
Photo Source: Katie Manning / Unsplash

9. Appendices

Photo Source: Michael Hicks / Flickr

A. Citations

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16 Central Transportation Planning Staff, Boston Region Metropolitan Planning Organization, Memorandum: MBTA Commuter Rail Passenger Count Results, Dec. 21, 2012.

17 Boston Region Metropolitan Planning Organization, Long-Range Transportation Plan – Needs Assessment, www.ctps.org/lrtp_needs

18 According to Reconnecting America, a national nonprofit that integrates transportation and community development, "Transit-oriented development… is a type of development that includes a mixture of housing, office, retail and/or other amenities integrated into a walkable neighborhood and located within a half-mile of quality public transportation." http://reconnectingamerica.org/what-we-do/what-is-tod/

19 The Metropolitan Area Planning Council data also contain information on future projects, categorized as either planned or projected. These projects are generally expected to be constructed prior to 2035, with a maximum completion date of 2042.

20 Metro-North Railroad, West of Hudson Regional Transit Access Study Alternatives Analysis Phase I Screening Report, Appendix D: Capital Cost and O&M Costs, Methodology and Estimates, May 2012.

21 Boston Region Metropolitan Planning Organization, Long-Range Transportation Plan – Needs Assessment, www.ctps.org/lrtp_needs

22 Dan Hodge and Benjamin Forman, 'The Promise and Potential of Transformative Transit-Oriented Development in Gateway Cities', April 24, 2018, https://2gaiae1lifzt2tsfgr2vil6c-wpengine.netdna-ssl.com/wp-content/uploads/2018/04/TTOD-Report.pdf

23 Handy, Susan, Increasing Highway Capacity Unlikely to Relieve Traffic Congestion, National Center for Sustainable Transportation, UC Davis, October 2015.

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26 A T-test is a statistical procedure that determines whether the mean of a population significantly differs from a specific value (the "hypothesized mean") or from the mean of another population; the T-test is then used to determine whether the difference is statistically significant. In this test, the T-test used the following criteria for determining significance: If $p<0.05$, the difference between an EJ community and a Non-EJ community is significant or likely to occur; If $p>=0.05$, the difference between an EJ community and a Non-EJ community is insignificant or unlikely to occur.

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B. Full List of Upstream Improvements

“Critical” interventions must be in place for a particular service plan to be implemented. “Recommended” interventions reduce performance risks for a particular service plan and its associated level of service.

Line	Service Alternative	Critical / Recommended	Intervention Required	Intervention Solution	Intervention Reason
All Lines	South Station Expansion & All-Day Peak Service (No NSRL), NSRL Regular Service (2-Track), NSRL All-Day Peak Service (2-Track), NSRL All-Day Peak Service (4-Track)	Recommended	Review of platform workings at locations where single platform face is provided on double track sections.	Provision of additional platform faces and related facilities.	The assumed track layout indicates locations where there is a single sided platform and it is understood that passengers can board/alight from trains on either line. While it may be feasible to do so with lower levels of services this approach may require reviewing with increases to the level of service. This is because an increased level of service may result in trains passing at locations whereby passengers are required to cross the track to board/alight trains. For the purposes of the scheduling no constraint on platform/boarding side is assumed, with trains operating on both lines (right-hand-side running)
All Lines	NSRL Regular Service (2-Track), NSRL All-Day Peak Service (2-Track), NSRL All-Day Peak Service (4-Track)	Critical	Removal of conflicts between trains entering the north & south tunnel portals and trains exiting the north & south tunnel portals to each route.	Grade separation between northbound and southbound services at each tunnel portal.	The service plans require 18-20tph trains in each direction through the tunnel core, it would not be feasible to cross opposing direction trains multiple times at this level service with an at-grade junction. This option potentially requires all four tracks running out towards Back Bay splitting between Worcester Line and Providence Lines (due short headways between services). However further schedule development may resolve some headway issues, but performance impact likely to be significant.

Line	Service Alternative	Critical / Recommended	Intervention Required	Intervention Solution	Intervention Reason
Fitchburg Line	South Station Expansion & All-Day Peak Service (No NSRL)	Critical	Additional terminal platform capacity	Provision of an additional platform	If turnaround times/junction margins cannot be reduced at Wachusett, then provision of an additional terminal platform is required.
Fitchburg Line	South Station Expansion & All-Day Peak Service (No NSRL)	Recommended	A review of signaling capability within the North Station throat, specifically looking at the ability to perform parallel crossings with same platform re-occupations. Requires at least 5-minute headways	Capability to support parallel crossing moves in the station throat to support 5-minute same platform re-occupation margins at North Station.	The schedule has been optimized around utilizing the minimum number of platforms at North Station. It is assumed the capability of 5-minute platform re-occupation is possible at North Station with a parallel crossing in the station throat. The ability to do so requires reviewing. Should it not be possible to do so then a review of the platform workings will be required.
Fitchburg Line	NSRL Regular Service (2-Track)	Critical	Additional terminal platform capacity	Provision of 1 additional terminal platform	The service plan requires 4 tph to start and terminate at Fitchburg. This is not possible from a single platform and therefore requires a minimum of 2 platforms (with a turnaround time/junction margin of less than 30 minutes). Note if the total turnaround time and junction margin can be reduced to 15 minutes then 1 platform could support 4 tph.
Fitchburg Line	NSRL Regular Service (2-Track)	Critical	Additional terminal platform capacity	Turnback siding for turning trains short	The service plan requires 4 tph to start and terminate at Fitchburg, This is not possible from a single platform and therefore this presents an alternative to the above. However, additional turnback facilities may be \required if this option is taken forward, i.e. a turnback siding.

Line	Service Alternative	Critical / Recommended	Intervention Required	Intervention Solution	Intervention Reason
Fitchburg Line	NSRL Regular Service (2-Track)	Critical	Enhance signal capability	Enhancements to the signaling capability to support 8-minute headways	The service plan requires 4 tph on the Fitchburg Line. While theoretically 4 tph is a train every 15 minutes, it is not possible to support even frequencies due to constraints on the southern lines. A headway reduction is therefore required from the assumed 10 minutes to at least 8 minutes.
Fitchburg Line	NSRL Regular Service (2-Track)	Critical	Reduction of single line re-occupation margin at Waltham	Reduction of single line re-occupation margin at Waltham to at least 5 minutes	The service plan requires 4 tph in each direction over the single track line between Beaver Brook and Riverview. With each train occupying the single track line for 4 minutes (including 30 sec dwell at Waltham). The current assumption of 7 minutes would not feasibly support the train plan and requires reducing to at least 5 minutes.
Fitchburg Line	NSRL All-Day Peak Service (2-Track), NSRL All-Day Peak Service (4-Track)	Critical	Additional terminal platform capacity	Provision of 1 or 2 additional terminal platforms	The service plans require 6 tph to start and terminate at Fitchburg. This is not possible from a single platform and therefore requires a minimum of 2 platforms (with a turnaround time/junction margin of less than 20 minutes) or 3 platforms (max 30 minutes turnaround/junction margin).
Fitchburg Line	NSRL All-Day Peak Service (2-Track), NSRL All-Day Peak Service (4-Track)	Critical	Additional terminal platform capacity	Turnback siding for turning trains short	The service plans require 6 tph to start and terminate at Fitchburg. This is not possible from a single platform and therefore as an alternative to the above. However, additional turnback facilities may be required if this option is taken forward, i.e. a turnback siding.

Line	Service Alternative	Critical / Recommended	Intervention Required	Intervention Solution	Intervention Reason
Fitchburg Line	NSRL All-Day Peak Service (2-Track), NSRL All-Day Peak Service (4-Track)	Critical	Double track throughout Fitchburg Line	Doubling of the single track line between Beaver Brook and Riverview	The service plan requires 6 tph in each direction over the single track line between Beaver Brook and Riverview. With each train occupying the single track line for 4 minutes (including 30 sec dwell at Waltham) this would only leave a 1-minute margin between trains, which is unlikely to be feasible.
Lowell Line	South Station Expansion & All-Day Peak Service (No NSRL)	Recommended	A review of signaling capability within the North Station throat, specifically looking at the ability to perform parallel crossings with same platform re-occupations. Requires at least 5-minute headways	Capability to support parallel crossing moves in the station throat to support 5-minute same platform re-occupation margins at North Station.	The schedule has been optimized around utilizing the minimum number of platforms at North Station. It is assumed the capability of 5-minute platform re-occupation is possible at North Station with a parallel crossing in the station throat. The ability to do so requires reviewing. Should it not be possible to do so then a review of the platform workings will be required.
Lowell Line	South Station Expansion & All-Day Peak Service (No NSRL) & South Station Expansion & All-Day Peak Service (No NSRL) & NSRL All-Day Peak Service (4-Track)	Critical	Additional terminal platform capacity	Provision of an additional terminal platform at Lowell and reduction in turnaround time and platform re-occupation time to less than 20 minutes	The service plan requires 6 tph terminating at Lowell, which can be turned around using 2 platforms, provided the turnaround time and re-occupation margins can be reduced to less than 20 minutes per train.
Lowell Line	NSRL All-Day Peak Service (4-Track)	Critical	Enhance signal capability	A reduction of the signaling headway to 5 minutes is required on the Lowell Line	The schedule requires 6 tph Lowell Line services, plus it is assumed to accommodate 1 tph each way on the Wildcat Line. Due to the level of service, a headway reduction is required to support this through re-signaling.

Line	Service Alternative	Critical / Recommended	Intervention Required	Intervention Solution	Intervention Reason
Haverhill Line	South Station Expansion & All-Day Peak Service (No NSRL)	Recommended	A review of signaling capability within the North Station throat, specifically looking at the ability to perform parallel crossings with same platform re-occupations. Requires at least 5-minute headways	Capability to support parallel crossing moves in the station throat to support 5-minute same platform re-occupation margins at North Station.	The schedule has been optimized around utilizing the minimum number of platforms at North Station. It is assumed the capability of 5-minute platform re-occupation is possible at North Station with a parallel crossing in the station throat. The ability to do so requires reviewing. Should it not be possible to do so then a review of the platform workings will be required.
Haverhill Line	South Station Expansion & All-Day Peak Service (No NSRL)	Critical	Reduction in the number of return movements to Haverhill	Review yard capacities on the Haverhill Line	The single-line section between Reading Junction and Fells on the Haverhill Line presents a constraint on the network. As an alternative to the above options, it may be feasible to operate the peak direction of services from units kept in yards on the Haverhill Line instead of return off-peak movements. A review of the yard capacity is required to confirm the maximum number of units which can be stored.
Haverhill Line	South Station Expansion & All-Day Peak Service (No NSRL), NSRL Regular Service (2-Track), NSRL All-Day Peak Service (2-Track), NSRL All-Day Peak Service (4-Track)	Critical	Enhance signal capability	A reduction of the signaling headway to 5 minutes is required	The level of service required in the service plan means that a signaling headway reduction from the base assumption of 10 minutes to at least 5 minutes is required.

Line	Service Alternative	Critical / Recommended	Intervention Required	Intervention Solution	Intervention Reason
Haverhill Line	South Station Expansion & All-Day Peak Service (No NSRL), NSRL Regular Service (2-Track), NSRL All-Day Peak Service (2-Track), NSRL All-Day Peak Service (4-Track)	Critical	Enhance signal capability	Improve signaling capability to support margins of at least 5 minutes	The single line section between Reading and Fells Junctions on the Haverhill Line presents a constraint on the network. It is potentially possible to develop a schedule around this constraint, however it would require a reduction of the margins at Fell Jn and Reading Junction.
Haverhill Line	South Station Expansion & All-Day Peak Service (No NSRL), NSRL Regular Service (2-Track), NSRL All-Day Peak Service (2-Track), NSRL All-Day Peak Service (4-Track)	Critical	Enhance signal capability	Improve signaling capability to support a junction margin of at least 3½ minutes.	The single line section between Reading and Fells Junctions on the Haverhill Line presents a constraint on the network. It is potentially possible to develop a schedule around this constraint, however it would require a reduction of the margins at Reading and Fells Junctions.
Haverhill Line	South Station Expansion & All-Day Peak Service (No NSRL), NSRL Regular Service (2-Track), NSRL All-Day Peak Service (2-Track), NSRL All-Day Peak Service (4-Track)	Critical	Doubling of Reading Junction and extension of siding.	Provision of a double junction and extension of siding at Reading Junction.	The single line section between Reading and Fells Junctions on the Haverhill Line presents a constraint on the network. As an alternative to the above options, provision of a double junction and extension of siding at Reading Junction would offer greater schedule flexibility and resilience.

Line	Service Alternative	Critical / Recommended	Intervention Required	Intervention Solution	Intervention Reason
Newburyport/ Rockport Lines	South Station Expansion & All-Day Peak Service (No NSRL)	Recommended	A review of signaling capability within the North Station throat, specifically looking at the ability to perform parallel crossings with same platform re-occupations. Requires at least 5-minute headways	Capability to support parallel crossing moves in the station throat to support 5-minute same platform re-occupation margins at North Station.	The schedule has been optimized around utilizing the minimum number of platforms at North Station. It is assumed the capability of 5-minute platform re-occupation is possible at North Station with a parallel crossing in the station throat. The ability to do so requires reviewing. Should it not be possible to do so then a review of the platform workings will be required.
Newburyport/ Rockport Lines	South Station Expansion & All-Day Peak Service (No NSRL)	Recommended	Review of the yard capacity at Newburyport and Rockport, should other enhancements to support full return movements not be delivered (i.e. Salem double-tracking).	Review yard capacities on the Newburyport/ Rockport Lines	Due to the network constraints outlined above, the resultant schedule has assumed a peak-direction flow of services, whereby 4 tph operate in the peak direction and 3 tph operate in the counter-peak direction, it is assumed 1 of the 4 counter-peak services operate between the MBTA CRMF depot and North Station. For the 3-hour AM and PM peaks, operating in such a manner means that to operate the peak-direction services, storage for at least 3 units is required before any return movements can be utilized (over the 3-hour peak).
Newburyport/ Rockport Lines	South Station Expansion & All-Day Peak Service (No NSRL), NSRL Regular Service (2-Track), NSRL All-Day Peak Service (2-Track), NSRL All-Day Peak Service (4-Track)	Recommended (Tier 3)	Double-track between McNall & Northey Point Junctions (between Swampscott and Salem stations)	Double-tracking between McNall and Northey Point Junctions (not in tunnel).	The single-line section between McNall and Northey Point Junctions (between Swampscott and Salem stations), further constrains the schedule. The number of trains that can be scheduled through the single-line section per hour is not sufficient to support the service plan alternatives. Double-tracking this section would remove this as a significant constraint on the network.

Line	Service Alternative	Critical / Recommended	Intervention Required	Intervention Solution	Intervention Reason
Newburyport/ Rockport Lines	South Station Expansion & All-Day Peak Service (No NSRL), NSRL Regular Service (2-Track), NSRL All-Day Peak Service (2-Track), NSRL All-Day Peak Service (4-Track)	Critical	Enhance signal capability	A reduction of the signaling headway to 5 minutes is required between North Station and Beverly	The level of service required in the service plan means that a signaling headway reduction from the base assumption of 10 minutes to at least 5 minutes is needed.
Worcester Line	South Station Expansion & All-Day Peak Service (No NSRL), NSRL Regular Service (2-Track), NSRL All-Day Peak Service (2-Track), NSRL All-Day Peak Service (4-Track)	Critical	Additional platform capacity at Worcester and reduction of junction margins	Provision of an additional terminal platform at Worcester	The level of service required in the service plan means that capability for more than 1 train terminating at Worcester is required. Provision of a second terminal platform and 3-5 minute junction margins is required.
Needham Line	South Station Expansion & All-Day Peak Service (No NSRL)	Critical	Provision of an additional siding.	A siding is required at Highland Station, preferably incorporating the station into the siding	The availability of paths on the main line route results in trains passing on the Needham Branch at approximately the same location as Highland Station.

Line	Service Alternative	Critical / Recommended	Intervention Required	Intervention Solution	Intervention Reason
Needham Line	NSRL All-Day Peak Service (4-Track)	Critical	Additional sidings	Additional sidings	The level of service on the Needham Line requires provision of an additional siding between Highland and Bellevue Stations, in additional to requiring the existing sidings at Need and Rox Junctions. While it is possible to plan a service using these two sidings, there is an impact to journey times with waiting times between 3 and 6 minutes in each siding. Relocating the crossing sidings to existing stations could improve journey times.
Franklin Line	South Station Expansion & All-Day Peak Service (No NSRL)	Critical	Ability to include parallel arrival and departures to/from the Franklin Line at Readville	Provision of an additional crossover at the country-end of Readville to allow Franklin Line services to reach both platforms	The margin between a train from the Franklin Line and a train to the Franklin Line is less than 2 minutes. To resolve this, providing access to both Readville platforms via a new crossover would avoid conflicts between services.

Line	Service Alternative	Critical / Recommended	Intervention Required	Intervention Solution	Intervention Reason
Franklin Line	NSRL Regular Service (2-Track), NSRL All-Day Peak Service (2-Track), NSRL All-Day Peak Service (4-Track)	Critical	Ability to include parallel arrival and departures to/from the Franklin Line at Readville and double-track to Endicott Station	Extension of double-track section between Endicott and Readville Stations into the two western side platforms at Readville. Provision of a parallel crossing so that simultaneous arrivals and departures at the city-end of the station can occur.	The margin between a train from the Franklin Line and a train to the Franklin Line is less than 2 minutes. To resolve this, providing access to both Readville platforms via a new crossover would avoid conflicts between services. A new crossover is also needed at Readville to enable parallel arrivals and departures.
Franklin Line	NSRL All-Day Peak Service (2-Track), NSRL All-Day Peak Service (4-Track)	Critical	Additional crossing sidings	Additional crossing sidings	Two additional crossing sidings are required for the Franklin Line, the first at approximately 20.5mi between Norfolk and Walpole West Junctions. The second (at approximately 26.5mi) is believed to be an existing siding named "Frank". Should this not be useable then a new siding is recommended at Franklin Station or towards the 28mi post. It is not possible for this schedule to make use of the Walpole siding without considerable impact to journey times.
Franklin Line	NSRL All-Day Peak Service (2-Track), NSRL All-Day Peak Service (4-Track)	Critical	Capability to turn back services at Dedham	A turnback crossover or siding	The service plans require 2 tph to terminate at Dedham, and facilities are required to support this.

Line	Service Alternative	Critical / Recommended	Intervention Required	Intervention Solution	Intervention Reason
Providence/ Stoughton Line	South Station Expansion & All-Day Peak Service (No NSRL)	Recommended	Review of platform workings at locations where a single platform face is provided on double-track sections.	Provision of additional platform faces and related facilities.	The assumed track layout indicates locations where there is a single-sided platform. It is understood that passengers can board/alight from trains on either line at these locations. While it may be feasible to do so with lower levels of service, this approach may require review once there are increases to the level of service. This is because an increased level of service may result in trains passing at locations whereby passengers are required to cross the track to board/alight trains. For the purposes of the schedule, no constraint on platform/boarding side is assumed, with trains operating on both lines (right-hand-side running)
Fairmount Line	South Station Expansion & All-Day Peak Service (No NSRL), NSRL Regular Service (2-Track), NSRL All-Day Peak Service (2-Track), NSRL All-Day Peak Service (4-Track)	Critical	Infrastructure to support the turning back of services at Fairmount	Provision of an additional turnback crossover at Fairmount, or double-track to Readville	As an alternative to running all the Fairmount Line services to Readville, which requires interventions on the single-track line, it would be feasible to turn back some services at Fairmount instead. Or another alternative is to double-track the route to Readville with 2 platforms

Line	Service Alternative	Critical / Recommended	Intervention Required	Intervention Solution	Intervention Reason
Old Colony Lines	South Station Expansion & All-Day Peak Service (No NSRL), NSRL Regular Service (2-Track), NSRL All-Day Peak Service (2-Track), NSRL All-Day Peak Service (4-Track)	Critical	Additional crossing locations on the Plymouth Line	Provision of an additional siding between Abington and Whitman Stations	The number of constraints coupled with the service plans necessitates an additional passing location for the Plymouth Line
Old Colony Lines	South Station Expansion & All-Day Peak Service (No NSRL), NSRL Regular Service (2-Track), NSRL All-Day Peak Service (2-Track), NSRL All-Day Peak Service (4-Track)	Critical	A reduction of the single-line re-occupation margins on the Old Colony Lines	Provision of improved signaling capability to reduce the single line re-occupation margins to 3 minutes	The number of constraints coupled with the service plans necessitates an additional passing location on the Plymouth Line in addition to a reduction in re-occupation times for the single-line sections
Old Colony Lines	South Station Expansion & All-Day Peak Service (No NSRL), NSRL Regular Service (2-Track), NSRL All-Day Peak Service (2-Track), NSRL All-Day Peak Service (4-Track)	Recommended	Removal of single lines between JFK/UMass and Braintree Stations, to support improved network resilience and performance	Doubling of the single line tracks between JFK/UMass and Braintree Stations	The single-track lines between JFK/Umass Stations and Braintree Station and Adams Junction would be operating near maximum capacity and presents a significant risk to performance.

Table B1: Full List of Upstream Improvements

C. Ridership Model Description

Introduction

The Central Transportation Planning Staff (CTPS) develops and then employs a regional travel demand model for use in forecasting changes that could occur during the consideration of transportation proposals. For the North South Rail Link Study, CTPS provided technical support and developed ridership forecasts, as requested by the Massachusetts Department of Transportation (MassDOT). This document describes the modeling techniques and methodologies CTPS used when conducting an analysis of potential ridership.

Overview of the Modeling Process

To perform the analysis, CTPS used a four-step travel demand model, which was developed by CTPS and updated and improved over a number of years. The four steps of travel demand forecasting and in the CTPS model, described in more detail later in this Appendix, are trip generation, trip distribution, mode choice and then trip assignment.

The basis for ridership forecasts are transportation analysis zones (TAZs). TAZs are the geographic unit where trips are produced by households, and where trips are attracted to non-household destinations. TAZs are necessary for transportation modeling because they provide a level of estimation midway between the community and individual households. They are typically formed around small neighborhoods within a municipality or represent a group of blocks with similar land uses, such as residential, retail, service, or manufacturing. The TAZ structure was developed based on Census block groups, which have been subdivided in areas with high growth. Typically, TAZs in suburban and rural areas are relatively larger than TAZs in urban areas.

Outputs from the model include projected transit ridership on different transit modes (including estimates of passenger boardings on all the existing and proposed transit lines) and traffic volumes on the highway network. These are used as inputs to the planning and analysis process for the project. A flow chart of the modeling process is shown in Figure C1.

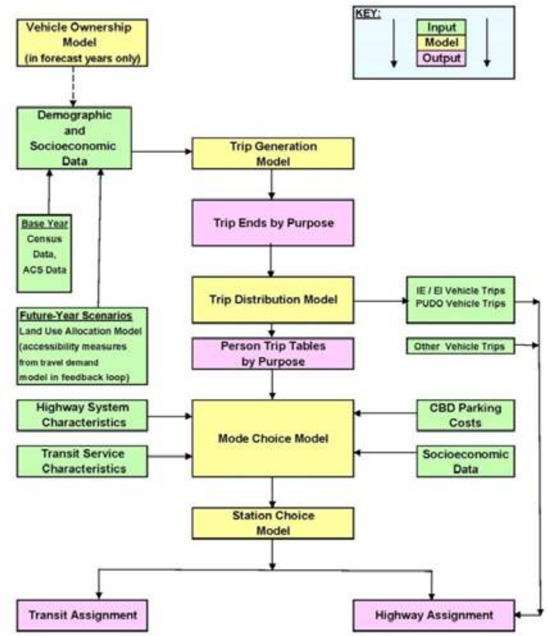

Figure C1: The CTPS Four-Step Travel Demand Modeling Process

ACS = American Community Survey. CBD = Central Business District. EI = External Internal.

IE = Internal External. PUDO = pick-up/drop-off.

Features of the CTPS Model – Data Inputs

General Modeling Characteristics

The CTPS travel demand forecasting model is an aggregate trip-based model. It is an aggregate model because it does not simulate the activities of each and every household (HH). Rather, the model simulates the travel behavior of groups of HHs, grouping them together based on common land use and access to travel modes. Geographically and physically, these groups make up the TAZs. These zones do not cross municipal boundaries and they are similar in terms of size (number of HHs or employers per zone) across the entire modeling region.

Modeled Area: The model encompasses all of Massachusetts, all of Rhode Island, and a portion of southern New Hampshire, as shown in Figure C52 below.

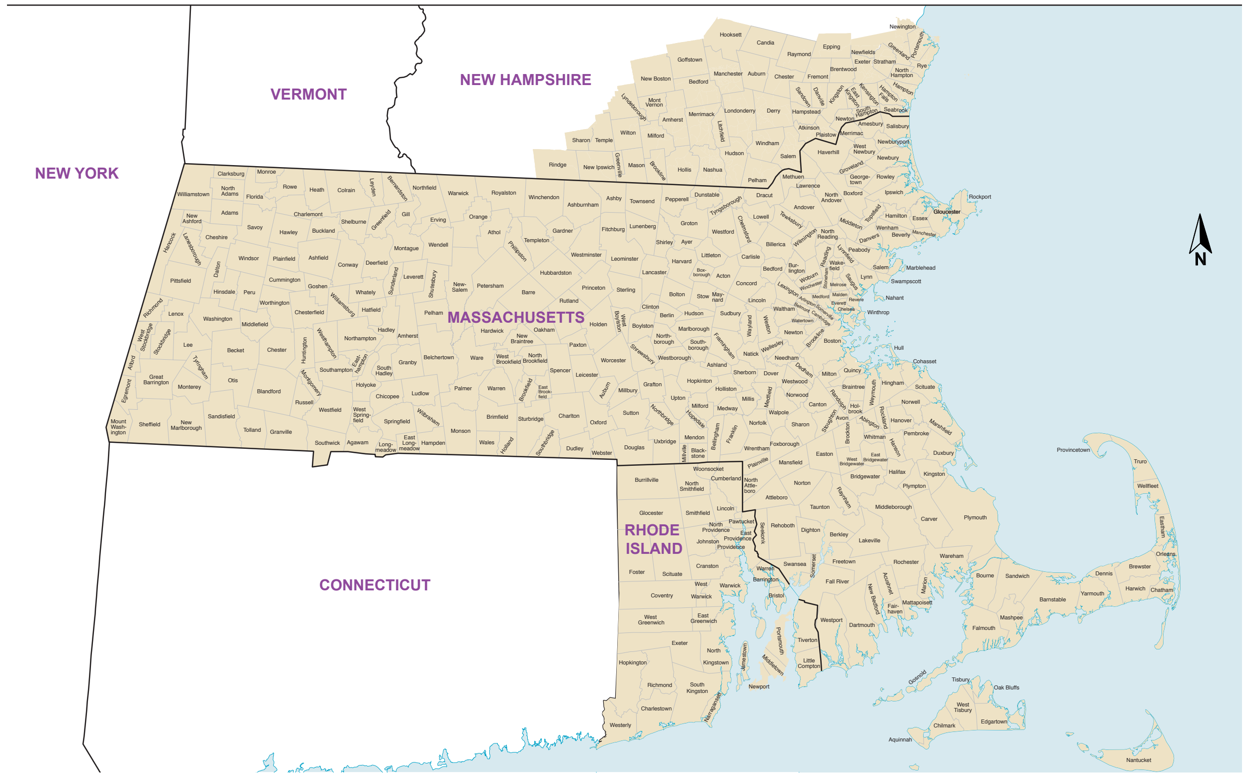

Figure C2: Extent of the CTPS Model Area

Zone System: The modeled area is divided into 5,739 internal TAZs. There are also 100 external stations around the periphery of the modeled area that account for travel between the modeled area and adjacent areas of Connecticut, New York, Vermont, and New Hampshire.

In a trip-based model, TAZs are the places where trips begin (trip producers) or end (trip attractors). TAZs can be as small as a single block (for example, in downtown Boston) or they can cover many square miles in rural areas. CTPS increased the number of TAZs in order to produce more reliable travel forecasts, but this comes at the cost of having to manage more data.

Modeling Years: Base and Future

The starting year for the model, referred to as the base year, is 2016, and incorporates data that CTPS uses in the model inputs. The model forecast extends to 2040.[1]

Table C1 details the employment and population changes forecast for the Boston region.

1 *Central Transportation Planning Staff, Boston Region Metropolitan Planning Organization,* Charting Progress to 2040: Long-Range Transportation Plan of the Boston Region Metropolitan Planning Organization*, July 2015,* *http://www.ctps.org/data/pdf/plans/lrtp/charting/2040_LRTP_Full_final.pdf*

Community Information				Total employment		Total population	
Area	Rail Line	Inside or outside MA-128	Town/City	2016	2040	2016	2040
North Central	Haverhill	Inside	Malden	14,797	14,983	62,948	76,825
	Haverhill	Inside	Melrose	7,151	7,343	27,148	27,487
	Haverhill	Inside	Saugus	11,275	11,269	27,128	28,740
	Haverhill	Inside	Stoneham	7,785	7,821	21,340	21,543
	Haverhill	Inside	Wakefield	14,167	14,237	25,221	26,075
	Lowell	Inside	Lexington	20,134	22,504	31,972	34,717
	Lowell	Inside	Winchester	8,547	8,569	21,329	21,733
	Lowell	Inside	Woburn	34,373	34,600	39,246	42,679
	SUBTOTALS	INSIDE		118,229	121,326	256,332	279,799
	Haverhill	Outside	Reading	6,061	6,110	25,384	27,975
	Lowell	Outside	North Reading	6,855	7,040	15,295	16,954
	Haverhill	Outside	Lynnfield	4,388	4,877	11,473	11,520

Community Information				Total employment		Total population	
Area	Rail Line	Inside or outside MA-128	Town/City	2016	2040	2016	2040
North Central	Haverhill	Outside	Andover	26,560	26,636	33,961	37,687
	Haverhill	Outside	Georgetown	2648	2651	8,501	9,442
	Haverhill	Outside	Groveland	910	911	6,683	7,572
	Haverhill	Outside	Haverhill	21,656	21,730	63,029	69,095
	Haverhill	Outside	Lawrence	26640	27014	80,210	88,691
	Haverhill	Outside	Merrimac	875	875	6,302	6,587
	Haverhill	Outside	Methuen	18,647	18,962	50,329	58,094
	Haverhill	Outside	North Andover	20883	21165	29,011	32,045
	Haverhill	Outside	West Newbury	879	882	4,179	4,341
	Lowell	Outside	Burlington	33,734	38,620	25,379	28,678
	Lowell	Outside	Wilmington	20,162	20,352	22,670	23,836
	Lowell	Outside	Billerica	23,779	23,011	40,661	43,583
	Lowell	Outside	Chelmsford	21,367	23,387	34,046	35,878

Community Information				Total employment		Total population	
Area	Rail Line	Inside or outside MA-128	Town/City	2016	2040	2016	2040
North Central	Lowell	Outside	Dracut	5827	6286	29,769	32,042
	Lowell	Outside	Dunstable	275	250	3,225	3,652
	Lowell	Outside	Lowell	36,795	36,465	107,103	110,090
	Lowell	Outside	Tewksbury	15,067	15,717	29,246	31,397
	Lowell	Outside	Tyngsborough	4,641	5,028	11,523	12,614
	SUBTOTALS	OUTSIDE		298,649	307,969	637,979	691,773
	SUBTOTALS	NORTH CENTRAL		416,878	429,295	894,311	971,572
					3%		9%

Community Information				Total employment		Total population	
Area	Rail Line	Inside or outside MA-128	Town/City	2016	2040	2016	2040
North East	Newburyport/ Rockport	Inside	Winthrop	4,155	4,182	17,512	17,311
	Newburyport/ Rockport	Inside	Everett	15,562	17,041	45,099	60,434
	Newburyport/ Rockport	Inside	Lynn	27,181	28,815	92,881	100,819
	Newburyport/ Rockport	Inside	Manchester-by-the-Sea	2,022	2,037	5,112	5,021
	Newburyport/ Rockport	Inside	Marblehead	6112	6138	19,775	20,515
	Newburyport/ Rockport	Inside	Nahant	506	509	3,309	3,113
	Newburyport/ Rockport	Inside	Peabody	27,536	27,739	52,998	58,884
	Newburyport/ Rockport	Inside	Revere	8,501	8,877	55,841	73,696
	Newburyport/ Rockport	Inside	Salem	18,980	20,027	42,433	45,390

Community Information				Total employment		Total population	
Area	Rail Line	Inside or outside MA-128	Town/City	2016	2040	2016	2040
North East	Newburyport/ Rockport	Inside	Swampscott	4,061	4,081	13,737	14,193
	Newburyport/ Rockport	Inside	Chelsea	16,919	17,136	36,657	42,054
	SUBTOTALS	INSIDE		131,535	136,582	385,354	441,430
	Newburyport/ Rockport	Outside	Beverly	24,386	24,815	40,051	42,404
	Newburyport/ Rockport	Outside	Rockport	2,397	2,397	6,907	6,813
	Newburyport/ Rockport	Outside	Topsfield	2,530	2,536	5,884	5,849
	Newburyport/ Rockport	Outside	Wenham	1,270	1,326	4,730	4,474
	Newburyport/ Rockport	Outside	Danvers	21,992	22,356	27,585	31,043
	Newburyport/ Rockport	Outside	Essex	1,605	1,610	3,591	3,737

Community Information				Total employment		Total population	
Area	Rail Line	Inside or outside MA-128	Town/City	2016	2040	2016	2040
North East	Newburyport/ Rockport	Outside	Gloucester	13,013	13,228	28,626	27,607
	Newburyport/ Rockport	Outside	Hamilton	1,973	1,979	7,670	7,602
	Newburyport/ Rockport	Outside	Ipswich	5,325	5,349	13,207	13,820
	Newburyport/ Rockport	Outside	Middleton	5,361	5,494	9,416	10,786
	Newburyport/ Rockport	Outside	Amesbury	5,297	5,305	16,366	17,290
	Newburyport/ Rockport	Outside	Boxford	1,254	1,260	7,650	7,758
	Newburyport/ Rockport	Outside	Newbury	1,729	1,731	6,533	6,680
	Newburyport/ Rockport	Outside	Newburyport	12,394	12,520	17,451	18,673
	Newburyport/ Rockport	Outside	Rowley	2,545	2,555	6,042	6,638

Community Information				Total employment		Total population	
Area	Rail line	Inside or outside ma-128	Town/city	2016	2040	2016	2040
North East	Newburyport/ Rockport	Outside	Salisbury	3,577	3,643	8,479	9,115
	SUBTOTALS	OUTSIDE		106,648	108,104	210,188	220,289
	SUBTOTALS	NORTH EAST		238,183	244,686	595,542	661,719
					3%		11%

Community Information				Total employment		Total population	
Area	Rail Line	Inside or outside MA-128	Town/City	2016	2040	2016	2040
North West	Fitchburg	Oustide	Petersham	123	123	1,260	1,350
	Fitchburg	Inside	Somerville	26,188	32,837	81,450	101,971
	Fitchburg	Inside	Waltham	56,175	59,401	62,556	70,009
	Fitchburg	Inside	Arlington	8,764	8,789	43,414	45,159
	Fitchburg	Inside	Belmont	7,277	7,305	25,367	27,977
	Fitchburg	Inside	Cambridge	113,070	123,395	109,486	123,808
	Fitchburg	Inside	Harvard	5,844	11,444	6,513	6,700
	SUBTOTALS	INSIDE		217,441	243,294	330,046	376,974
	Fitchburg	Outside	Phillipston	168	158	1,694	1,600
	Fitchburg	Outside	Royalston	121	113	1,238	1,150
	Fitchburg	Outside	Templeton	1,720	1,649	8,734	10,975
	Fitchburg	Outside	Wayland	3,845	3,934	12,651	12,395

Community Information				Total employment		Total population	
Area	Rail Line	Inside or outside MA-128	Town/City	2016	2040	2016	2040
North West	Fitchburg	Outside	Westminster	2,568	2,398	7,414	7,445
	Fitchburg	Outside	Weston	6,646	6,665	11,297	12,053
	Fitchburg	Outside	Shirley	2,262	2,271	7,639	8,650
	Fitchburg	Outside	Stow	2,441	2,583	6,757	7,421
	Fitchburg	Outside	Sudbury	6,808	6,869	17,344	17,303
	Fitchburg	Outside	Townsend	2,072	1,998	8,971	7,900
	Fitchburg	Outside	Winchendon	1,636	1,549	10,625	11,175
	Fitchburg	Outside	Pepperell	1,855	1,759	11,588	12,553
	Fitchburg	Outside	Westford	12,034	13,832	22,260	25,105
	Fitchburg	Outside	Abington	4,420	4,704	17,032	20,382
	Fitchburg	Outside	Barre	1230	1332	5,534	5,936
	Fitchburg	Outside	Princeton	780	811	3,514	3,828
	Fitchburg	Outside	Acton	10,779	10811	22,315	24,253

Community Information				Total employment		Total population	
Area	Rail Line	Inside or outside MA-128	Town/City	2016	2040	2016	2040
North West	Fitchburg	Outside	Ashburnham	1019	932	6,302	6,900
	Fitchburg	Outside	Ashby	282	274	3,166	3,313
	Fitchburg	Outside	Athol	3,379	3,299	12,011	14,700
	Fitchburg	Outside	Ayer	4,807	4,816	7,499	7,700
	Fitchburg	Outside	Bolton	2,510	2,514	4,982	5,177
	Fitchburg	Outside	Boxborough	2,082	2,180	4,893	4,730
	Fitchburg	Outside	Carlisle	1,021	1,021	4,739	4,692
	Fitchburg	Outside	Clinton	4,902	4,907	14,032	15,200
	Fitchburg	Outside	Concord	13,935	14,591	17,795	18,497
	Fitchburg	Outside	Fitchburg	12,740	12,598	41,038	42,340
	Fitchburg	Outside	Gardner	8,255	8,023	19,909	17,600
	Fitchburg	Outside	Groton	4361	4363	10,903	12,042
	Fitchburg	Outside	Hubbardston	501	484	4,628	5,480

Community Information				Total employment		Total population	
Area	Rail Line	Inside or outside MA-128	Town/City	2016	2040	2016	2040
North West	Fitchburg	Outside	Hudson	8,293	8,751	19,548	20,807
	Fitchburg	Outside	Leominster	17,690	17,498	40,210	36,500
	Fitchburg	Outside	Lincoln	2,748	2,755	6,199	5,900
	Fitchburg	Outside	Littleton	6,012	6,969	9,189	10,376
	Fitchburg	Outside	Lunenburg	2,262	2,199	10,364	10,480
	Fitchburg	Outside	Bedford	16,114	16,564	13,823	16,093
	Fitchburg	Outside	Lancaster	1,962	1,970	8,464	9,600
	Fitchburg	Outside	Maynard	3,201	3,210	10,158	10,208
	SUBTOTALS	OUTSIDE		179,461	183,354	446,459	468,459
	SUBTOTALS	NORTH WEST		396,902	426,648	776,505	845,433
					7%		9%

Community Information				Total employment		Total population	
Area	Rail Line	Inside or outside MA-128	Town/City	2016	2040	2016	2040
South Central	Franklin	Inside	Dedham	14,895	15,162	25,563	28,539
	Franklin	Outside	Hopedale	1,592	1,636	6,122	6,809
	Franklin	Outside	Norwood	24,127	24,435	29,076	30,771
	Franklin	Outside	Walpole	10,693	11,089	24,646	26,910
	Franklin	Outside	Westwood	11,505	12,374	14,571	15,253
	Franklin	Outside	Mendon	1362	1487	5,986	6,416
	Franklin	Outside	Millville	290	300	3,274	3,522
	Franklin	Outside	Blackstone	1,148	1,457	9,313	10,213
	Franklin	Outside	Uxbridge	3,257	3,689	14,247	17,022
	Franklin	Outside	Bellingham	5,747	5,759	16,797	17,912
	Franklin	Outside	Franklin	15,566	17,567	32,029	34,241
	Franklin	Outside	Medfield	3,267	3,298	11,635	11,558

Community Information				Total employment		Total population	
Area	Rail Line	Inside or outside MA-128	Town/City	2016	2040	2016	2040
South Central	Franklin	Outside	Medford	18,828	19,254	57,776	64,380
	Franklin	Outside	Medway	3,430	3,433	12,649	12,764
	Franklin	Outside	Milford	18,962	19,856	29,102	32,978
	Franklin	Outside	Millis	2,436	2,486	7,678	7,260
	Franklin	Outside	Milton	7,442	7,463	27,385	28,917
	Franklin	Outside	Norfolk	2,642	2,647	11,431	11,844
	Franklin	Outside	Wrentham	5,885	6,158	10,952	11,257
	Providence/ Stoughton	Outside	Canton	28,097	28,444	22,096	24,190
	Providence/ Stoughton	Outside	Foxborough	9,938	11,608	16,992	17,434
	Providence/ Stoughton	Outside	Sharon	5,188	5,291	17,462	18,474
	Providence/ Stoughton	Outside	Stoughton	14,505	15,510	27,020	27,209

Community Information				Total employment		Total population	
Area	Rail Line	Inside or outside MA-128	Town/City	2016	2040	2016	2040
South Central	Providence/ Stoughton	Outside	Easton	10,597	10,737	23,135	23,019
	Providence/ Stoughton	Outside	Attleboro	16,896	18,409	44,823	48,889
	Providence/ Stoughton	Outside	Dighton	1,823	1,873	7,208	7,422
	Providence/ Stoughton	Outside	Fairhaven	6,028	5,982	16,146	16,625
	Providence/ Stoughton	Outside	Mansfield	11,162	12,140	23,058	24,157
	Providence/ Stoughton	Outside	Marion	2,183	2,140	4,991	5,140
	Providence/ Stoughton	Outside	North Attleborough	11,291	12,293	29,328	31,624
	Providence/ Stoughton	Outside	Norton	6,078	6,690	19,277	20,617
	Providence/ Stoughton	Outside	Plainville	3,934	4,653	8,578	9,511

Community Information				Total employment		Total population	
Area	Rail Line	Inside or outside MA-128	Town/City	2016	2040	2016	2040
South Central	Providence/ Stoughton	Outside	Rehoboth	1,687	1,719	11,808	12,159
	Providence/ Stoughton	Outside	Seekonk	8,301	8,643	13,958	14,371
	Providence/ Stoughton	Outside	Swansea	5,426	5,676	16,138	16,618
	SUBTOTALS	OUTSIDE		281,313	296,196	626,687	667,486
	SUBTOTALS	SOUTH CENTRAL		296,208	311,358	652,250	696,025
					5%		7%

Community Information				Total employment		Total population	
Area	Rail Line	Inside or outside MA-128	Town/City	2016	2040	2016	2040
South East	Old Colony	Inside	Quincy	36,820	41,942	96,630	111,114
	Old Colony	Outside	Braintree	23,712	23,992	37,465	44,036
	Greenbush	Outside	Norwell	8,426	8,437	10,645	11,196
	Greenbush	Outside	Scituate	4,055	4,078	18,022	19,347
	Greenbush	Outside	Weymouth	22,402	22,764	54,168	56,420
	Greenbush	Outside	Cohasset	3,314	3,497	8,049	10,306
	Greenbush	Outside	Hingham	14,889	15,361	22,521	23,426
	Greenbush	Outside	Hull	1,888	1,893	10,095	9,376
	Greenbush	Outside	Marshfield	8,704	9,741	25,235	26,097
	Kingston/ Plymouth	Outside	Rockland	7,711	7,740	17,486	17,468
	Kingston/ Plymouth	Outside	Hanover	7,270	7,286	14,035	14,551
	Kingston/ Plymouth	Outside	Duxbury	3,571	3,594	15,108	18,622

Community Information				Total employment		Total population	
Area	Rail Line	Inside or outside MA-128	Town/City	2016	2040	2016	2040
South East	Kingston/ Plymouth	Outside	Pembroke	5,006	5,040	18,141	15,472
	Kingston/ Plymouth	Outside	Halifax	1,446	1,461	7,513	7,448
	Kingston/ Plymouth	Outside	Hanson	2,146	2,149	10,524	11,351
	Kingston/ Plymouth	Outside	Kingston	6,892	7,806	13,060	14,630
	Kingston/ Plymouth	Outside	Plymouth	26458	28,368	59,142	64,342
	Kingston/ Plymouth	Outside	Plympton	832	1,130	2,860	3,002
	Kingston/ Plymouth	Outside	Whitman	2,707	2,738	14,773	15,235
	Kingston/ Plymouth	Outside	Carver	2,777	3,139	11,819	12,911
	Middleborough/ Lakeville	Outside	Randolph	8,233	8,263	33,240	37,119
	Middleborough/ Lakeville	Outside	Holbrook	2,972	2,990	10,850	11,110

Community Information				Total employment		Total population	
Area	Rail Line	Inside or outside MA-128	Town/City	2016	2040	2016	2040
South East	Middleborough/ Lakeville	Outside	Avon	5,294	5,389	4,362	4,327
	Middleborough/ Lakeville	Outside	Bridgewater	8,661	9,117	26,859	27,456
	Middleborough/ Lakeville	Outside	Brockton	37,765	38,276	95,513	97,886
	Middleborough/ Lakeville	Outside	East Bridgewater	3,282	3,503	14,212	14,967
	Middleborough/ Lakeville	Outside	West Bridgewater	7,734	8,196	7,070	7,559
	Middleborough/ Lakeville	Outside	Acushnet	1226	1296	10,480	10,792
	Middleborough/ Lakeville	Outside	Berkley	571	616	6,521	6,715
	Middleborough/ Lakeville	Outside	Dartmouth	16,030	17,022	34,616	35,645
	Middleborough/ Lakeville	Outside	Fall River	35,017	35,584	90,383	91,557
	Middleborough/ Lakeville	Outside	Freetown	4,201	4,658	9,022	9,289

Community Information				Total employment		Total population	
Area	Rail Line	Inside or outside MA-128	Town/City	2016	2040	2016	2040
South East	Middleborough/ Lakeville	Outside	Lakeville	3,174	3,620	10,889	11,909
	Middleborough/ Lakeville	Outside	Mattapoisett	1,750	1,763	6,148	6,331
	Middleborough/ Lakeville	Outside	Middleborough	8,456	9,514	24,491	28,130
	Middleborough/ Lakeville	Outside	New Bedford	35,894	35,332	96,710	99,580
	Middleborough/ Lakeville	Outside	Raynham	8515	9355	14,290	16,552
	Middleborough/ Lakeville	Outside	Rochester	768	763	5,322	5,479
	Middleborough/ Lakeville	Outside	Somerset	4,482	4,517	18,477	19,026
	Middleborough/ Lakeville	Outside	Taunton	24,542	26,971	56,404	59,958
	Middleborough/ Lakeville	Outside	Wareham	8,961	9,131	22,199	22,857

Community Information				Total employment		Total population	
Area	Rail Line	Inside or outside MA-128	Town/City	2016	2040	2016	2040
South East	Middleborough/ Lakeville	Outside	Westport	3,304	3,206	15,798	17,775
	SUBTOTALS	OUTSIDE		385,038	399,296	984,517	1,037,255
	SUBTOTALS	SOUTH EAST		421,858	441,238	1,081,147	1,148,369
					5%		6%

Community Information				Total employment		Total population	
Area	Rail Line	Inside or outside MA-128	Town/City	2016	2040	2016	2040
West	Worcester	Inside	Brookline	20,402	20,739	62,015	72,613
	Worcester	Inside	Newton	47,995	49,184	86,416	90,182
	Worcester	Inside	Watertown	18,296	18,437	33,040	36,901
	SUBTOTALS	INSIDE		86,693	88,360	181,471	199,696
	Needham	Outside	Dover	884	888	5,482	5,410
	Needham	Outside	Needham	18,209	18,441	29,251	31,623
	Worcester	Outside	Auburn	10,071	10,684	16,603	17,814
	Worcester	Outside	Wellesley	21825	21959	27,873	27,403
	Worcester	Outside	Berlin	462	497	3,177	4,336
	Worcester	Outside	Boylston	1671	1727	4,519	5,051
	Worcester	Outside	Brookfield	494	498	3,479	3,745
	Worcester	Outside	Charlton	3824	4,394	13,534	15,380
	Worcester	Outside	Douglas	874	1,045	8,788	9,820

Community Information				Total employment		Total population	
Area	Rail Line	Inside or outside MA-128	Town/City	2016	2040	2016	2040
West	Worcester	Outside	Dudley	2842	3107	11,674	12,503
	Worcester	Outside	East Brookfield	396	401	2,235	2,382
	Worcester	Outside	Grafton	4134	4463	18,792	22,390
	Worcester	Outside	Hardwick	392	395	3,066	3,289
	Worcester	Outside	Holden	3,561	3,873	17,945	19,862
	Worcester	Outside	Leicester	2,228	2,416	11,243	12,048
	Worcester	Outside	Millbury	5093	5489	13,749	15,319
	Worcester	Outside	New Braintree	239	243	1,019	1,071
	Worcester	Outside	North Brookfield	901	916	4,800	5,154
	Worcester	Outside	Northborough	6,245	7,157	14,973	17,836
	Worcester	Outside	Northbridge	5372	6233	16,424	18,855
	Worcester	Outside	Oakham	211	225	1,942	2,053
	Worcester	Outside	Oxford	4266	4690	14,164	15,601

Community Information				Total employment		Total population	
Area	Rail Line	Inside or outside MA-128	Town/City	2016	2040	2016	2040
West	Worcester	Outside	Paxton	834	914	4,970	5,493
	Worcester	Outside	Rutland	1,096	1,220	8,332	9,543
	Worcester	Outside	Shrewsbury	13,135	14,068	36,914	41,171
	Worcester	Outside	Southbridge	5,941	6,876	17,030	17,814
	Worcester	Outside	Spencer	3,079	3,343	11,997	12,915
	Worcester	Outside	Sturbridge	4,711	5,186	9,949	12,392
	Worcester	Outside	Sutton	2,203	2,350	9,263	10,213
	Worcester	Outside	Upton	1170	1597	8,150	10,357
	Worcester	Outside	Warren	585	628	5,278	5,709
	Worcester	Outside	Webster	6,835	7,931	17,335	19,142
	Worcester	Outside	West Boylston	3842	4318	7,930	8,766
	Worcester	Outside	West Brookfield	851	859	3,800	4,096
	Worcester	Outside	Westborough	24,300	26,165	18,918	21,010

Community Information				Total employment		Total population	
Area	Rail Line	Inside or outside MA-128	Town/City	2016	2040	2016	2040
West	Worcester	Outside	Worcester	97,734	105,113	185,257	197,196
	Worcester	Outside	Ashland	5,634	5,718	17,519	20,892
	Worcester	Outside	Framingham	52,557	55,001	69,863	75,997
	Worcester	Outside	Holliston	4,840	6,236	13,266	12,870
	Worcester	Outside	Hopkinton	10,223	10,856	15,117	16,551
	Worcester	Outside	Natick	24,204	24,543	33,469	34,850
	Worcester	Outside	Marlborough	26321	27146	40,081	45,653
	Worcester	Outside	Sherborn	946	952	3,919	3,682
	Worcester	Outside	Southborough	7,453	8,174	9,909	11,082
	Worcester	Outside	Sterling	2,344	2,298	7,893	7,500
	SUBTOTALS	OUTSIDE		395,032	421,233	800,891	873,839
	SUBTOTALS	WEST		481,725	509,593	982,362	1,073,535
					6%		9%

Community Information				Total employment		Total population	
Area	Rail Line	Inside or outside MA-128	Town/City	2016	2040	2016	2040
Boston	ALL LINES	INSIDE	Boston	600,371	646,946	645,570	743,967
					8%		15%

Community Information				Total employment		Total population	
Area	Rail Line	Inside or outside MA-128	Town/City	2016	2040	2016	2040
Totals							
	COMMUTER RAILSHED		(Does not include Boston)	2,251,754	2,362,818	4,982,117	5,396,653
				5%		8%	
	Inside 128			605,613	646,666	1,275,396	1,437,552
					7%		13%
	Outside 128			1,646,141	1,716,152	3,706,721	3,959,101
					4%		7%
	North Side			1,051,963	1,100,629	2,266,358	2,478,724
	South Side			1,199,791	1,262,189	2,715,759	2,917,929
	TOTAL REGIONAL GROWTH - INCLUDES BOSTON			**2,852,125**	**3,009,764**	**5,627,687**	**6,140,620**
					6%		9%

Table C1: Boston Metro Employment and Population Projections

Source: Metropolitan Area Planning Council (MAPC) 2015 Projections; Long-Range Transportation Plan (LRTP), Charting Progress to 2040, Needs Assessment

Model Inputs

Inputs to the model include population by age; HHs by type (HHs by worker, by HH income, and by auto availability); and employment categories: basic, retail, and service.

The US Census is the source for population and HH data, while InfoUSA (a private data vendor) is the source for employment data. CTPS and the Metropolitan Area Planning Council (MAPC) purchased the data from InfoUSA in 2011, and spent a year analyzing and correlating the data before the agency staff were confident of their accuracy for use in the model. The census data do not require the same degree of verification as the InfoUSA data, but analysis was also required to check and prepare the census data for inputs to the model.

The transit information used in the model is from transit schedules published by the Massachusetts Bay Transportation Authority (MBTA). CTPS periodically updates the schedules in the model to reflect the most current schedule information. Typically, future-year No Build scenarios reflect base-year transit schedules. As shown in Table C2, the transit system simulation is based on four time periods: AM peak period (6:00 AM to 9:00 AM), midday (9:00 AM to 3:00 PM), PM peak period (3:00 PM to 6:00 PM), and early evening and night (6:00 PM to 6:00 AM).

Time Period	Highway Vehicle-Trips and Transit Person-Trips
AM peak period	6:00 AM to 9:00 AM
Midday	9:00 AM to 3:00 PM
PM peak period	3:00 PM to 6:00 PM
Early evening/night	6:00 PM to 6:00 AM

Table C2: Time Periods of Trip Assignments

Highway Data: Roadway information was taken from the 2012 MassDOT road inventory file. This information includes number of travel lanes per direction, segment length, posted travel speed, and functional classification for each road and highway.

The following cost data were used in the model:

- Mode-specific weighted transit fare (weighted based on the relative shares of pass holders, those paying full fares, and those with discount fares)
- Data on park-and-ride lot fees collected in 2012 for every known lot in the model area
- Information on applicable highway tolls collected in 2012 by individual toll facilities
- Auto operation costs calculated for the year 2012

MassDOT and the Boston Region MPO contributed funds to hire a consultant to conduct a statewide household travel survey during an 18-month period between June 2010 and November 2011, known as the 2011 Massachusetts Travel Survey (2011-MTS). The 2011–MTS was used extensively to estimate, calibrate, and validate the CTPS model.

Trip Purposes

Daily HH activities are defined by trip purpose. The trip purposes that are represented in the CTPS model are home-based work (HBW) trips (work trips that have one end associated with the traveler's home), home-based personal business (HBPB) trips, home-based social-recreational (HBSR) trips, home-based school (HBSC) trips, home-based pick-up/drop-off (PUDO) trips, non-home-based work (NHBW) trips (trips that neither begin nor end at home, but begin or end at work), and non-home-based other (NHBO) trips (trips that neither begin nor end at home).

Truck, Taxi, Logan International Airport, and Through Trips

Other types of trips are also considered by the model, such as commercial vehicle trips (trucks), taxi trips, trips to and from Logan Airport, and through trips (trips that neither begin nor end in the modeled area, but pass through the modeled area).

Description of Future-Year Land-Use Scenario

MassDOT, through an extensive effort involving other state agencies, the UMass Donahue Institute, and the state's regional planning agencies, has developed a set of community forecasts for the state. For the Boston region, MAPC allocated these community forecasts—or regional control totals—to TAZs.

MAPC allocated the MassDOT regional control totals to individual TAZs based on the Cube Land land-use allocation model, which is third-party software that forecasts land use by simulating the real estate market under different economic conditions. Cube Land forecasts the supply, location and rents by zone for different types of properties, estimating the location of households and non-residential activities for different demographic groups. The basis for Cube Land's land-use allocation model is a development tracking database (developed by MAPC), changes in parcel transportation accessibility (computed by CTPS), and community assessor and zoning maps. MAPC's application of Cube Land covers all 164 cities and towns in the MPO modeling area. (Note that this modeling area differs from the area covered by the MPO, which includes 101 cities and towns.)

CTPS Model – Four-Step Process

Trip Generation

Trip generation is the first step in the conventional four-step transportation forecasting process. It predicts the number of trips that are associated with HHs (trip productions) and the number of trips associated with employment sites (trip attractions). Every trip has two ends—a production end at the HH where the trip is initiated and an attraction end at the location where the trip culminates. This means that land use is characterized by two broad categories, residential and nonresidential. On the residential side, trip generation is thought of as a function of the social and economic attributes of HHs. On the nonresidential side, trip generation is thought of as a function of the number of jobs by activity.

Trip Distribution

The trip distribution model combines the estimated trip productions and trip attractions prepared by the trip generation model into tables showing both interregional and intraregional vehicle trips, which are then used as inputs into the highway assignment model (the fourth step of the modeling process, described below). Intraregional person-trip tables also are produced and are used as inputs for the mode choice model (the third step of the modeling process).

The trip distribution process used in the CTPS model is a gravity model, which uses travel time and employment density to determine how *attractive* destinations are to travelers.

The gravity model takes the trips produced in one TAZ and distributes them to each of the other TAZs, based on the *attractiveness* of and distance to the other TAZs. The distance to possible destinations is the other factor used in the gravity model. The number of trips from an origin TAZ to all destination TAZs decreases as the distance between these destinations increases (this relationship is inversely proportional). The distance effect goes through a calibration process that leads to trip distribution in the model that is similar to that observed data.

Distance can be measured in several ways:

- Auto travel times between TAZs as the measurement of distance (this is the simplest method)
- A combination of auto travel time and cost as the measurement of distance
- Composite impedance, which is a combination of both transit and auto times, plus costs

The CTPS model uses composite impedance. This method involves calculating a share of the highway time and a share of the transit time. These time shares vary by origin-destination pair based on the number of auto trips and transit trips. The model must run through multiple iterations to balance the trip numbers, so that they match the trip productions and attractions, which are independently estimated in the trip generation step.

Mode Choice

Mode choice is the third step in the travel demand forecasting process. It is the process in which the trips from the distribution step are allocated to the available travel modes from the transportation network. Trip distribution establishes the volume of trips from one place to another, whereas mode choice estimates the mode that those travelers will use to make their trip.

CTPS used 2011 MTS data, information about travel impedances on the highway and transit networks, 2006-10 US Census data, and a variety of other data sources to develop a mode choice model by trip purpose. The mode choice model estimates what percentage of travelers will use each mode for four trip purposes:

- Home-based work (HBW) and work-related
- Home-based other (HBO)—including home-based shopping, personal business, social, recreation, and other miscellaneous purposes
- Home-based school (HBSC)—this trip purpose was further divided into HBSC1 (ages 0 to 13), HBSC2 (ages 14 to 18), and HBSC3 (ages 19 and older)
- Non-home based (NHB)—including non-home-based work and non-home-based other trips

The mode choice model is applied, by trip purpose, to the distributed trip tables that result from the trip distribution model, and splits the trip purposes between the following modes:

- Auto: drive alone (DA)
- Auto: two occupants (SR2)
- Auto: three or more occupants (SR3+; for HBW only)
- Transit: drive access to commuter rail (DAT_CR)
- Transit: drive access to rapid transit (DAT_RT)
- Transit: drive access to local bus (DAT_LB)
- Transit: drive access to boat/ferry (DAT_B/F; not for HBSC)
- Walk to transit (Boat, CR, RT, and bus)
- Nonmotorized: walk, bike

The number of trips in the 2011–MTS data by trip purpose, as well as the characteristics of the transportation system in the modeling area, determined the modes and trip purposes considered in the mode choice model. The transportation system characteristics can be thought of as a kind of level-of-service metric that aggregates various facility characteristics into one metric.

Transit Path-Building

The following topics have been discussed: how many trips will be made; where these trips will go; and what mode they will take. This section covers what route within that mode will be taken.

For transit trips, the path selected is based on the lowest generalized cost. This means that all components of the transit trip (access time, egress time, waiting time, in-vehicle time, fare, and transfer cost and time) are converted to one variable, which is cost. The transit path with the lowest cost is chosen.

Wait-time estimations in the model vary depending on the frequency of a particular service but are capped at ten minutes' waiting time. Transfer time includes the time it takes to walk between two stops. The model caps the allowed number of transfers at six.

Highway Path-Building

For highway trips, the path is based on the minimum congested travel time path. The travel time is calculated based on the traffic volumes, which result from the highway assignment.

Trip Assignment

Trip assignment is the fourth step in the travel demand forecasting process. Trip assignment models are used to estimate the traffic and passenger flows on a transportation network. Trip assignment is the most time-consuming step—as well as one of the most data-intensive steps—of the four-step modeling process. The process is somewhat different for highway travel than for transit travel.

Highway Assignment Overview

The highway assignment model predicts the flows on the network, generates estimates of travel times, and produces attributes that are the basis for traffic volume and capacity analyses. This model is also used to generate the estimates of network performance that are used in the mode choice and trip distribution models.

The CTPS roadway/highway assignment procedure assigns highway trips to the highway network so that each user of the highway network chooses the route that he or she perceives to be the best. The assignment procedure is performed for each time period.

For more realistic assignment results, the assignment procedure recognizes that different groups of highway users value network attributes (for example, travel time) differently. The highway users are represented by drive-alone auto trips, shared-ride auto trips, and truck trips.

The generalized cost is computed as the combination of the travel time and a toll equivalent time. Toll costs affect the assignment and are stored on the network. The generalized cost is converted to an equivalent time by applying the value time to the toll. The value of time for autos is $0.20 per minute ($12.00 per hour). This value is based on the average hourly rate for the region in 2010 dollars. Trucks have a significantly higher value of time. For small single-unit trucks, the value of time is $0.75 per minute. For large single-unit trucks and combination vehicles, the value of time is $1.00 per minute.

The assignment procedure uses the user equilibrium method—an iterative process which assigns trips to a series of routes until a level of travel time parity is achieved across the network. Travel time is a function of the assigned traffic volume and the road capacity. Road capacity is estimated based on the roadway attributes, such as the number of lanes. For each iteration of assignment, the highway trips between zone pairs are assigned to routes with the minimum cost and travel time is calculated after trip assignment. The iterative process stops when changing user's paths will not achieve a faster route.

Transit Assignment Overview

To perform a transit assignment, the following inputs are needed:

- Transit route system
- Fare structure
- Demand for passenger trips between different origins and destinations
- After the demand matrices of drive access trips (DAT) and walk access trips (WAT) are forecast, the trips are assigned to the transit network and combined by time period. The congestion of passengers at stops and terminals does not influence travel times or behavior in the model.

Finally, summaries of transit boardings by submode (for example, buses, rapid transit, ferry, commuter rail) and time of day are produced, along with boardings and alightings at rapid transit and commuter rail stations, with subtotals by line. For buses, summaries of boardings are produced that are classified by the MBTA bus route number and time of day.

Other Model Outputs

Environmental Justice

When required, CTPS performs an environmental justice (EJ) analysis in the model. The EJ analysis examines the benefits and burdens of the project on EJ communities in the study area.

The EJ analysis is performed at the level of the TAZ. TAZs are identified as being EJ TAZs if their populations meet certain thresholds with regard to income, race, or in some cases, English language proficiency. The thresholds are based on regional or statewide averages.

The EJ analysis typically measures the change in accessibility to employment for a given alternative. That change is measured for trips within a particular area, or travel shed. The travel shed that is established depends on the particulars of the study and the alternatives being examined.

For example, if the study focuses on a commuter rail extension that would involve a 90-minute train ride to Boston, the travel shed would be defined as the area around the train route being analyzed.

Air Quality

When required, CTPS also performs an air quality mobile source emissions analysis. CTPS uses the travel demand model in conjunction with MOVES 2014a—the US Environmental Protection Agency's (EPA) Motor Vehicle Emission Simulator—to estimate mobile source emissions from all modes of transportation for the different alternatives studied. Commuter rail emissions are estimated based on guidance from the EPA.

MOVES 2014a uses vehicle-miles traveled as well as vehicle speed, in combination with 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 2014a 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.

The EPA guidance employs a similar methodology to estimate emissions for locomotives. Track miles are considered along with specific emission factors to develop air quality estimates associated with the trains. CTPS estimates train emissions for vehicle fleets of different ages, using a methodology employed by the EPA.

D. Fire and Life Safety

This Appendix provides further detail on Fire and Life Safety requirements and design, as they pertain to the NSRL project.

Means of Egress: Stations

The National Fire Protection Association (NFPA) publishes consensus codes and standards for minimization of fire and other risks, and the NFPA 130 Standard specifies fire protection and life safety requirements for fixed guideway transit and passenger rail. Per NFPA 130, the means of egress system at each station must be designed based on the station's passenger load. This occupant load is calculated based on projected peak period train loads at the station in question, and is the sum (assuming simultaneous train movements on all tracks in normal traffic directions) of all passengers entering the station and outgoing passengers awaiting trains on the platforms.

NFPA 130 takes a performance-based approach to egress system design, requiring that evacuation time from the platform be less than four minutes, and that the total evacuation time from the most remote point of a platform to a Point of Safety be less than six minutes. Evacuation time is based on the design passenger load, means of egress components used, their maximum capacity and travel speed as prescribed by NFPA 130, and travel distances. The predicted passenger load at each station informs the number and capacity of the exits required for the station.

Since ridership numbers are fluid and can change significantly over the useful life of the station, for maximum flexibility each station should have at least four exits (the minimum requirement under the Ninth Edition of the Massachusetts Building Code for a space serving more than 1,000 occupants). NFPA 130 limits the travel distance between the platform and a point where an egress route leaves the platform to 325 feet, and limits the common path of travel from the platform ends to 82 feet or one car length (whichever is greater).

Since NFPA 130 allows stairs, ramps, escalators, elevators, and doorways to be part of the means of egress system, and since these components also serve as points of ingress to the station, the recommended means of egress strategy (again, with a minimum of four exits/entrances) complies with code for a space with a large occupant load (over 1,000 people), and can provide convenient access points to and from the station for the riders and the general public.

Furthermore, the Standard specifies the following requirements:

- Escalators may not account for more than 50% of the required means of egress capacity at any one level except where the escalators can be brought to a stop remotely
- Each station level is also served by at least one stairwell, with at least one enclosed exit stairwell or exit passageway providing continuous access between platforms and the public way.
- Elevators used as a means of egress must not account for more than 50% of required egress capacity.

- Elevators used as a means of egress must be accessible via holding areas that are smoketight and fire-rated for a minimum of one hour or lobbies that are served by a stairwell. Elevator shafts must be fire-rated for at least two hours.

In addition to meeting the specific NFPA 130 component requirements shown in Table D15, the means of egress from stations must be provided with emergency lighting.

An alternative would be to base the egress system and features on a performance-based analysis (performance approach). A performance approach is an engineered process that focuses on meeting goals and objectives rather than prescriptive requirements. Based upon the unique nature of these deep stations, a performance-based egress analysis would be appropriate and would be recommended as part of future assessments.

Means of Egress Component	Minimum Clear Width [in]	Maximum Means of Egress Capacity [person/in-min]	Maximum Travel Speed [ft/min]
Platforms Corridors Ramps	44	2.08	124
Concourses Areas of lower pedestrian density	44	2.08	200
Stairs Escalators	44	1.41	48 (vertical)
Doors Gates[single leaf]	n/a	60 person per minute for each component	n/a
Doors Gates [bi-parting multi-leaf]	n/a	2.08	n/a
Fare barriers	21	50 person per minute for each component	n/a

Table D1: NFPA 130 Means of Egress Component Requirements

Means of Egress: Tunnels

Evacuation from a vehicle within the trainway tunnel must allow the riders to proceed to the nearest station or another Point of Safety. Within the tunnel, exits must be located within 2,500ft of one another. Exit stairs must be constructed along the tunnels. This configuration can be cost-prohibitive, depending on proposed tunnel depth and the availability of open land on the surface.

However, NFPA 130 also allows cross-passageways in lieu of emergency exit stairways when tunnels are divided by fire separation that is rated for a minimum of two hours or where tunnels are in twin bores. The cross-passageways must be within 800ft of one another and of station boundaries or tunnel portals, and must have minimum dimensions of 44in clear width and 7ft clear height. The intent is for the cross-passageways to allow riders from one trainway or bore to enter into another trainway or bore, thereby separated from the hazard and able to continue on the evacuation route. To facilitate egress, ventilation for the incident trainway must be designed to control smoke spread in the vicinity of the passengers.

Fire Protection Features: Stations

Each station must be provided with an accessible fire command center. The fire command center is the main area displaying the status of the detection; containing alarm communications, control systems, and other emergency systems; and from where the systems can be manually controlled.

Automatic sprinklers are required in areas of a station used for concessions, storage, and trash collection, and in other similar spaces with combustible loadings (except tunnels). The sprinkler system is provided with a water flow alarm and supervisory signal service, and the system design and installation are required to comply with NFPA 13, the standard for sprinkler system installation. The City of Boston may require additional areas, such as back-of-house, lobbies, MEP rooms, or concourses, to be protected by automatic sprinkler systems.

Class I standpipes in accordance with NFPA 14, the standard for standpipe and hose systems, are required at each station. The standpipe system must be enclosed in fire construction unless the system is cross-connected or fed from two locations and the isolation valves are installed 800ft apart or less. The system is also required to be 'wet type' (standpipes with a continuous water supply) except where approved by the authority with jurisdiction, and where the system is designed so that water is delivered to all hose connections within 10 minutes and combination air relief-vacuum valves are installed at each high point of the system.

Each station is required to:

- Be protected by a fire alarm system designed and installed per NFPA 72. The fire alarm system must be provided with a fire alarm annunciator panel at an approved location accessible to emergency response personnel.
- Incorporate automatic fire detection in all unsprinklered ancillary spaces by temperature and rate-of-rise heat detectors or smoke detectors that achieve listed standards. Activation of initiating devices must be announced at the Panels must announce activation of devices by audible alarm and visually display the location of the actuated device.
- Include separate alarm zones to monitor water flow and supervise main control valves for the automatic sprinkler. All indicator signals for fire alarms, smoke detection, valve switches, and water flow must be simultaneously transmitted to the local fire station and to the operations control center for the rail system.
- Provide an emergency communications system at each station that is in compliance with Chapter 10 of NFPA 130 .

NFPA 130 requires that the authority with jurisdiction determines the number, size, type, and location of any portable fire extinguishers to be installed in a train station.

Emergency power, in accordance with Article 700 of NFPA 70 and Chapter 4 of NFPA 100, is required for each station. The emergency power system is sized to selective load pickup and load shedding of the following systems:

- Emergency lighting
- Protective signaling
- Emergency communications
- Fire command center
- Elevators providing required egress capacity

Fire Protection Features: Tunnels

An emergency communications system in compliance with Chapter 10 of NFPA 130 is required within the tunnels.

At traction power substations and signal bungalows, heat and smoke detectors connected to the operations control center are required per NFPA 130. An automatic sprinkler system is not required within the tunnels per NFPA 130.

Class I standpipes are required to be installed within the tunnels. In addition to the requirements for standpipes for station structures, an approved water supply must provide the system demand for a minimum of one hour. Approved water supplies include a municipal or privately owned waterworks system, automatic or manually controlled fire pumps connected to a water source, or pressure-type or gravity-type storage tanks per NFPA 22. A fire department connection is required for the system, and a fire department access road must reach within 100ft of the fire department connections. The authority with jurisdiction determines the number, size, type, and location of any portable fire extinguishers to be installed within the tunnels.

Emergency power is required for the enclosed tunnels. The emergency power system will connect to the following systems within the trainway tunnel:

- Emergency lighting
- Protective signaling
- Emergency communications
- Fire command center

Ventilation

NFPA 130 requires a tunnel ventilation system, which performs a number of functions. The primary function is to ventilate any smoke produced during a fire event, to allow a clear path for evacuating passengers from any trains either in the tunnels between stations or in the stations themselves.

The tunnels will be cleared using a fan plant at either end of a tunnel segment, and these operate using the 'push-pull' principle (the fan plant at one end of the affected tunnel segment will be operated in supply mode, while the plant at the other end will operate in exhaust mode, as shown in Figure D3). A critical velocity is attained to force smoke in one direction while passengers exit in the opposite direction.

In the event of a train fire within a station, the fan plants at that station operate in exhaust mode. An over-track exhaust duct clears smoke from all areas of the platform outside the immediately affected area to meet visibility, temperature and carbon monoxide concentration tenability criteria at 6ft (1.8 meters) above platform level.

A fan plant is provided at both ends of each station to meet these ventilation needs. A series of dampers and ducts allows the same fan plant to ventilate either the station or the adjacent tunnel. These fan plants are connected by large shafts to a surface structure (vent building) to discharge or intake air.

A piston relief system, as shown in Figure D4, keeps air velocities on the platform within acceptable limits and prevents heat buildup within the tunnels and stations. This directs the air carried along with the trains on an alternate path, rather than allowing the air to find its way to the surface through station entrances. To minimize costs, piston relief shafts are combined with fan shafts to the greatest extent possible.

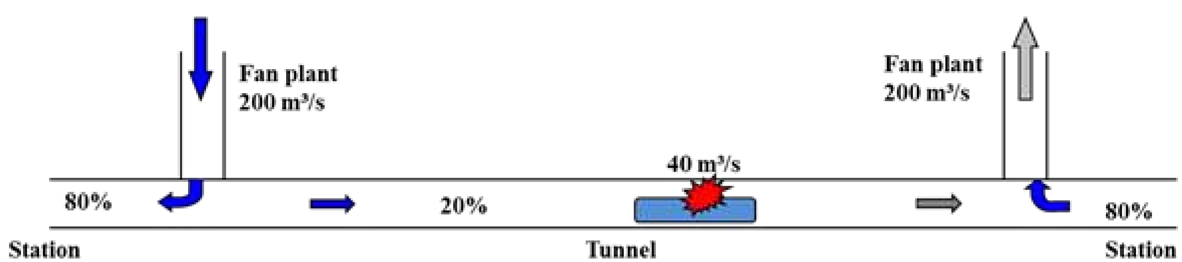

Figure D1: Tunnel Ventilation

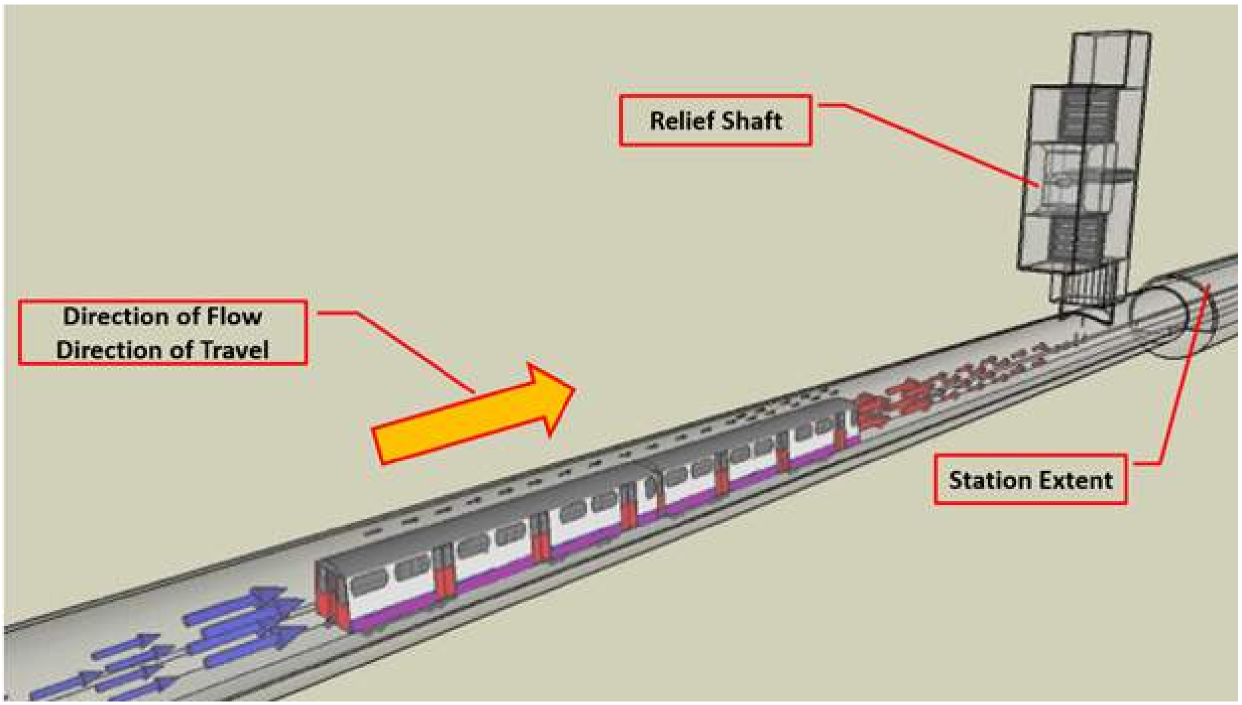

Figure D2: Piston Effects in a Train Tunnel

If a train is stopped between stations in the tunnel and the temperature within the tunnel rises above acceptable limits, the tunnel vent plants at each end operate in push-pull mode. This provides cooling air to prevent the train's air conditioning units from overheating and shutting off. While all locomotives in revenue service or routine operation in the NSRL tunnels are assumed to be electric, on occasions that diesel equipment uses the tunnels, the fans can also be used to purge diesel exhaust.

Fan plants can be located in a number of configurations, depending on various site conditions. If real-estate is available, the fan plants can be located above-grade, otherwise the generally more expensive option of providing space within the station box applies, as shown in Figure D5. The fans themselves can be mounted horizontally or vertically to suit the available space. A typical horizontal fan plant requires an approximate 75ft by 50ft space. In addition, there are associated electrical spaces to house the starters, transformers and controls for the fans.

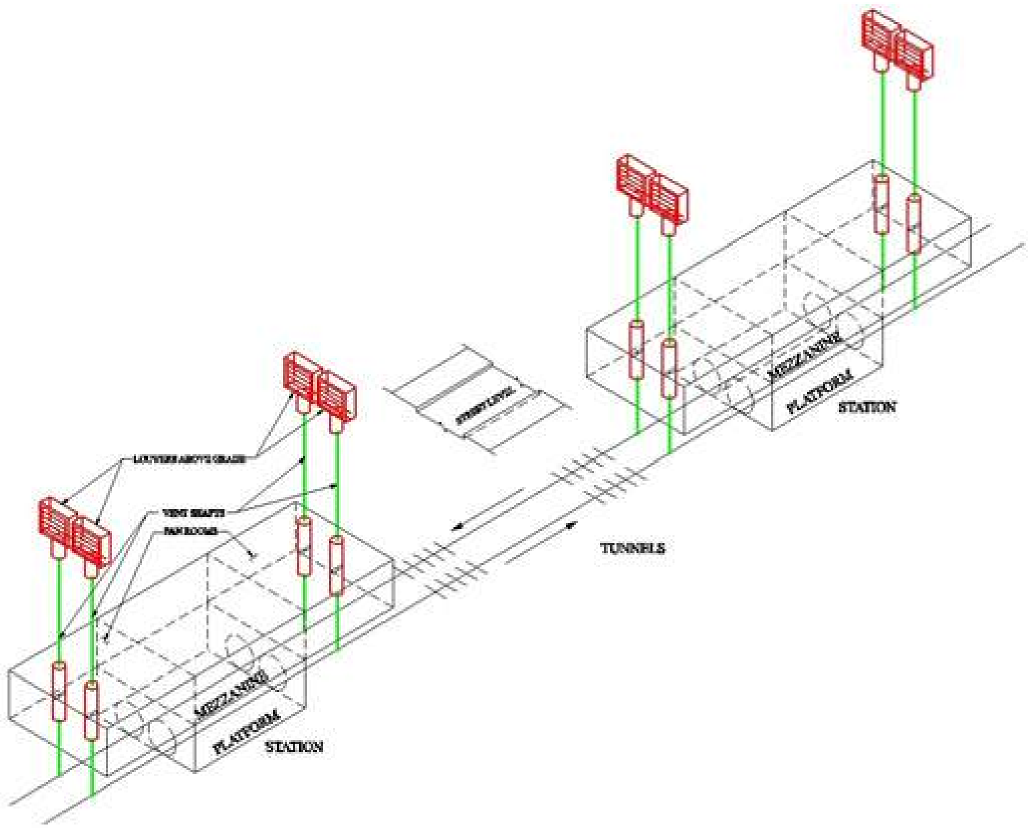

Figure D3: Integrate Tunnel-Station Ventilation Fan Plant

NFPA 130 requires two independent electrical power sources for each fan system for redundancy. Spare fan capacity is provided such that the required performance can be maintained with the most critical fan out of service. The fans are reversible axial type with associated sound attenuators. Dampers are provided to allow fans to be taken out of service as well as to allow the system to operate in the various modes. A Supervisory Control and Data Acquisition (SCADA) system is provided to control the fans, which are interfaced with the rail control center.

In order to facilitate effective ventilation for the tunnel sections between the portals and the adjacent stations, a fan plant or a set of jet fans is required. Similar to fans inside a vent building, jet fans can provide makeup or exhaust air into the tunnel to control the smoke spread. Jet fans are recommended for both the North and South portals due to lower costs than a vent building. However, at the South portal location, smoke exhausted by jet fans at the tunnel opening may pose an environmental and pollution issue due to the high building/occupant density in the adjacent area. Thus, at the South portal location, a vent building may be necessary.

The following maps show possible locations for the vent buildings, based on adjacency to stations, the availability of land, and the potential costs related to acquisition.

Figure D4: Possible Vent Building Locations at North / State/Haymarket Station

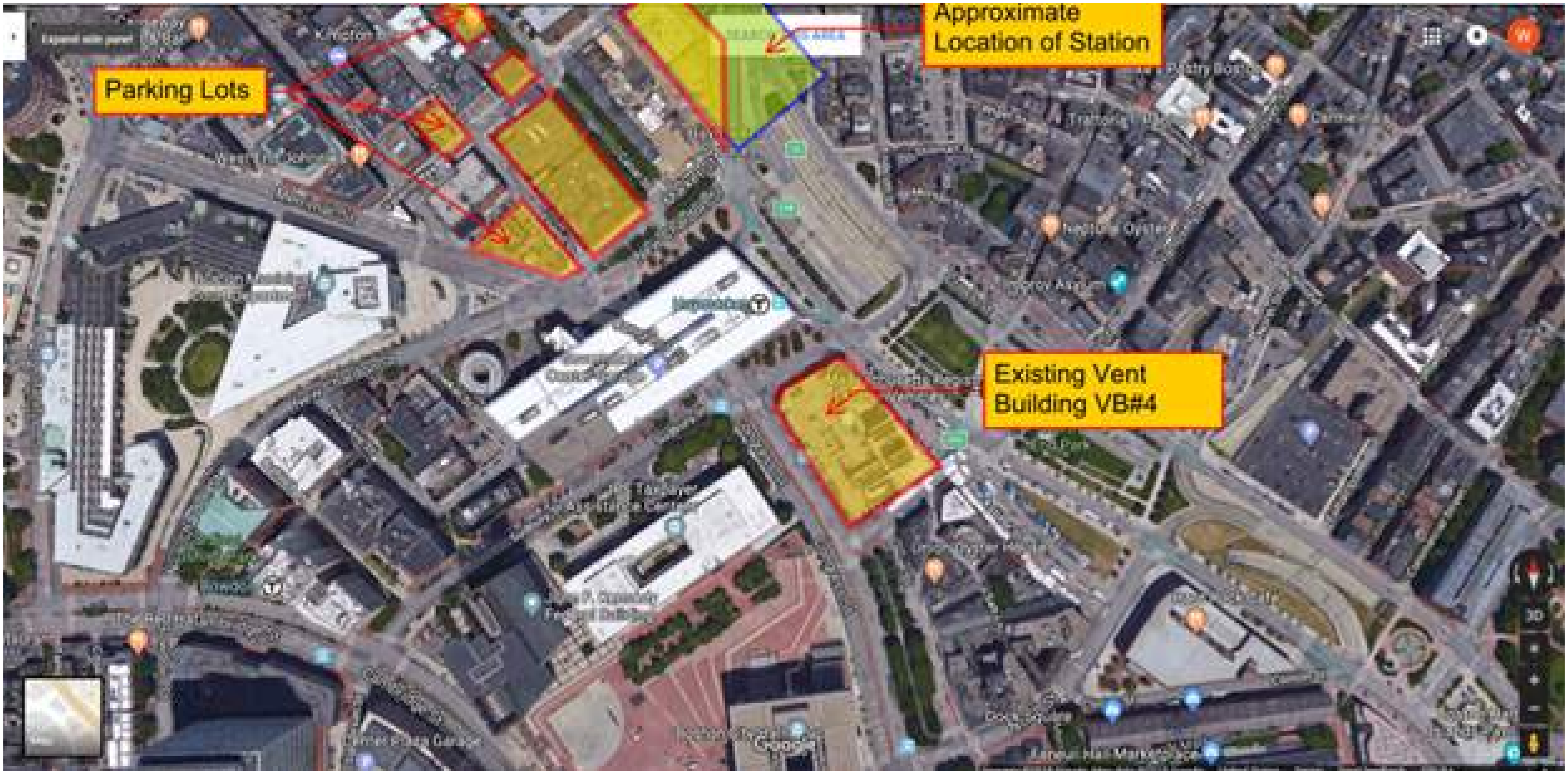

Figure D5: Possible Vent Building Locations at North / State/Haymarket Station (Cont.)

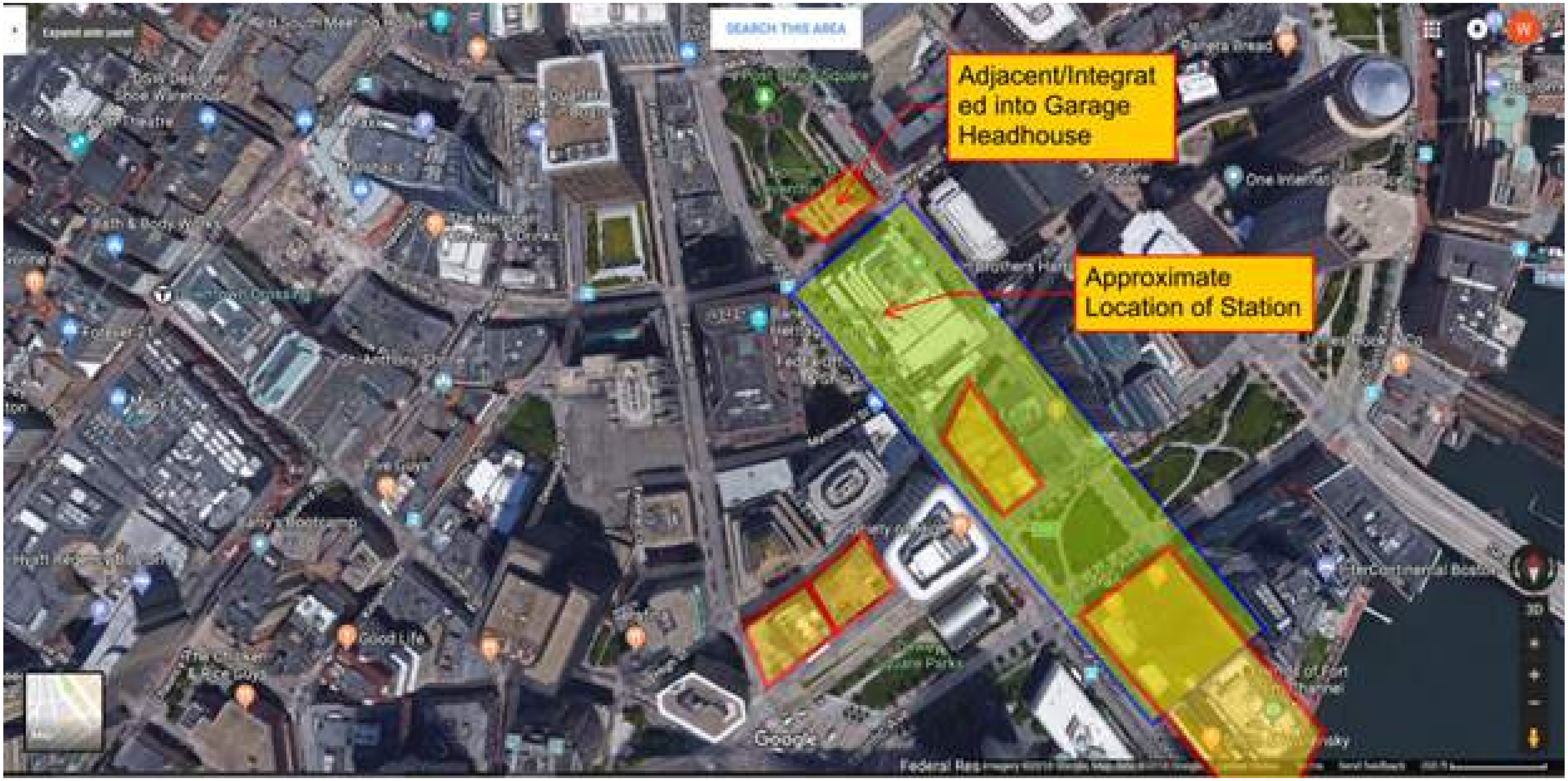

Figure D6: Possible Vent Building Locations at South Station Pearl/Congress Alignment

Figure D7: Possible Vent Building Locations at South Station Central Artery Two-Track Alignment

Figure D8: Possible Vent Building Locations at South Station Central Artery Two-Track Alignment (Cont.)

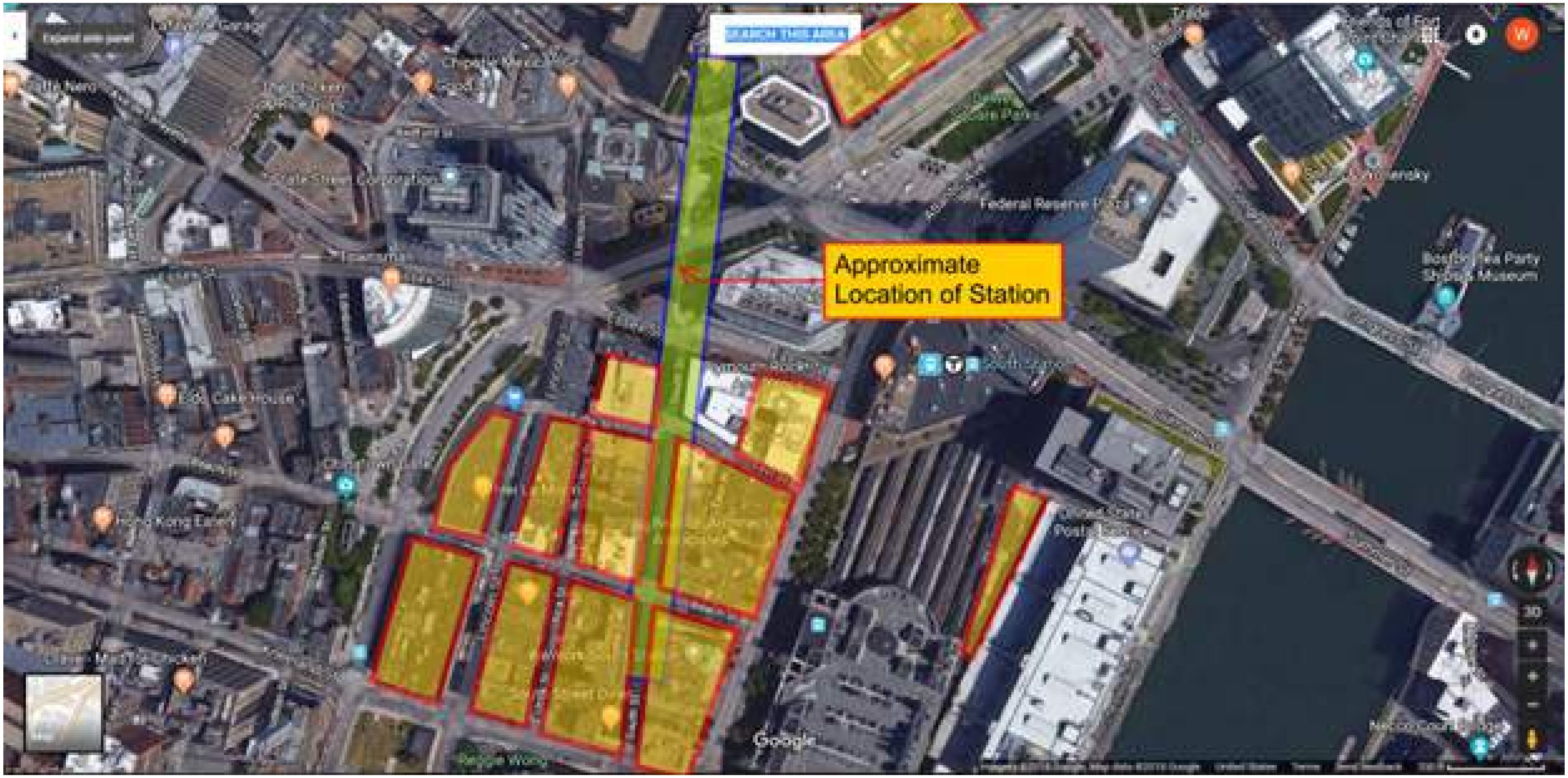

Figure D9: Possible Vent Building Locations at South Station South/Congress Alignment

Figure D10: Possible Vent Building Locations at North Portal

Figure D11: Possible Vent Building Locations at South Portal