truck trip generation model.

The External-Internal gravity model uses an exponential decay function. The parameters are shown in Table 64, which produce decay curves as shown in Figure 27.

Table 64
External Trip Distribution Parameters

Segment	Distribution
Autos	0.07
Medium Trucks	0.06
Heavy Trucks	0.032

Figure 27
External Trip Distribution Decay



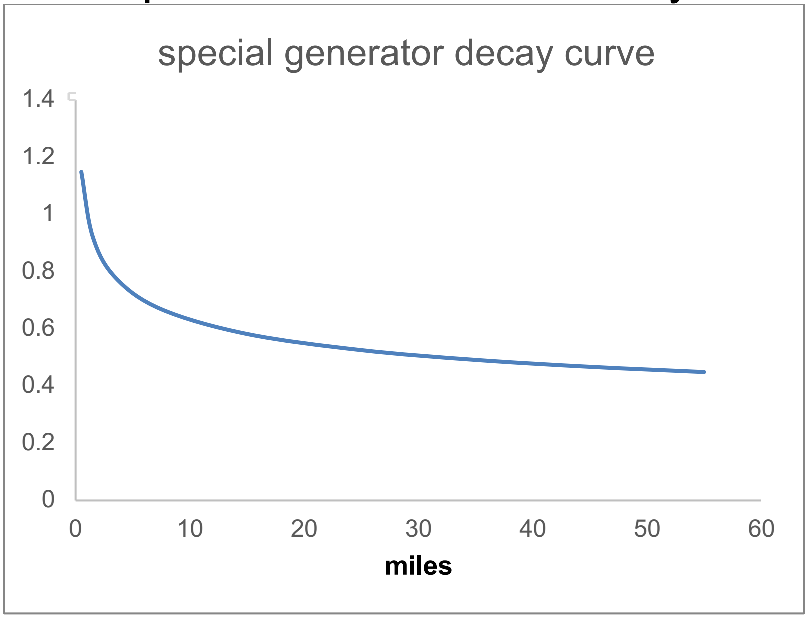
Auto and medium truck trips are more sensitive to distance and thus have shorter trips. Heavy truck trips are longer.

2.6.15 Special Generators

Special generator trips are input at the attraction TAZ and segmented by HBSR and HBPB 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

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.

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

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 65.

Table 65
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.

Notes on 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, MD, and PM periods are all relatively consistent with not too much variation between the peak hour and other times in the period, so we expect their capacity factors to be close to the number of hours in the periods (3, 5.5, and 4 respectively). Most of the demand in the NT period is concentrated in the evening times of 19:00 to 23:30, therefore we expect the NT capacity factor to be substantially less than the 11.5 hour period.

Table 66
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

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 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 PnR parking capacity 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 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 67.

Table 67
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 (most transit auto are production to attraction the AM and Midday Periods) and that parking spaces are freed up as travelers return to their vehicles later in the day.

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 on the north shore with the Orange Line and the south shore with the Red Line.

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.

[9] alpha * (Volume/Capacity) ^ beta

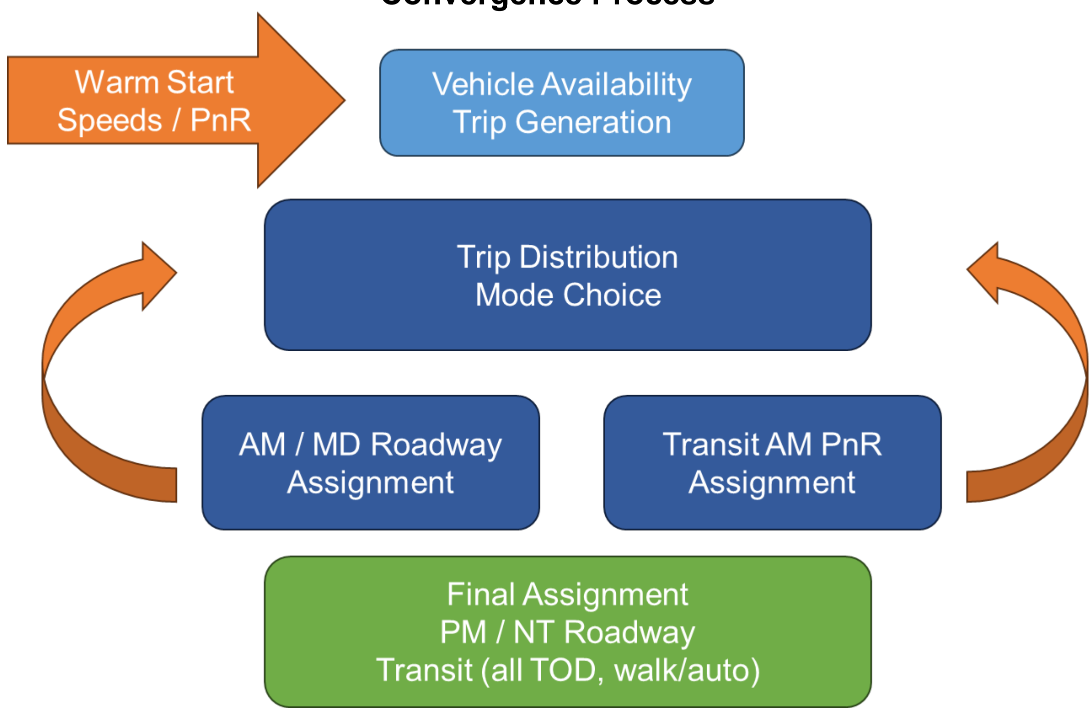
Logan Express

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 MD 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 an MSA process with each iteration contributing 1/N to the rolling average. The link travel time fed back to distribution is calculated from the MSA'd volumes. 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 BPR function to calculate congested speed, which considers the dynamic Volume-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.

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

[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,when%20vehicles%20are%20on%20roads

Region MPO 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.

The destination access type and time by highway or transit are listed in Table 68.

Table 68
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

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 the Usability-Scenario Management section). 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 69.

Table 69
Outputs by Component

Component	SQLite Database	Matrix	Table
Pre-Processors	Household category by household Access Density by TAZ Employment access by TAZ Terminal Times by TAZ		
Skimming		DA and SR skims by AM and MD TW and TA skim by AM and MD NM skims (daily)	PnR Use by Interchange
Vehicle Availability	Vehicles available by household		
Work from Home	Commuter rate by worker		
Trip Generation	Trips produced by worker Trips produced by household NHB Trips produced by TAZ Trips attracted by TAZ Segmented trips by time period		
Trip Distribution		Mode Choice Logsums PA trips by purpose and market segment	
Mode Choice		Mode Shares PA trips by mode, purpose, and market segment	
Trucks	Truck trips produced by TAZ	Truck trip table by time of day	
Airport Ground Access	Airport trips produced by TAZ	Airport trips by mode, purpose, and time of day	
Time of Day		OD trips by mode	
Highway Assignment			DA, SR, MTRK, HTRK volumes, vmt, vht by time of day
Transit Assignment			TW, TA access, TA egress, LX ons, offs, loading by time of day
Air Quality			Emissions by link, TAZ
Equity			Equity metrics by link, aggregate by population

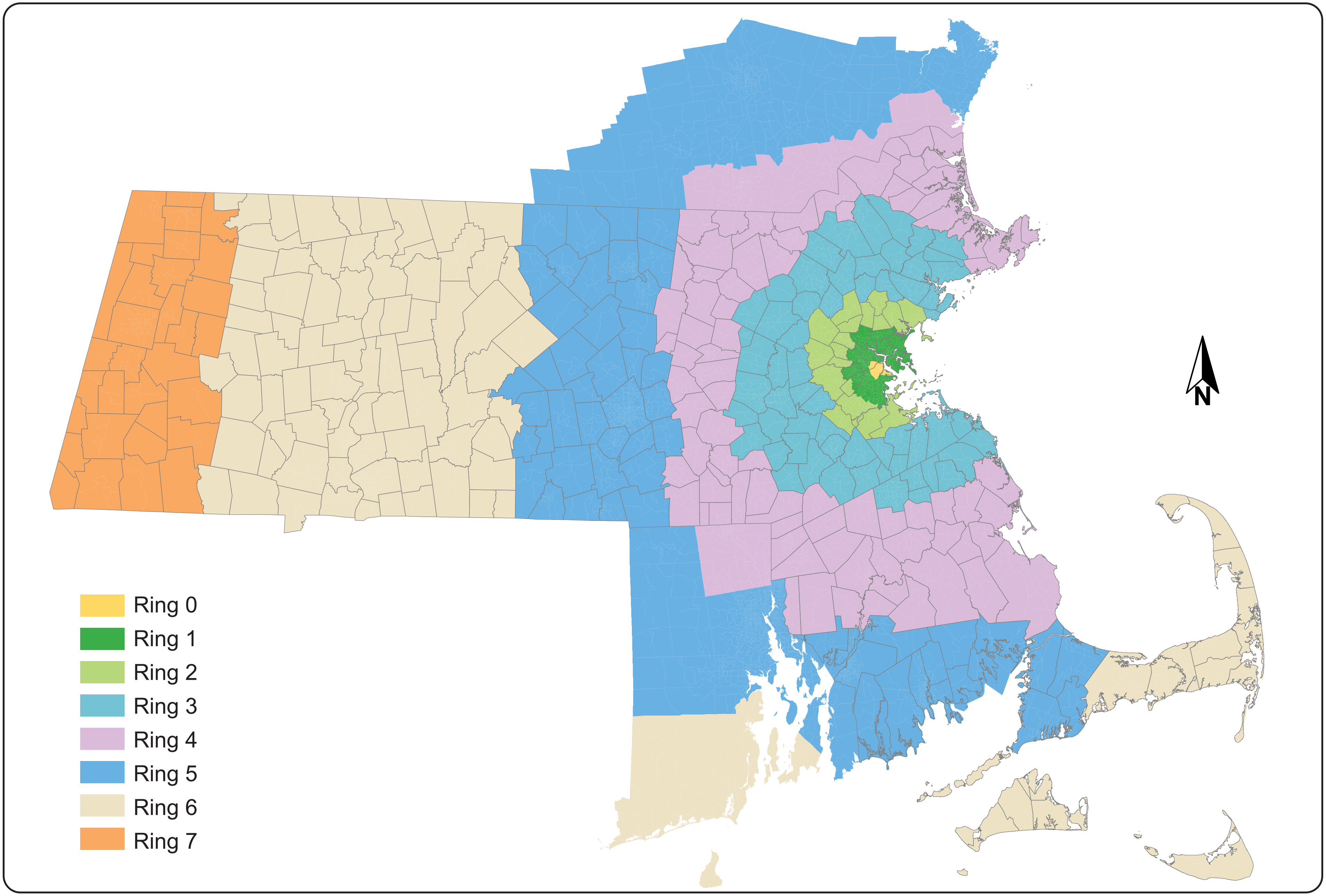
DA = drive alone. HTRK = heavy truck. LX = Logan Express. MD = midday. MTRK = medium truck. NHB = non-home based. NM = non-motorized OD = origin-destination. PA = production-attraction. PnR = Park and Ride. SR = shared ride. TAZ = travel analysis zone. TA = auto access to transit. TW = walk access to transit. vht = vehicle-hours traveled. vmt = vehicle-miles traveled.

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

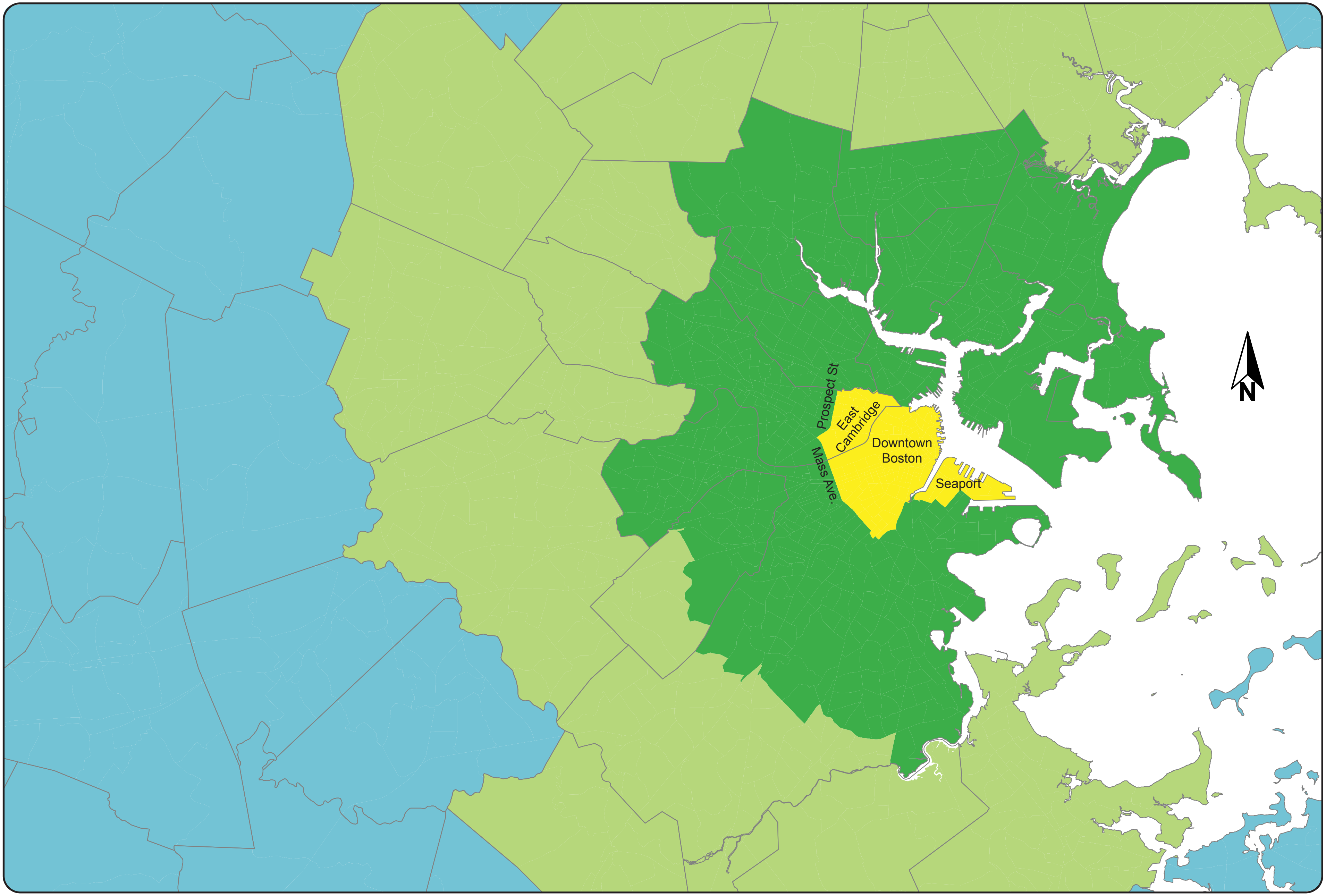
Downtown Boston is Ring 0, the outlying ring in Berkshire county is Ring 7.



BOSTON
REGION
MPO

Figure 30
Model Analysis Rings, A

TDM23 Structures, Applications, and Performance



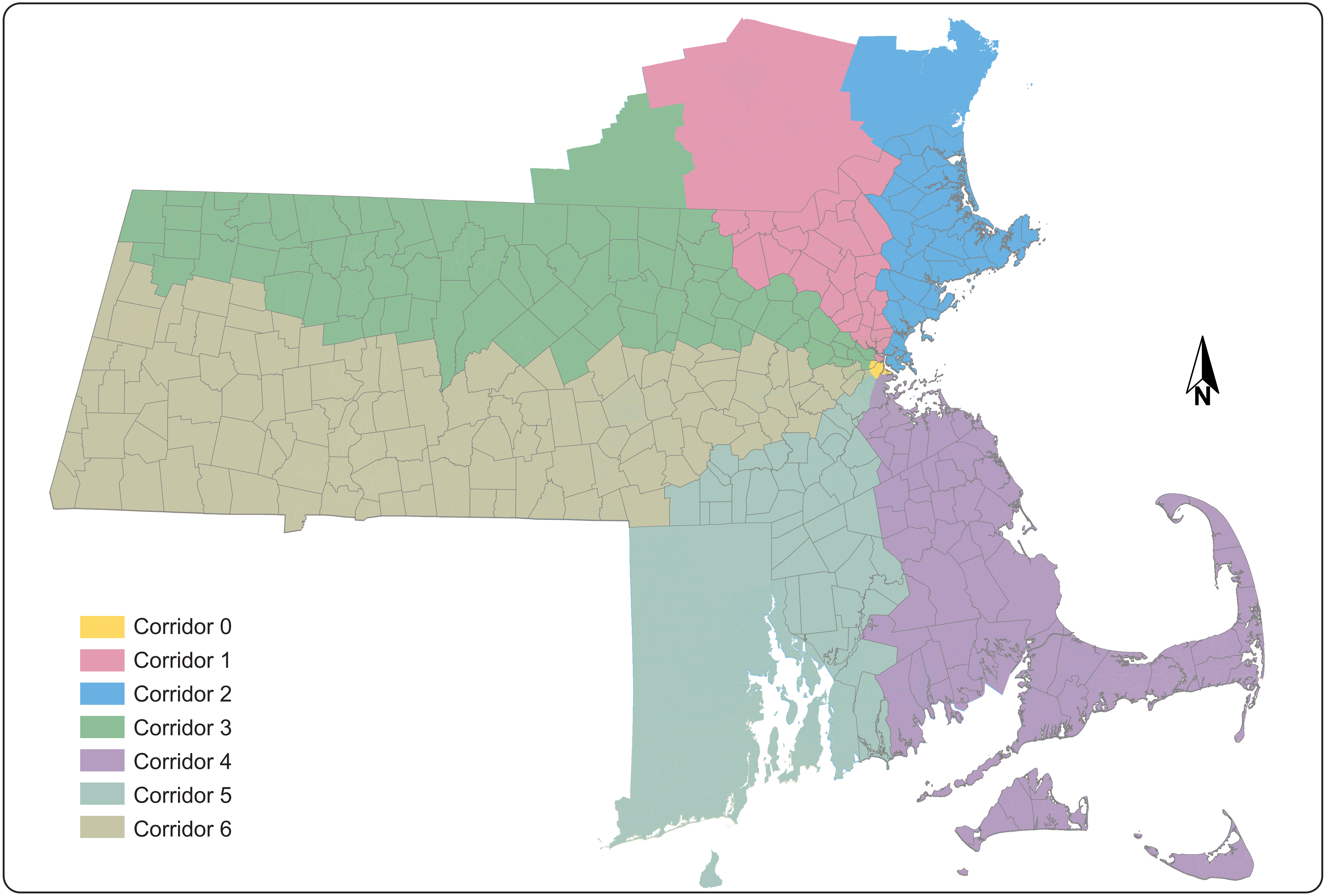
BOSTON
REGION
MPO

Figure 31
Model Analysis Rings, B

TDM23 Structures, Applications, and Performance

Corridors

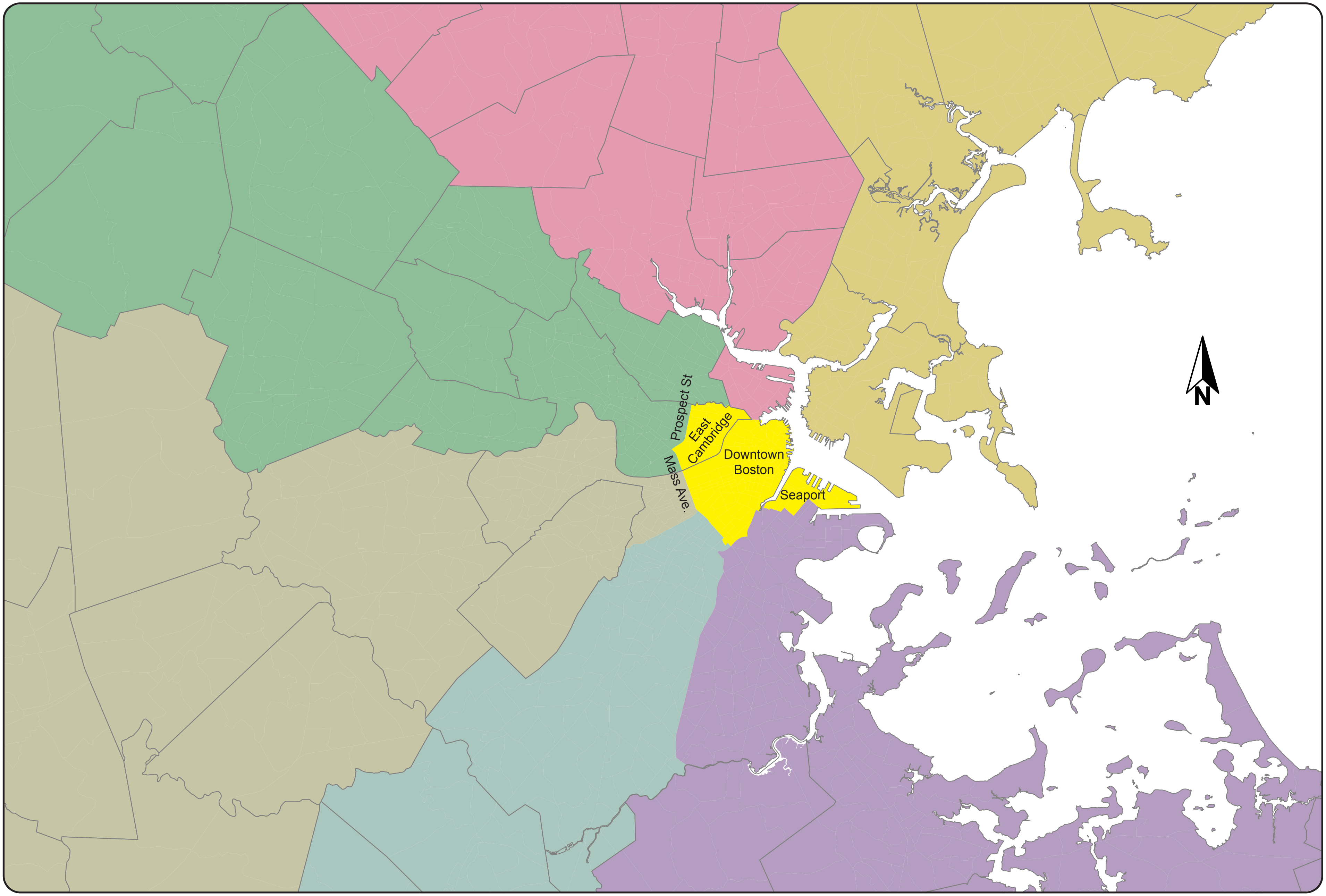
Downtown Boston is both corridor and ring 0. Corridors are numbered as shown in Figure 32.



BOSTON
REGION
MPO

Figure 32
Model Analysis Corridors, A

TDM23 Structures, Applications, and Performance



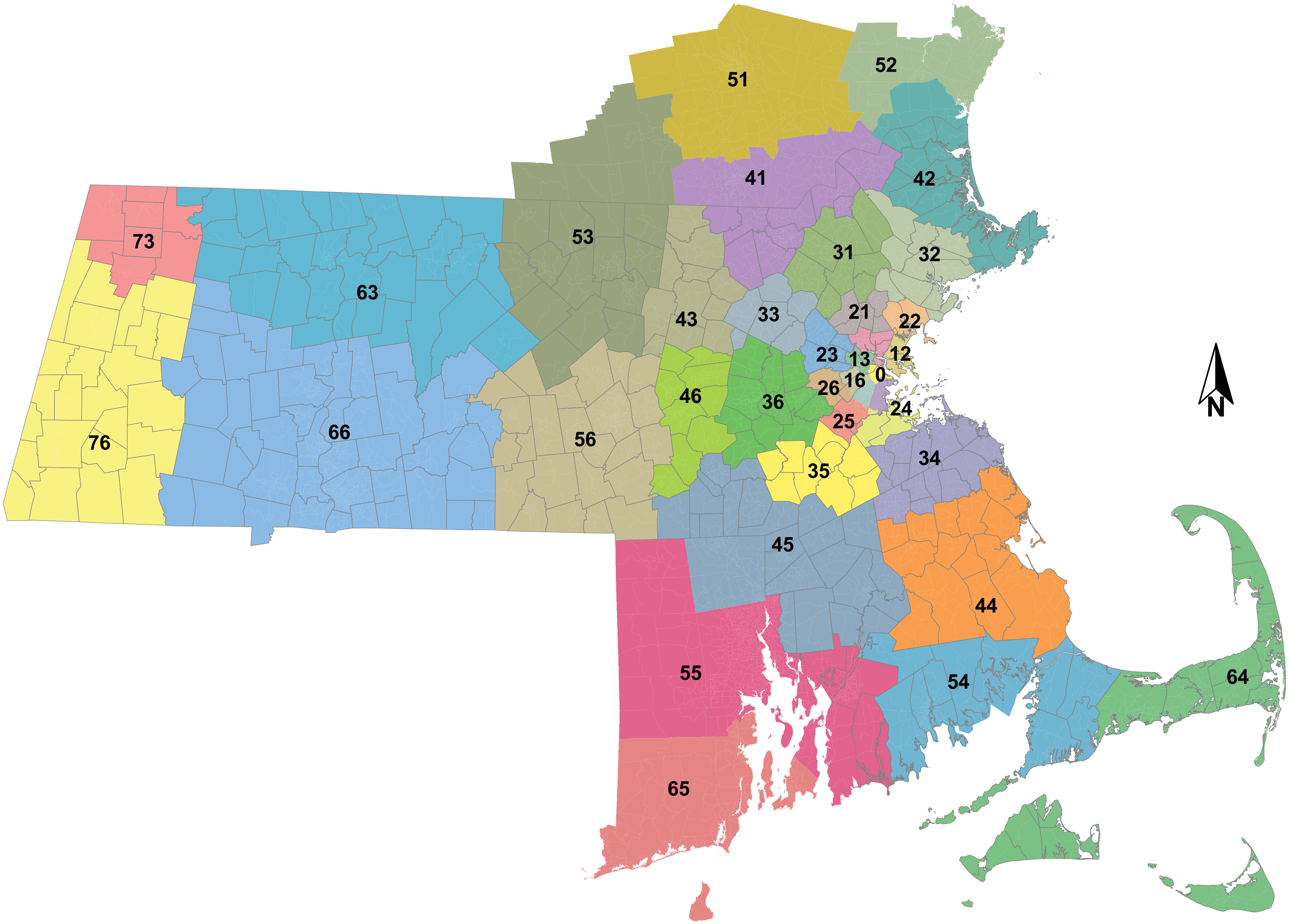
BOSTON
REGION
MPO

Figure 33
Model Analysis Corridors, B

TDM23 Structures, Applications, and Performance

Districts

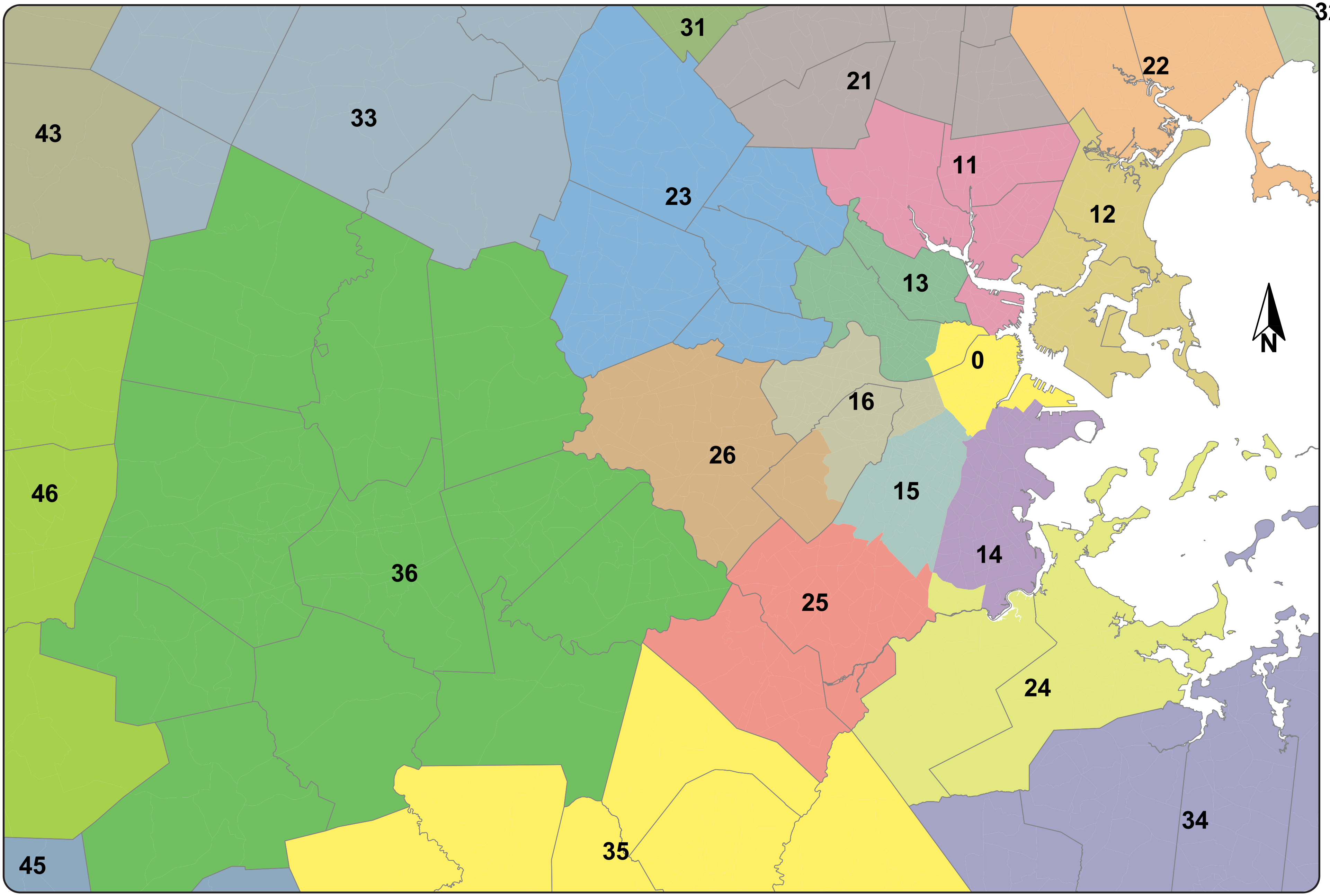
The districts are the intersection of the rings and corridors.



BOSTON
REGION
MPO

Figure 34
Model Analysis Districts, A

TDM23 Structures, Applications, and Performance



BOSTON
REGION
MPO

Figure 35
Model Analysis Districts, B

TDM23 Structures, Applications, and Performance

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.

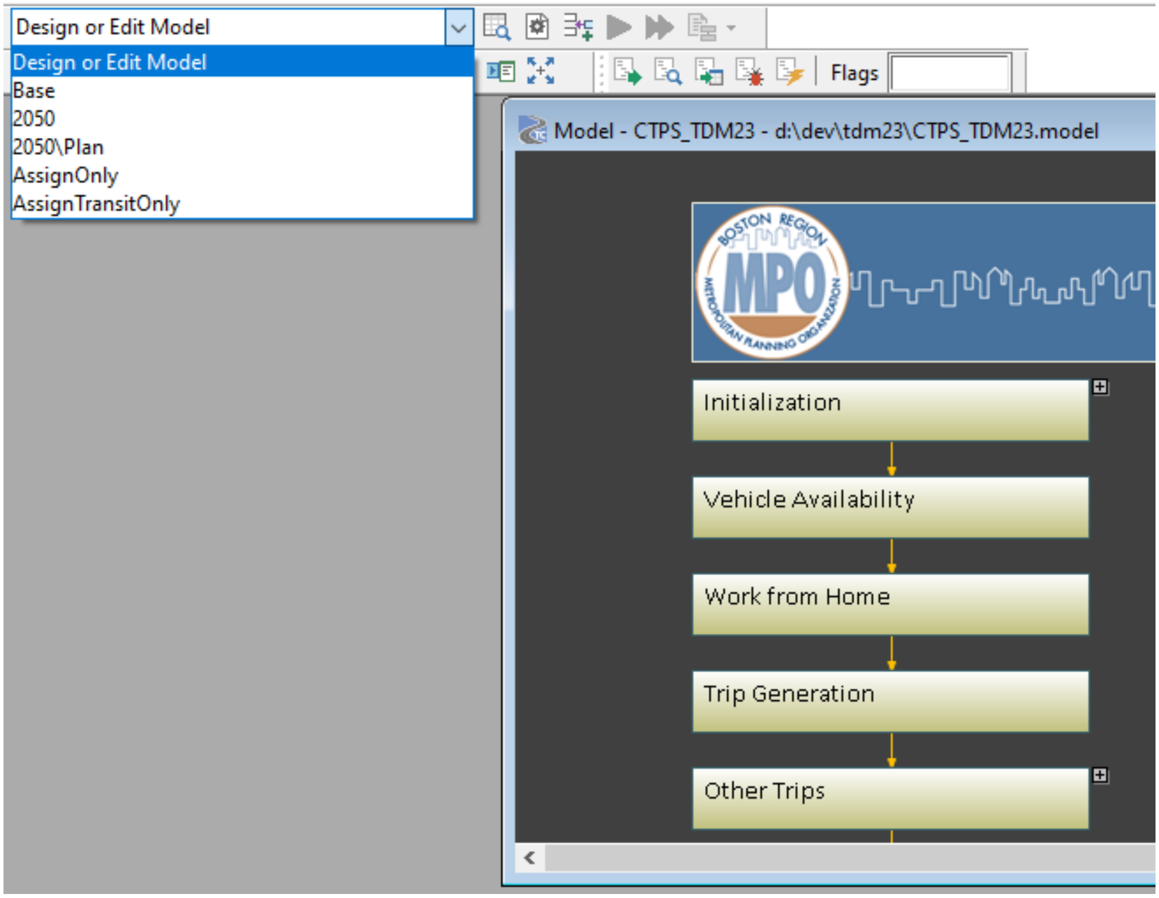
Less frequently changed inputs, such as parameter values are arranged by Demand and Supply components. This structure helps avoid accidental or missed settings while maintaining full functionality.

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:

- **Base** (2019)—full model run with feedback using 2019 networks and SE 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 the Platforms section, input files 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 70 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 70
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

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 (over 100GB per scenario).

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

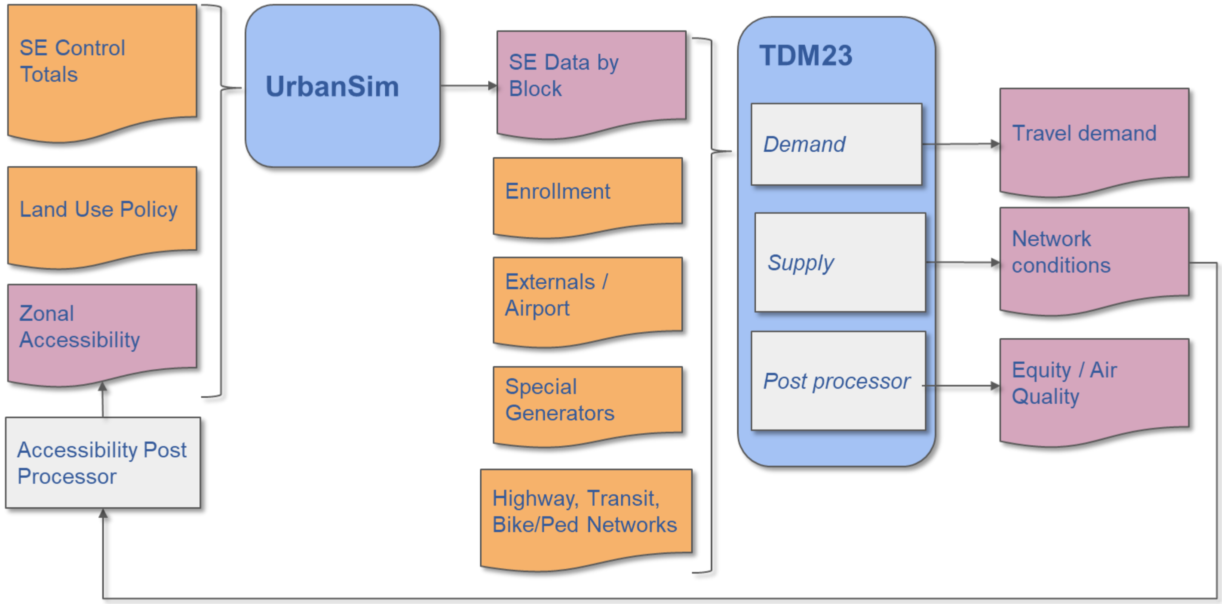
2.9 TRANSPORTATION AND LAND USE MODEL CONNECTION

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.

Figure 37
Travel Demand and Land Use Model Interactions



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 (BRMPO). Most of the results and summary reports in this chapter are for BRMPO areas.

Thresholds and Targets

Where applicable, reference thresholds are included in the validation summaries. However, as the 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 BRMPO.

[11] Travel Model Validation and Reasonableness Checking Manual—Second Edition (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 Census Bureau from American Community Survey (ACS) responses under a pooled funding from 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/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 DPU publishes the total annual TNC trip start, end, and duration at the community level.[12] Unfortunately, the requirement to provide additional information was removed from the H5248 bill. A later bill restored the requirement to provide additional information, but this information is not yet available for analysis.

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 percent and 47 percent of total ride source VMT.[14]

3.2.5 Logan Airport Ground Access Survey

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]

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[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-Haling 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 along 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:

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

3.2.7 Origin-Destination (OD) Travel Data

OD Travel Data was 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 Interstate 95 (I-95) Corridor Coalition, CTPS has access to INRIX data through the RITIS platform. The relevant data for roadway speed validation

[16] https://www.streetlightdata.com/
[17] https://www.replicahq.com/

is available 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/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/line, direction, stop, day type, and time period. These data are sourced from 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/line, direction, stop, day type, and time period. Data is sourced from AFC and a modeled derivation of trip OD and is available for Fall 2019.[18]

3.2.10 PnR 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.

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

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[18] https://www.massdottracker.com/wp/

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 average vehicles per household and vehicle sufficiency share is within five percent with an overestimate of sufficient vehicle households, but an underestimate of average vehicles.

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 household survey, which 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

[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

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]

Table 71
NCHRP Trip Generation Rates

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

Number of Workers by Number of Autos

	Workers				
Autos	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

	Household Size					
Children	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**

[20] NCHRP Report 716 - Travel Demand Forecasting: Parameters and Techniques

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

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

	Household Size					
Vehicles	**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

	Household Size					
Vehicles	**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 72
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

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 73 to show the production rates by household, person, and worker.

Table 73
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	17.28	0	1.90	1.45	0	0.80	1.45	1.08	1.41
hbsc_p	11.76	0	0.59	1.20	0	0.15	11.73	0	0.48
hbsr_p	11.30	0.02	1.77	1.58	0.02	0.74	10.96	0.02	1.26
hbpb_p	12.76	0.93	2.13	2.12	0.30	1.03	11.68	0.30	1.43
nhbw_p	5.60	0	0.52	0.40	0	0.22	0.40	0.30	0.38
nhbnw_p	9.72	1.19	2.33	1.91	0.54	1.11	6.66	0.61	1.64
all_trips	42.76	3.08	9.24	7.67	2.19	4.05	38.55	2.67	6.59

The non-home-based trips per household (hh_mean column) are 0.52 + 2.33 = 2.85, 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 1.77 + 2.13 = 3.90, which is still less than the 4.9 NCHRP rate. The 1.90 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. However, the trend by income is not as specific because of the different distributions of household sizes (a larger share of one-person households in middle income than low income).

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, BRMPO 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 full model and calibrate mode choice parameters to better fit transit and roadway observations.

The Mode Choice validation report compares mode share by purpose, 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 (Source DPU) were allocated to weekdays using the trip purpose and vehicle splits based on the MAPC rider survey data.[21]

Table 74 shows the impact that introducing ride-source modes on mode choice has on other modes by 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, 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 74
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. HBU = home-based university. 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.

[21] Mass.gov. 2019 Data Report: Rideshare in Massachusetts. https://tnc.sites.digital.mass.gov/

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.

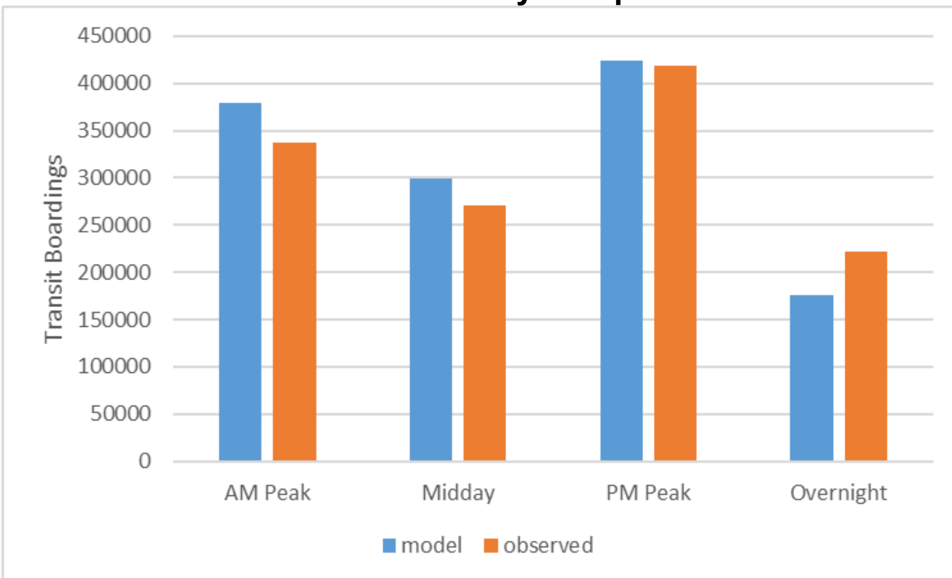
3.3.5 Time of Day

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 household survey, 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



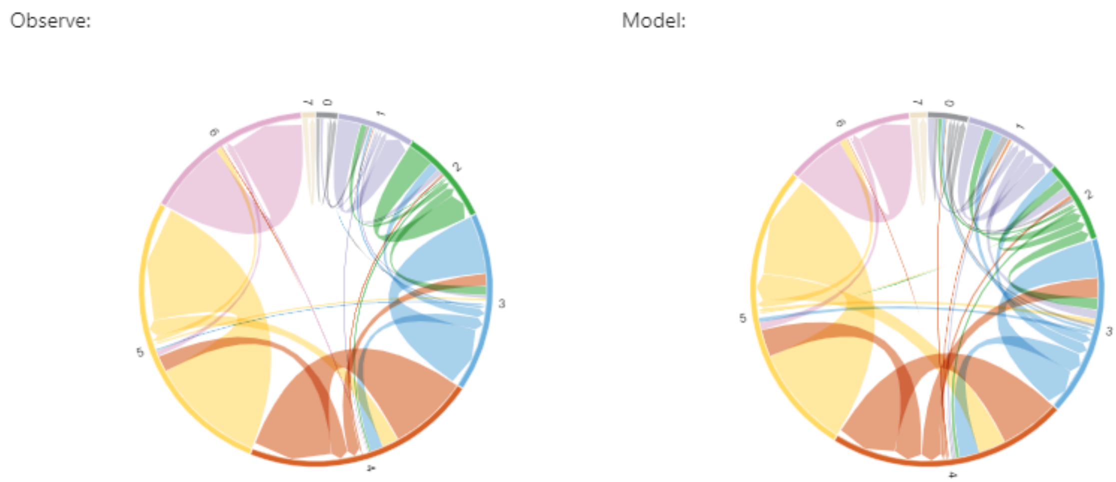
3.3.6 Trucks and Commercial Vehicles

Truck calibration is limited to an evaluation of the trip distribution. The average trip lengths and coincidence ratios are shown in the truck distribution 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.

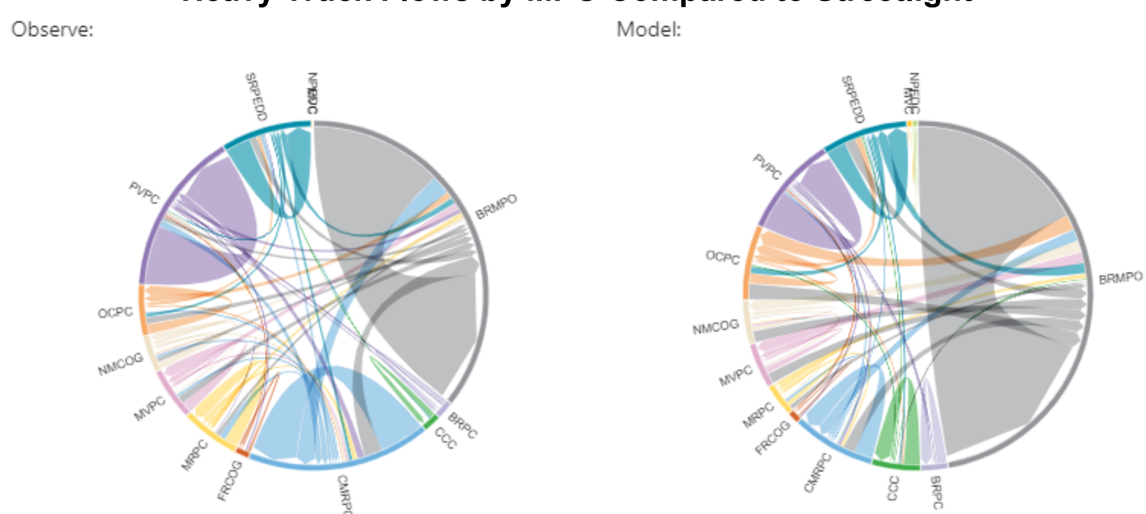
Overall truck flows are relatively consistent between TDM23 and observations. Figure 39 shows the flows by ring.

Figure 39
Truck Flows by Ring Compared to Replica



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



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 trips 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

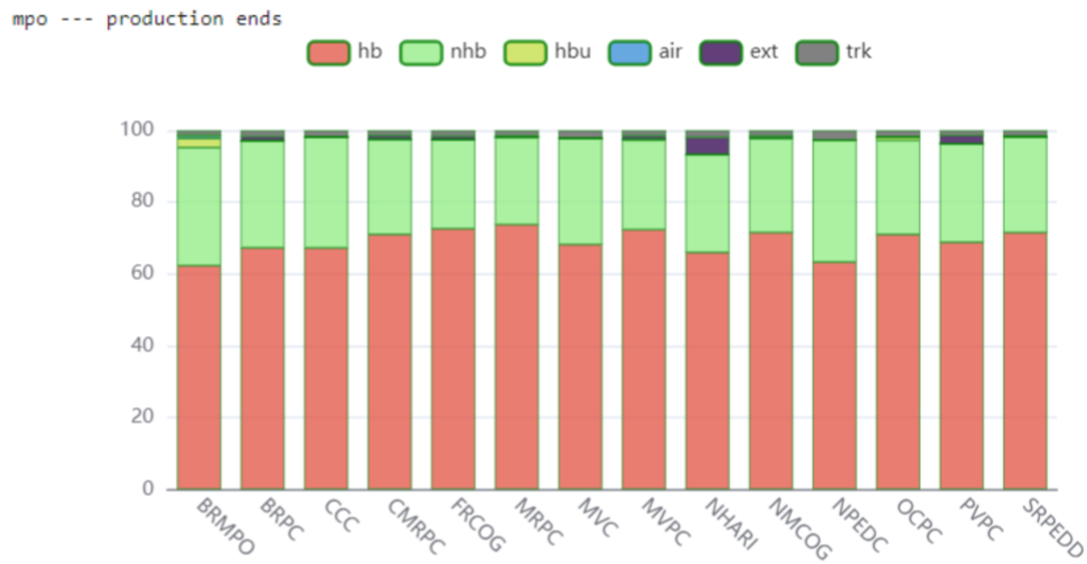
The examination of travel flows is conducted by first examining the reasonableness of the generation and distribution component outputs and then comparing flows by mode.

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, BRMPO subregion, ring, and corridor.

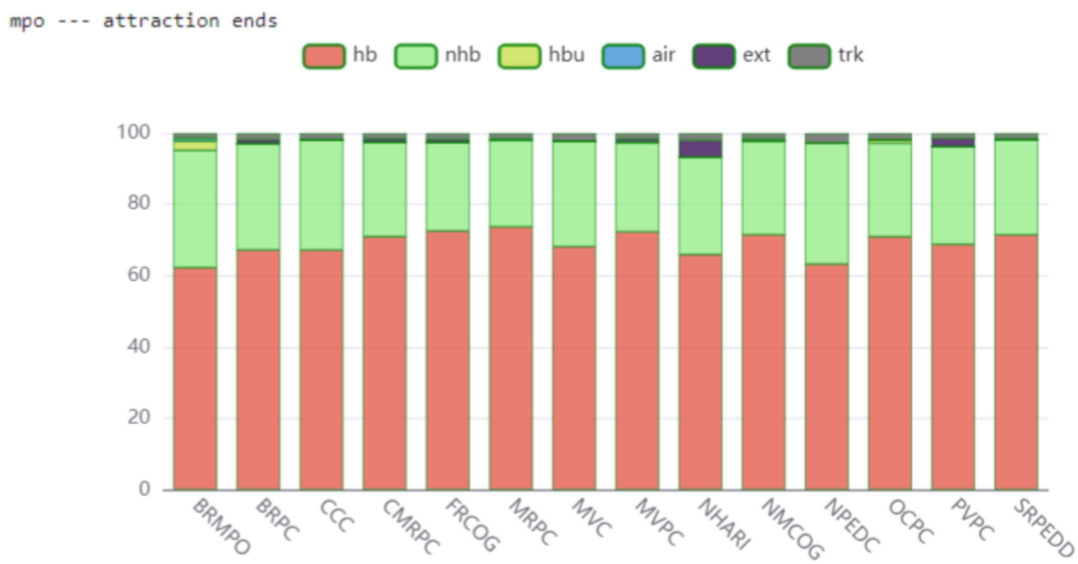
The validation report is previewed below in Figures 41 and 42 that show the marginal distributions of trip ends by MPO. Note that New Hampshire and Rhode Island (NHARI) have the highest share of external trips. BRMPO has the highest share of university trips.

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. 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. 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.

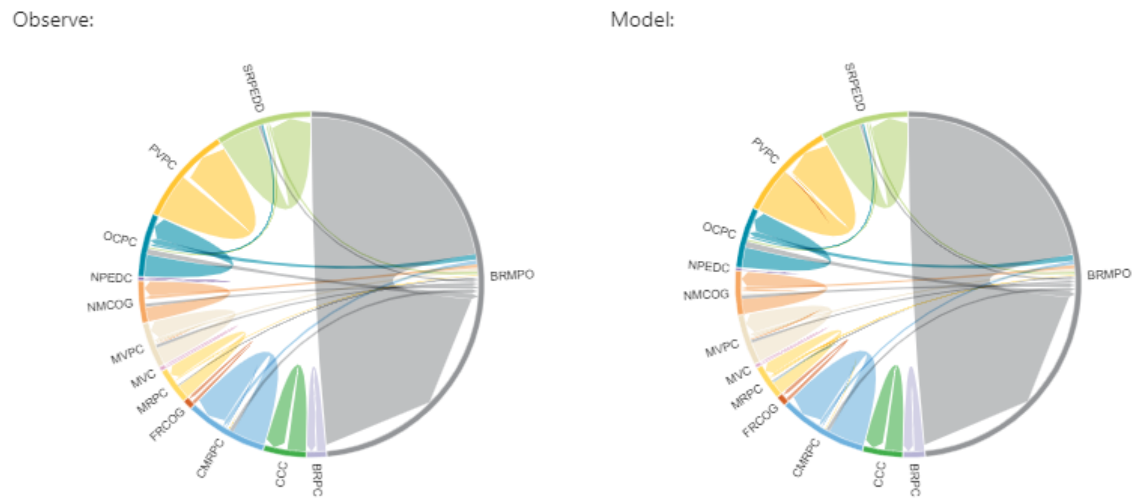
Mode Choice

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. 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.

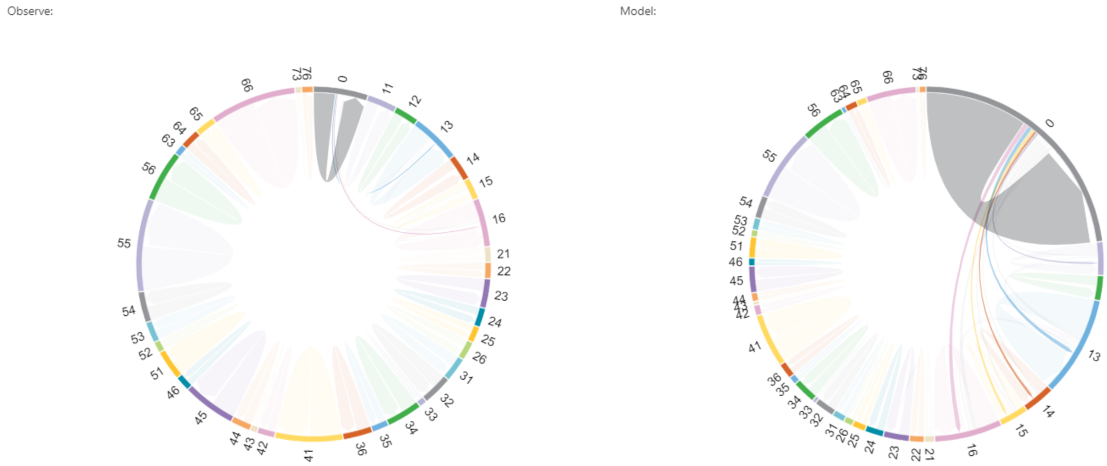
Auto flows are consistent between the model and Streetlight and Replica data at both the district and ring geographies as well.

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 15 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.

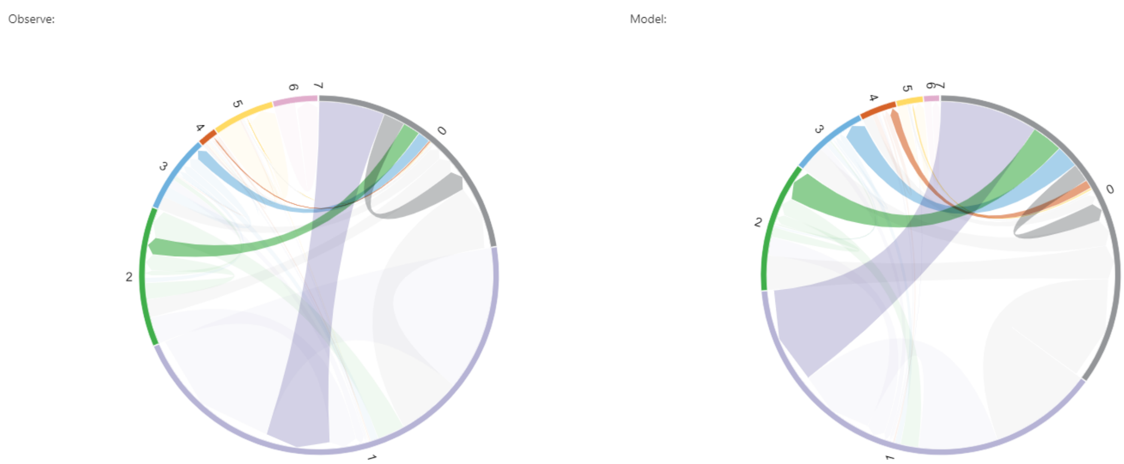
Figure 44
District Nonmotorized Trip Flows—CBD (District 0) Highlighted



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 connects 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 HPMS Interstate VMT shows a strong correlation between the model and observed data by MPO. The modeled VMT for the BRMPO and statewide are within two percent 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 13 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 75 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 incorporate more comprehensive count data from Replica is underway and will give better insight into the model performance for small roadways. The validation report tables include the target percent differences and RMSE thresholds.

Table 75
Highway Comparisons by Volume Group

Volume Group	Model	Observed	Percent Difference	RMSE %	Peak Hour RMSE
1-999	1,127	716	57.5	115.5	66.1
1000-2499	2,616	1,739	50.4	143.3	199.3
2500-4999	4,570	3,699	23.5	66.1	195.6
5000-9999	7,542	7,160	5.3	40.3	230.8
10000-24999	14,864	15,478	-4.0	32.5	402.4
25000-49999	37,678	37,323	1.0	17.6	525.5
50000-74999	61,163	60,228	1.6	11.1	534.8
75000+	93,044	91,885	1.3	8.4	617.5

RMSE = root mean squared error.

Table 76 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 76
Highway Comparisons by Facility Type

Volume Group	Model	Observed	Percent Difference	RMSE %	Peak Hour RMSE
Freeway	72,839	71,727	1.6	9.8	562.3
Expressway	36,121	34,921	3.4	22	614.6
Major Arterial	18,065	17,923	0.8	34.4	493.2
Minor Arterial	10,149	10,540	-3.7	40.1	338.1
Collector	5,200	5,064	2.7	53	214.7
Local Road	3,659	4,149	-11.8	86.2	286.1
Freeway-Freeway Connector	23,830	23,294	2.3	19.6	365.2
Ramp	8,293	8,309	-0.2	37	245.9

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. 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.

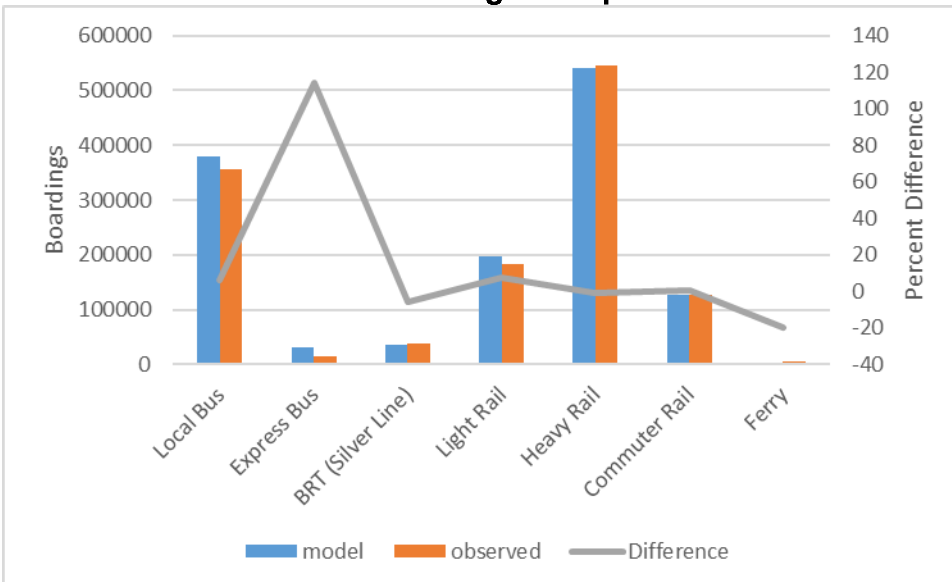
3.4.3 Transit Assignment

The calibration proceeded iteratively from higher to lower levels to 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 was available. Every mode except express bus and ferry are within 10percent of observed.

Figure 46
Transit Boardings Comparison



BRT = bus rapid transit.

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 due to the lack of capturing the enjoyable experience of riding a ferry. Furthermore, travelers using the ferry for the pleasure of it would not be estimated in the model.

Transfers

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

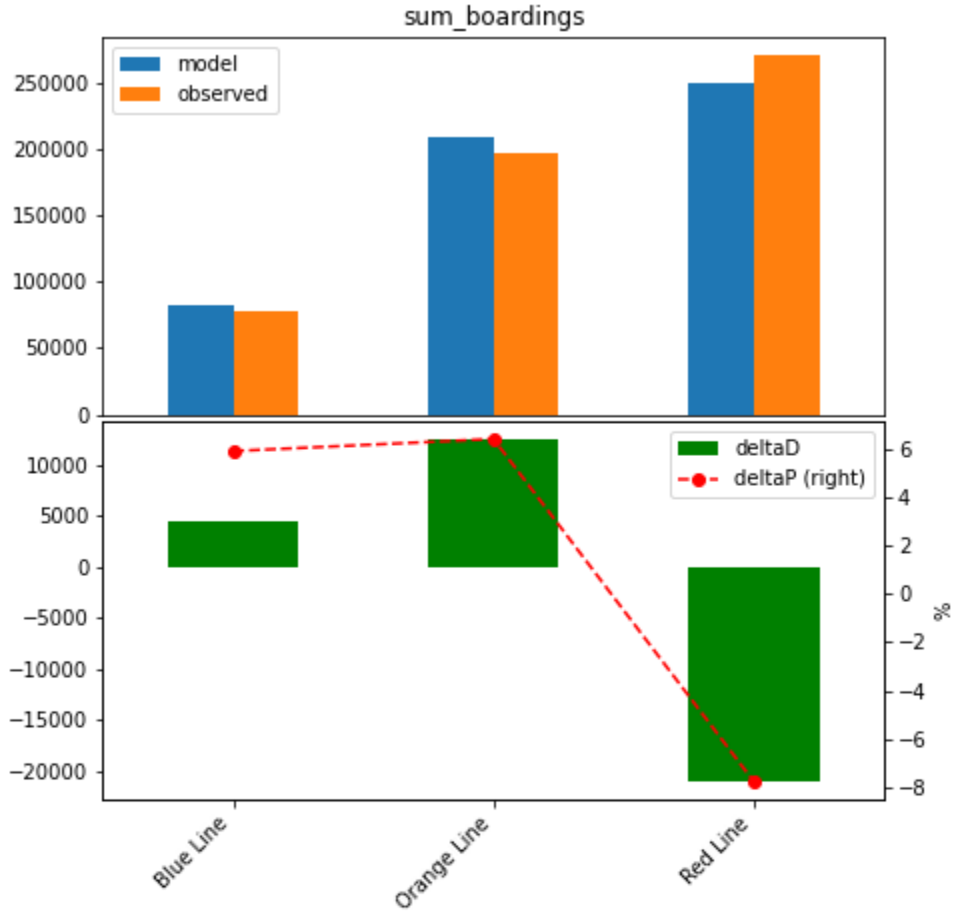
Transfers using MBTA routes in the model are compared to the onboard survey data by access mode and time period in Figure 47. Transfers across all transit operators are presented in the Transfer validation report.

Route Level

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

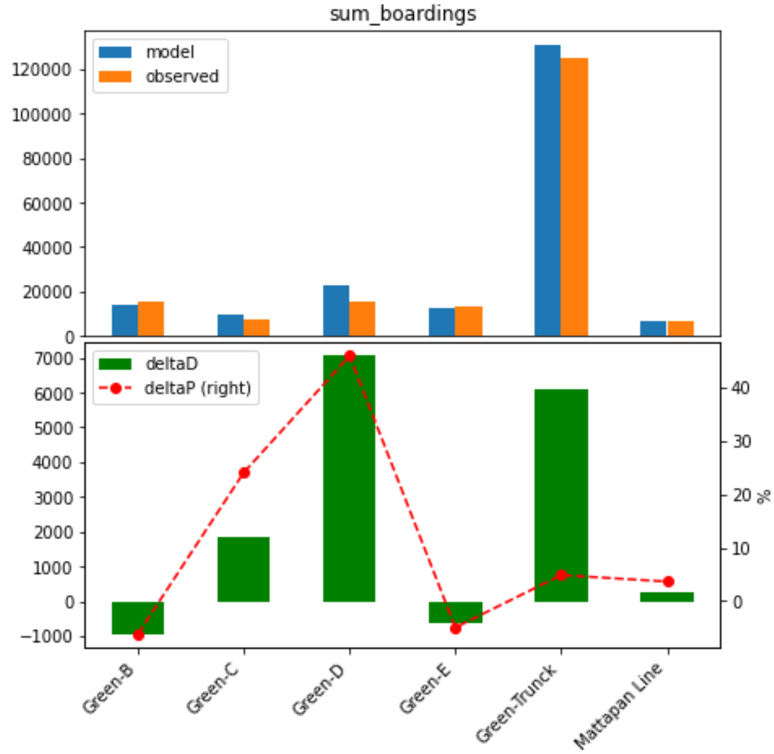
Heavy rail boarding estimates are all very close to observed, with less than a 10 percent difference.

Figure 47
Heavy Rail Boardings Comparison



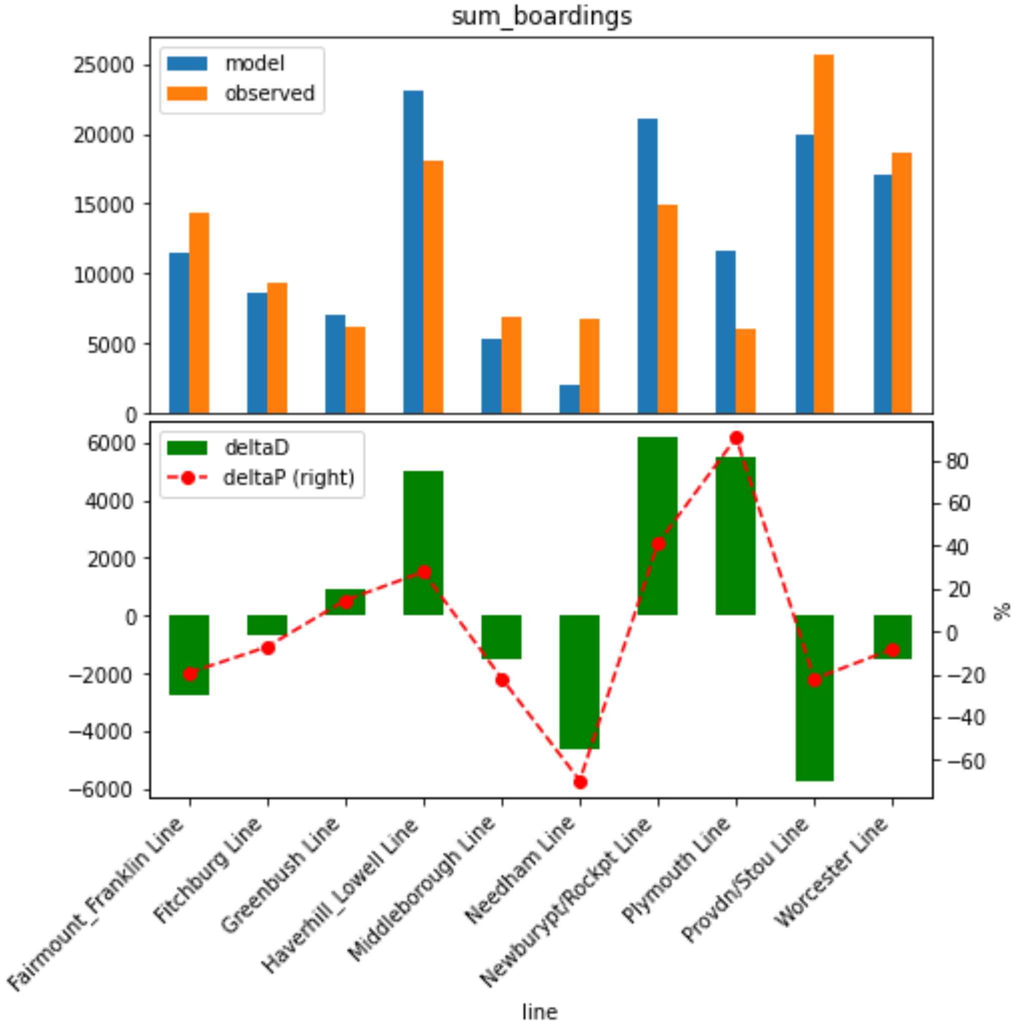
Light rail boardings are good on the trunk section, but the C and D branches are overestimated.

Figure 48
Light Rail Boardings Comparison



The commuter rail is overestimated across several lines, particularly on the South Shore with the Plymouth, Greenbush, and Middleborough lines all being over estimated by more than 20 percent. The Providence line is underestimated, but Rhode Island Public Transit Authority services are not represented in the model and this restricts some transit paths between zones. The Needham line is underestimated and requires further investigation to resolve.

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 with 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 Chapter 2, 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 BRMPO input rate. Overall, trips are reduced by 6.7 percent. Transit trips are reduced at a higher rate than auto and non-motorized 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 consistent with the change in trips (6.7 percent) while the change in vehicle hours traveled (VHT) is substantially larger (11.6 percent), indicating that congestion is reduced. This is borne out in the reduction of congested VMT (15.3 percent).

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

3.5.2 Ride-Source Availability

To represent the increased availability of ride-source services, say 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 to ride-source. Across transit modes, there is less decrease in rail than bus 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 Micromobility

To represent micromobility, the electrification and proliferation of scooters, unicycles, e-bikes, and other small transporters, an adjustment is made to the existing walk and bike modes. To represent that walking may be done in part with an electric scooter and biking may be done with an electric bike, the average speed and maximum range are both increased by 33 percent: from 3 mph and three miles walking to 4 mph and four miles and from 12 mph and 12 miles to 16 mph and 16 miles biking respectively.

This change is applied to the walk and bike speed inputs and availability thresholds. Trip mode choice and distribution will utilize the new parameters in calculating walk and bike utilities and availability. The transit paths will also use the increased speed to estimate walk access and egress times. Although the transit walk access and egress time threshold is held constant, the increased speed effectively increases the access and egress distance threshold by 33 percent.

This scenario produced a large increase in nonmotorized trips, shifting from auto and school bus use. There was a substantial increase in linked transit trips as well due to the improved walk access and egress times and distances. These improvements created transit paths with fewer transfers, further improving the attractiveness of transit.

Transit modes that had the largest increase were higher service level modes (rail and express bus). Local bus and shuttle routes decreased in boardings as walk and bike modes were more competitive for shorter trips and transfer connections.

This scenario had the largest impact on emissions reductions besides the work from home scenario. Emission reductions benefit equity populations at a higher rate.

3.5.4 Highway Toll Increase

Highway tolls currently coded in the model network are doubled. Tolls are coded along I-90, the Calahan 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 six percent and four percent, respectively, as highway congestion is slightly reduced.

Overall VMT is reduced by 1.2 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 3.5 percent and boardings by four percent. The modes with the largest increases are those that are more expensive: commuter rail, ferry, regional bus. The percentage increase in boardings implies a fare elasticity of negative 0.133 [-0.30 / 0.04]. 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/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 the Scenarios appendix to this report. The projects coded into this network are those defined in the LRTP plan as well as any projects completed since the model base year (2019) or are in an MPO or State Transportation/Capital Improvement Program. 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 (~0.2 percent) and increases the insufficient and zero vehicle households. This change has a small impact on the trips generated, but the majority of the mode shift is 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 since 2019, as well as the service improvements in Bus Network Redesign and Commuter Rail Transformation.

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. There are many more bus lanes coded in the LRTP network, so this test was done with the LRTP Highway and Transit Projects as a reference scenario. A comparison of these two scenarios is available in the Bus Lane Sensitivity Test report.

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. Interestingly, the magnitude of emissions increase is similar to the emissions decrease seen in the Transit Fare Reduction scenario.

Appendix A—Scenario Definitions

Appendix A describes the preset parameter inputs. The preset scenarios are

- 2019 base year, and
- 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 with 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 the Walnut Street to intersection 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 & University Avenue/Everett Street (Norwood)	605857
10	Route 146 (NB & SB) bridge replacement over West Main Street and improvements on Route 146 at Elm Street, Elmwood Street & 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 & 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 & 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 St/Hartwell Ave): Reconstruction of major intersections as multi-lane roundabouts. (Lexington)	

MassDOT = Massachusetts Department of Transportation. MBTA = Massachusetts Bay Transportation Authority. NB = Northbound. SB = Southbound.

A.1.2 Transit network

TDM23 includes all MBTA fixed route services and most of the fixed route services provided by regional transit agencies (RTA), 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 Agency Service Included in TDM23

Regional Transit Agency
Brockton Area Transit Authority (BAT)
Burlington
Cape Ann Transit Authority (CATA)
Greater-Attleboro-Taunton RTA (GATRA)
Lexpress (Lexington)
Lowell RTA (LRTA)
Merrimack Valley RTA (MVRTA)
Metrowest RTA (MWRTA)
Pioneer Valley RTA (PVTA)
Southeastern RTA (SRTA)
Worcester RTA (WRTA)

RTA = Regional Transit Agency.

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
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

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.mbta.com/projects/better-bus-project
[23]Service Plan received from MBTA as GTFS file on November 2022.
[24] Service patterns for power study received from MassDOT Rail and Transit, 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	
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

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 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.

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 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.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 being 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.

Massachusetts

TDM23.1.0 utilizes the MAPC run 139, Statewide run 97 UrbanSim outputs. The 2050 scenario is represented by the ‘2049’ named year from UrbanSim.

New Hampshire

New Hampshire has developed population projections at the municipal level to 2050.[25] The TDM19 2016 and 2040 populations were scaled to the projected 2020 and 2050 populations, respectively. Therefore, the 2020 and 2050

[25] https://www.nheconomy.com/office-of-planning-and-development

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 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 only assume that school locations and relative sizes are consistent between 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 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 to and from Logan Airport in 2019 was 42,522,411.[26] Based on the analysis from the 2019 air passenger survey and Massport inputs, the average weekday airport passengers in May 2019 is estimated to be 125,883. Ten percent of passengers are assumed to transfer, therefore the passengers using ground access transportation are 113,295. These passengers are assumed to be evenly split between enplanements and deplanements.

The 2050 scenario leverages Massport projections to their 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, approximately a 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 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 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 opening.

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

Appendix B describes the changes implemented between successive releases of TDM23. TDM23.0.1 was the initial release version of TDM23, used for the LRTP *Destination 2050*. The current version of the model is TDM23.1.0.

B.1 TDM23.1.0

This section describes the changes between TDM23.1.0 and TDM23.0.1. 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 through a menu option.
- I-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 can be input at the model region, state, MPO, or town level.
- Walk and bike trip tables are 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 are 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 six 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)**.** To implement, the number of lanes on Rourke Bridge was updated.

- **Reconstruction of East Street (Route 9) in Pittsfield** (MassDOT Project ID 604003). To implement, increased 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.

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 are the following:

- Removed flyover link cutting across the rotary (at routes 18, 28, and 44) in Middleborough.
- Added roundabout on Route 6 EB at Route 149 (exit 65)
- Added 495 NB 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 WB in Boston
    - I-90 exit 125 (Route 16 West Newton)
    - I-95 exit 43 A-B (Winter St/Totten Pond Rd)
    - Route 3 exit 3
    - Route 2 in Devens, MA
    - I-90 WB interchange with I-95
    - I-90 exit 3 (Route 41) in West Stockbridge

Network attribute

Network attribute changes include the following:

- Updated free flow speeds on all facilities with estimated free flow speeds from Replica
- Tolls and PnR costs converted to 2010 dollars
- Freeway to Freeway ramps distinguished from other ramps in facility type designation
- Roadway lanes and directionality corrected in the West Boston area as reported through the Red/Blue Connector Study

- Corrected functional class and facility type on Pleasant Street in Lee
- Corrected number of lanes on Route 18
- Corrected facility type on Rt 3 south between Braintree and Cape Cod.
- Corrected facility type for an Everett roadway

Socioeconomic Inputs

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 Logan airport passengers were updated to be consistent with Massport and Federal Aviation Administration forecasts.