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Ridership Methodology and Results

TECHNICAL MEMORANDUM

DATE: December 19, 2019
TO: Rail Vision Project Team
FROM: Bruce Kaplan, Central Transportation Planning Staff
RE: Rail Vision Modeling: Methodology, Assumptions, and Results

The Massachusetts Department of Transportation (MassDOT) requested that the Central Transportation Planning Staff (CTPS) provide technical support for the Rail Vision study. For this work, CTPS used the Massachusetts Statewide Travel Demand Model (TDM), developed in 2016, to forecast transit ridership and mode shares, conduct air quality and environmental justice analyses, and calculate highway statistics for a variety of alternatives.

This memorandum begins with a brief discussion of the modeling process and an overview of the TDM's features. An explanation of the calibration of the TDM specifically for analyzing Rail Vision alternatives follows with a catalog of the assumptions behind each modeled alternative. The memorandum concludes with a discussion of the results and outputs of the travel demand forecasting process in the areas of ridership, revenue, passenger-miles traveled, passenger-hours of travel, and air quality.

CTPS applied the TDM for a 2018 base year and a future 2040 horizon year. The 2040 projections are consistent with the adopted socioeconomic forecasts and transportation network assumptions presented in the most recent Long-Range Transportation Plan (LRTP) for each Massachusetts regional planning agency (RPA) and metropolitan planning organization (MPO), including those in the Massachusetts Bay Transportation Authority's (MBTA) service area—the Boston Region MPO, Central Massachusetts Regional Planning Commission, Merrimack Valley Planning Commission, Metropolitan Area Planning Council (MAPC), Montachusett Regional Planning Commission, Northern Middlesex Council of Governments, Old Colony Planning Council, and Southeastern Regional Planning and Economic Development District. Agencies in New Hampshire and Rhode Island were consulted for similar information. For the Boston Region MPO area, these network and land use assumptions were taken from the LRTP *Destination 2040*.

1 OVERVIEW OF THE MODELING PROCESS

CTPS used a four-step travel demand modeling process to perform its forecasting. Figure 1 displays a pictorial representation of this process.

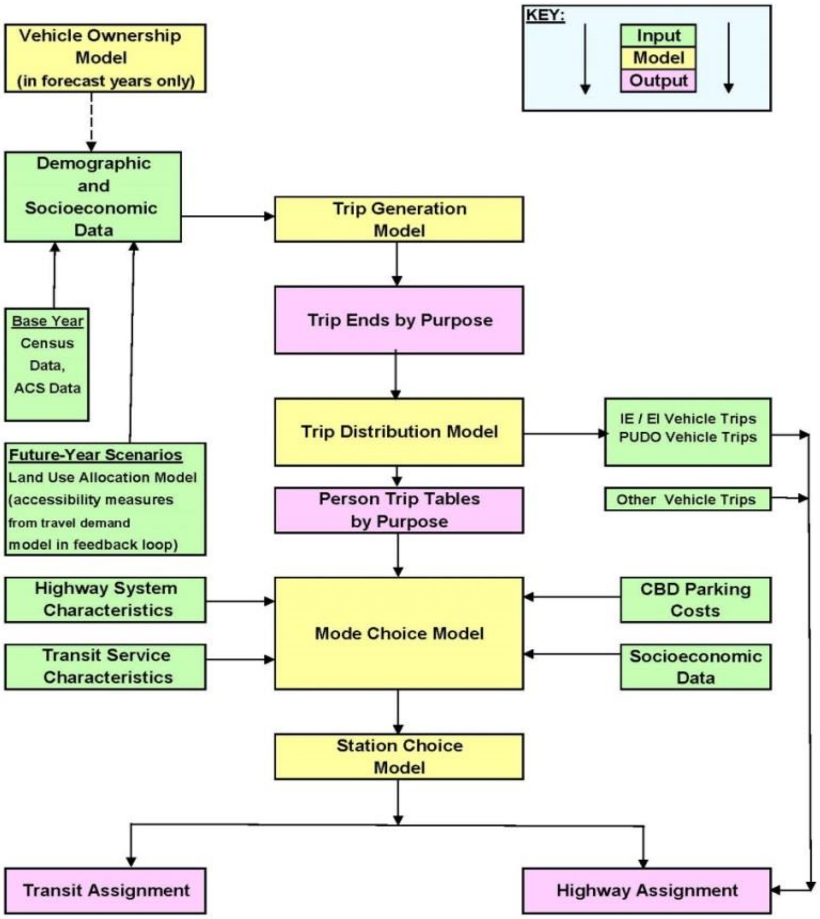
Trip generation is the first step in travel demand modeling. In trip generation, the total number of trip ends generated by residents of the modeled area is calculated using demographic and socioeconomic data. Similarly, the number of trip ends attracted to different types of land uses, such as employment centers, schools, hospitals, and shopping centers, is estimated using land use data and trip generation rates obtained from travel surveys. This information is produced and calculated at the level of disaggregated geographic areas known as transportation analysis zones (TAZs).

In the second step of the modeling process, *trip distribution*, the model determines how the trip ends generated in each TAZ are distributed throughout the region. Trip ends are distributed based on transit and highway travel times between TAZs and the relative attractiveness of each TAZ, which is influenced by the number of jobs available and the size of schools, hospitals, and shopping centers.

Once the total number of trips between each pair of TAZs is determined, the *mode choice* step (step three) allocates the total trips among the available modes of travel. In this case, the available modes of travel are *walk/bike, auto* (*single-occupant vehicle [SOV]* and *carpool / high-occupancy vehicle [HOV]*), and *transit* (subdivided by access mode: *walking/biking to transit* or *driving to transit [including parking and drop-offs]*). To determine the proportions of each mode, the model takes into account the travel times, number of transfers required, parking availability, and costs associated with these options. Other variables, such as auto ownership and household size, are also included in the model.

After estimating the number of trips by mode for all possible TAZ combinations, the *trip assignment* step (step four) assigns trips to their respective specific routes. This step is necessary because there is often more than one highway route or transit service connecting two TAZs.

Figure 1
The CTPS Four-Step Travel Demand Modeling Process



ACS = American Community Survey. CBD = Central Business District. EI = External Internal. IE = Internal External. PUDO = pick-up/drop-off.

2 FEATURES OF THE CTPS TRAVEL DEMAND MODEL

The TDM is a key tool that supports the analyses in the LRTP and the Transportation Improvement Program (TIP), as well as numerous agency-funded technical studies. The model is maintained with the latest population and employment statistics (both existing and forecast), and it represents the latest version of the transportation network (highway, transit, and non-motorized modes) as well as proposed projects and projects for which funding has been committed. Some of the recent benchmark dates and enhancements to the model are as follows:

- In 2011, the regional model highway network representation was rebuilt using the latest MassDOT road inventory file (RIF) data in TransCAD.
- In 2012–13, the regional model transit system network representation was also completely rebuilt.
- From 2012 to 2015, all demand components of the regional model were re-estimated using the 2011 Massachusetts Household Travel Survey data.
- In 2016–17, the statewide highway model and the 2015 regional model were merged into a single modeling system. This enhanced regional model allowed for full representation of the regional commuter rail system as well as the travel market overlaps between Greater Boston and neighboring communities in New Hampshire and Rhode Island.
- In 2017, under contract to MassDOT, transit route systems in Worcester and Springfield were added to the model.
- In 2018, all features of this new modeling system were brought to a common 2016 base.
- In 2019, most features of this new modeling system were brought to a common 2018 base.
- Currently, the TDM covers all of Massachusetts, all of Rhode Island, and the southern third of New Hampshire. In total, the model covers 448 communities.

This version of the TDM is a traditional four-step travel demand forecasting model. The steps in the model are trip generation, trip distribution, mode choice, and trip assignment.

The total 2018 population simulated in the model is 8.5 million (6.8 million in Massachusetts, 1.0 million in Rhode Island, and 0.7 million in New Hampshire). This population is contained within a total of 5,839 TAZs. There are 4,497 TAZs in Massachusetts, 812 in Rhode Island, and 430 in New Hampshire, and 100 TAZs are external.

The model simulates over 1,700 transit routes in Massachusetts (inclusive of eight regional transit authorities). The model contains over 27,000 miles of highway (22,500 miles in Massachusetts, 2,500 miles in Rhode Island, and 2,000 miles in New Hampshire).

Modes simulated in the model are characterized as *single-occupancy vehicle* (*SOV), high-occupancy vehicle with two occupants (HOV2), high-occupancy vehicle with three or more occupants (HOV3plus), walk/bike, drive to commuter boat, drive to commuter rail, drive to rapid transit, drive to bus,* and *walk/bike to transit*. The model also reflects the following truck types: *light commercial truck, medium commercial truck, heavy commercial truck, hazmat medium truck,* and *hazmat heavy truck*. Other types of trips such as taxi trips and through trips (trips that neither begin nor end in the modeled area, but pass through the modeled area) are considered in the TDM.

Trips associated with several major facilities in Massachusetts have characteristics that are not fully captured by any of the TDM’s trip generation or trip distribution sub-models. The socio-economic data associated with these facilities cannot truly reflect the travel volumes associated with these locations. Since the standard trip generation and distribution models are not expected to provide reliable estimates of travel patterns from these models, special models were created to better represent these special trip generators. Special generators in the model include the following:

- Logan International Airport
- Encore Casino
- MGM Casino in Springfield
- Plainridge Park Slot Parlor

Daily travel activities made by residents are modeled according to trip purpose. The trip purposes simulated in the model are as follows:

- home-based work (work trips that have one trip end associated with the traveler’s home)
- home-based personal business
- home-based social/recreational
- pick-up/drop-off
- non-home-based work (trips that neither begin nor end at home but begin or end at work),
- non-home based non-work (trips that neither begin nor end at home)
- school: pre-kindergarten to grade 8 (school trips made by students younger than 9th graders)
- school: grades 9 through 12 (school trips made by high school students)

- college commuter (school trips made by college students living off-campus)
- college dorm (school trips made by college students living on-campus)

Forecast years simulated in the model include 2020, 2030, and 2040. These forecasts represent the intersection of two different forecasting methodologies:

1. **Top Down**: MassDOT retained the University of Massachusetts’ (UMass) Donahue Institute to examine state birth and death rates, migration rates, household characteristics and national trends to predict likely population, household, and employment forecasts. The UMass Donahue Institute then examined county to county historical growth trends and relationships between population growth and employment growth. In addition, MassDOT assembled a committee of advisors (representatives from CTPS and each of the State’s regional planning agencies) to direct and review the work of the UMass Donahue Institute. As a result, county and regional planning agency forecasts were prepared.
2. **Bottom Up**: In a parallel effort, MassDOT partnered with the Boston area’s MAPC to develop a web-based development tracking system (MassBuilds) whereby regional agencies enter proposed development projects, which are currently in permitting stages. Using MassBuilds and consulting with member communities, each of the State’s regional planning agencies allocated the UMass Donahue Institute’s forecasts to individual communities and TAZs.

The specific details of the four-step modeling process are discussed below.

2.1 Model Data Inputs and Storage

The structure of the TDM is largely defined by the software (TransCAD) in which the model is run. In the TransCAD system, the most important input is the *link layer*. The link layer contains both real and imaginary data elements. The real data elements are the lines which represent roads, rail lines, walk and bike trails, and other transportation network features. The imaginary elements include items such as TAZ centroid connectors and representative walk links. Each TAZ is assigned a center point, known as a centroid, with which is associated trip data. This centroid is connected to the real data element links and lines by means of imaginary links known as centroid connectors and walk links; it is through these imaginary links that travel volumes flow between the real links and the centroids. Within the TDM, there are over 115,000 links. Each link has over 300 attributes associated with it. Attributes include the following: length; functional classification; posted speed; area type; number of travel lanes; TAZ, community, county, and state traversed by the link; mobile emissions on the link; traffic volumes on the link; and others.

The *node layer* represents breakpoints along the links. These breakpoints are intersections or any other points where the attributes on a link are different or change. The node layer also has attributes associated with each node. There are over 150 attributes associated with each node and these attributes include the following: node coordinates; node location (TAZ, community, county, and state); type of traffic control; and many other attributes to support the mode choice and trip assignment steps.

In the TransCAD system, the transit routes and stops cannot exist without link and node layers underneath. Route systems also have many attributes such as headway, route name, period of operation, run time, and other data. Route stops are attached to both the route they serve as well as the node on which they are located. Stops also have an extensive array of data associated with them.

In addition, there are many other data tables used by the TransCAD modeling system. These data include the input land use files required for trip generation; trip generation rates; roadway capacity lookup tables; trip distribution model parameters; mode choice model structure and parameters; and post-processing data, such as vehicle emission rates.

2.2 Trip Generation

The trip generation production process is a cross-classification process that produces daily trips for each of the ten aforementioned trip purposes. That is, trip generation rates for each individual purpose are based on the following: household size, household vehicle ownership, and workers in households. Thus, the household data developed by the UMass Donahue Institute supports this level of detail.

In the TDM, households with autos are simulated separately from households without autos. This allows the model to more accurately reflect mode choice options and travel pattern limitations for households without autos.

Trip attraction rates are based on employment. The employment categories in the model are *retail, service, basic, school K-12 employment,* and *college employment*. Basic employment includes employment associated with economic activity in the manufacturing, wholesale trade, agriculture, mining, utilities, transportation, and warehousing economic sectors. Retail employment includes employment associated with economic activity in the retail sector. Service employment includes employment associated with economic activity in the service, government, arts, health care, education, management, finance, and other technical and professional sectors.

The trip generation process was validated against the household trip-rate data in the 2011 Massachusetts Household Travel Survey.

2.3 Trip Distribution

Trip distribution is based on a tri-proportional gravity model. The three proportions are *productions, attractions,* and *community-to-community travel patterns*. The target community-to-community travel patterns reflect the use of census data in conjunction with the 2011 Massachusetts Household Travel Survey data.

Trip distribution is performed independently for households with autos and households without autos. The distribution is based on a composite of highway and transit travel time.

The distribution produces *daily person travel patterns* for each of the trip purposes discussed above. For kindergarten through grade 12 school trips, the school trips are limited to the school district service area.

The trip distribution process is calibrated to the census and 2011 Massachusetts Household Travel Survey data in terms of both travel patterns and trip length frequency distribution.

2.4 Mode Choice

The mode choice model also maintains the distinction between households with autos and households without autos. The mode choice model is a multinomial logit model that computes the probability associated with the use of each modal option. These probabilities are then applied to the results of the trip distribution process.

The mode choice process considers the travel time cost associated with each mode option. Types of cost and time variables are as follows:

- auto operating cost
- auto tolls
- time spent traveling by auto
- parking cost
- transit access/egress time
- transit fare
- transit transfer time and cost

- transit travel time
- initial transit wait time as a function of headway

The 2011 Massachusetts Household Travel Survey data disclosed not only travel behavior in terms of travel patterns, trip lengths, and trip purposes, but also how people value their time and the modes by which they choose to make their trips. Transfers and out-of-vehicle time (e.g. initial transit wait time, transit access/egress time, and transfer) affect trip choice considerably more than other travel time cost elements. Consequently, the various components of travel time are weighted differently depending on mode. For example, out-of-vehicle time is twice as costly as in-vehicle travel time or fares. Transfers and transfer times are four times as costly as in-vehicle travel time or fares. This indicates that reductions in transfers or out-of-vehicle time (shorter access/egress times or more frequent service resulting in shorter headways) would be more likely to attract riders to transit than minor changes to transit fares or run times.

2.5 Station Choice for Drive to Transit Trips

In the Boston region and specifically near the commuter rail and rapid transit systems, there are many park-and-ride lots that do not have enough capacity to meet the demand. In addition, some park-and-ride lots are shared by several modes (commuter rail, bus, and rapid transit). Thus, a parking choice model is required.

This model prepares an initial assignment for the AM peak period. Based on this initial assignment, the share of the lot occupied by vehicles whose drivers are accessing the various modes is computed and the available parking spaces are allocated accordingly to each mode. Then a full allocation of the trips for each mode is completed and the demand associated with each park-and-ride lot is compared to the parking supply. Vehicles that cannot be accommodated are then reassigned. However, even after this second assignment, some vehicles cannot be accommodated and are shifted to other travel modes.

During the assignment process, the park-and-ride lot used for a trip must be saved, as the return trip in the afternoon or evening must end in the same lot. Thus the station choice process is very detailed and somewhat unique.

Outputs of this process include the transit stop and route trip assignments as well as the highway travel volumes, which are used to pre-load the equilibrium highway assignment discussed below.

2.6 Trip Assignment

The highway and transit trip assignment processes are run for four time periods as follows:

- AM peak period (6:00 AM–9:00 AM)
- Midday (9:00 AM–3:00 PM)
- PM peak period (3:00 PM–6:00 PM)
- Off peak (6:00 PM–6:00 AM)

For the highway trip assignment, the truck trips and the drive access component of the transit trips are pre-loaded to a network which reflects truck restrictions (hazmat and vehicle restrictions). Then an equilibrium assignment process is used, which considers congested travel conditions in an iterative assignment process.

Transit assignment is also performed for the same four time periods as transit route headways change from one time period to the other. The transit assignment is simply made to the best available transit path. Boardings and alightings (on/off) by stop as well as routes passengers would take between stops are all generated in this assignment process.

2.7 Overall Model Calibration

On the highway side, there are over 3,600 roadway segments in the model with observed traffic count data. The basis for the overall model calibration is a comparison of the model assignment to this count data with stratifications as follows:

- direction and time of day
- vehicle type
- functional class and area type
- screen lines
- cut lines

In addition, travel time is also a calibration metric. Bing and INRIX data are compared to the model's predicted travel times. The model is adjusted to replicate these times and a comparison between these times is another calibration tool.

On the transit side, overall model calibration is performed using the following data:

- park-and-ride observed demand compared with model output
- transit directional flows compared with counts
- on/off station activity of commuter rail and rapid transit

- key bus route boardings by time of day
- system level boardings by time of day
- directional transit flow by time of day
- transit travel time based on 2011 Massachusetts Household Travel Survey data

2.8 Model Output and Post Processing

Model output files are extensive. Trip distribution patterns by trip purpose and travel mode are often used to evaluate travel patterns. Highway and transit skim data, which are impedance estimates between TAZs, are also used to evaluate congestion levels.

In addition, the modeling process saves the highway and transit assignment information in extensive detail. On the highway side, this detailed information is used in conjunction with the US Environmental Protection Agency’s (EPA) Motor Vehicle Emission Simulator (MOVES) program and detailed mobile emissions data are computed for each highway link, which is aggregated to TAZ, community, county, and state levels.

The modeling process also has an extensive reporting system whereby transit trips on each bus route, ferry route, commuter rail line, and rapid transit line are reported by time of day and stop.

3 MODEL CALIBRATION FOR RAIL VISION

This section describes the process used to ensure that the TDM accurately reflects the 2018 base-year condition in the study area. This is achieved when modeled data for roadway and transit volumes closely matches empirical data. After checking and editing the transportation network of the regional model, CTPS made a number of small modifications in the model to make the model estimates of travel volumes closer to corresponding observed travel volumes. CTPS established benchmarks for comparing the empirical data to the model results and succeeded in most instances. These standards focused on roadway and transit measures.

3.1 Roadway Traffic Volumes

The roadway calibration process focused on matching the assigned volumes on the roadway links to count data for the AM and PM peak periods and times throughout the day. Average counts and modeled volumes per roadway link were calculated for each of the model’s major roadway classifications for each of the time periods. Table 1 displays these figures as well as the standard volumes recommended by federal transportation agencies for each roadway type.

The desired calibration standard for overall assigned model volumes requires total volumes to be within 10 percent of the total roadway counts. Following calibration, the collective differences between the assigned volumes and the counts were *4.6 percent in the AM peak period, 2.9 percent in the PM peak period, and 4.5 percent throughout the entire day*. The root mean square error (RMSE) percentage is another measure of how well modeled volumes replicate the observed data. In general, an RMSE percentage of less than 30 percent represents an acceptable data fit for roadways. Following calibration, RMSE percentages were *30.4 percent in the AM peak period, 27.7 percent in the PM peak period, and 23.2 percent throughout the entire day*.

Table 1
Daily Systemwide Roadway Counts: Observed Counts and Modeled Volumes

Roadway Type	AM Mean Count	PM Mean Count	Daily Mean Count	AM Mean Volume	PM Mean Volume	Daily Mean Volume	FTA Target Percent	AM Percent Difference	PM Percent Difference	Daily Percent Difference
Interstate	14,494	15,240	77,079	15,139	15,807	79,621	+/-7	4.5	3.7	3.3
Limited access principal arterial	7,942	8,420	41,045	7,880	8,049	42,000	+/-10	-0.8	-4.4	2.3
Principal arterial	2,620	2,991	14,023	3,174	3,338	15,555	+/-15	21.1	11.6	10.9
Minor arterial	1,379	1,627	7,191	1,716	1,857	8,202	+/-15	24.4	14.1	14.1
Collector	686	850	3,744	933	1,065	4,374	+/-30	36.0	25.3	16.8
Local	512	618	2,763	687	765	3,538	+/-40	34.2	23.8	28.0
HOV lanes AM and GP lanes for other times of day	2,504	3,032	13,746	3,720	3,791	19,971	+/-7	48.6	25.0	45.3
Ramp: interstate to principal arterial	2,324	2,484	38,050	2,332	2,548	33,179	+/-25	0.3	2.6	-12.8
Ramp: interstate to minor arterial	1,462	1,831	33,227	1,464	1,760	36,120	+/-25	0.1	-3.9	8.7
Ramp: principal arterial to interstate	2,341	2,427	27,599	2,159	2,388	27,706	+/-25	-7.8	-1.6	0.4
Ramp: principal arterial to principal arterial	1,305	1,660	14,371	1,340	1,519	18,717	+/-25	2.7	-8.5	30.2
Ramp: collector to principal arterial	1,405	1,304	39,100	1,404	1,417	29,203	+/-25	-0.1	8.7	-25.3
Ramp: interstate to interstate	4,062	4,666	27,314	3,354	3,674	24,609	+/-25	-17.4	-21.3	-9.9
Average Total	**5,760**	**6,163**	**32,480**	**6,024**	**6,342**	**33,937**	**+/-10**	**4.6**	**2.9**	**4.5**
Root Mean Square Error				**30.4%**	**27.7%**	**23.2%**				

FTA = Federal Transit Administration. GP = general purpose. HOV = high-occupancy vehicle.

Source: Central Transportation Planning Staff.

3.2 Transit Volumes

Transit calibration efforts focused on transit services in and near the study area, with the major focus on the MBTA’s services. The ridership volumes in the travel model were compared with and validated against 2018 MBTA transit counts. Daily systemwide transit measures, such as unlinked transit trips, commuter rail boardings, rapid transit boardings, MBTA bus (including Silver Line bus rapid transit) boardings, and ferry boardings, were sought to be within approximately 10 percent of observed data. As Table 2 displays, this target was achieved for nearly every MBTA service on a systemwide modal level, as well as for an overall systemwide total.

Daily modeled unlinked systemwide transit trips were 6 percent less than the observed daily systemwide unlinked trips. Daily modeled systemwide commuter rail boardings were 6.2 percent less than the observed boardings, with modeled trips for commuter rail lines serving North Station being 2.6 percent less than observed data and modeled trips for commuter rail serving South Station being 8.0 percent less than observed data. Daily modeled systemwide rapid transit trips were 11.3 percent less than the observed boardings. Daily modeled systemwide trips taken on MBTA buses were 0.1 percent greater than the observed boardings, and modeled trips on MBTA ferries were 5.5 percent greater than observed data.

Given that the model produced data chiefly within these acceptable benchmarks and thresholds, it was deemed acceptable for use. Reported transit outputs and results were subsequently post-processed at the mode, line, and station levels to incorporate and reflect the aforementioned empirical conditions.

Table 2
Daily Systemwide Transit Boardings:
Observed Counts and Modeled Volumes

Transit Mode	2018 Daily Count	Modeled Daily Volume	Percent Difference
Commuter rail total	126,744	118,915	-6.2
North side commuter rail Lines	42,358	41,240	-2.6
South side commuter rail lines	84,386	77,675	-8.0
Rapid transit	814,087	722,118	-11.3
MBTA bus (includes Silver Line)	401,352	401,716	0.1
MBTA boat	5,166	5,449	5.5
Non-MBTA transit services	111,255	123,481	11.0
Total	**1,585,348**	**1,490,594**	**-6.0**

Note: Non-MBTA transit services include Logan Express buses, Logan Airport shuttles, privately operated buses, buses operated by other regional transit authorities, and Massachusetts General Hospital shuttles. MBTA = Massachusetts Bay Transportation Authority.

Source: Central Transportation Planning Staff.

4 OVERVIEW OF ALTERNATIVES ANALYZED

Seven distinct commuter rail alternatives were analyzed and projections were made for the 2040 horizon year, following the model base-year calibration and the establishment of a no-action/no-build scenario as a baseline point of comparison. These alternatives varied widely in terms of service frequencies, service plans and patterns, line alignments, rolling stock, power sources, fares, parking restrictions, and commuter rail infrastructure expansions. Each alternative was comprised of differing combinations of these and other elements to produce a unique commuter rail alternative. More detailed descriptions and service plans for these alternatives can be found in the main report’s Appendix C and Appendix D.

The assumptions for the modeled alternatives are as follows:

a) Base Year 2018:

- The model was calibrated using the most recent highway counts and transit boarding data, and data from the 2011 Massachusetts Household Travel Survey.
- Highway projects and transit route changes completed by 2016 were included.

- Land use was based on 2016 estimates made in light of the latest household and employment estimates and considering the 2020 regional control totals from MassDOT and the UMass Donahue Institute.

b) 2040 No-Build:

- Land use assumptions were based on the Boston Region MPO's LRTP *Destination 2040*, the LRTPs of other Massachusetts RPAs and MPOs, and consulted Rhode Island and New Hampshire agencies.
- The highway and transit networks included all committed projects adopted by Massachusetts MPOs and consulted Rhode Island and New Hampshire agencies. The Boston Region MPO's LRTP list of committed projects is available on the MPO's website, https://www.ctps.org/data/pdf/plans/LRTP/destination/Destination-2040-LRTP.pdf.
- One exception to the above assumption was the establishment of a new commuter rail station at West Station, which will be on the Worcester Line. Although this planned station is not present in the Boston Region MPO's LRTP, it is included in MassDOT's future preferred plans as part of the Allston Multimodal Project.
- South Coast Rail, Phase 1, via the Middleborough Line would be operating.

c) 2040 Alternative 1: Higher Frequency Commuter Rail

- Commuter rail service would be provided more frequently, at a minimum of every 30 minutes, to stations during peak periods and at least every 60 minutes during off-peak periods.
- South Coast Rail, Phase 1, via the Middleborough Line would be operating.

d) 2040 Alternative 2: Regional Rail to Key Stations (Diesel):

- Commuter rail service would be provided at least every 15 minutes throughout the entire day to many key stations.
- Commuter rail service would be provided at a minimum of every 30 minutes to other stations during peak periods and at least every 60 minutes during off-peak periods.
- The Providence Line between Boston and Providence would be electrified.
- Diesel locomotives would be used for all commuter rail service except on the Providence Line, where electric locomotives would be in service.
- Foxboro Station would be operational.
- South Coast Rail, Phase 1, via the Middleborough Line would be operating.

- Unlimited parking would be available at the following stations: Gloucester, Newburyport, Beverly Depot, Salem, Lynn, Haverhill, Lawrence, Reading, Lowell, Anderson, Fitchburg, Littleton/495, Waltham, Worcester, Framingham, Natick Center, Forge Park/495, Walpole, Norwood Central, Providence, Mansfield, Route 128, Brockton, Kingston, Braintree, Fall River Depot, and Whale’s Tooth.

e) 2040 Alternative 3: Regional Rail to Key Stations (Electric):

- Commuter rail service would be provided every 15 minutes or more frequently throughout the entire day to all key stations.
- Commuter rail service would be provided at least every 30 minutes to other stations during peak periods and at least every 60 minutes during off-peak periods.
- All commuter rail lines would be electrified.
- Electric multiple units (EMUs) would be used for all commuter rail service.
- Foxboro Station would be operational.
- South Coast Rail via the Stoughton Line (Full Build) would be operating.
- The South Station Expansion was assumed.
- The Grand Junction Line would be in operation with service every 15 minutes to stops at West Station, a new station at Kendall/MIT, and North Station.
- Unlimited parking would be available at the following stations: Gloucester, Newburyport, Beverly Depot, Salem, Lynn, Haverhill, Lawrence, Reading, Lowell, Anderson, Fitchburg, Littleton/495, Waltham, Worcester, Framingham, Natick Center, Forge Park/495, Walpole, Norwood Central, Providence, Mansfield, Route 128, Brockton, Kingston, Braintree, Fall River Depot, and Whale’s Tooth.

f) 2040 Alternative 4: Urban Rail (Diesel):

- There would be new commuter rail stations at Interstate 95, Interstate 93, Wonderland, and Riverside.
- Commuter rail service would be provided every 15 minutes or more frequently throughout the entire day to Urban Rail stations[1].

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[1] Urban Rail stations are defined as follows:

- All Fairmount Line stations
- All Needham Line stations
- Beverly Depot, Salem, Swampscott, Riverworks, Wonderland, Chelsea, and North Station on the Newburyport/Rockport Line
- Interstate 93, Reading, Wakefield, Greenwood, Melrose Highlands, Melrose/Cedar Park, Wyoming Hill, Malden Center, and North Station on the Haverhill Line
- Anderson, Mishawum, Winchester Center, Wedgmere, West Medford, and North Station on the Lowell Line

- Commuter rail service would be provided at least every 30 minutes to other stations during peak periods and at least every 60 minutes during off-peak periods.
- Diesel multiple units (DMUs) would be used for urban rail service and diesel locomotives would be used all other commuter rail service.
- South Coast Rail, Phase 1, via the Middleborough Line would be operating.
- The South Station Expansion was assumed.
- Unlimited parking would be available at the following Urban Rail terminal stations: Beverly Depot, Interstate 93, Anderson, Interstate 95, Woburn, Riverside, Needham Heights, and Route 128.

g) 2040 Alternative 5: Urban Rail (Electric):

- There would be new commuter rail stations at Interstate 95, Interstate 93, Wonderland, and Riverside.
- Commuter rail service would be provided at least every 15 minutes or more frequently throughout the entire day to Urban Rail stations.
- Commuter rail service would be provided at least every 30 minutes to all other stations during peak periods and at least every 60 minutes during the off-peak periods.
- South Coast Rail via the Stoughton Line (Full Build) would be operating.
- Urban Rail service would be electrified as would the entire Providence/Stoughton Line, including the South Coast Rail via Stoughton (Full Build).
- EMUs would be used on electrified portions of the commuter rail network and diesel locomotives would be used for all other commuter rail service.
- The South Station Expansion was assumed.
- The Grand Junction Line would be in operation with service every 15 minutes to stops at West Station, the new station at Kendall/MIT, and North Station.
- Unlimited parking would be available at the following Urban Rail terminal stations: Beverly Depot, Interstate 93, Anderson, Interstate 95, Woburn, Riverside, Needham Heights, and Route 128.
- The Kingston/Plymouth and the Greenbush Lines would no longer provide direct service to South Station; they would each be truncated at Braintree

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- Interstate 95, Brandeis/Roberts, Waltham, Waverly, Belmont, Porter Square, and North Station on the Fitchburg Line
- Riverside, Auburndale, West Newton, Newtonville, Boston Landing, West Station, Landsdowne, Back Bay, and South Station on the Worcester Line

Station. Instead, these two commuter rail lines would be combined into a single line passing through Braintree Station.

h) 2040 Alternative 5B: Urban Rail—Special Fares (Electric):

- Alternative 5B is identical to Alternative 5 in every aspect except fare structure.
- The new fare structure in this alternative is as follows:
    - Passengers boarding at current fare Zone 1A stations would pay the same fare as today.
    - Fares for trips between Zone 1A stations and Urban Rail stations in other zones would be a flat $3.40.
    - Fares for trips between Urban Rail stations outside of Zone 1A would be a flat $3.40, unless the current fare between the two stations is less.
    - Current fares would be in effect between Urban Rail and non-Urban Rail stations as well as between non-Urban Rail stations.

i) Full Transformation:

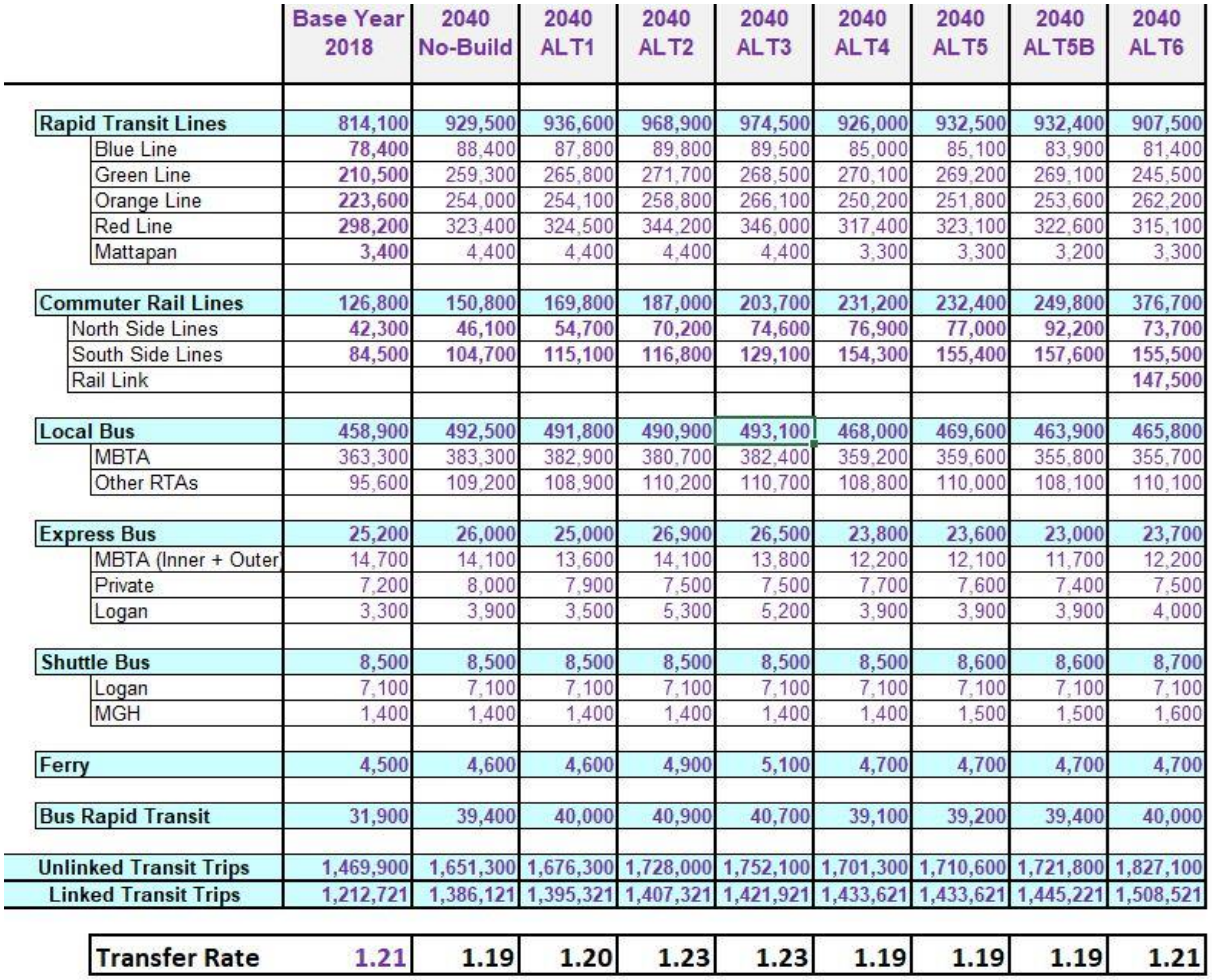
- New commuter rail stations would be located at Interstate 95, Interstate 93, Wonderland, Riverside, South Station (Rail Link), and Haymarket/North Station (Rail Link).
- Commuter rail service would be provided every 15 minutes or more frequently throughout the entire day to most stations.
- South Coast Rail via the Stoughton Line (Full Build) would be operating.
- The North-South Rail Link tunnel and its two aforementioned new stations would be operational for commuter rail service.
- All commuter rail lines would be electrified.
- EMUs would be used for all commuter rail service.
- Foxboro Station would be operational.
- The Grand Junction Line would be in operation providing service every 15 minutes to stops at West Station, the new station at Kendall/MIT, and North Station.
- All commuter rail stations that do not share their park-and-ride lots with rapid transit stations would have unconstrained parking.
- The fare structure used in the North-South Rail Link study would be in effect, with the following exceptions:
    - Passengers boarding at current fare Zone 1A stations would pay the same fare as today.
    - Fares for trips between Zone 1A stations and Urban Rail stations in other fare zones would be a flat $3.40.
    - Fares for trips between Urban Rail stations outside of Zone 1A would be a flat $3.40, unless the current fare between the two stations is less.

5 RIDERSHIP FORECASTING

Several distinct commuter rail alternatives were analyzed for the 2040 horizon year following the establishment of a no-action/no-build scenario as a baseline point of comparison. These alternatives varied widely in terms of assumptions about service frequencies, service plans, line alignments, rolling stock, power sources, fares, parking restrictions, and infrastructure expansion projects. Each alternative comprised differing combinations of these and other elements in order to produce a unique commuter rail scenario. Detailed descriptions and service plans for these alternatives can be found in Appendix D as well as in the memorandum titled *Methodology and Assumptions of Rail Vision Modeling*.

This section briefly summarizes the forecasting results and findings in the realms of ridership, revenue, passenger-miles traveled, passenger-hours of travel, and air quality. Ridership was analyzed in more detail than the other aforementioned components. Table 3 summarizes the ridership by scenario at the modal and systemwide levels, while Table 4 summarizes commuter rail boardings by line. Detailed results can be found in Appendix A of this memorandum.

Table 3
Daily Transit Boardings by Mode



	Base Year 2018	2040 No-Build	2040 ALT1	2040 ALT2	2040 ALT3	2040 ALT4	2040 ALT5	2040 ALT5B	2040 ALT6
Rapid Transit Lines	814,100	929,500	936,600	968,900	974,500	926,000	932,500	932,400	907,500
Blue Line	78,400	88,400	87,800	89,800	89,500	85,000	85,100	83,900	81,400
Green Line	210,500	259,300	265,800	271,700	268,500	270,100	269,200	269,100	245,500
Orange Line	223,600	254,000	254,100	258,800	266,100	250,200	251,800	253,600	262,200
Red Line	298,200	323,400	324,500	344,200	346,000	317,400	323,100	322,600	315,100
Mattapan	3,400	4,400	4,400	4,400	4,400	3,300	3,300	3,200	3,300
Commuter Rail Lines	126,800	150,800	169,800	187,000	203,700	231,200	232,400	249,800	376,700
North Side Lines	42,300	46,100	54,700	70,200	74,600	76,900	77,000	92,200	73,700
South Side Lines	84,500	104,700	115,100	116,800	129,100	154,300	155,400	157,600	155,500
Rail Link									147,500
Local Bus	458,900	492,500	491,800	490,900	493,100	468,000	469,600	463,900	465,800
MBTA	363,300	383,300	382,900	380,700	382,400	359,200	359,600	355,800	355,700
Other RTAs	95,600	109,200	108,900	110,200	110,700	108,800	110,000	108,100	110,100
Express Bus	25,200	26,000	25,000	26,900	26,500	23,800	23,600	23,000	23,700
MBTA (Inner + Outer)	14,700	14,100	13,600	14,100	13,800	12,200	12,100	11,700	12,200
Private	7,200	8,000	7,900	7,500	7,500	7,700	7,600	7,400	7,500
Logan	3,300	3,900	3,500	5,300	5,200	3,900	3,900	3,900	4,000
Shuttle Bus	8,500	8,500	8,500	8,500	8,500	8,500	8,600	8,600	8,700
Logan	7,100	7,100	7,100	7,100	7,100	7,100	7,100	7,100	7,100
MGH	1,400	1,400	1,400	1,400	1,400	1,400	1,500	1,500	1,600
Ferry	4,500	4,600	4,600	4,900	5,100	4,700	4,700	4,700	4,700
Bus Rapid Transit	31,900	39,400	40,000	40,900	40,700	39,100	39,200	39,400	40,000
Unlinked Transit Trips	1,469,900	1,651,300	1,676,300	1,728,000	1,752,100	1,701,300	1,710,600	1,721,800	1,827,100
Linked Transit Trips	1,212,721	1,386,121	1,395,321	1,407,321	1,421,921	1,433,621	1,433,621	1,445,221	1,508,521
Transfer Rate	1.21	1.19	1.20	1.23	1.23	1.19	1.19	1.19	1.21

ALT = alternative. MBTA = Massachusetts Bay Transportation Authority. MGH = Massachusetts General Hospital. RTA = regional transit authority.
Source: Central Transportation Planning Staff.

Table 4
Daily Commuter Rail Boardings by Line

	Base Year 2018	2040 No-Build	2040 ALT1	2040 ALT2	2040 ALT3	2040 ALT4	2040 ALT5	2040 ALT5B	2040 ALT6
Commuter Rail Total	**126,800**	**150,800**	**169,800**	**187,000**	**203,700**	**231,200**	**232,400**	**249,800**	**376,700**
North Side Lines	**42,300**	**46,100**	**54,700**	**70,200**	**74,600**	**76,900**	**77,000**	**92,200**	**73,700**
Rockport/Newburyport	**15,000**	15,700	20,200	17,400	20,600	28,900	29,100	33,800	24,400
Haverhill	**7,100**	8,900	14,100	20,000	19,300	15,000	14,800	17,500	17,500
Lowell	**10,900**	11,100	6,500	7,300	7,200	13,900	13,900	16,000	10,900
Fitchburg	**9,300**	10,400	13,900	25,500	27,500	19,100	19,200	24,900	20,900
South Side Lines	**84,500**	**104,700**	**115,100**	**116,800**	**129,100**	**154,300**	**155,400**	**157,600**	**155,500**
Framingham/Worcester	**18,600**	20,200	25,600	28,900	35,100	40,500	39,900	40,500	55,900
Needham	**6,700**	9,100	11,000	11,100	11,700	19,800	20,700	21,200	0
Franklin	**11,700**	11,900	12,300	16,500	16,000	8,300	7,900	8,200	27,500
Providence/Stoughton	**25,700**	31,200	33,500	35,400	41,900	44,700	42,400	43,200	33,300
Fairmount	**2,700**	3,500	3,900	0	0	20,900	22,100	22,100	0
Middleboro	**6,900**	11,200	11,200	12,200	17,300	9,200	8,600	8,600	12,300
Kingston/Plymouth	**6,100**	8,800	8,800	6,900	5,300	5,400	10,700	10,700	10,200
Greenbush	**6,100**	8,800	8,800	5,800	1,800	5,500	0	0	11,800
Grand Junction	**0**	0	0	0	2,900	0	3,100	3,100	4,500
Rail Link									**147,500**
Needham - Beverly									32,900
Riverside - Woburn									29,500
Readville - Beverly									22,700
Needham - I-93									38,400
Readville - I-95									24,000

ALT = alternative.
Source: Central Transportation Planning Staff.

5.1 Ridership

The three key factors driving the increase in commuter rail ridership across all the alternatives are parking availability, service frequency, and fares. When parking restrictions are lifted at commuter rail station parking lots, more people will drive to the stations with unconstrained parking capacity located closest to downtown Boston, presumably, to take advantage of lower fares and frequent service. Also, the percentage of commuter rail riders using non-motorized modes (walk/bike) to access and egress stations will increase in all alternatives compared to the no-build scenario, thus outpacing even the large ridership growth attributable to unlimited station parking facilities. This outcome is most pronounced in Alternatives 4, 5, and 5B, in which the majority of commuter rail riders either walk or bike to and from stations. This finding lends credence to the assertion that service frequency improvements are greater drivers of commuter rail ridership than reduced fares or limitless parking.

The modeling for Rail Vision's Alternatives 2 and 3 demonstrates major growth at the key stations with unconstrained parking and service offered as frequently as every 15 minutes. The greatest impacts are projected to occur at the stations closest to Boston and located near freeways (Braintree, Route 128, Waltham, and Reading Stations). This pattern continues in the Urban Rail scenarios. The Urban Rail terminal stations in Alternatives 4 and 5, which are the commuter rail stations with unlimited parking and 15-minute service located closest to Boston, would see the greatest ridership gains. Boardings would increase the most at these stations in Alternative 5B, as people would drive to them to take advantage of the special discounted Urban Rail fare.

Alternative 1

When compared with the no-build scenario, Alternative 1 would result in a 0.7 percent increase in the number of linked transit trips and a 1.5 percent increase in the number of unlinked transit trips systemwide. Commuter rail is the mode that would have the greatest increase in boardings, an average of 12.6 percent, with the North Side lines increasing by 18.7 percent and the South Side Lines increasing by 9.9 percent; although, the South Side lines would experience a greater numerical growth in boardings. The Newburyport/Rockport, Fitchburg, Needham, Worcester, and Providence/Stoughton Lines would each gain more than 1,000 new daily riders.

Increased trip-making on the commuter rail system would result in an accompanying increase of 0.8 percent in rapid transit boardings, particularly on the Green, Orange, Red, and Silver Lines, as new riders transfer at South Station and North Station. This change is reflected in the increase in the systemwide transfer rate, which would rise from 1.19 to 1.20. Some existing local and express bus riders also would be expected to take advantage of the improved commuter rail service and shift transit modes.

Alternative 2

In Alternative 2, the provision of commuter rail service throughout the entire day to designated key stations at typical frequencies of every 15 minutes on the North Side lines and 30 minutes on the South Side lines would result in 21,200 new linked transit trips and an increase of 76,700 unlinked transit boardings systemwide when compared to the no-build scenario. Commuter rail is the mode that would have the greatest increase in boardings, an average of 24 percent, with the North Side lines increasing by 52.3 percent and the South Side lines increasing by 11.6 percent. Dramatic boarding increases, primarily driven by the lifting of capacity restrictions at park-and-ride facilities, would be seen on the Haverhill, Fitchburg, Needham, Worcester, and Providence/Stoughton Lines.

Increased trip-making on commuter rail would result in an accompanying increase of 4.2 percent in rapid transit boardings, particularly on the Green, Orange, Red, and Silver Lines, as new riders transfer at South Station and North Station. This outcome is reflected in the increase in the systemwide transfer rate, which would rise from 1.19 to 1.23. Red Line ridership growth also would result from the lifting of parking capacity restrictions at Braintree Station, which is shared by both the Red Line and commuter rail. Some existing local bus riders also would be expected to take advantage of the improved commuter rail service and shift transit modes.

Alternative 3

In Alternative 3, the provision of commuter rail service at typical frequencies of every 15 minutes throughout the entire day to designated key stations combined with Grand Junction service, South Coast Rail (Full Build), South Station Expansion, and the electrification of the entire commuter rail system would result in 35,800 new linked transit trips and an increase of 100,800 unlinked transit boardings systemwide when compared with the no-build scenario. Commuter rail is the transit mode that would have the greatest increase in boardings; boardings would rise by 52,900 trips (35.1 percent) with the North Side lines increasing by 61.8 percent and the South Side lines increasing by 23.3 percent. Dramatic boarding increases, primarily driven by the lifting of capacity restrictions at key park-and-ride facilities, would be seen on the Haverhill, Fitchburg, Needham, Worcester, Middleborough, and Providence/Stoughton Lines.

Assessing the ridership differences on North Side commuter rail service among Alternatives 1, 2, and 3, provides insight into the specific impact of electrification. The largest increase in North Side ridership would occur between Alternative 1 and Alternative 2, implying that improved service frequencies and parking availability account for more ridership growth than electrification. More riders would be attracted to commuter rail because of improved frequencies and unlimited parking than because of the improvements from electrification.

Increased trip-making on the commuter rail would result in an accompanying increase of 4.8 percent in rapid transit boardings, particularly on the Green, Orange, Red, and Silver Lines, as new riders transfer at South Station and North Station. This outcome is reflected in the increase in the systemwide transfer rate, which would rise from 1.19 to 1.23. Red Line ridership growth also would result from the lifting of parking capacity restrictions at Braintree Station, which is shared by both the Red Line and commuter rail.

Alternative 4

In Alternative 4, the provision of commuter service at least as frequently as every 15 minutes throughout the entire day on an Urban Rail network would result in 47,500 new linked transit trips and an increase of 50,000 unlinked transit boardings systemwide when compared to the no-build scenario. Commuter rail is the transit mode that would have the greatest increase in boardings; there would be 80,000 more boardings daily, increasing the mode’s overall ridership by 53.3 percent. Boardings on the North Side lines would increase by 66.8 percent and boardings on the South Side lines would increase by 47.4 percent; although, the South Side lines would experience a greater numerical growth in boardings. Dramatic boarding increases, driven by the lifting of capacity restrictions at park-and-ride facilities at the terminal ends of the Urban Rail network and increased service frequencies, would be seen on all North Side lines, as well as the Fairmount, Needham, Worcester, and Providence/Stoughton Lines.

Increased trip-making on the commuter rail would result in an accompanying decrease in rapid transit boardings (-0.4%), local bus boardings (-5%), and express bus boardings (-8.5%) as riders would use the parallel Urban Rail network to make trips to and from downtown Boston instead of other transit modes, particularly the Blue, Red, and Orange Lines. Boardings on the Green Line would still increase compared to the no-build scenario as there would be less overlap with the Urban Rail network; new commuter rail riders would still transfer to the Green Line at locations such as North Station and Back Bay Station. The systemwide transfer rate for this alternative is nearly identical to that of the no-build scenario, which indicates that the increase in Green Line boardings would be counterbalanced by riders using Urban Rail to make their entire trips instead of transferring to bus or rapid transit for a portion of their trips.

Alternative 5

Alternatives 4 and 5 are relatively similar, thus the modeling results are similar. Both alternatives would produce the same number of linked transit trips, but Alternative 5 would have 9,300 more unlinked transit boardings and 1,200 more commuter rail boardings. The difference in the commuter rail boardings is due in large part to the introduction of Grand Junction service. Also, in Alternative 5, fewer bus riders would shift to commuter rail. Further, rapid transit ridership in Alternative 5 would increase slightly, chiefly due to more ridership on the Red Line. The increase in Red Line riders, compared to Alternative 4, would result from the new configuration of the Plymouth and Greenbush Lines, which would no longer provide service to downtown Boston; in Alternative 5, riders would be forced to transfer at Braintree Station to either the commuter rail or the Red Line to make those trips.

Alternative 5B

The only difference between Alternative 5 and Alternative 5B is the reduced fare offered for Urban Rail service. This fare structure would result in 11,600 new linked transit trips compared to Alternative 5; unlinked transit trips would increase by approximately the same amount compared to Alternative 5. Commuter rail boardings would increase by an average of 7.5 percent, with the North Side lines increasing by 19.7 percent and the South Side lines increasing by 1.4 percent. This is not surprising, as the Newburyport/Rockport Line would allow for Zone 4 commuter rail trips to be made at significantly reduced fares, and the Haverhill, Lowell, Fitchburg, and Worcester Lines would permit reduced fare commuter rail trips to be made at Urban Rail terminal stations that are easily accessible by highway (I-93, Anderson/Woburn, I-95, and Riverside) and that were modeled with unconstrained parking facilities. Combined ridership at those four Urban Rail terminal stations would grow by nearly 51 percent and account for nearly 44 percent of the ridership growth on the Haverhill, Lowell, Fitchburg, and Worcester Lines as compared to Alternative 5.

Alternative 6

The full transformation scenario, which includes high frequency service to most stations, full system electrification, improved service frequencies, unlimited parking available at nearly every station, South Coast Rail (Full Build), Foxboro Station, the Grand Junction Line, the North–South Rail Link (and its two downtown stations), and a new fare structure, would result in the most new linked transit trips (122,400) and new unlinked transit boardings (175,800) of any alternative compared to the no-build scenario. Accordingly, daily commuter rail ridership would increase by nearly 150 percent (nearly 226,000 riders) compared to the no-build scenario and rapid transit ridership would decrease the most (-2.4 percent) compared to the no-build scenario. Limitless parking availability is a major component of the ridership increase as approximately 42 percent of new commuter rail boardings would involve the use of park-and-ride facilities at one end of the trip. Since Alternative 6 has a fare structure most similar to the reduced fare structure in Alternative 5B, it can be inferred that if the current fare structure was implemented in Alternative 6, ridership would decrease. Thus, Alternative 6’s new reduced fare structure probably accounts for an increase in commuter rail boardings akin to the increase between Alternatives 5 and 5B (7.5 percent). A portion of the new commuter rail ridership would be attributable to other commuter rail enhancements such as the systemwide 15-minute service frequency, reduced travel times, and improved connectivity from the North–South Rail Link. Approximately 35,000 daily commuter rail riders would use the new through-service available via the North–South Rail Link, some of whom currently take rapid transit and local buses.

5.2 Commuter Rail Access Mode

Overall, the commuter rail improvements in each alternative would cause changes in modal access patterns for commuter rail riders. Table 5 displays that a greater share of riders would walk to commuter rail stations, and a smaller share drive to them, in all alternatives compared to the no-build scenario. In fact, the Urban Rail alternatives (Alternatives 4, 5, and 5b) would result in a greater percentage of riders walking to transit than driving to transit. This is most likely due to the areas of relatively high population and employment density located along the Urban Rail corridors with the highest service frequencies. Alternative 6, which includes the North–South Rail Link, would result in nearly as many people walking as driving to commuter rail stations.

Table 5
Access Mode of Commuter Rail Boardings

Access Mode	Base	No-Build	Alt 1	Alt2	Alt 3	Alt 4	Alt 5	Alt 5B	Alt 6
Walk	33%	37%	40%	41%	42%	54%	55%	54%	49%
Drive	67%	63%	60%	59%	58%	46%	45%	46%	51%
Total Boardings	**126,800**	**150,800**	**169,800**	**187,000**	**203,700**	**231,200**	**232,400**	**249,800**	**376,700**

ALT = alternative.
Source: Central Transportation Planning Staff.

5.3 Commuter Rail Station Boarding Locations

Using AM peak directional boardings as a guide for judgment, the modeling results show that most commuter rail station boardings would occur closer to downtown Boston with each successive alternative. Commuter rail boardings currently are assigned to the station closest to one's home, given the constrained nature of park-and-ride facilities at commuter rail stations. Consequently, more than 70 percent of AM inbound boardings would occur at outer stations in the no-build scenario.

Table 6 displays how this percentage changes with each successive alternative as patrons increasingly choose to board at inner stations. Alternative 1 would result in increased boardings, due to improved service, at both inner and outer commuter rail stations in approximately the same proportion as in the no-build scenario. However, the combination of unconstrained parking facilities and increased service frequencies changes this phenomenon in the other alternatives. People would drive to unconstrained park-and-ride facilities closer to downtown Boston to take advantage of lower commuter rail fares.

In Alternative 2 and 3, this activity would occur at the key stations, especially ones located near freeways such as Braintree, Route 128, Reading, Natick, and Waltham Stations. In Alternatives 4, 5, and 5B, this activity would occur at Urban Rail terminal stations, and in Alternative 6 this would occur at Urban Rail stations that do not share park-and-ride facilities with rapid transit services. The aforementioned increase in walk-access commuter rail trips along the Urban Rail/Rail Link corridors also contributes to this outcome. Substantial proportional shifts to the inner stations from the outer stations would occur in Alternatives 2 and 3.

Less than half of AM peak directional commuter rail boardings would occur at the outer stations in the Urban Rail and Full Transformation scenarios. Understandably, this outcome would affect MBTA revenue, causing the decreases in revenue discussed in Section 6.1 and displayed in Table 9.

Table 6
Commuter Rail Station Location: AM Peak Period Boardings

Station Type	No-Build	Alt 1	Alt2	Alt 3	Alt 4	Alt 5	Alt 5B	Alt 6
Outer	71.1%	71.1%	61.8%	54.8%	43.1%	38.9%	34.9%	49.6%
Inner	28.9%	28.9%	38.2%	45.2%	56.9%	61.1%	65.1%	50.4%

Note: Inner stations are defined as the following:

- Stations south of and including Beverly Depot on the Newburyport/Rockport Lines
- Stations south of and including Anderson and I-93 on the Lowell and Haverhill Lines
- Stations east of and including I-95 on the Fitchburg Line
- Stations east of and including Riverside on the Worcester Line
- Stations north of and including Route 128 on the Providence/Stoughton Line
- Stations north of and including Readville on the Franklin Line
- Stations north of and including Braintree on the Old Colony Lines
- All stations on the Needham and Fairmount Lines

Source: Central Transportation Planning Staff.

5.4 Service in the Off-Peak Periods and Reverse Peak Directions

Increases in commuter rail service in the off-peak time periods (midday and nighttime) would result in increased ridership. Alternative 1’s provision of at least 60-minute service to all stations in the off-peak periods would result in a 12.5 percent growth in ridership compared to the no-build scenario. The introduction of 15-minute service to North Side key stations and 30-minute service to South Side key stations, coupled with unlimited parking at key stations, would increase ridership by more than 26 percent compared to Alternative 1. The subsequent provision of 15-minute service at South Side stations in Alternative 3 would only result in a further 7 percent ridership increase, with the bulk of the growth occurring in the nighttime period. The 15-minute service provided to Urban Rail stations in Alternatives 4, 5, and 5B would dramatically increase ridership compared to Alternatives 1, 2, and 3, despite the restriction of unlimited parking to Urban Rail terminal stations. Ridership would increase by nearly 40 percent in Alternatives 4 and 5 compared to Alternative 3. This outcome indicates that 15-minute service to inner core stations with high activity density (population and employment) has more impact than merely providing 15-minute service to key stations alone. The reduced fare in Alternative 5b would result in a 6.8 percent ridership increase compared to Alternative 5. Ridership would dramatically increase in Alternative 6 compared to the Urban Rail alternatives due to many factors, such as the connectivity offered by the North–South Rail Link and the limitless parking offered at nearly every station. These factors magnify, enhance, and underscore the underlying impacts on ridership of 15-minute frequencies in off-peak periods and the sensitivity of Urban Rail stations to headway improvements.

Table 7
Off-Peak Period Commuter Rail Boardings

Period	No-Build	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Alt 5B	Alt 6
Midday	16,100	18,400	22,700	22,900	33,000	33,700	34,500	49,500
Nighttime	16,600	18,400	23,900	27,000	35,500	35,900	39,900	56,400
Total	32,700	36,800	46,600	49,900	68,500	69,600	74,400	105,900

ALT = alternative.
Source: Central Transportation Planning Staff.

Table 9 displays a somewhat similar story for the reverse peak directional service during the AM and PM periods. When commuter rail frequencies are improved to provide at least 30-minute service for reverse peak service in Alternative 1, ridership nearly doubles compared to the no-build scenario. There is a minor increase in ridership when the North Side key stations receive 15-minute service in Alternative 2, but a larger reverse peak ridership increase (35 percent) compared to Alternative 1 only occurs when all key stations receive 15-minute service in Alternative 3. Provision of 15-minute service to Urban Rail stations would result in a 8.8 percent increase in ridership in Alternative 4 and a 26.4 percent increase in Alternative 5 compared to the 15-minute service to key stations in Alternative 3. This finding indicates that in terms of ridership, the Urban Rail stations would be more sensitive to improved frequencies than the key stations, which was the case in the aforementioned off-peak periods. Similar to the off-peak periods, Alternative 5B's fare reduction would cause a minor increase (nearly 5 percent) in reverse peak ridership. The improved connectivity afforded by the North–South Rail Link and the limitless parking availability at nearly all stations in Alternative 6 would contribute to that dramatic ridership increase in the reverse peak direction.

Table 8
Peak Period Commuter Rail Boardings by Direction

Direction	No-Build	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Alt 5B	Alt 6
Peak	108,600	114,600	120,900	128,800	135,500	131,200	142,400	223,500
Reverse	9,500	18,500	19,600	25,000	27,200	31,600	33,100	47,300

Source: Central Transportation Planning Staff.

Although the provision of 15-minute service in the off-peak periods and in the reverse peak directions would significantly affect ridership, the locations of the stations receiving the improved 15-minute commuter rail service appear to be the most important element for increasing ridership, not the provision of 15-minute service in and of itself. People would drive to Urban Rail stations closer to the core to take advantage of the combination of frequent service, shorter commuter rail trips, and lower fares. Moreover, the Urban Rail service, given its 15-minute frequencies, would attract existing bus and rapid transit riders because of its faster travel times and also entice new riders to shift from the auto mode because it serves areas of relatively high population and employment densities. In effect, Urban Rail would be perceived as a slightly less frequent but faster rapid transit service, even if it is costlier. Fares do affect ridership as the reduced fares in Alternative 5B would result in an increase in ridership, but not nearly to the magnitude caused by service frequency increases.

6 OTHER FORECASTING OUTPUTS

6.1 Revenue

Table 9 displays the daily systemwide MBTA fare revenue generated by each alternative. The table does not include revenue associated with parking fees at lots operated by the MBTA.

Not surprisingly, the alternatives would produce increases in revenue compared to the no-build scenario because they increase ridership. Alternative 6 generates the most revenue and the most boardings of any of the scenarios, although its average fare is the second lowest of any alternative. This revenue increase is due to a few components: a different fare structure than any of the other scenarios, the presence of the Rail Link, and the unconstrained parking at stations served by the Rail Link commuter rail lines. Alternative 5B has the lowest average fare because of its unique fare structure.

Table 9
Average Weekday Daily MBTA Revenue

Alternative	MBTA Fare Revenue	Unlinked MBTA Transit Trips	Average Fare
Base	$2,445,000	1,355,300	$1.80
No Build	$3,169,000	1,521,700	$2.08
Alt 1	$3,269,000	1,547,500	$2.11
Alt 2	$3,348,000	1,598,000	$2.10
Alt 3	$3,349,000	1,620,200	$2.07
Alt 4	$3,370,000	1,574,000	$2.14
Alt 5	$3,335,000	1,580,500	$2.11
Alt 5B	$3,221,000	1,593,800	$2.02
Alt 6	$3,445,000	1,696,800	$2.03

ALT = alternative. MBTA = Massachusetts Bay Transportation Authority.
Source: Central Transportation Planning Staff.

6.2 Passenger-Miles and Passenger-Hours of Travel

Appendix B contains data on the passenger-miles and passenger-hours of travel produced by each alternative. As ridership increases, so do the associated passenger-miles and passenger-hours of travel. Alternative 5 is the one exception as the South Coast Rail Full Build service pattern would cause some riders on the Stoughton branch to drive to stations closer to Boston that receive more frequent service than the stations they would have been attracted to in Alternative 4. Additionally, Alternative 5's lack of direct service to South Station for the Greenbush and Kingston/Plymouth Lines also would cause passenger mileage to decrease, as riders previously using those lines would drive to other commuter rail stations providing access to the Boston core.

6.3 Air Quality Analyses

An air quality mobile source emissions analysis was performed for private vehicles (automobiles and trucks) modeled in each Rail Vision alternative. The travel demand model was used in conjunction with MOVES 2014b—the most recent version of the EPA's Motor Vehicle Emission Simulator—to estimate mobile source emissions that would result from the alternatives studied. The analysis focused on six pollutants. This analysis did not involve any estimation of pollutant emissions generated by the operation of transit vehicles such as locomotives, ferries, buses, or rapid transit vehicles.

MOVES 2014b uses vehicle-miles traveled (VMT) and vehicle speed in combination with motor vehicle fleet emissions rates to estimate mobile source emissions. Emissions factors for motor vehicles are specific to each vehicle model year, pollutant type, temperature, and travel speed. MOVES utilizes a wide range of input parameters, including inspection and maintenance program information and other data, such as hot/cold start mix, emission failure rates, vehicle fleet mix, and fleet age distribution.

Table 10 displays the daily mobile emissions produced by each of the modeled alternatives. Not surprisingly Alternative 6 produced the greatest reductions in emissions, as compared to the baseline and no-build scenario, since it also produced the largest reduction in VMT. Alternative 3 resulted in more auto emissions reductions than either of the Urban Rail scenarios. The Boston Region MPO area experienced the greatest emissions reduction of any MPO area in the state, which is not surprising because the Boston Region MPO area has the largest population and the most employers and contains the most extensive transit network.

The ridership model projected that several MPOs would have minor increases in VMT, which produces increased emissions. Increased emissions were projected to occur in the following MPO areas: Montachusett Regional Planning Commission in Alternative 5B; Southeastern Regional Planning and Economic Development District in Alternatives 2 and 4; and Old Colony Planning Council in every alternative except Alternative 6. Presumably, this increase would result from people traveling longer distances to access unconstrained park-and-ride facilities at commuter rail stations with better service and lower fares than in the baseline and no-build scenarios. More detailed data and analysis for each alternative can be found in Appendix C.

Table 10
Average Weekday Vehicle-Miles Traveled, Vehicle-Hours Traveled, and Emissions

	VMT (miles)	VHT (hours)	VOC s(kg)	NOX w(kg)	CO s(kg)	CO_2 w(kg)	PM_{25} w(kg)	PM_{10} s(kg)
Base	195,164,583	6,775,105	8,548	32,592	462,304	74,836,064	980	1,107
No-Build	208,739,761	7,789,600	4,430	8,075	197,556	50,132,610	411	466
Alt 1	208,551,580	7,765,051	4,419	8,070	197,344	50,046,857	410	466
Alt 2	208,147,330	7,649,432	4,392	8,058	196,675	49,759,374	409	464
Alt 3	207,922,079	7,624,137	4,382	8,054	196,419	49,661,506	409	464
Alt 4	208,195,115	7,665,725	4,396	8,059	196,718	49,795,839	409	465
Alt 5	208,218,385	7,672,551	4,398	8,060	196,745	49,809,793	409	465
Alt 5B	208,222,773	7,670,756	4,397	8,061	196,723	49,805,269	409	464
Alt 6	207,400,918	7,583,436	4,363	8,039	195,848	49,470,741	408	463

CO = carbon monoxide. CO_2 = carbon dioxide. NOX = nitrogen oxides. PM = particulate matter. s(kg) = summer kilograms. VHT = vehicle-hours traveled. VMT = vehicle-miles traveled. VOC = volatile organic compounds. w(kg) = winter kilograms.

Source: Central Transportation Planning Staff.