CITY OF BOSTON
HAZMAT ROUTE EVALUATION

Report

Prepared for

City of Boston
Department of Transportation

By

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CHAPTER 1: INTRODUCTION

The Commonwealth of Massachusetts Department of Transportation (MassDOT) is the designated routing agency responsible for all Non-Radioactive Hazardous Materials (NRHM) routing designations and restrictions in the Commonwealth. The City of Boston established the hazardous material (hazmat) routing designations through Boston before the U.S. Department of Transportation/Federal Motor Carrier Safety Administration (USDOT/FMCSA) established their highway routing regulations (FMCSA 49 CFR Part 397) in the early 1990's; thus the City is the organization of record for designating hazmat highway routes within its boundaries. Since the construction of the depressed section of I-93, portions of the initially designated route no longer exist. To update the routing analysis and make it consistent with the USDOT regulations which now must be followed when establishing routes, the City of Boston retained Battelle Memorial Institute to perform a series of highway routing analyses that meet the requirements of 49 CFR Part 397. The major objective of the project is to provide the technical basis for a hazmat route risk assessment to identify routes through downtown Boston and proposed alternative routes that significantly reduce risk for purposes of evaluating enhancement of public safety, which is the primary consideration in the routing designation process. The risk analysis conducted in accordance with 49 CFR 397.71(b)(1)(i)-(ii), evaluates and characterizes approximately 20 routes, many just providing local routing alternatives for portions of the downtown route currently used as a through route.

The analyses performed by Battelle will become the basis for Boston's recommendations to MassDOT concerning a suitable route or routes for hazmat within the Greater Boston region and through downtown Boston. Once approved by MassDOT and formally designated in accordance with the procedures and requirements of 49 CFR Part 397, it is anticipated that MassDOT will provide the updated routing designation information to FMCSA so FMCSA can update its national hazmat route registry.

PROJECT AND TASK OBJECTIVES

The major objectives of this project are to conduct studies and analyses for the City of Boston so its leadership will be able to provide recommendations for MassDOT relating to prescribed NRHM routing designations though downtown Boston. In brief, the specific recommendations must meet the requirements outlined in the Non-Radioactive Hazardous Material Routing Guidelines specified in Part C of 49 CFR Part 397 (FMCSA). Paragraph 397.71(b) lists the Federal Standards that must be met by the routing analysis. The standards and where they are discussed in this document are:

(1) Enhancement of Safety – compliance by following the Routing Guidelines
(2) Public Participation – responsibility of the Commonwealth of Massachusetts
(3) Consultation with Others – City of Boston and Commonwealth of Massachusetts have already started this process and a formal public notice and notice to affected parties process, consistent with 49 CFR 397.71 requirements, will be undertaken as part of the proposed routing designation process
(4) Through Routing – evaluated in this report
(5) Agreement with other States – including Burden on Commerce – evaluated in this report

(6) Timeliness – to be completed within 18 months of the notice of a proposed routing designation made per 49 CFR 397.71(b)(2) and (3) – programmatic

(7) Reasonable Routes to Terminals and Other Facilities – evaluated in this report

(8) Responsibility for Local Compliance – delegated to Commonwealth of Massachusetts

(9) Other Factors to Consider – evaluated in this report

    i. Population Density
    ii. Type of Highway
    iii. Types and Quantities of Hazmat
    iv. Emergency Response Capabilities
    v. Results of Consultations with Affected Persons – (survey)
    vi. Exposure and Other Risk Factors – (hospitals, nursing homes)
    vii. Terrain Considerations
    viii. Continuity of Routes
    ix. Alternative Routes
    x. Effects on Commerce
    xi. Delays in Transportation
    xii. Climatic Conditions
    xiii. Congestion and Accident History

Using the federal criteria for Through Routing Analyses to ensure continuity of movement so as not to impede or unnecessarily delay the transportation of NRHM, the following results will be developed:

1. Which through routes should be recommended?
    a. Primarily, this would be based on an evaluation of risks to human populations and the environment. The risk assessment would also include an evaluation of emergency response capabilities.
    b. Secondarily, this would be based on consideration of other factors that reflect priorities or values that may influence a decision among routes that otherwise present similar risk, including potential burdens to commerce resulting from a particular route selection.
2. Should any restrictions be imposed on the recommended route or routes?

The analyses of these routes will be conducted in accordance with: FMCSA 49 CFR 397.71 (b) and the USDOT Federal Highway Administration's (FHWA) *Highway Routing of Hazardous Materials, Guidelines for Applying Criteria to Designate Routes for Transporting Hazardous Materials, Publication No. FHWA-HI-97-003* (FHWA 1996).

PROJECT TEAM

This project was conducted by the Battelle Memorial Institute. The principal investigators were Arthur Greenberg and Thomas McSweeney. The project manager was Arthur Greenberg.

CHAPTER 2: TECHNICAL APPROACH

The project has been divided into five major steps:

1. Obtain Accident Data and Truck Accident Rates on Selected Route Segments
2. Estimate Hazmat Commodity Flows
3. Obtain Population and Environmental Data along Selected Route Segments
4. Apply Through-Routing Methodology to Selected Routes to conduct risk assessment
5. Recommend Prescribed through hazmat routes along with any justified restrictions

The fifth step is the goal of the analysis; the other steps support the fifth by providing the essential information required to evaluate the difference in transport risk for the routes being considered in the analysis. The technical approach follows the steps outlined in the Routing Guide (FHWA 1996) prepared to fulfill the regulations in FMCSA 49 CFR Part 397, Subpart C.

SELECTION OF POTENTIAL ALTERNATIVE HAZMAT TRUCK ROUTES FOR EVALUATION

This section describes the process used to select the alternative hazmat truck routes for evaluation and consideration and briefly describes each of the routes.

Route Selection Process

The alternative routes were selected for evaluation and consideration through an iterative process that involved Boston officials from the Transportation, Fire and Police departments, MassDOT officials, Central Transportation Planning Staff (CTPS), and staff and members of the Massachusetts Motor Transportation Association (MMTA). After the alternative routes were identified for further evaluation, they were mapped by MassDOT in a Geographic Information System (GIS) format. Subsequently, the routes were driven by City transportation and MassDOT officials in order to judge whether the routes were suitable for hazmat truck traffic. Battelle project staff participated in this process. Based on the field reconnaissance, modifications to some of the routes were made. For example, based on Fire Department recommendations, the Congress Street route was modified to avoid a large parking garage and office building built in the air space directly over the road a short distance north of City Hall. In addition, the Battelle staff added a couple of routes with common starting and ending points in order to facilitate risk comparisons.

The Selected Alternative Routes for Risk Evaluation

The alternative routes selected by the process described above extend through the cities of Boston, Somerville, Everett, Cambridge and other cities, communities and towns transected by I-90, I-93, I-95 and the beltway often referred to as Route 128. Among the 20 routes, there is generally some overlap on the outermost north and south ends of the routes, with more variation in the middle segment of the routes, many of which run through downtown Boston. The alternative routes include major highways in the Boston area, extending around the 1-95 beltway and along I-90 through Boston, but exclude the eastern portion of I-90 after the Cambridge Exit and the depressed section of I-93 in Downtown Boston from which hazmat cargoes are prohibited by State law. The alternative routes also include such major roads as Massachusetts

Avenue, Cambridge Street, Charlestown Avenue/Gilmore Bridge, Rutherford Avenue, North Washington Street, Atlantic Avenue, and Frontage Road.

The types of bridges along these alternative routes were also examined because the limiting restrictions and quality of construction of the bridge will have an effect on the feasibility for transporting hazmat through Boston. Prospective routes are eliminated if the total roadway width is less than 10 feet, if the minimum vertical height underneath the bridge is less than 15 feet, or if the bridge has a width and/or clearance restriction, (FHWA 1995). Bridge condition is also an important consideration. The condition of the bridge is characterized by a number and any condition equal to or less than “5” is restricted as these bridge conditions may compromise the quality and safety of the bridge. The restricted bridges on these alternative routes fall between rating ranges of 3-5, indicating the bridges are still functional. A rating of “5” indicates a fair condition for the bridge in which it is structurally sound but may have minor construction flaws. A rating of “4” indicates a bridge in poor condition in which there are advanced flaws in the bridge’s construction. A rating of “3” indicates a bridge in serious condition in which the advanced flaws in the bridge’s construction have seriously affected the primary structure of the bridge and local failures are possible (FHWA 1995). Table B-1 in Appendix B shows data for the bridge conditions and key characteristics for the bridges found on the alternative routes.

The description of each alternative route included selected roadway characteristics. Data on the number of lanes, their widths and the presence of any shoulders were thought to be important for evaluating the potential safety of the roadway for large truck traffic. In general, the lanes on interstates are 12 feet wide and narrower on lesser road classes such as principal urban arterials. The 12 foot lane width can accommodate a higher average vehicle speed that can be accommodated on roads with narrower lanes. All of the roads listed for each of the alternative routes should have a large enough design width to accommodate hazmat trucks. There may be instances where the hazmat trucks may encounter some difficulties, but the roads should still be able to accommodate them. For instance, Western Avenue, Binney Street, and Galileo Galilei Way contain segments where the lane width is 10 feet; this is a tight fit for large trucks. Also the Cambridge to I-90 eastbound (EB) and westbound (WB) in Boston, Massachusetts route includes Pleasant Street which has a 10 foot lane width with parked vehicles. These parked vehicles may affect the turning radius as well as make the street narrower. A couple of other areas have only a ten foot lane width. These include the I-95N to I-93S Ramp north of Boston and I-93S to Mystic Avenue Ramps. Tables B-2 to B-19 show the basic road specifications obtained from MassDOT.

The following sections describe each of the alternative routes and include a description of the generally northbound and southbound route pairs as well as maps showing the location of the routes.

2.2.1A: Quincy to Everett NB (Route Alternative 1 – Through Boston)[RA1]

This route runs northbound (NB) through the City of Boston. The route begins on the southern part of I-93, runs north along I-93 and ends on MA-99 in Boston. Specifically, the route starts at Exit 9 on I-93 and continues as follows:

Start at Exit 9 on I-93

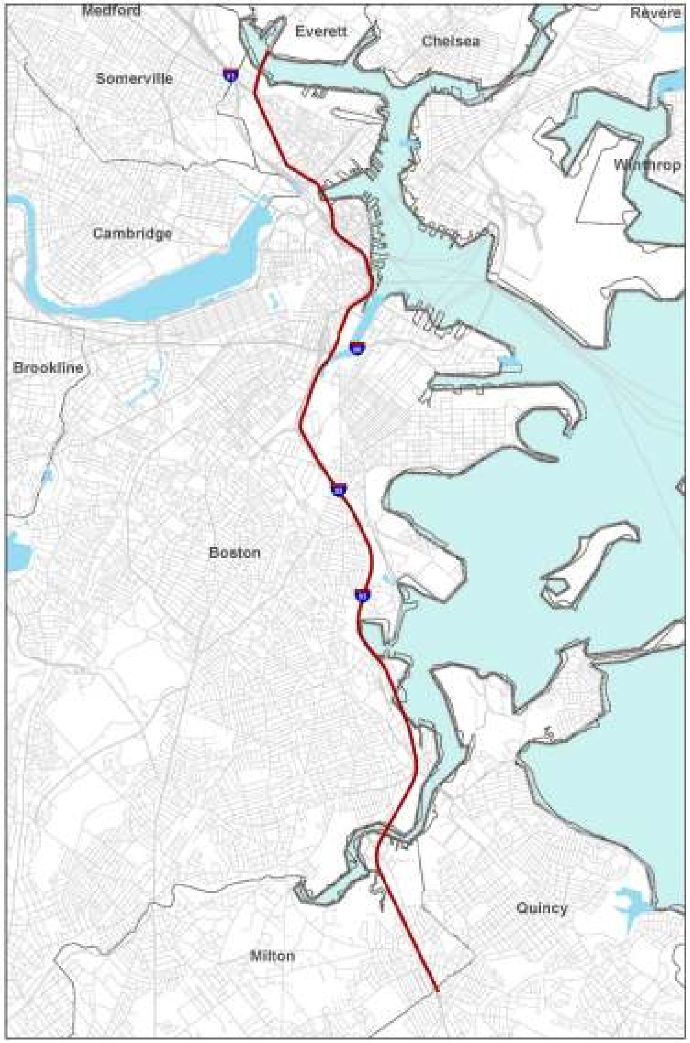
North on I-93
North on I-93 Frontage Road
Northeast on Atlantic Avenue
Northwest onto Cross Street
North on North Washington Street
Northwest on Rutherford Avenue
Northeast on Alford Street/MA-99
End on Alford Street/MA-99 Bridge just before Everett

2.2.1B: Everett to Quincy SB (Route Alternative 1 – Through Boston) [RA1]

This route runs southbound (SB) through the City of Boston. The route begins on MA-99, runs south through Boston and ends on the southern part of I-93. Specifically, the route starts on the Alford Street/MA-99 Bridge just before Everett and continues as follows:

Start at the Alford Street Bridge/MA-99 just before Everett
Southwest on Alford Street/MA-99
Southeast on Rutherford Avenue
South on North Washington Street
Southwest onto John F. Fitzgerald Surface Road
South on Purchase Street
South on Surface Road
South on Albany Street
South on I-93 Frontage Road
South on I-93
End on I-93 at Exit 9

Note that the northbound route ends at the Alford Street Bridge/MA-99 just before entering Everett and the southbound route begins at the same point, just before starting over the Alford Street Bridge/MA-99. This starting/end point was selected because so much of the fuel used in Boston is distributed from terminals that use the Alford Street Bridge/MA-99 as a route from the terminals. This point was selected in preference to the ramp on I-93 where southbound hazmat traffic has to Exit I-93 to avoid the depressed section of I-93 and the entrance ramp where northbound hazmat traffic can once again travel on I-93.



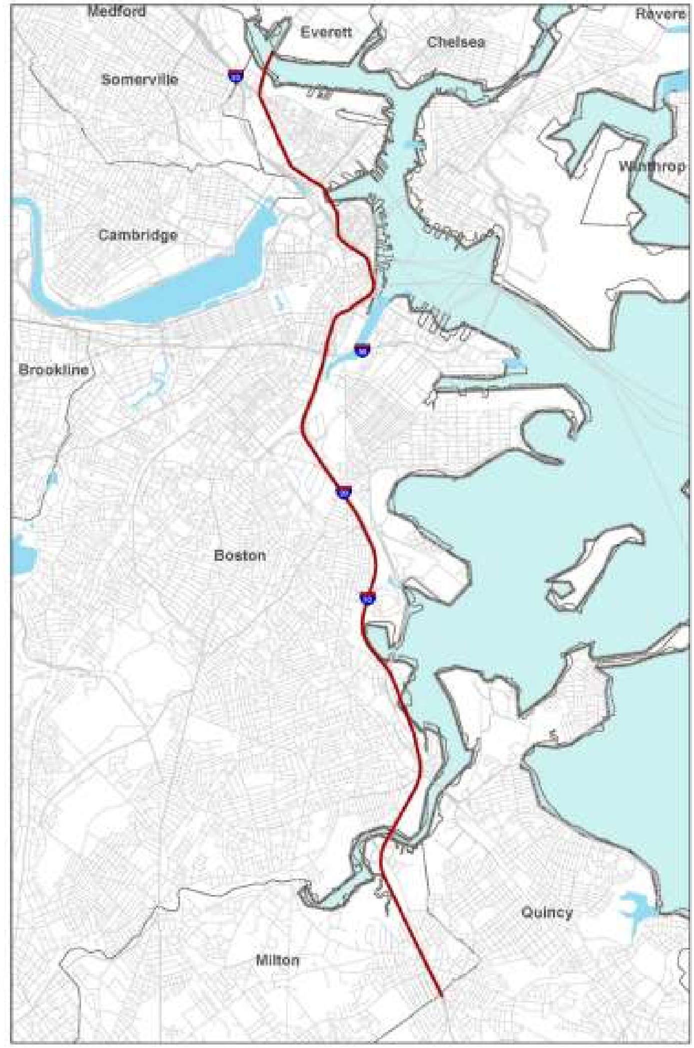


Figure 1: Map of 2.2.1A, Quincy to Everett NB (Route Alternative 1 – Through Boston) and 2.2.1B, Everett to Quincy SB (Route Alternative 1 – Through Boston) [RA1] in Boston, Massachusetts

2.2.2A: Quincy to Everett NB (Route Alternative 2 – Through Cambridge) [RA2]

This route runs northbound through the cities of Canton, Westwood, Dedham, Needham, Wellesley, Newton, Weston, Boston, Cambridge, Somerville, Milton, Quincy, and Braintree. The route begins at the southern portion on I-93, runs northeast along I-95 and I-90, and ends on MA-99 in Boston. Specifically, the route starts at Exit 9 on I-93 and continues as follows:

Start on I-93 at Exit 9
South on I-93 to I-95N Ramp
North on I-95 to I-90 access ramp (Exit 15)
East on I-90
Exit I-90 towards Cambridge Street
Continue east onto River Street
Southeast on Massachusetts Avenue/State Highway 2A
North on Sidney Street
East on Main Street
North on Galileo Galilei Way
Continue east on Binney Street
Northeast on Edwin H. Land Boulevard
Continue northeast onto Austin Street/Charlestown Avenue to Rutherford Avenue
Northwest on Rutherford Avenue
Northeast on Alford Street/MA-99
End on Alford Street/MA-99 Bridge just before Everett

2.2.2B: Everett to Quincy SB (Route Alternative 2 – Through Cambridge) [RA2]

This route runs southbound through the cities of Canton, Westwood, Dedham, Needham, Wellesley, Newton, Weston, Boston, Cambridge, Somerville, Milton, Quincy, and Braintree. The route begins on MA-99, runs southwest on I-90 and I-95 and ends on the southern part of I-93. Specifically, the route starts on the Alford Street/MA-99 Bridge just before Everett and continues as follows:

Start on Alford Street/MA-99 Bridge just before Everett
Southwest on Alford Street/MA-99
Southeast on Rutherford Avenue
Southwest on Austin Street/Charlestown Avenue
Continue southwest onto Edwin H. Land Boulevard
West on Binney Street
Continue south on Galileo Galilei Way
West on Main Street
South on Sidney Street
Northwest on Massachusetts Avenue/State Highway 2A
Southwest on Pleasant Street
West on Western Avenue
North on Soldiers Field Road
South on Allston Toll Plaza access road
Southwest on I-90 to the I-95S ramp (Exit 15)
South on I-95 to the I-93N ramp
North on I-93
End on I-93 at Exit 9

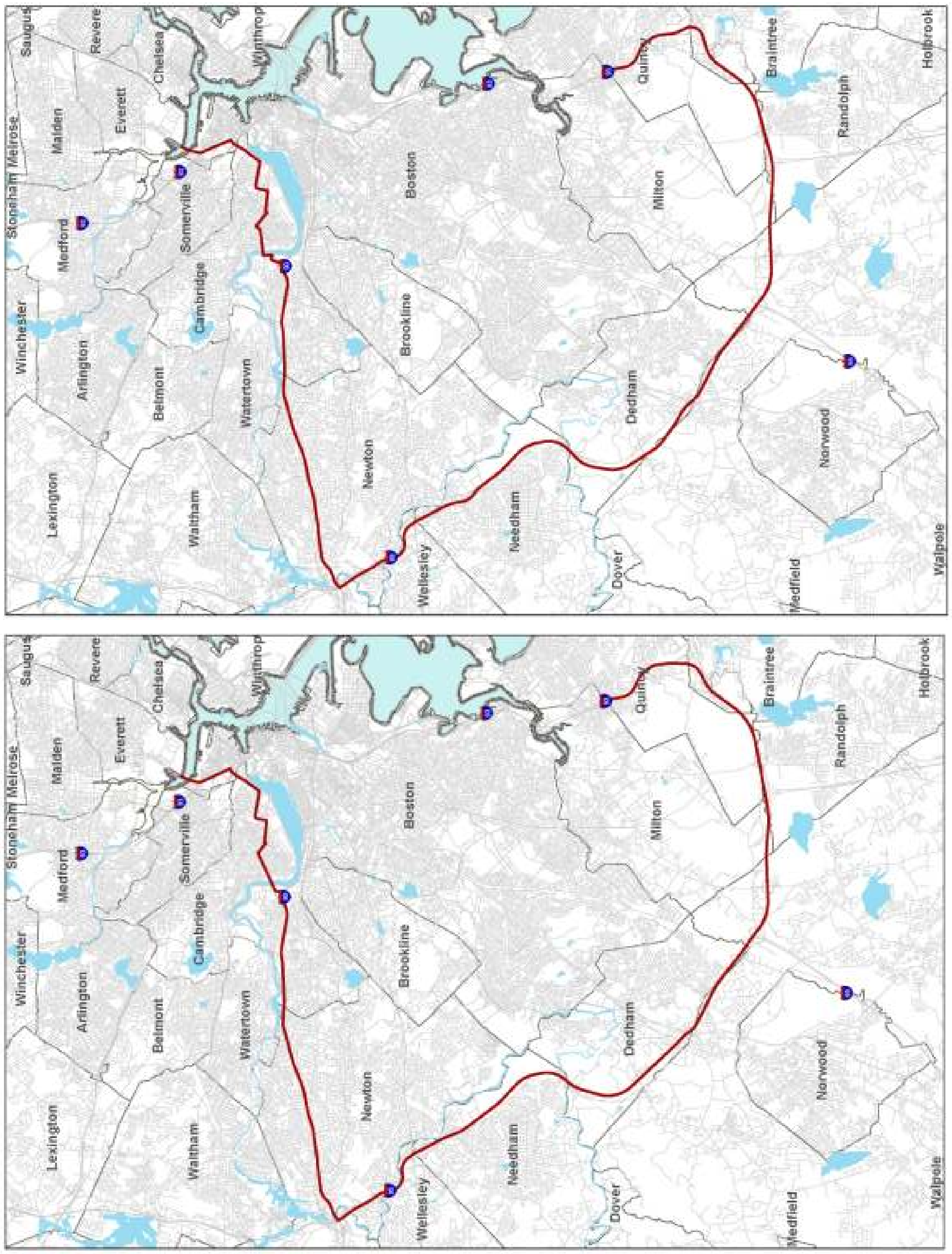


Figure 2: Map of 2.2.2A, Quincy to Everett NB (Route Alternative 2 –Through Cambridge) and 2.2.2B, Everett to Quincy SB (Route Alternative 2 –Through Cambridge) [RA2] in Boston, Massachusetts

2.2.3A: Quincy to Everett NB (Route Alternative 3 – I-93S to I-95N to I-93S Beltway Route) [RA3]

This beltway route runs northbound through the cities of Boston, Milton, Quincy, Braintree, Randolph, Canton, Dedham, Needham, Wellesley, Newton, Weston, Waltham, Lexington, Burlington, Woburn, Stoneham, Medford, and Somerville. The route begins at the southern part of I-93, extends along the I-95 belt, continues along the northern part of I-93, and ends at MA-99 in Boston. Specifically, the route starts at Exit 9 on I-93 and continues as follows:

Start on I-93 at Exit 9
South on I-93 to I-95N access ramp
North on I-95 to I-93S access ramp
South on the I-93 to MA-38 ramp
South on MA-38
South on Maffa way to Rutherford Avenue
Northwest on Rutherford Ave to Alford Street
Northeast on Alford Street/MA-99
End on Alford Street/MA-99 Bridge before Everett

2.2.3B: Everett to Quincy SB (Route Alternative 3 – I-93N to I-95S to I-93N Beltway Route) [RA3]

This beltway route runs southbound through the cities of Somerville, Medford, Stoneham, Woburn, Burlington, Lexington, Waltham, Weston, Newton, Wellesley, Needham, Dedham, Canton, Randolph, Braintree, Quincy, Milton, and Boston. The route begins on MA-99 in Boston, continues along the northern part of I-93, extends along the I-95 belt, and ends at the southern part of I-93 in Boston. Specifically, the route starts on MA-99 Bridge before Everett and continues as follows:

Start on Alford Street/MA-99 Bridge just before Everett
Southwest on Alford Street/MA-99
Northwest onto Main Street to Mystic Avenue/MA-38
North on the Mystic Avenue to I-93 ramp
North on the I-93 to I-95S ramp
South on I-95 to I-93N ramp
North on I-93
End on I-93 at Exit 9

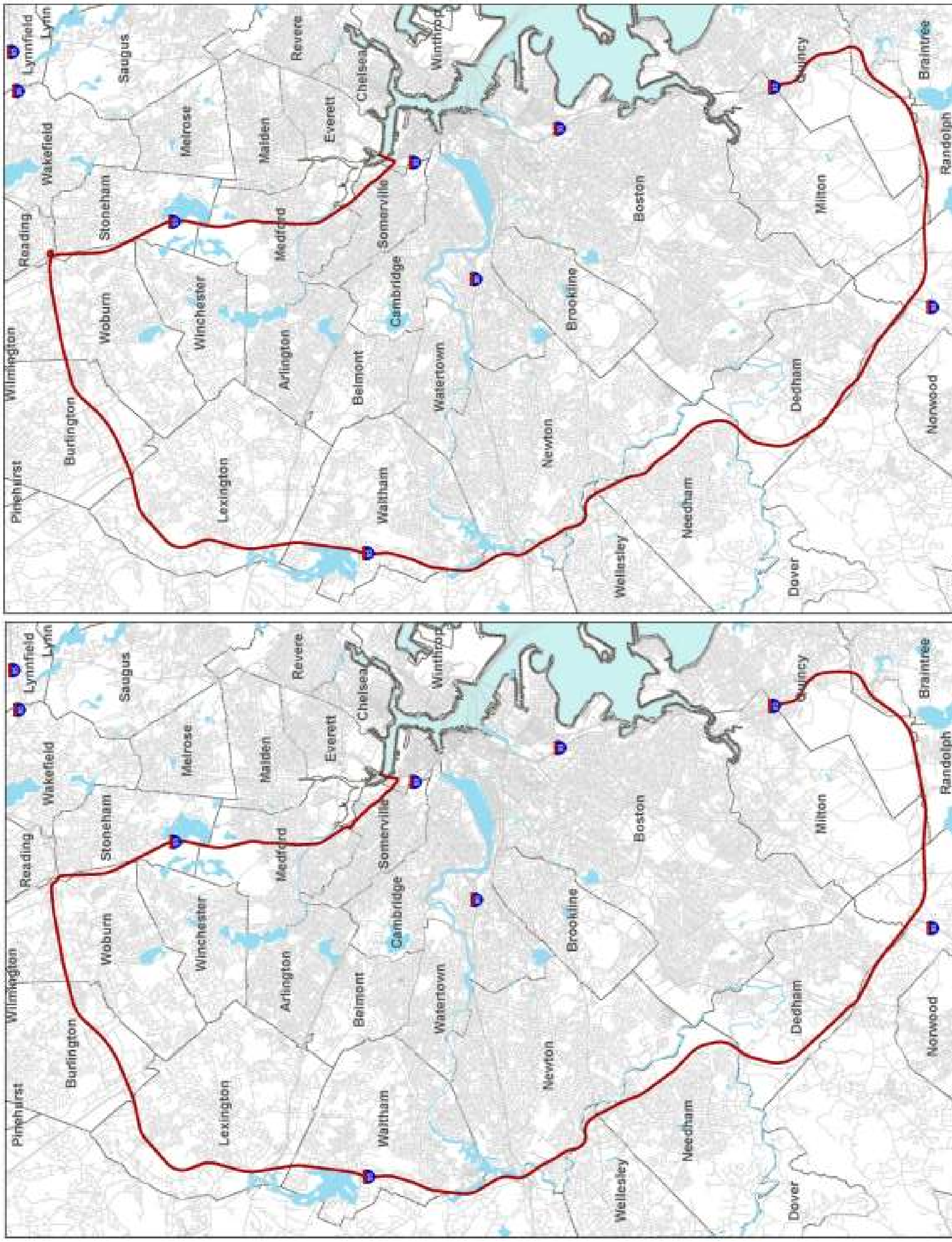


Figure 3: Map of 2.2.3A, Quincy to Everett NB (Route Alternative 3-I-93S to I-95N to I-93S Beltway Route) and 2.2.3B, Everett to Quincy SB (Route Alternative 3-I-93N to I-95S to I-93N Beltway Route) [RA3] in Boston, Massachusetts

2.2.4A: I-95 Exit 12 to Everett NB (Route Alternative 4 – Through Boston) [RA4]

This route runs northbound through the cities of Canton, Milton, Randolph, Braintree, Quincy, and Boston. The route begins at the southern intersection of I-95 and I-93, runs north along I-93 and ends on MA-99 in Boston. Specifically, the route starts at Exit 12 on I-95 and continues as follows:

Start on I-95 at Exit 12 (Start of I-93)
North on I-93 to Exit 18
North on I-93 Frontage Road
Northeast on Atlantic Avenue
Northwest on Cross St
North on North Washington Street
Northwest on Rutherford Avenue
Northeast on Alford Street/MA-99
End on Alford Street/MA-99 Bridge just before Everett

2.2.4B: Everett to I-95 Exit 12 SB (Route Alternative 4 – Through Boston) [RA4]

This route runs southbound through the cities of Canton, Milton, Braintree, Quincy, and Boston. The route begins on MA-99, and runs south along I-93 and ends on the southern part of I-95. Specifically, the route starts on the Alford Street/MA-99 Bridge just before Everett and continues as follows:

Start on Alford Street/MA-99 Bridge just before Everett
Southwest on Alford Street/MA-99
Southeast on Rutherford Avenue
Continue on Rutherford Avenue
South on North Washington Street
Southeast onto John F. Fitzgerald Surface Road
Southwest on Purchase Street
Southwest on Surface Road
South on Albany Street
South on I-93 Frontage Road
South on I-93
End on I-95 at Exit 12 (End of I-93)

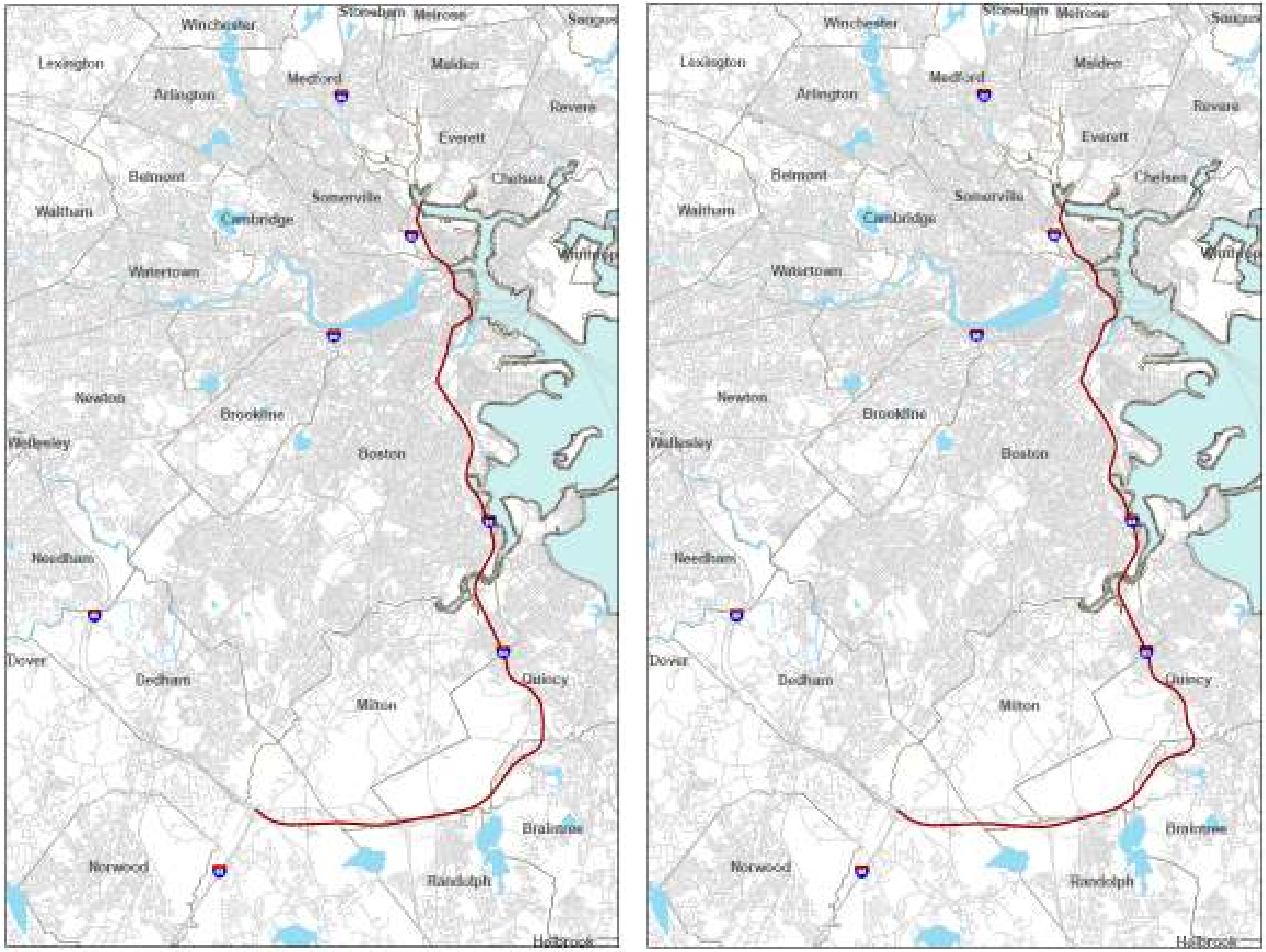


Figure 4: Map of 2.2.4A, I-95 Exit 12 to Everett NB (Route Alternative 4 – Through Boston) and 2.2.4B, Everett to I-95 Exit 12 SB (Route Alternative 4 – Through Boston) [RA4] in Boston, Massachusetts

2.2.5A: I-95 Exit 12 to Everett NB (Route Alternative 5 – Through Cambridge) [RA5]

This route runs northbound through the cities of Canton, Westwood, Dedham, Needham, Wellesley, Newton, Weston, Boston, Cambridge, and Somerville. The route begins at the southern intersection of I-95 and I-93, runs north along I-95 and I-90 and ends on MA-99 in Boston. Specifically, the route starts at Exit 12 on I-95 and continues as follows:

Start on I-95 at Exit 12
North on I-95 to I-90E ramp
East on I-90 to Cambridge Street Exit (Exit 18)
Continue east onto River Street
Southeast on Massachusetts Avenue/State Highway 2A
North on Sidney Street
East on Main Street
North on Galileo Galilei Way
Continue east on Binney Street
Northeast on Edwin H. Land Boulevard
Continue northeast onto Austin Street/Charlestown Avenue to Rutherford Avenue
Northwest on Rutherford Avenue/MA-99
Northeast on Alford Street/MA-99
End on Alford Street/MA-99 Bridge just before Everett

2.2.5B: Everett to I-95 Exit 12 SB (Route Alternative 5 – Through Cambridge) [RA5]

This route runs southbound through the cities of Canton, Westwood, Dedham, Needham, Wellesley, Newton, Weston, Boston, Cambridge, and Somerville. The route begins on MA-99, and runs west through Boston and Cambridge to I-90 and ends on the southern part of I-95. Specifically, the route starts on the Alford Street/MA-99 Bridge just before Everett and continues as follows:

Start on Alford Street/MA-99 Bridge just before Everett
Southeast on Rutherford Avenue
Southwest on Austin Street/Charlestown Avenue
Continue southwest onto Edwin H. Land Boulevard
West on Binney Street
Continue south on Galileo Galilei Way
West on Main Street
South on Sidney Street
Northwest on Massachusetts Avenue/State Highway 2A
Southwest on Pleasant Street
West on Western Avenue
South on Soldiers Field Road
South on Allston Toll Plaza access road to I-90
West on I-90 to I-95S ramp
South on I-95
End on I-95 at Exit 12

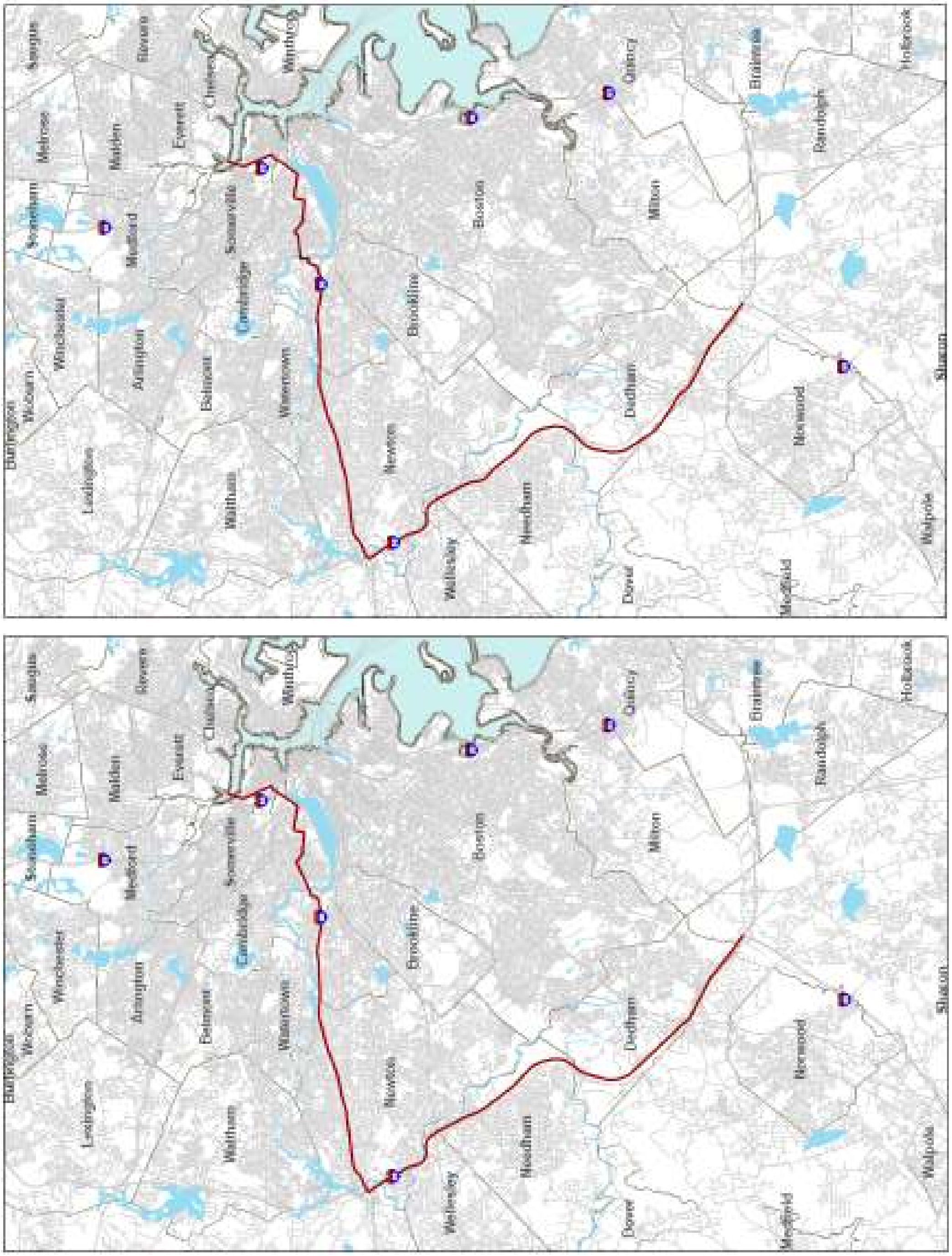


Figure 5: Map of 2.2.5A, I-95 Exit 12 to Everett NB (Route Alternative 5 – Through Cambridge) and 2.2.5B, Everett to I-95 Exit 12 SB (Route Alternative 5 – Through Cambridge) [RA5] in Boston, Massachusetts

2.2.6A: I-95 Exit 12 to Everett NB (Route Alternative 6 – I-95N to I-93S) [RA6]

This route runs northbound through the cities of Canton, Westwood, Dedham, Needham, Wellesley, Newton, Weston, Waltham, Lexington, Burlington, Woburn, Stoneham, Medford, Somerville, and Boston. The route begins at the southern intersection of I-95 and I-93, runs north along I-95 and ends on MA-99 in Boston. Specifically, the route starts at Exit 12 on I-95 and continues as follows:

Start on I-95 at Exit 12
North on I-95 to I-93 ramp
South on the I-93 to Mystic Avenue ramp
Southeast on Mystic Avenue/MA-38
Northeast on Rutherford Avenue/MA-99
Northeast on Alford Street/MA-99
End on Alford Street/MA-99 Bridge before Everett

2.2.6B: Everett to I-95 Exit 12 SB (Route Alternative 6 – I-95N to I-93S) [RA6]

This route runs southbound through the cities of Canton, Westwood, Dedham, Needham, Wellesley, Newton, Weston, Waltham, Lexington, Burlington, Woburn, Stoneham, Medford, Somerville, and Boston. The route begins on MA-99, and runs north along I-93 and ends on the southern part of I-95. Specifically, the route starts on Alford Street/MA-99 Bridge just before Everett and continues as follows:

Start on Alford Street/MA-99 Bridge just before Everett
Southwest on Alford Street/MA-99
Northwest onto Main Street to Mystic Avenue/MA-38
North on the Mystic Avenue to I-93 ramp
Continue north on I-93
North on the I-93 to I-95S ramp
South on I-95
End on I-95 at Exit 12

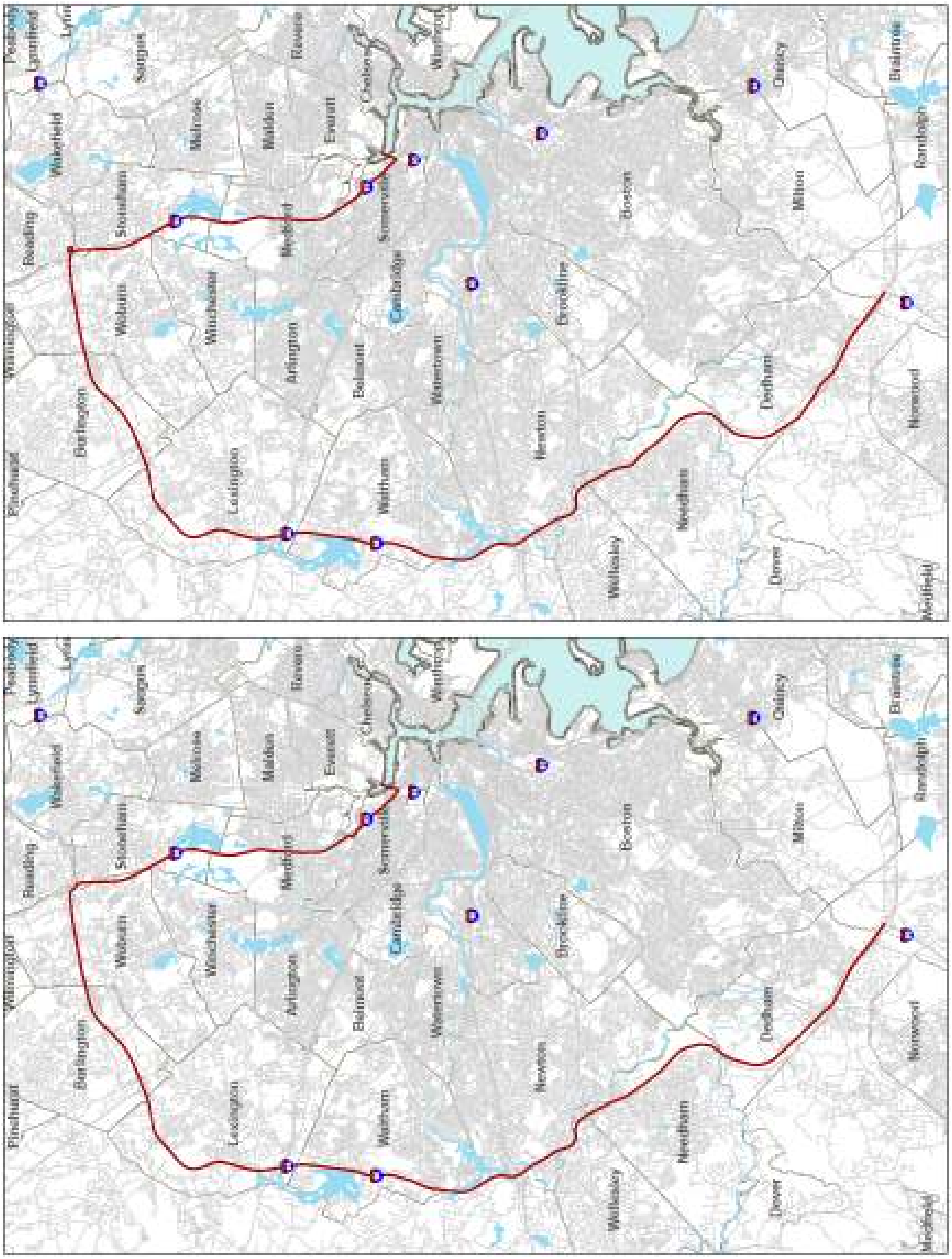


Figure 6: Map of 2.2.6A, I-95 Exit 12 to Everett NB (Route Alternative 6-I-95N to I-93S) and 2.2.6B, Everett to I-95 Exit 12 SB (Route Alternative 6-I-95N to I-93S) [RA6] in Boston, Massachusetts

2.2.7A: Cambridge to I-90 EB (Route Alternative 7) [RA7]

This route runs eastward through the cities of Boston, Cambridge, Somerville, and Everett in Massachusetts. The route extends east from I-90 W in Cambridge and runs north along MA-99 in Boston and MA-38 in Somerville. Specifically, the route starts at Exit 18 on I-90 W and continues as follows:

Northeast on I-90 E towards Cambridge Street
Northeast on Allston Toll Plaza access road
Continue east onto River Street
Southeast on Massachusetts Avenue/State Highway 2A
North on Sidney Street
East on Main Street
North on Galileo Galilei Way
Continue east on Binney Street
Northeast on Edwin H. Land Boulevard
Continue northeast onto Austin Street/Charlestown Avenue to Rutherford Avenue
Northwest on Rutherford Avenue/MA-99

At Rutherford Avenue, there are two destination points. The two routes continue from the above directions as follows:

Destination 1:
Northeast on Alford Street/MA-99
End on Alford Street/MA-99 Bridge just before Everett

Destination 2:
Northeast on Rutherford Avenue
North on Sullivan Square
West on Sullivan Square
Northwest onto Main Street to Mystic Avenue/MA-38
End on MA-38 at I-93 Exit 29

2.2.7B: Cambridge to I-90 WB (Route Alternative 7) [RA7]

This route runs westward through the cities of Boston, Cambridge, and Somerville in Massachusetts. The route runs south from MA-38 in Somerville and MA-99 in Boston and extends west to I-90 W through Boston into Cambridge. Specifically, the route begins at two origin points and is described as follows:

Origin 1:
Start on Alford Street/MA-99 Bridge just before Everett
Southwest on Alford Street/MA-99 until Rutherford Avenue

Origin 2:
Start at MA-38 at Exit 29
South on Maffa Way/MA-38 to Sullivan Square Southeast onto Rutherford Avenue/MA-99

At New Rutherford Avenue, the route continues from either of the above origins and is described as follows:

Southeast on Rutherford Avenue
Southwest on Austin Street/Charlestown Avenue
Continue southwest onto Edwin H. Land Boulevard
West on Binney Street
Continue south on Galileo Galilei Way
West on Main Street
South on Sidney Street
Northwest on Massachusetts Avenue/State Highway 2A
Southwest on Pleasant Street
West on Western Avenue
South on Soldiers Field Road
South on Allston Toll Plaza
Southwest on I-90 W at Exit 18

This route is the only route alternative that has a unique end/starting point at Exit 18 on I-90. As a result of this unique start/end point, this route cannot be used in any assessment prepared to fulfill the *through routing* federal standard specified in [49 CFR 397(b)(4)]. To be used in a *through routing* assessment, the routes being compared must have the same starting and ending point.

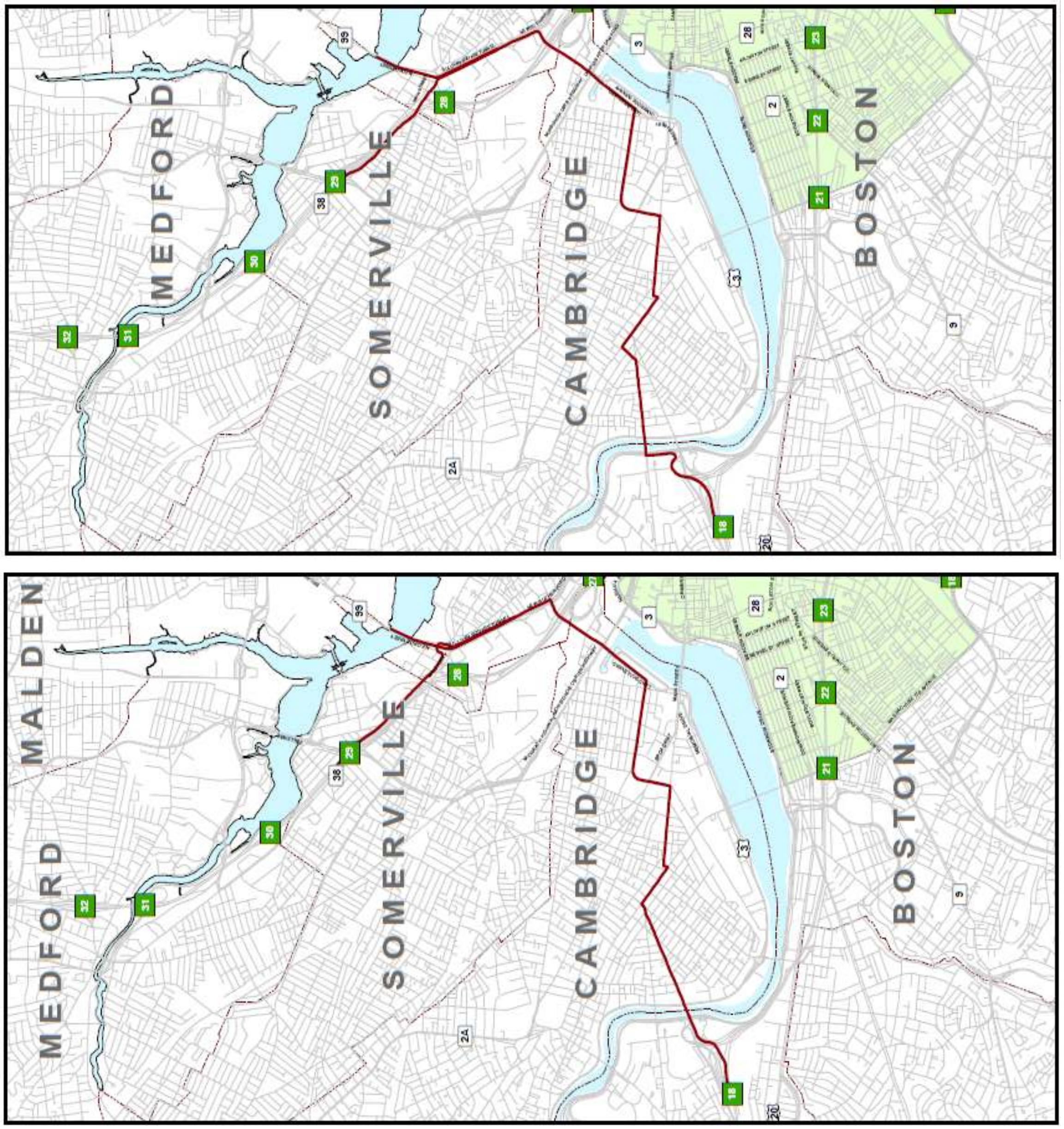


Figure 7: Map of 2.2.7A, Cambridge to I-90 EB and 2.2.7B, Cambridge to I-90 WB, (Route Alternative 7) [RA7] in Boston, Massachusetts

2.2.8A: Cross/North Washington NB (Route Alternative 8) [RA8]

This route runs northward through the cities of Boston and Somerville in Massachusetts. The route runs north along Cross Street and North Washington Street to MA-99 in Boston and MA-38 in Somerville. Specifically, the route starts on I-93 Frontage Road at Exit 16 and continues as follows:

Start on I-93 at Exit 16
North on I-93 Frontage Road
Continue north onto Atlantic Avenue
Continue northwest onto Cross Street
North on North Washington Street
East on Causeway Street
Northwest on North Washington Street
Continue northwest onto Rutherford Avenue

At Rutherford Avenue, there are two destination points. The two routes continue from the above directions as follows:

Destination 1: (used when comparing alternative routing)
Northeast on Alford Street/MA-99
End on Alford Street/MA-99 Bridge just before Everett

Destination 2:
Northwest on Rutherford Avenue
North on Sullivan Square
West on Sullivan Square
Northwest onto Main Street to Mystic Avenue/MA-38
End on MA-38 at Exit 29

2.2.8B: Surface Road/North Washington SB (Route Alternative 8) [RA8]

This route runs southward through the cities of Boston and Somerville in Massachusetts. The route runs south from MA-38 in Somerville and MA-99 in Boston and continues south along North Washington Street and Surface Road through Boston. Specifically, the route has two origin points and is described as follows:

Origin 1: (used when comparing alternative routing)
Start on Alford Street/MA-99 Bridge just before Everett
Southwest on Alford Street until Rutherford Avenue

Origin 2:
Start at MA-38 at Exit 29
Southeast on Maffa Way/MA-38 to Sullivan Square
Southeast on Rutherford Avenue/MA-99

At Rutherford Avenue, the route continues from either of the above origins and is described as follows:

Southeast on Rutherford Avenue
South on North Washington Street
Southeast on John F. Fitzgerald Surface Road
Continue southwest onto Purchase Street
Continue southwest onto Surface Road
Southwest onto Albany Street
End on Albany Street at Randolph Street intersection

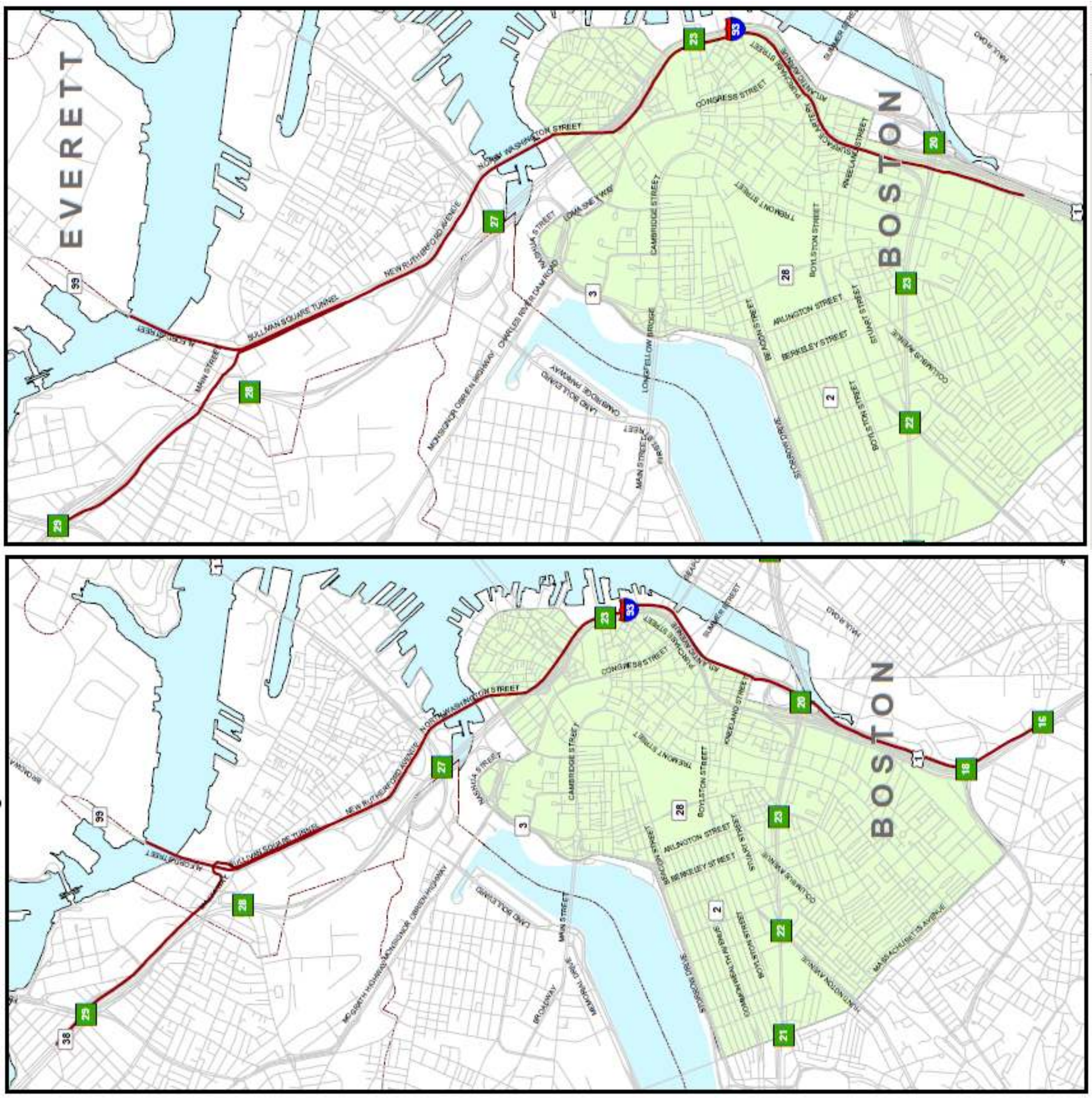


Figure 8: Map of 2.2.8A,Cross/North Washington NB and 2.2.8B, Surface Road/North Washington SB (Route Alternative 8) [RA8] in Boston, Massachusetts

2.2.9A: Commercial/North Washington NB (Route Alternative 9) [RA9]

This route runs northward through the cities of Boston and Somerville in Massachusetts. The route runs north along Atlantic Avenue and Commercial Street to MA-99 in Boston and MA-38 in Somerville. Specifically, the route starts on I-93 Frontage Road at Exit 16 and continues as follows:

Start on I-93 at Exit 16
North on I-93 Frontage Road
Continue north onto Atlantic Avenue
Northeast onto Commercial Street
Northwest on North Washington Street
Continue northwest onto Rutherford Avenue

At Rutherford Avenue, there are two destination points. The two routes continue from the above directions as follows:

Destination 1: (used when comparing alternative routing)
Northeast on Alford Street/MA-99
End on Alford Street/MA-99 Bridge just before Everett

Destination 2:
Northwest on Rutherford Avenue
North on Sullivan Square
West on Sullivan Square
Northwest onto Main Street to Mystic Avenue/MA-38
End on MA-38 at Exit 29

2.2.9B: Commercial/North Washington SB (Route Alternative 9) [RA9]

This route runs southward through the cities of Boston and Somerville in Massachusetts. The route runs south from MA-38 in Somerville and MA-99 in Boston and continues south along Commercial Street and Surface Road/Purchase Street through Boston. Specifically, the route has two origin points and is described as follows:

Origin 1: (used when comparing alternative routing)
Start at Alford Street/MA-99 Bridge just before Everett
Southwest on Alford Street until Rutherford Avenue

Origin 2:
Start at MA-38 at Exit 29, intersecting with MA-28
Southeast on Maffa Way/MA-38 to Sullivan Square
Southeast on Rutherford Avenue

At Rutherford Avenue, the route continues from either of the above origins and is described as follows:

Southeast on Rutherford Avenue
Northeast on Commercial Street
Southeast on John F. Fitzgerald Surface Road
Southwest on Purchase Street
Southwest on Surface Road
South on Albany Street
End on Albany Street at Randolph Street intersection

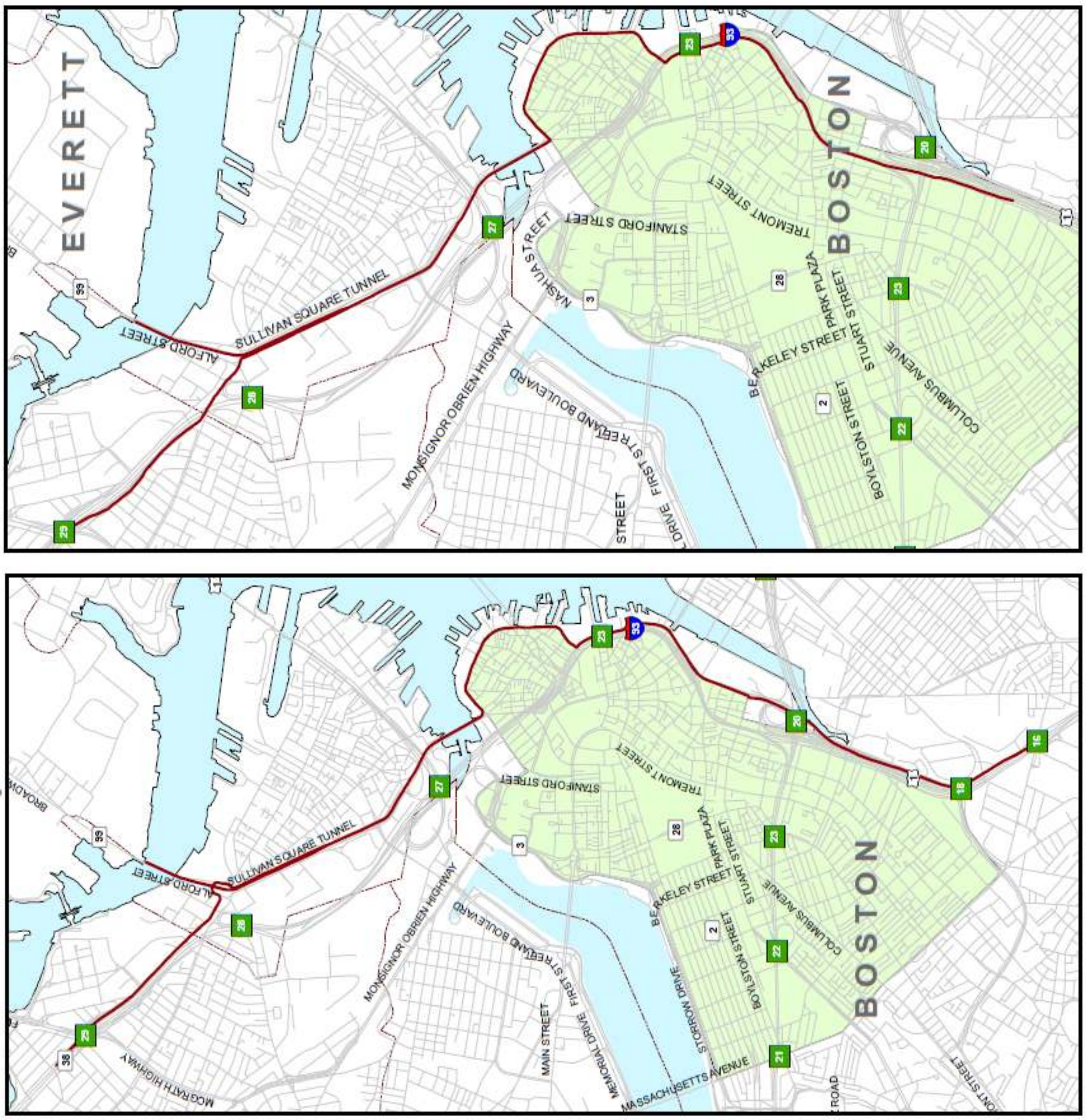


Figure 9: Map of 2.2.9A, Commercial/North Washington NB and 2.2.9B, Commercial/North Washington SB (Route Alternative 9) [RA9] in Boston, Massachusetts

2.2.10A: Land Boulevard/Mass Avenue NB (Route Alternative 10) [RA10]

This route runs northward through the cities of Boston, Cambridge and Somerville in Massachusetts. The route runs north from I-93 in Boston and detours north through Boston and Cambridge along Massachusetts Avenue and Edwin H. Land Boulevard until it meets up with MA-38 in Somerville and MA-99 in Boston. Specifically, the route starts on I-93 Frontage Road at Exit 16 and continues as follows:

Start on I-93 at Exit 16
North on I-93 Frontage Road
West on Massachusetts Avenue Connector
Continue northwest onto Melnea Cass Boulevard
Northeast on Washington Street
Northwest on Massachusetts Avenue
North on Sidney Street
East on Main Street
North on Galileo Galilei Way
East on Binney Street
Northeast on Edwin H. Land Boulevard
Northwest on Rutherford Avenue

At Rutherford Avenue, there are two destination points. The two routes continue from the above directions as follows:

Destination 1: (used when comparing alternative routing)
Northeast on Alford Street/MA-99
End on Alford Street/MA-99 Bridge just before Everett

Destination 2:
Northwest on New Rutherford Avenue
North on Sullivan Square
West on Sullivan Square
Northwest onto Main Street to Mystic Avenue/MA-38
End on MA-38 at Exit 29

2.2.10B: Land Boulevard/Mass Avenue SB (Route Alternative 10) [RA10]

This route runs southward through the cities of Boston, Cambridge and Somerville in Massachusetts. The route runs south from MA-38 in Somerville and MA-99 in Boston and detours south through Cambridge and Boston along Edwin H. Land Boulevard and Massachusetts Avenue. Specifically, the route has two origin points and is described as follows:

Origin 1: (used when comparing alternative routing)
Start at Alford Street/MA-99 Bridge just before Everett
Southwest on Alford Street until New Rutherford Avenue

Origin 2:
Start at MA-38 at Exit 29
Southeast on Maffa Way/MA-38 to Sullivan Square Southeast on Rutherford Avenue/MA-99

At Rutherford Avenue, the route continues from either of the above origins and is described as follows:

Southwest on Rutherford Avenue
Southeast on Edwin H. Land Boulevard
West on Binney Street
South on Galileo Galilei Way
West on Main Street
South on Sidney Street
Southwest on Massachusetts Avenue
Southwest on Washington Street
Continue southeast onto Melnea Cass Boulevard
East on Massachusetts Avenue Connector
South on I-93 Frontage Road
End on I-93 Frontage Road at Boston Road intersection

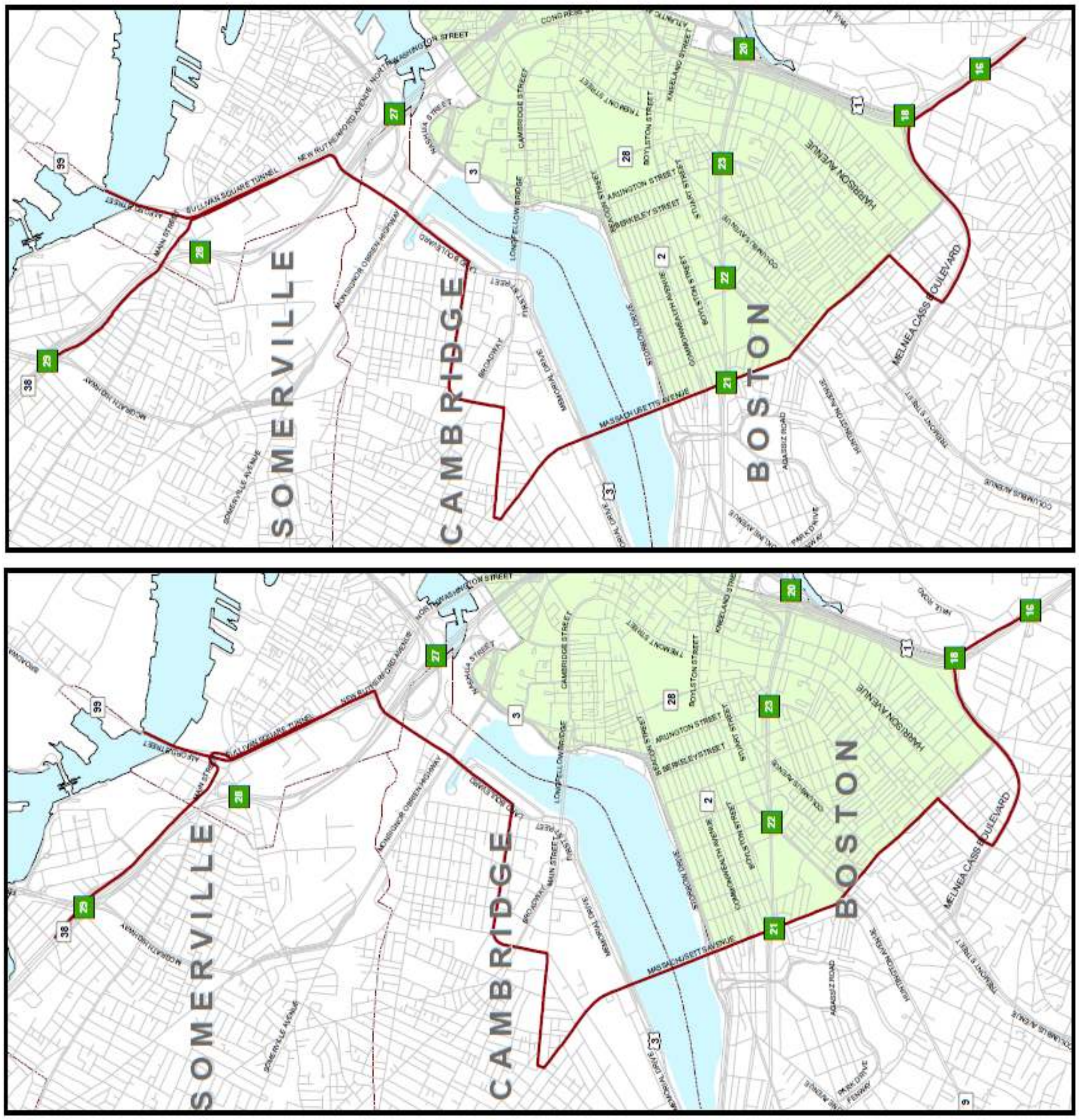


Figure 10: Map of 2.2.10A, Land Boulevard/Mass Avenue NB and 2.2.10B, Land Boulevard/Mass Avenue SB (Route Alternative 10) [RA10] in Boston, Massachusetts

2.2.11A: Congress/North Washington NB (Route Alternative 11) [RA11]

This route runs northward through the cities of Boston and Somerville in Massachusetts. The route runs north through Boston along Congress Street and North Washington Street until it meets up with MA-38 in Somerville and MA-99 in Boston. Specifically, the route starts on I-93 and continues as follows:

Start on I-93 at Exit 16 – Frontage Road Exit
North on I-93 Frontage Road
Continue north onto Atlantic Avenue
Northwest on Pearl Street
North on Congress Street
East on New Sudbury Street
Northwest on Cross Street
North on North Washington Street
Northwest on Rutherford Avenue

At Rutherford Avenue, there are two destination points. The two routes continue from the above directions as follows:

Destination 1: (used when comparing alternative routing)
Northeast on Alford Street/MA-99
End on Alford Street/MA-99 Bridge just before Everett

Destination 2:
Northwest on Rutherford Avenue
North on Sullivan Square
West on Sullivan Square
Northwest onto Main Street to Mystic Avenue/MA-38
End on MA-38 at Exit 29

2.2.11B: North Washington/Congress SB (Route Alternative 11) [RA11]

This route runs southward through the cities of Boston and Somerville in Massachusetts. The route runs south from MA-38 in Somerville and MA-99 in Boston and detours south through Boston along North Washington Street and Congress Street to I-93. Specifically, the route has two origin points and is described as follows:

Origin 1: (Used when comparing alternative routing)
Start at Alford Street/MA-99 Bridge just before Everett
Southwest on Alford Street to New Rutherford Avenue

Origin 2:
Start at MA-38 at Exit 29
Southeast on Maffa Way/MA-38 to Sullivan Square
Southeast on New Rutherford Avenue

At New Rutherford Avenue, the route continues from either of the above origins and is described as follows:

- Southeast on New Rutherford Avenue
- South on North Washington Street
- Southwest on Causeway Street
- South on Staniford Street
- East on Cambridge Street
- Northeast on New Sudbury Street
- Southeast on Congress Street
- Southwest on Purchase Street
- Continue southwest on Surface Road
- South on Albany Street
- South on I-93 Frontage Road
- End on I-93 Frontage Road at Boston Street intersection

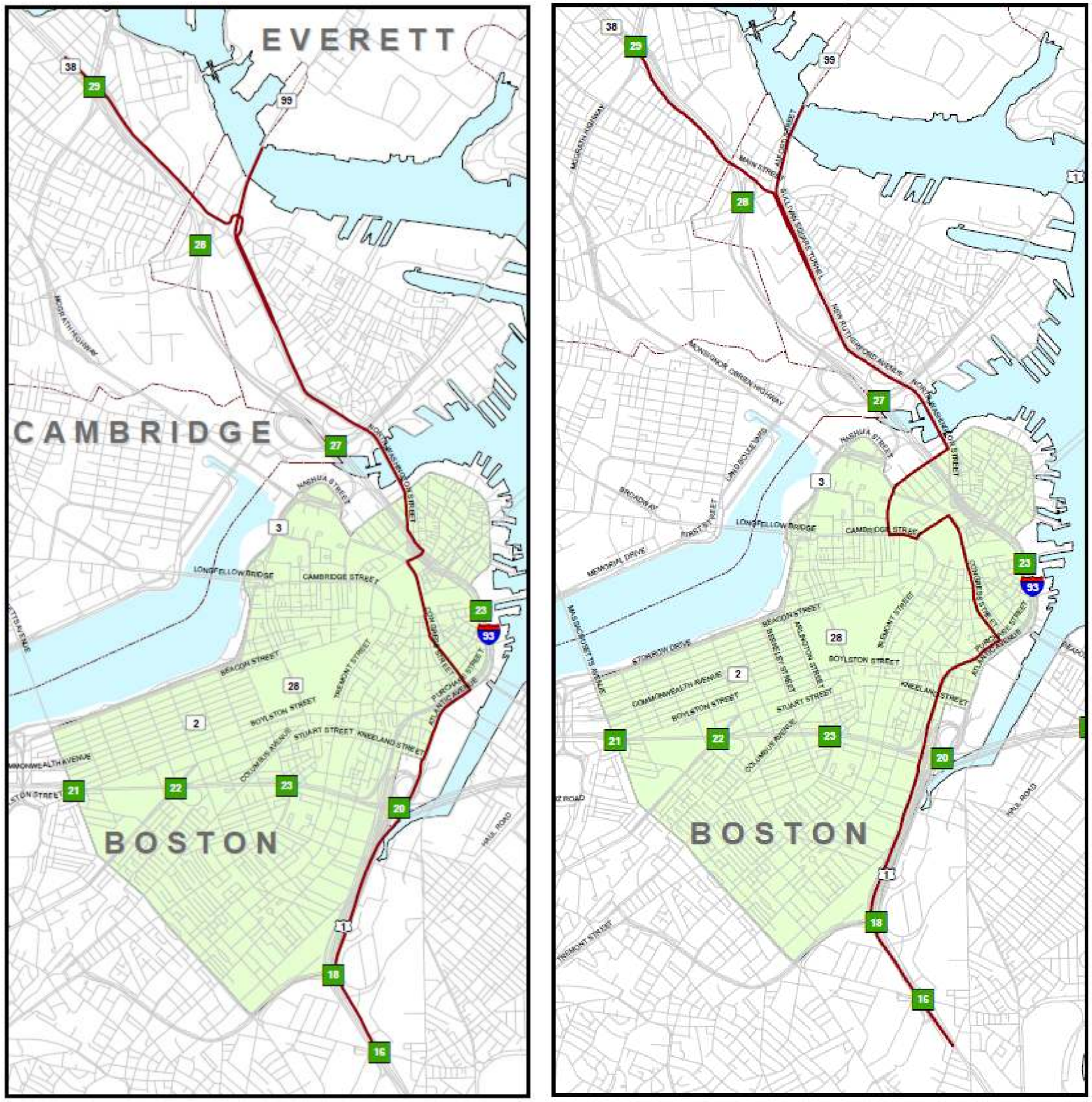


Figure 11: Map of 2.2.11A, Congress/North Washington NB and 2.2.11B, North Washington/Congress SB (Route Alternative 11) [RA11] in Boston, Massachusetts

2.2.12: Haul Road/Congress/North Washington NB (Route Alternative 12) [RA12]

This route runs northward through the cities of Boston and Somerville in Massachusetts. The route runs north through Boston along Haul Road, Congress Street, and North Washington Street until it meets up with MA-38 in Somerville and MA-99 in Boston. Specifically, the route starts on I-93 and continues as follows:

Start on I-93 at Exit 16 – Frontage Road Exit
North on I-93 Frontage Road
Northeast on Haul Road/South Boston Bypass Road
Northeast on West Service Road
Northwest on Congress Street
North on Atlantic Avenue
Northwest on Pearl Street
North on Congress Street
East on New Sudbury Street
Northwest on Cross Street
North on North Washington Street
Northwest on Rutherford Avenue

At Rutherford Avenue, there are two destination points. The two routes continue from the above directions as follows:

Destination 1: (Used when comparing alternative routing)
Northeast on Alford Street/MA-99
End on Alford Street/MA-99 Bridge just before Everett

Destination 2:
Northwest on Rutherford Avenue
North on Sullivan Square
West on Sullivan Square
Northwest onto Main Street to Mystic Avenue/MA-38
End on MA-38 at Exit 29

Figure 12: Map of 2.2.12, Haul Road/Congress/North Washington NB (Route Alternative 12) [RA12] in Boston, Massachusetts

2.2.13A: Haul Road/Cambridge/Lomasney NB (Route Alternative 13) [RA13]

This route runs northward through the cities of Boston, Cambridge and Somerville in Massachusetts. The route runs north through Boston and Cambridge along Haul Road, Cambridge Street and Lomasney Way until it meets up with MA-38 in Somerville and MA-99 in Boston. Specifically, the route starts on I-93 and continues as follows:

Start on I-93 at Exit 16 – Frontage Road Exit
North on I-93 Frontage Road
Northeast on Haul Road/South Boston Bypass Road
Northeast on West Service Road
Northwest on Congress Street
North on Atlantic Avenue
West on State Street/Court Street
Continue northwest on Cambridge Street
North on Staniford Street
North on Lomasney Way/Nashua Street

At Lomasney Way, there are two destination points. The two routes continue from the above directions as follows:

Destination 1:
East on Leverett Connector
End on Exit 28

Destination 2: (Used when comparing alternative routing)
Northwest on Monsignor O'Brien Highway
East on Charlestown Avenue/Austin Street
Northwest on Rutherford Avenue
Northeast on Alford Street/MA-99
End on Alford Street/MA-99 Bridge just before Everett

2.2.13B: Lomasney/Congress/Purchase SB (Route Alternative 13) [RA13]

This route runs southward through the cities of Boston, Somerville and Cambridge in Massachusetts. The route runs south from MA-38 and MA-99 in Boston and detours south through Boston along Lomasney Way, Congress Street and Purchase Street. Specifically, the route has two origin points and is described as follows:

Origin 1:
Start on Exit 28
South on Leverett Connector
North on Nashua Street
Southeast on Lomasney Way/Cotting Street

Origin 2: (Used when comparing alternative routing)
Start on Alford Street/MA-99 bridge just before Everett
Southwest on Alford Street/MA-99
Continue southeast on New Rutherford Avenue
West on Edwin H. Land Boulevard

Southeast on Monsignor O’Brien Highway
Southeast on Lomasney Way/Cotting Street

At Lomasney Way, the route continues from either of the above origins and is described as follows:

East on Merrimac Street
East on New Chardon Street
Southeast on John F. Fitzgerald Surface Road
Continue southwest on Purchase Street
Continue southwest on Surface Road
South on Albany Street
End on Albany Street near Thayer Street

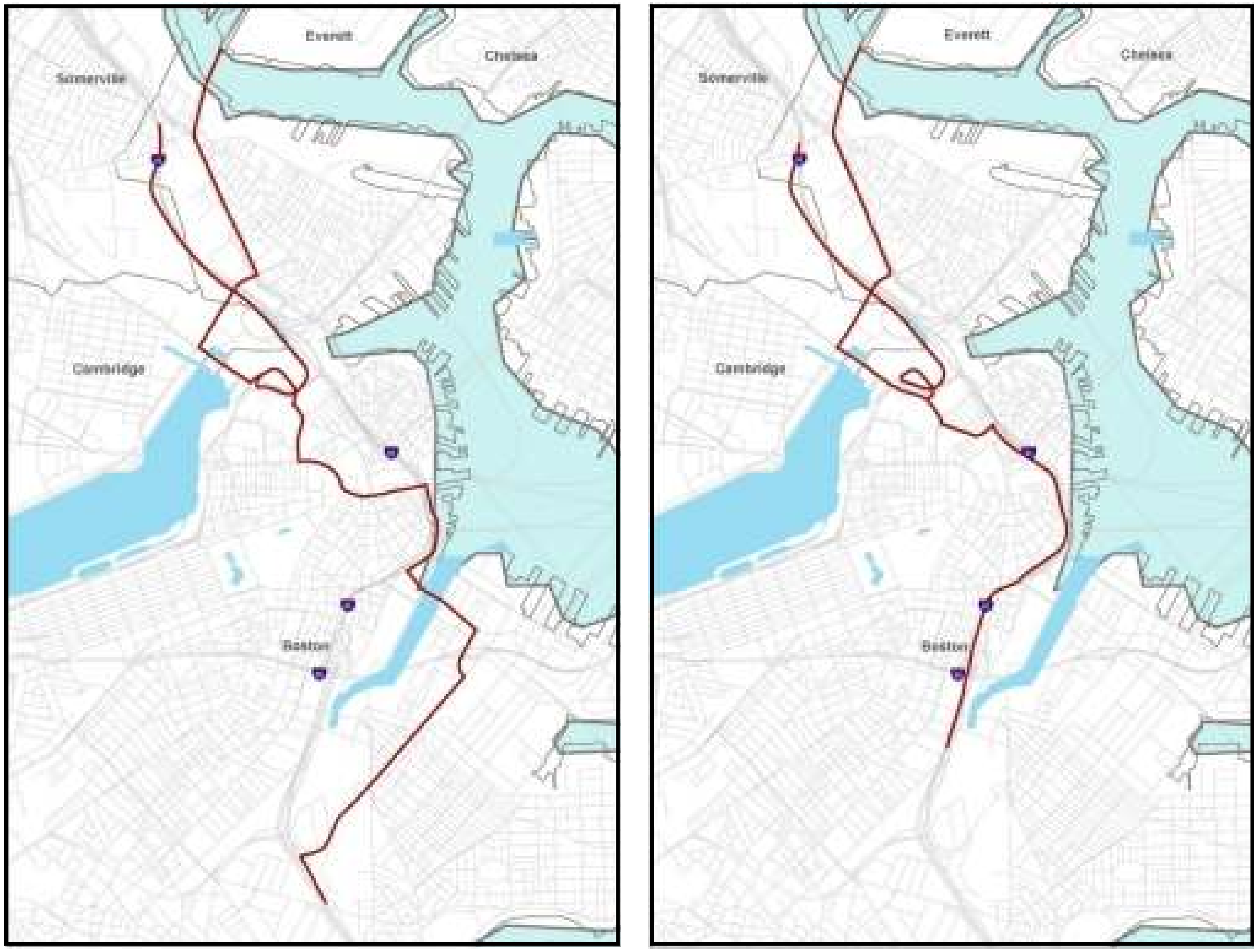


Figure 13: Map of 2.2.13A, Haul Road/Cambridge/Lomasney NB and Map of 2.2.13B, Lomasney/Congress/Purchase SB (Route Alternative 13) [RA13] in Boston, Massachusetts

2.2.14A: Haul/Cross/North Washington NB (Route Alternative 14) [RA14]

This route runs northward through the cities of Boston and Somerville in Massachusetts. The route runs north through Boston along Haul Road, Cross Street and North Washington Street until it meets up with MA-38 in Somerville and MA-99 in Boston. Specifically, the route starts on I-93 and continues as follows:

Start on I-93 at Exit 16 – Frontage Road Exit
North on I-93 Frontage Road
Northeast on Haul Road/South Boston Bypass Road
Northeast on West Service Road
Northwest on Seaport Boulevard
North on Atlantic Avenue
Northwest on Cross Street
North on North Washington Street
Northwest on Rutherford Avenue

At Rutherford Avenue, there are two destination points. The two routes continue from the above directions as follows:

Destination 1: (Used when comparing alternative routing)
Northeast on Alford Street/MA-99
End Alford Street/MA-99 Bridge just before Everett

Destination 2:
North on Sullivan Square
West on Sullivan Square
Northwest onto Main Street to Mystic Avenue/MA-38
End on MA-38 at Exit 29

2.2.14B: Lomasney/Congress/Haul SB (Route Alternative 14) [RA14]

This route runs southward through the cities of Boston, Somerville and Cambridge in Massachusetts. The route runs south from MA-38 and MA-99 in Boston and detours south through Boston along Lomasney Way, Congress Street and Haul Road. Specifically, the route has two origin points and is described as follows:

Origin 1:
Start at Exit 28
South on Leverett Connector
North on Nashua Street
Southeast on Lomasney Way/Cotting Street

Origin 2: (Used when comparing alternative routing)
Start on Alford Street/MA-99 bridge just before Everett
Southwest on Alford Street/MA-99
Continue southeast on Rutherford Avenue
West on Austin Street/Charlestown Avenue
Southeast on Monsignor Obrien Highway
Southeast on Lomasney Way/Cotting Street

At Lomasney Way, the route continues from either of the above origins and is described as follows:

South on Staniford Street
East on Cambridge Street
Northeast on New Sudbury Street
Southeast on Congress Street
Southwest on West Service Road
Southwest on Haul Road/South Boston Bypass Road
South on I-93 Frontage Road
End on I-93 Frontage Road at Exit 16

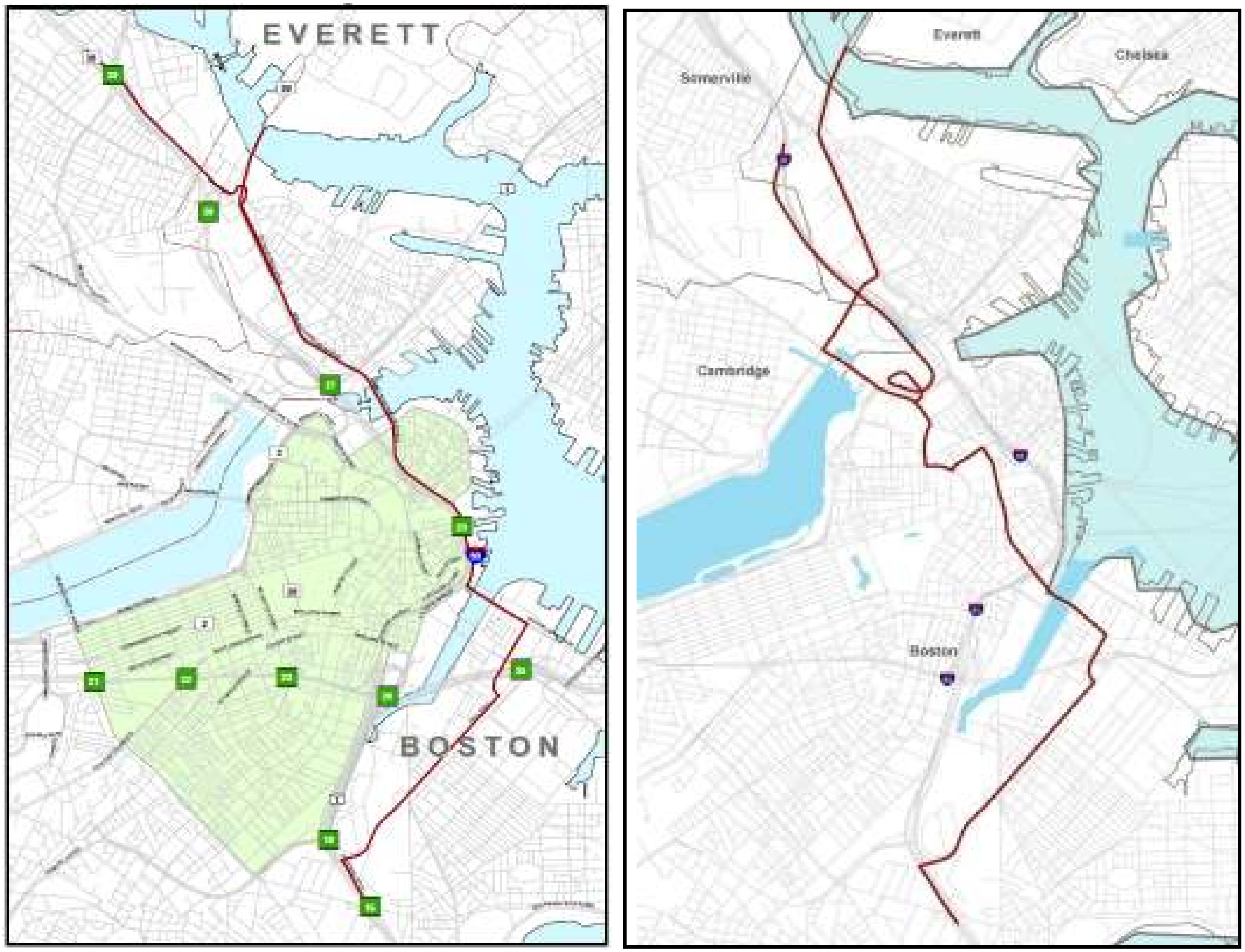


Figure 14: Map of 2.2.14A, Haul/Cross/North Washington NB and 2.2.14B, Lomasney/Congress/Haul SB (Route Alternative 14) [RA14] in Boston, Massachusetts

2.2.15A: Commercial Street/Haul Road NB (Route Alternative 15) [RA15]

This route runs northward through the cities of Boston and Somerville in Massachusetts. The route runs north from I-93 Frontage Road in Boston and continues through Boston along Haul Road and Commercial Street and ends on MA-99 in Somerville. Specifically, the route starts on I-93 Frontage Road at Exit 16 and continues as follows:

Start on I-93 at Exit 16 – Frontage Road Exit
North on I-93 Frontage Road
Northeast on Haul Road/South Boston Bypass Road
Northeast on West Service Road
Northwest on Seaport Boulevard
North on Atlantic Avenue
Northeast onto Commercial Street
Northwest on North Washington Street
Continue northwest onto Rutherford Avenue

At Rutherford Avenue, there are two destination points. The two routes continue from the above directions as follows:

Destination 1: (Used when comparing alternative routing)
Northeast on Alford Street/MA-99
End on Alford Street/MA-99 before entering Everett

Destination 2:
Northwest on Rutherford Avenue
North on Sullivan Square
West on Sullivan Square
Northwest onto Main Street to Mystic Avenue/MA-38
End on MA-38 at Temple Street intersection

2.2.15B: Commercial Street/Haul Road SB (Route Alternative 15) [RA15]

This route runs southward through the cities of Boston and Somerville in Massachusetts. The route runs south from MA-38 in Somerville and MA-99 in Boston and continues south along Commercial Street and Haul Road. Specifically, the route has two origin points and is described as follows:

Origin 1: (Used when comparing alternative routing)
Start at Alford Street/MA-99 Bridge just before Everett
Southwest on MA-99 until Rutherford Avenue

Origin 2:
Start at MA-38 at Exit 29
Southeast on Maffa Way/MA-38 to Sullivan Square
Southeast on Rutherford Avenue/MA-99

At New Rutherford Avenue, the route continues from either of the above origins and is described as follows:

Southeast on Rutherford Avenue
Northeast on Commercial Street
Southeast on John F. Fitzgerald Surface Road
Southwest on Purchase Street
Southeast on Congress Street
Southwest on West Service Road
Southwest on S Boston Bypass Road/Haul Road
South on I-93 Frontage Road
End on I-93 at Frontage Road Exit – Exit 16

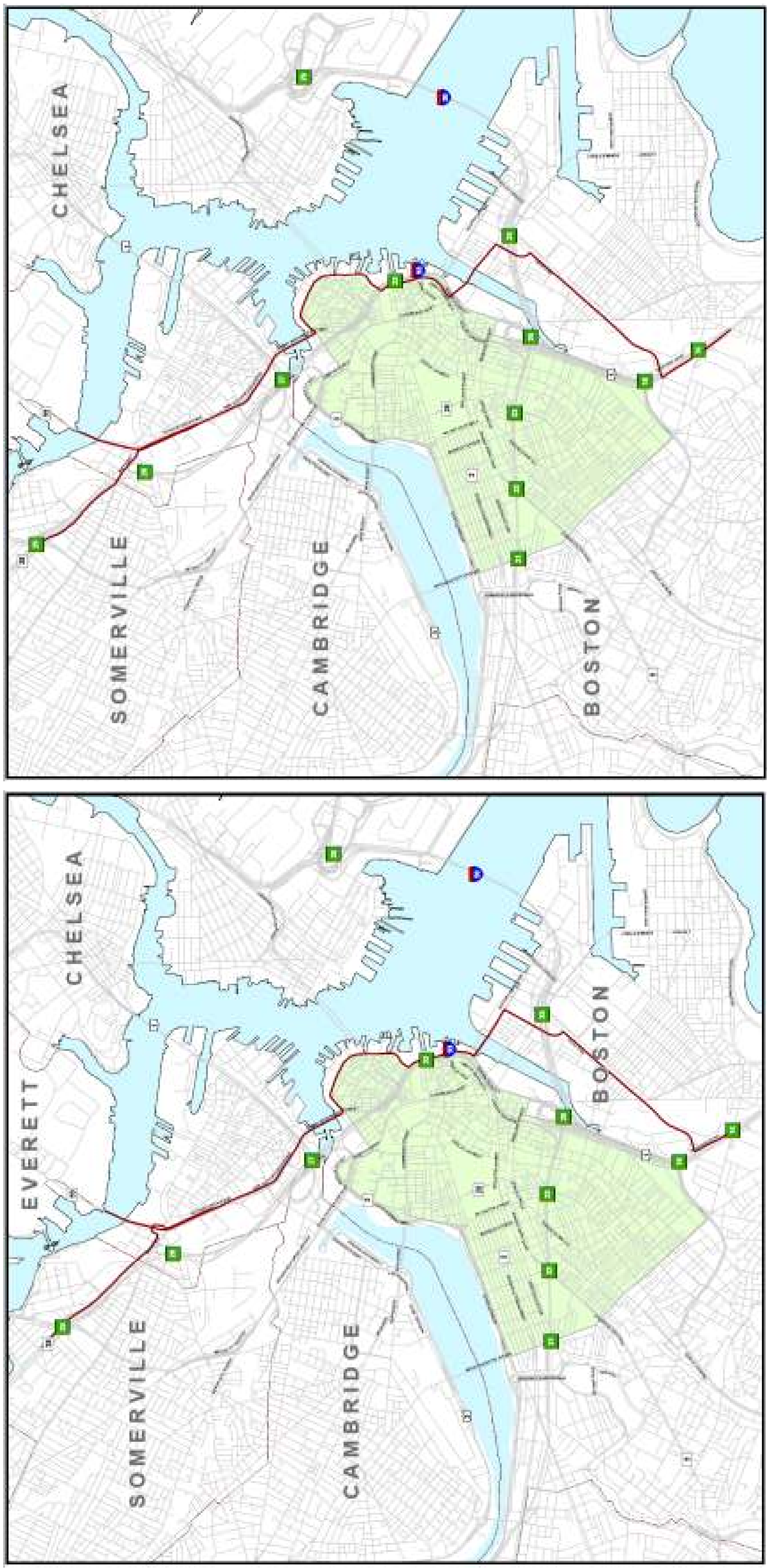


Figure 15: Map of 2.2.15A, Commercial/Haul Road NB and 2.2.15B,Commercial/Haul Road SB (Route Alternative 15) [RA15] in Boston, Massachusetts

2.2.16: Lomasney NB (Route Alternative 16) [RA16]

This route runs northward through the cities of Boston, Cambridge and Somerville in Massachusetts. The route runs north from I-93 Frontage Road in Boston and detours north through Boston until it meets up with MA-38 in Somerville and MA-99 in Boston. The route starts on I-93 and continues as follows:

Start on I-93 at Exit 16 – Frontage Road Exit
North on I-93 Frontage Road
Continue north onto Atlantic Avenue
West on State Street/Court Street
Continue northwest on Cambridge Street
North on Staniford Street
North on Lomasney Way/Nashua Street

At Lomasney Way, there are two destination points. The two routes continue from the above directions as follows:

Destination 1:
East on Leverett Connector
End on Exit 28

Destination 2: (Used when comparing alternative routings)

Northwest on Monsignor O'Brien Highway
East on Edwin H. Land Boulevard
Northwest on Rutherford Avenue
Northeast on Alford Street/MA-99
End on Alford Street/MA-99 bridge just before Everett

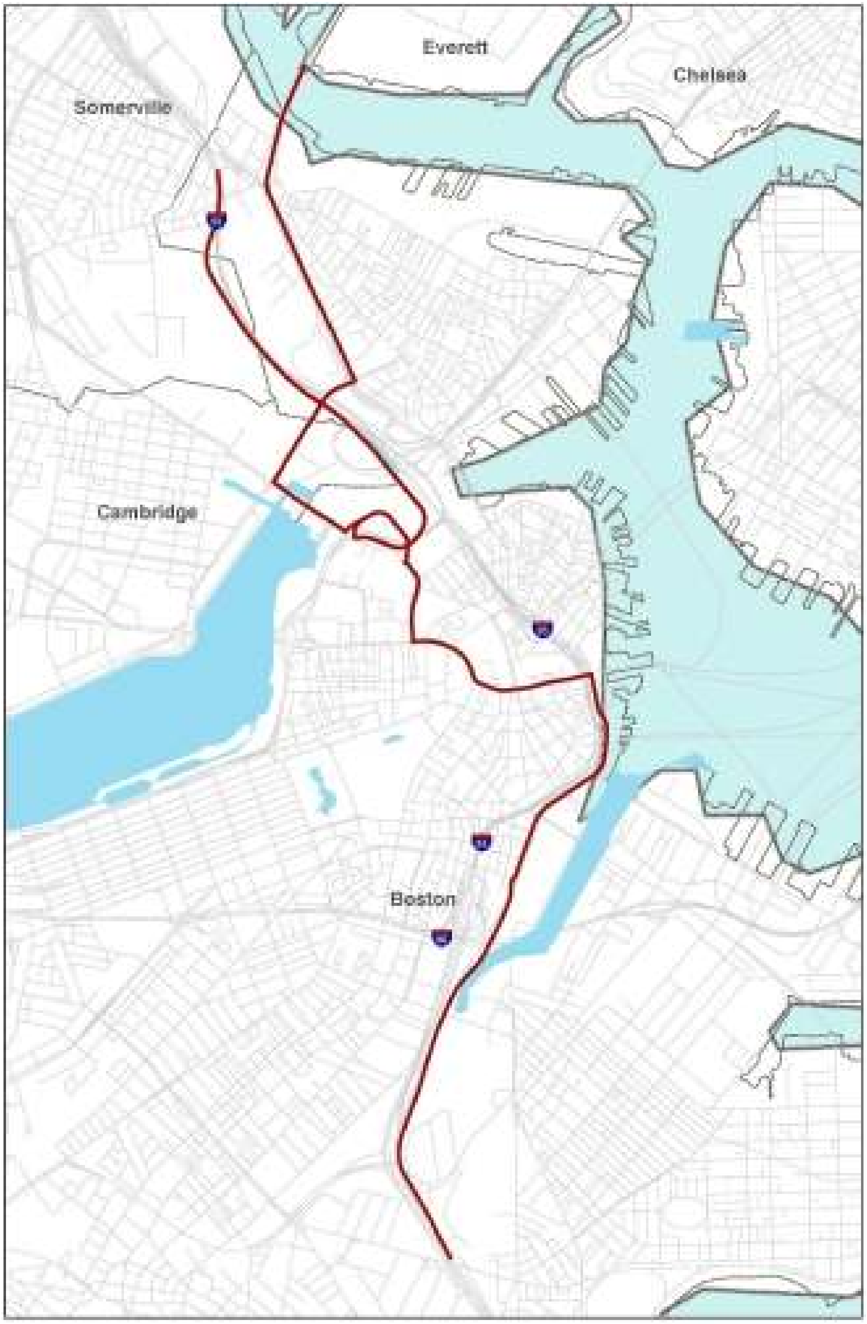


Figure 16: Map of 2.2.16, Lomasney Road NB (Route Alternative 16) [RA16] in Boston, Massachusetts

2.2.17: Surface Road/Haul Road SB (Route Alternative 17) [RA 17]

This route runs southward through the cities of Boston and Somerville in Massachusetts. The route runs south from MA-38 in Somerville and MA-99 in Boston and continues south to I-93 Frontage Road through Boston. The route has two origin points and is described as follows:

Origin 1: (Used when comparing alternative routings)
Start at Alford Street/MA-99 Bridge just after Everett
Southwest on Alford Street/MA-99 to Rutherford Avenue

Origin 2:
Start at MA-38 at Exit 29
Southeast on Maffa Way/MA-38 to Sullivan Square Southeast on Rutherford Avenue/MA-99

At Rutherford Avenue, the route continues from either of the above origins and is described as follows:

Southeast on Rutherford Avenue
South on North Washington Street
Southeast on John F. Fitzgerald Surface Road
Continue southwest onto Purchase Street
Southeast on Congress Street
Southwest on West Service Road
Southwest on Haul Road/South Boston Bypass Road
South on I-93 Frontage Road
End on I-93 Frontage Road at Exit 16

Figure 17: Map of 2.2.17, Surface Road/Haul Road SB (Route Alternative 17) [RA17] in Boston, Massachusetts

2.2.18: Congress Street/Haul Road SB (Route Alternative 18) [RA18]

This route runs southward through the cities of Boston and Somerville in Massachusetts. The route runs south from MA-38 in Somerville and MA-99 in Boston and continues south through Boston. Specifically, the route has two origin points and is described as follows:

Origin 1: (Used when comparing alternative routings)
Start at Alford Street/MA-99 Bridge just before Everett
Southwest on Alford Street/MA-99 to Rutherford Avenue

Origin 2:
Start at MA-38 at Exit 29
Southeast on Maffa Way/MA-38 to Sullivan Square
Southeast on Rutherford Avenue/MA-99

At Rutherford Avenue, the route continues from either of the above origins and is described as follows:

Southeast on Rutherford Avenue
South on North Washington Avenue
Southwest on Causeway Street
South on Staniford Street
East on Cambridge Street
Northeast on New Sudbury Street
Southeast on Congress Street
Southwest on West Service Road
Southwest on Haul Road/South Boston Bypass Road
South on I-93 Frontage Road
End on I-93 Frontage Road at Boston Street

Figure 18: Map of 2.2.18, Congress Street/Haul Road SB (Route Alternative 18) [RA18] in Boston, Massachusetts

Accident Data and Truck Accident Rates on Selected Alternative Route Segments

Identification of truck accident rates is a key data element required to conduct a risk assessment of the alternative routes. In addition, data covering the nature and quantity of hazmat spills provides essential information for estimating hazmat flows in a region. This section has two parts. The first describes the process followed to obtain truck accident rates while the second examines the number of hazmat releases that have occurred in the Boston Area over a seven-year period beginning in 2003 and continuing until the end of 2010.

Accident Rate

Following a literature review and a search for existing truck accident data within the City of Boston, a determination was made that there were insufficient truck crash data to obtain a truck accident rate for highways and major roads within the City of Boston using Boston accident data. After discussing the limitation with the City and representatives of MassDOT, MassDOT facilitated a meeting with the Truck Team of the Massachusetts State Police. The State Police had a contractual relationship with the University of Massachusetts (UMass) to collect data concerning and geographically locate truck accidents within the Commonwealth. These analyses were used to identify problem roadways and for establishing targeted accident reduction campaigns. Discussions between UMass and Battelle resulted in an agreement for UMass to supply estimated accident rates for designated road classes in three regional population classes – urban, urban clusters and rural. An essential part of the analysis was provided by Battelle. Battelle maintains a GIS-based compilation of average annual daily traffic (AADT) flows for trucks as part of the Freight Analysis Framework (FAF) program funded by the FHWA. These truck flows were given to UMass in a format compatible with MassDOT's GIS system to facilitate merging of accident and truck flow data. There was not always a perfect match between the route segments used in assembling the accident data and the route segments used in estimating flows. Where gaps existed, for each road classification the fraction of the routes with flow data was estimated, the total annual truck miles for those route segments was estimated, and then that number was divided by the fraction of the routes with flow data to get the total estimated annual miles traveled by truck on all the route segments by road class. The accident rate was then obtained by road class by dividing the total number of accidents recorded on that road class by the total annual truck miles traveled on that road class.

As mentioned above, the UMass analysis considered accident rates in three population zones – urban areas, urban clusters and rural areas. Discussions with the UMass personnel verified that all the alternative routes being evaluated in this analysis were urban. The results for an urban area in the Commonwealth of Massachusetts, (UMass, 2010), are shown in Table 1. The total road miles by functional class are based on the functional classification assigned by MassDOT. MassDOT maintains a GIS link, http://services.massdot.state.ma.us/maptemplate/RoadInventory that can be used to determine the functional classification assigned to any route segment. The total miles for which truck flow estimates are available for each functional class of highway is based on data from the FAF GIS network maintained by Battelle for the FHWA. The estimated truck percentage is from the FAF. The total crashes are taken from a database maintained by UMass for the State Police. The total estimated truck miles traveled is a calculated number that is obtained by extrapolating the annual truck miles estimated from the FAF data and then prorating it to the entire functional class. To obtain the estimate, the annual truck miles from the FAF was multiplied by the total road miles and divided by the total miles with truck flow data, column 2 divided by column 3. The accident rate was obtained by dividing the total crashes by the annual truck miles traveled, column 5 divided by column 6.

As expected, the accident rates are lowest on expressways and increase as the level of access control decreases. The uncertainty in the accident rate decreases as the number of accidents increases. Specifically, the variance is inversely proportional to the number of accidents. Thus if there are 1,000 accidents, the variance is 0.001 and the 95 percent confidence level in the accident rate is two times the square root of 0.001 or ± 6 percent. When just the number of accidents is considered, all the differences shown in Table 1 are statistically significant. A greater source of uncertainty is associated with the fraction of the road classification for which there is truck flows from the FAF GIS network. For the Interstate, Principal Arterial and Urban Principal Arterial classes, the fraction of the roads for which there is truck flow data is above

85 percent. However, it is less than 4 percent for the urban minor arterial and less than one percent for the local and urban collector road functional classifications. If any Local or Urban Collector road classes are used in the routing analysis, the analysis will use sensitivity analyses to verify that the data from those road functional classifications do not play an important role in any routing recommendation.

Table 1: Estimated Annual Truck Accident Rates by Functional Class Applicable to the City of Boston, Massachusetts

Urban Accident Rates by Functional Class	Total Road Miles	Total Miles with Truck Flow Data	Estimated Truck Percentage	Total Truck Crashes (2007 thru 2009)	Annual Truck Miles Traveled	Accident Rate / 10^6 Miles
Local	24,619	1.1	5.0	1,347	239,756,951	1.87
Interstate	982	932	7.1	1,881	2,085,665,880	0.30
Principal Arterial	1091	986	7.5	1,096	1,237,903,630	0.30
Urban Principal Arterial	1,816	1,580	6.5	1,893	613,415,784	1.03
Urban Minor Arterial	3,962	182	6.6	2,200	603,623.948	1.21
Urban Collector	2,876	0.6	6.3	847	170,704,340	1.65
All	35,345	3,682	6.9	9.269	6,009,991,603	0.51

TYPES AND QUANTITIES OF NRHM

Consistent with the Non-Radioactive Hazardous Material Highway Routing Regulations, this section estimates the types and quantities of NRHM flowing through the City of Boston. There are no studies documenting the hazmat flows in the City of Boston or on any of the routes that could be used to circumvent Boston, such as SR 128. While there are signs on I-95 and I-93 directing trucks carrying hazmat cargoes to use I-95 (SR 128) due to restrictions prohibiting hazmat cargoes in the I-93 tunnels through Boston, the number of vehicles that must be diverted from going through Boston is not known. Trucks carrying hazmat cargoes which must avoid the I-93 tunnels also transport these materials through Boston on designated surface roadways that are marked as hazmat cargo routes. Thus, the quantity of hazmat traffic that would go through Boston with and without the current signed travel restrictions is unknown.

Since there are no formal commodity flow surveys on any of the alternative routes in Metropolitan Boston, ancillary sources must be used to identify hazmat flows. Fortunately, there are several. These sources include:

Lists of hazmat spills reported to the U.S. Department of Transportation Pipeline and Hazardous Material Administration (PHMSA). These spills are found in the Hazardous Materials Information Reporting System (HMIRS). While the data are limited to accidents that result in hazmat spills, the HMIRS database can be used to identify any carrier-reported spills that occurred in the City of Boston or occurred at some other location but originated from a shipper located in the City of Boston or was destined to be delivered to a location within the City of Boston. While hazmat spills are an extremely small fraction of the hazmat shipments, it does provide a distribution of hazmat classes/divisions for which a carrier has reported spills. The limitation of these data are that some packagings are much more robust than others so for those with robust packaging, such as Class 2 materials (compressed gasses). As a result, any projection of the total number of shipments of Class 2 materials based on the spill data will be under predicted and any projection of the number of shipments of materials in less robust packages, Class 3 (flammable and combustible liquids) and Class 9 materials (miscellaneous hazmat) will be over predicted.

Inspections of hazmat vehicles conducted by Boston. Although the inspections are not random, they do provide some indication of the distribution of hazardous classes/divisions that are using Boston thoroughfares and consequently a distribution of hazmat classes/divisions can be developed from that data. The inspections are not random because they are only performed on a few of the possible hazmat routes and they are typically performed during normal business hours, 8:00 AM to 5:00 PM. Note that MassDOT and the State Police could provide no hazmat inspection data outside the City of Boston.

Hazmat permits and applications for transporting hazmat in Boston. This system is mandated by ordinance and regulations of the City of Boston for selected hazmat classes. Although permits are not required for all classes/divisions of hazmat, those classes accounting for the predominance of hazmat shipments are included. Therefore, the permits and especially the permit applications, provide an indication of the classes/divisions of hazmat using Boston thoroughfares. Unfortunately, many permit applications do not indicate the number of vehicles in each class/division that will be traveling through Boston if the permit were granted. Even if it did contain an estimate of the number of shipments that will occur if the permit were granted, there would be no way of knowing whether the estimate represented the actual number of vehicles that travel through Boston once the permit has been issued. There could be many more vehicles using Boston streets or many fewer vehicles. In spite of these limitations, a distribution has been developed from those data as they may provide some indication of the quantities and types of materials using Boston thoroughfares.

Survey of shippers and carriers registered with PHMSA located within 75 miles of Boston. A survey form was sent to over 1,500 carriers and shippers registered with PHMSA and located within 75 miles of Boston. The survey form requested the respondents to indicate whether they transport hazmat through Boston and if so, to list the types and quantities of hazmat being transported. About 100 of the surveys were returned as undeliverable, and about 150 replies to the survey were received. This represents a successful return rate of approximately 11 percent. The hazmat routes being used by the carriers and shippers were also requested in the survey. This provided an estimate of the number and types of hazmat being transported in the Boston Metropolitan area.

The U.S. Census Bureau commodity flow survey data. In the past, the Census Bureau has issued reports documenting the hazmat flows at the national level and at the State level. A year ago all the State level hazmat commodity flow survey data were available for download from the Census Bureau website using 2003 census data (U.S. Census 2003). The 2003 reports are no longer posted on the Census Bureau website as they will eventually be replaced by reports using the 2007 commodity flow survey results. A formal request to the Census Bureau was made for both the Commonwealth of Massachusetts and Boston Metropolitan Regions hazmat flow survey results (U.S. Census 2011). These data are one more source of information regarding hazmat flows in the Commonwealth and perhaps in the Boston region.

In addition to the sources cited above, Boston has traffic cameras that are used to control the lights on many of the major thoroughfares in Boston, and MassDOT operates traffic cameras on many of the major routes, particularly in the Boston area. Boston has the capability of positioning and recording information for their traffic cameras and they provided a 24-hour recording of the traffic at eight locations, all along the central artery. A sample of these route tapes was examined in more detail. The quality of the picture was sufficient to identify the shape of the truck, and in most cases it was possible to identify the presence of a holder for a diamond shaped placard. Unfortunately, the picture resolution was of insufficient clarity to identify whether the holder contained a placard or more importantly the United Nations (UN) Number displayed on the placard. Cargo tank vehicles were easily identified, and since non-placarded vehicles can use the central artery tunnels, it is reasonable to assume that any cargo tank vehicles using the surface streets are placarded. It is also reasonable to assume that truck vans, particularly the single unit truck vans, were not placarded since the vast majority of these vehicles are used to supply the many businesses in the downtown Boston area. The traffic cameras maintained by MassDOT were stationary and had a fixed focus. They provide a view of the entire roadway and can be used only to identify points of congestion. There is no possibility of recording data, and even if they could, placarded vehicles could not be identified. Recognizing the limitations ahead of time, the video tapes were reviewed to get a very cursory view of hazmat flows and to see whether any insights regarding day/night traffic characteristics could be gleaned from the recordings.

The following sections describe the major sources of hazmat flow information in more detail.

HazMat Spills Reported by Carriers and Shippers to PHMSA

The available accident data, although not the best source to determine commodity flows because only releases reported by carriers are tabulated, do provide one reasonable surrogate for estimating the types of hazmat moving through an area. However, there are some considerations that must be followed when evaluating hazmat spill data. Among the hazmat classes and divisions, there are major differences in packaging that could bias the results toward packagings with less integrity. For example, because of the outstanding robustness of the package, one would not expect to find a report of a release of radioactivity from a Type B Radioactive Material Package (Class 7 release). Similarly, a Class 1 (explosives) package could be involved in an accident, but if no explosive packages were lost from the vehicle a report to PHMSA would be unlikely. These biases might be somewhat balanced by considering releases during loading or unloading, releases less dependent on the packaging and more dependent on human errors, a factor more constant for all types of hazmat. The approach followed for this analysis was to look at the HMIRS data for shipments destined for, shipped from or that experienced an incident occurring in one of the counties in the Boston metropolitan area during the years 2005 through 2009. During this time period there were a total of 115 in-route releases. Many of these were small. Table 2 shows the distribution of these releases in Essex, Middlesex, Norfolk, Plymouth, and Suffolk counties and for the five county region.

Table 2: In Route Incidents Reported to HMIRS by Carriers for Years 2005 through 2009

Hazardous Class Code	ESSEX	MIDDLESEX	NORFOLK	PLYMOUTH	SUFFOLK	TOTAL
2.1		3.50%		14.29%		3.69%
2.2		0.70%		4.76%		0.92%
3	47.37%	53.85%	47.62%	33.33%	46.15%	50.23%
4.1		0.70%				0.46%
5.1	5.26%	4.20%	4.76%	19.05%		5.53%
5.2		0.70%				0.46%
6.1	5.26%	2.10%	4.76%			2.30%
6.2		0.70%				0.46%
7	5.26%	0.70%				0.92%
8	26.32%	32.87%	33.33%	28.57%	46.15%	32.72%
9	5.26%		4.76%		7.69%	1.38%
ORM-D	5.26%		4.76%			0.92%
Total Releases	9	70	11	20	5	115
≥ 1,000 gal	0	1	1	1	2	5

The results in Table 2 are presented without consideration of the amount spilled or the number of packages involved in the incident. If the spills of more than 1,000 gallons are considered, the list of reportable accidents is reduced to 5 Class 3 releases, one each in Middlesex, Norfolk and Plymouth, and 2 in Suffolk County. Thus of the 5 total releases shown in Table 3 for Suffolk County, two released more than 1,000 gallons of flammable liquid. In Suffolk County 2 of the 5 releases were major releases of flammable or combustible material whereas in Middlesex County, only 1 of the 70 was a major release. This shows the difficulty in predicting the magnitude of releases. If several decades of data were collected, and assuming no change in packaging design, the fraction of releases that are major in each county would tend toward the same number, and most likely the percentage of spills that were major would tend toward 5 of 115 or 4.3 percent in each county. The point is that the county data are too sparse to draw any significant conclusions about differences in releases among the counties. The data do show the dominance of Class 3 materials (flammable liquids) among the shipments traversing the five county area.

Boston Police Department Inspections of Trucks Carrying Hazmat

The Boston Police Department Commercial Vehicle Enforcement Unit routinely performs inspections of trucks traveling through the City. In support of the routing study, the available inspection data was provided for 641 inspections, beginning in 2003 and continuing until 2010. These results are summarized in Table 3. Table 3 shows that the number of inspections differed considerably from year to year. In some years, very few inspections were performed. The inspections cannot be considered random because all inspections were conducted during the day and no attempt was made to select the inspection locations randomly or to make the time spent at each inspection location of the same duration. The data shows that of the 647 inspections conducted between 2003 and mid-2010, almost 78 percent of the inspected vehicles were hauling

Class 3 hazmat. Flammable gases, HM Division 2.1, and Non-flammable gases, HM Division 2.2, made up between 6 and 7 percent of the inspections. Corrosives, Class 8 and Miscellaneous Dangerous Goods, Class 9 made up 4 and 3 percent of the shipments respectively. The other listed HM classes and divisions consisted of less than three inspections and under one percent of the inspections.

Table 3: Distribution of Inspections by Year and Hazmat Class/Division

HAZMAT CLASS	2003	2004	2005	2006	2007	2008	2009	2010	Total	Percentage
2.1			26	6		1	1	10	44	6.8%
2.2			28	6		1		6	41	6.3%
2.3								3	3	0.46%
3	1	1	318	85	2	13	11	71	502	77.6%
4.1			1						1	0.15%
5.1				1				2	3	0.46%
5.2				1					1	0.15%
6.1								1	1	0.15%
7			2					1	3	0.46%
8			21	3		1	1		26	4.0%
9			17	1		1		3	22	3.4%
Totals	1	1	413	103	2	17	13	97	647	

Over the seven plus years of inspection data, no inspections were performed on vehicles carrying Explosives, Class 1; Spontaneously Combustible Material, Division 4.2; Dangerous When Wet, Division 4.3; and Infectious Substances, Division 6.2. While it is not possible to definitively conclude from Boston Police Department roadside inspection data that there are no shipments for these hazmat through Boston, the application of professional judgment results in the conclusion that they make up less than one percent of the shipments.

Hazmat Permits and Applications for Transporting Hazmat in Boston

The Boston Fire Department provided copies of permits they issued over the last three years for transporting hazmat though downtown Boston. Some of the permits had the application form attached. The application and not the permit contained the estimated number of weekly or monthly shipments. About 70 percent of the permits had the applications attached and for those permits, the total number of authorized weekly shipments was about 900. For the other shipments, the weekly shipments were estimated by looking for carriers with a similar number of trailers and assume the trailer use rate was the same. In many cases it was about 2 trailer shipments per week. Adding in these additional shipments, the estimated number of weekly shipments came to 1,060 per week. It was also estimated that of the 1,060 weekly placarded shipments, 950 might be shipments of Class 3 flammable and combustible liquids, 100 might be shipments of Class 2 gases and 10 might be shipments of Class 1 explosives. The shipments of Class 2 gases were divided about equally between Division 2.1 Flammable Gases and Division 2.2 Non-flammable gases. Based on the shipper, the vast majority of the explosives were believed to be fireworks. In terms of percentages, about 90 percent of the shipments listed in the permits were Class 3, 9 percent Class 2, and 1 percent Class 1. Based on the other data sources (e.g., the survey of hazmat shippers and receivers in the Boston area), there are probably a few dozen weekly placarded shipments traveling through downtown Boston that are not covered by the permit system (e.g., classes 8 and 9).

Since an organization seeking a permit would be unlikely to underestimate the number of shipments, the approximately 1,000 shipments per week, or 200 per day, is considered an upper bound. While there are uncertainties in determining the actual distribution of classes and divisions of hazmat being transported in Boston, it is clear that vehicles hauling Class 3 flammable or combustible liquids are the dominant placarded vehicle using the streets in the City of Boston.

Survey Results of Shippers and Carriers Registering with PHMSA who List Offices within 75 Miles of Downtown Boston

To solicit the input from carriers and shippers, thereby initiating compliance with the requirement to obtain results from consultation with affected persons, a survey was sent out to the list of carriers who applied for PHMSA registration to haul hazmat, of which there are approximately 1,500 who gave a business address within 75 miles of downtown Boston. A survey (see Appendix C) was sent to all 1,500 businesses and approximately 150 replied. These results were tabulated and analyzed to determine whether a distribution of hazmat flows by class and division could be determined. The results shown in Table 4 once again show the dominance of the Class 3 shipments. Some of the data were difficult to understand, and calls were made to selected carriers in order to better understand the data they provided. Many immediately clarified the entries, but there was a case in which the respondent listed 4,000 shipments per month where it was not possible to clarify the entry. In this case, multiple attempts to contact the person who filled out this form were unsuccessful. This case was not included in the total.

The distribution suggests about 1,200 shipments per week might be traveling through downtown Boston, a number quite similar to the number obtained from the permits issued by the Boston Fire Department, 1,060 weekly shipments. The survey results also show that approximately 90 percent of the shipments are Class 3 flammable and combustible liquids. The permit data obtained from the City of Boston Fire Department has a higher percentage of Class 2 shipments. This can be partially explained by the use of trucks carrying numerous small cylinders containing pressurized industrial gases. A single truck can carry multiple “shipments” of flammable and non-combustible gases to several industrial clients. The comparisons of the explosive shipments show about 12 per month from the survey and 10 per week from the permits. A difference of this magnitude can be easily explained by the intermittent nature of such shipments. The permit request would typically be for the peak number of expected shipments in a week, 10. There could still be a shipment rate, averaged over a year, of 12 shipments per month. As shown in the previous assessments, Table 4 shows Class 3 flammable or combustible liquids are the dominant hazmat class being shipped on the streets of Boston.

Table 4: HM Shipment Distribution from Carrier/Shipper Survey

HM CLASS	Monthly Shipments	Percentage
1.1	4	0.08%
1.2	4	0.08%
1.3	4	0.08%
2.1	48	1.00%
2.2	47	0.98%
2.3	9	0.19%
3	4382	90.93%
4.1	23	0.48%
4.2	9	0.19%
4.3	19	0.39%
5.1	11	0.23%
5.2	8	0.17%
6.1	11	0.23%
6.2	3	0.06%
7	1	0.02%
8	218	4.52%
9	18	0.37%
Total	4819	

U.S. Census Commodity Flow Results

The U.S. Census Bureau, as the result of a request for a specialized data run, provided the hazmat commodity flow survey results for the Commonwealth of Massachusetts; the Massachusetts part of the Boston, Worcester, Manchester Economic Census Region; and for the remaining part of the Commonwealth of Massachusetts. Note that the Boston area extends into Rhode Island and New Hampshire, and the Worcester and Manchester areas include significant parts of New Hampshire. The areas outside Massachusetts were not excluded from the data assembled by the Census Bureau. These data were used to supplement the other sources used to compile a portrait of the type and quantity of hazmat moving by truck through Boston and the surrounding region. The results of the data analysis are shown in Table 5. To compile the table, the project team considered only categories that had a truck component, therefore the 'All' and 'Single Mode' numbers are very close to the 'Truck' numbers. The next three categories after 'Truck,' 'Private Truck,' 'For Hire Truck,' and 'Package and Courier,' are all part of the 'Truck' category. 'Single Mode' adds 'Air (including Truck)' to the 'Truck' totals and 'All' adds 'Multiple Modes' and 'Other Unknown' to the 'Single Mode' total. Since the special run was made for 'Truck,' the additional totals do not add substantially to the 'Truck' totals.

Table 5: Results of 2007 U.S. Census HM Commodity Flow Survey for the Massachusetts Part of the Boston, Worcester, Manchester Region

Mode of Transport	Hazard Class / Division	Value (millions of Dollars)	Value CV	Tons (thousands)	Ton CV	Ton-Miles (millions)	Ton-Mile CV	Average Miles per Shipment	Avg Mile CV
All	All	16692	25.2	35208	40.3	1450	36.8	190.42	20.9
Single Modes	All	16366	25.4	35003	40.6	1438	37.2	61.41	41.7
Truck	All	16183	25.8	35000	40.6	1435	37.3	29.77	20.7
For Hire Truck	All	7782	34.1	S	S	S	S	S	S
Private Truck	All	8401	22.6	11373	20.7	367	25.8	16.92	11.4
Package and Courier	All	220	27.5	4	27.1	4	26.8	1162.10	10.9
Air (including Truck)	All	183	13.4	3	24	3	7.1	1546.27	5.8
Multiple Modes	All	220	27.5	4	27.1	4	26.8	1162.10	10.9
Other Unknown	All	S	S	S	S	S	S	S	S
All	1	19	28.9	S	S	S	S	829.30	30.8
Single Modes	1	4	40.8	S	S	S	S	S	S
Truck	1	4	40.8	S	S	S	S	S	S
For Hire Truck	1	2	27.3	S	S	S	S	S	S
Private Truck	1		S	S	S	S	S	S	S
Package and Courier	1		S	S	S	S	S	918.78	27.3
Multiple Modes	1		S	S	S	S	S	918.78	27.3
Other Unknown	1		S	S	S	S	S	1164.70	0
All	1.4	17	36.6	S	S	S	S	889.42	27.8
Single Modes	1.4	S	S	S	S	S	S	S	S
Truck	1.4	S	S	S	S	S	S	S	S
For Hire Truck	1.4	S	S	S	S	S	S	S	S
Private Truck	1.4	S	S	S	S	S	S	S	S
Package and Courier	1.4	S	S	S	S	S	S	918.78	27.3
Multiple Modes	1.4	S	S	S	S	S	S	918.78	27.3
Other Unknown	1.4	S	S	S	S	S	S	1164.70	0
All	1.5	S	S	S	S	S	S	S	S
Single Modes	1.5	S	S	S	S	S	S	S	S
Truck	1.5	S	S	S	S	S	S	S	S
For Hire Truck	1.5	S	S	S	S	S	S	S	S
All	2	297	30.1	277	42.8	19	47.8	S	S
Single Modes	2	246	29.2	170	31.9	S	S	S	S
Truck	2	246	29.2	170	31.9	S	S	S	S
For Hire Truck	2	S	S	S	S	S	S	880.08	9.6
Private Truck	2	190	33.4	162	32.2	4	34.1	19.89	8.6
Package and Courier	2	S	S	S	S	S	S	S	S
Multiple Modes	2	S	S	S	S	S	S	S	S
Other Unknown	2	S	S	S	S	S	S	S	S
All	2.1	166	44.7	143	43.8	3	44.8	S	S

Table 5: Results of 2007 U.S. Census HM Commodity Flow Survey for the Massachusetts Part of the Boston, Worcester, Manchester Region (Cont.)

Mode of Transport	Hazard Class / Division	Value (millions of Dollars)	Value CV	Tons (thousands)	Ton CV	Ton-Miles (millions)	Ton-Mile CV	Average Miles per Shipment	Avg Mile CV
Single Modes	2.1	164	42.9	143	41.1	3	43.9	18.85	7.7
Truck	2.1	164	42.9	143	41.1	3	43.9	18.85	7.7
Private Truck	2.1	164	42.9	143	41.1	3	43.9	18.85	7.7
Package and Courier	2.1	S	S	S	S	S	S	1024.10	15.3
Multiple Modes	2.1	S	S	S	S	S	S	1024.10	15.3
Other Unknown	2.1	S	S	S	S	S	S	S	S
All	2.2	124	43.2	S	S	15	46.9	S	S
Single Modes	2.2	75	31.7	S	S	S	S	S	S
Truck	2.2	75	31.7	S	S	S	S	S	S
For Hire Truck	2.2	S	S	S	S	S	S	880.08	9.6
Private Truck	2.2	S	S	S	S	S	S	S	S
Package and Courier	2.2	S	S	S	S	S	S	S	S
Multiple Modes	2.2	S	S	S	S	S	S	S	S
Other Unknown	2.2	S	S	S	S	S	S	S	S
All	2.3	S	S	S	S	S	S	31.24	12.4
Single Modes	2.3	S	S	S	S	S	S	S	S
Truck	2.3	S	S	S	S	S	S	S	S
Private Truck	2.3	S	S	S	S	S	S	S	S
Package and Courier	2.3	S	S	S	S	S	S	S	S
Multiple Modes	2.3	S	S	S	S	S	S	S	S
All	3	15520	26.8	33679	42.6	1287	41.6	38.03	43.2
Single Modes	3	15438	26.8	33582	42.7	1284	41.7	27.21	21.1
Truck	3	15417	26.8	33582	42.7	1283	41.8	23.26	19.1
For Hire Truck	3	7484	34.6	S	S	S	S	S	S
Private Truck	3	7933	24.1	10247	24.1	285	30.8	15.86	12.7
Package and Courier	3	S	S	S	S	S	S	1132.81	23.3
Air (including Truck)	3	S	S	S	S	S	S	1301.51	35.3
Multiple Modes	3	S	S	S	S	S	S	1132.81	23.3
Other Unknown	3	S	S	S	S	S	S	S	S
All	4	S	S	S	S	S	S	S	S
Single Modes	4	S	S	S	S	S	S	S	S
Truck	4	S	S	S	S	S	S	S	S
Private Truck	4	S	S	S	S	S	S	S	S
Package and Courier	4	S	S	S	S	S	S	S	S
Air (including Truck)	4	S	S	S	S	S	S	S	S
Multiple Modes	4	S	S	S	S	S	S	S	S
All	4.1	S	S	S	S	S	S	S	S
Single Modes	4.1	S	S	S	S	S	S	S	S

Table 5: Results of 2007 U.S. Census HM Commodity Flow Survey for the Massachusetts Part of the Boston, Worcester, Manchester Region (Cont.)

Mode of Transport	Hazard Class / Division	Value (millions of Dollars)	Value CV	Tons (thousands)	Ton CV	Ton-Miles (millions)	Ton-Mile CV	Average Miles per Shipment	Avg Mile CV
Package and Courier	4.1	S	S	S	S	S	S	S	S
Air (including Truck)	4.1	S	S	S	S	S	S	S	S
Multiple Modes	4.1	S	S	S	S	S	S	S	S
All	4.2	S	S	S	S	S	S	S	S
Package and Courier	4.2	S	S	S	S	S	S	S	S
Multiple Modes	4.2	S	S	S	S	S	S	S	S
All	4.3	S	S	S	S	S	S	S	S
Single Modes	4.3	S	S	S	S	S	S	S	S
Truck	4.3	S	S	S	S	S	S	S	S
Private Truck	4.3	S	S	S	S	S	S	S	S
Package and Courier	4.3	S	S	S	S	S	S	S	S
Air (including Truck)	4.3	S	S	S	S	S	S	S	S
Multiple Modes	4.3	S	S	S	S	S	S	S	S
All	5	S	S	2	46.7	Z	45.8	1031.12	34.1
Single Modes	5	S	S	2	47.7	Z	44.2	1428.27	35.3
Truck	5	5	40.1	S	S	S	S	113.20	22.9
For Hire Truck	5	S	S	S	S	S	S	176.82	17.5
Private Truck	5	2	47.2	S	S	S	S	52.11	24.7
Package and Courier	5	S	S	S	S	S	S	S	S
Air (including Truck)	5	S	S	S	S	S	S	S	S
Multiple Modes	5	S	S	S	S	S	S	S	S
All	5.1	S	S	S	S	Z	47.5	933.13	41.5
Single Modes	5.1	S	S	S	S	Z	45.9	1347.58	42.6
Truck	5.1	S	S	S	S	S	S	78.05	18.3
For Hire Truck	5.1	S	S	S	S	S	S	133.06	27.6
Private Truck	5.1	S	S	S	S	S	S	38.37	40.4
Air (including Truck)	5.1	S	S	S	S	S	S	S	S
Package and Courier	5.1	S	S	S	S	S	S	S	S
Multiple Modes	5.1	S	S	S	S	S	S	S	S
All	5.2	S	S	S	S	S	S	S	S
Single Modes	5.2	S	S	S	S	S	S	S	S
Truck	5.2	S	S	S	S	S	S	143.62	32.7
For Hire Truck	5.2	1	39.8	S	S	S	S	205.61	1.4
Private Truck	5.2	S	S	S	S	S	S	S	S
Air (including Truck)	5.2	S	S	S	S	S	S	S	S
All	6	S	S	S	S	S	S	1026.93	20.5
Single Modes	6	S	S	S	S	Z	35	1854.66	36
Truck	6	S	S	S	S	Z	42.1	625.73	29.1

Table 5: Results of 2007 U.S. Census HM Commodity Flow Survey for the Massachusetts Part of the Boston, Worcester, Manchester Region (Cont.)

Mode of Transport	Hazard Class / Division	Value (millions of Dollars)	Value CV	Tons (thousands)	Ton CV	Ton-Miles (millions)	Ton-Mile CV	Average Miles per Shipment	Avg Mile CV
For Hire Truck	6	S	S	Z	39.4	S	S	857.62	30.2
Private Truck	6	S	S	S	S	S	S	S	S
Package and Courier	6	S	S	S	S	S	S	696.55	37.4
Air (including Truck)	6	S	S	S	S	S	S	S	S
Multiple Modes	6	S	S	S	S	S	S	696.55	37.4
All	6.1	S	S	S	S	S	S	1026.93	20.5
Single Modes	6.1	S	S	S	S	Z	35	1854.66	36
Truck	6.1	S	S	S	S	Z	42.1	625.73	29.1
For Hire Truck	6.1	S	S	Z	39.4	S	S	857.62	30.2
Private Truck	6.1	S	S	S	S	S	S	S	S
Package and Courier	6.1	S	S	S	S	S	S	696.55	37.4
Air (including Truck)	6.1	S	S	S	S	S	S	S	S
Multiple Modes	6.1	S	S	S	S	S	S	696.55	37.4
All	7	341	24	3	20.2	4	22	1384.17	4.1
Single Modes	7	212	16.6	2	9.6	3	7.8	1185.19	3.7
Truck	7	67	38.7	1	25.6	Z	28.5	452.63	28.4
For Hire Truck	7	67	38.7	1	25.6	Z	28.5	452.63	28.4
Package and Courier	7	129	41.3	S	S	S	S	1448.76	14.4
Air (including Truck)	7	145	7.4	S	S	2	8.3	1599.00	4.6
Multiple Modes	7	129	41.3	S	S	S	S	1448.76	14.4
All	8	171	48.6	S	S	S	S	656.87	23.3
Single Modes	8	168	49.9	S	S	S	S	472.20	26.4
Truck	8	S	S	S	S	S	S	249.04	39.9
For Hire Truck	8	S	S	S	S	S	S	S	S
Private Truck	8	27	49.5	24	39.2	1	39.9	42.18	19.7
Package and Courier	8	S	S	S	S	S	S	1036.13	23.5
Air (including Truck)	8	S	S	S	S	S	S	S	S
Multiple Modes	8	S	S	S	S	S	S	1036.13	23.5
All	9	S	S	S	S	S	S	1075.64	36.3
Single Modes	9	S	S	S	S	S	S	S	S
Truck	9	S	S	S	S	S	S	116.76	47.4
For Hire Truck	9	S	S	S	S	S	S	S	S
Private Truck	9	S	S	S	S	S	S	85.38	26.3
Package and Courier	9	S	S	S	S	S	S	1170.12	1.3
Air (including Truck)	9	S	S	S	S	S	S	S	S
Multiple Modes	9	S	S	S	S	S	S	1170.12	1.3

If a line is shown in Table 5, then data was collected for that Hazmat Class or Division and the information collected would be reflected in the All Hazard Class totals. The Census Bureau follows a convention whereby if the data are not sufficient to meet the minimum test for significance, they include the line but enter an 'S.' The data were collected for nine hazmat classes and also by the hazmat divisions falling under those classes, if the class has divisions. As might be expected, for many of the divisions and even many of the classes, the amount of data was too sparse to estimate the Shipment Value, Tons, Ton-Miles and Average Miles per Shipment. The CV column after each of the data entry columns is the Coefficient of Variation. It is expressed as a percent, and if it were changed to a fraction, multiplied by the value to its left and then multiplied by 1.96, the resultant range would be the 95 percent confidence interval. Thus for the first entry, 16,592 million dollars, the total value of all hazmat shipments in the Boston, Worcester, Manchester Region, when multiplied by 0.252 * 1.96 = 8,244. Thus, the estimated value of all hazmat shipments in the region, each year is 16.6 billion dollars ± 8.2 Billion, at the 95 percent confidence level if the value is normally distributed.

For most of the hazardous divisions shown in the table, the majority of the entries are 'S" indicating insufficient data. The table also shows that a large quantity of hazmat is shipped in and through the region annually. The quantity of hazmat truck shipments measured by 'Tons" shipped exceeds 35 million tons per year. Of that total, 33.8 million tons were Class 3, flammable liquids, 96.6 percent of the total. The next largest quantities of hazmat in the regional area that included the Massachusetts part of Boston, Worcester, and Manchester are; Class 2.1 (flammable gases) at 143 thousand tons; Class 8 (corrosives) at 24 thousand tons; Class 5 (oxidizing substances and organic peroxides) at 2 thousand tons and Class 7, (radioactive materials) at one thousand tons annually.

Tonnages of hazmat can be translated to shipments by estimating the average quantity of each class/division of hazmat in the shipment. If the quantity is the same for each class/division, then the tonnage distribution is the same as the shipment distribution. The capacity of the flammable liquid cargo tanks is probably greater than the capacity of the other classes/divisions packaging. Thus, while the flammable liquid shipments probably represent less than 96 percent of the shipments, even if the capacity of the other classes/divisions packages were half that of the flammable liquids, the fraction of shipments that are Class 3, flammable liquids, would still be well above 90 percent. Clearly, flammable liquids followed by flammable gases dominate the truck hazmat transport in the Boston metropolitan area. Each of the other classes/divisions represents less than 1 percent of all the shipments. While this finding is not representative of the United States as a whole, given that Boston is a major importer of flammable and combustible liquids, Class 3 materials, this result is reasonable.

OBTAIN POPULATION AND ENVIRONMENTAL DATA ALONG SELECTED ALTERNATIVE ROUTES

In the routing guideline document (FHWA 1996), the risk measure used is the probability of an accident involving a single shipment of a typical hazmat times the number of potentially exposed people along the route. Although not all accidents will result in a release and for a route segment several miles long on which only a small fraction of the people along the route will be exposed to the potential consequences of a release, the use of the risk of exposure provides a useful method for comparing alternative hazmat routes. Before collecting population and environmental data, the sections below provide a discussion of the most likely hazmat accidents and potential consequences of a release of hazmat.

Most Likely Hazmat Accident

The sections above show that many of the hazmat classes/divisions listed in Table 5 could be present along a route in the City of Boston. The data also show that Class 3, flammable and combustible liquids, are the most commonly shipped material being transported in the Boston metropolitan area. All the counts developed from surveys, permits and observations indicate that more than 70 percent of the hazmat shipments are Class 3. Therefore, the most likely hazmat accident would involve a Class 3, flammable or combustible liquid. The type and characteristics of the hazard associated with a particular hazmat class can vary considerably. Since shipments with Class 3 or Division 2.1 placards constitute the vast majority of flammable shipments, denying shipments placarded with a flammable label from using a particular route would effectively prohibit all but a few percent of the flammable shipments from using the route segment. Based on the number of corrosives and toxic materials that experiences boiling liquid – expanding vapor explosions (BLEVEs) or are involved in a fire following an accident, the number of flammable materials that are shipped under a different hazard label is likely to be between 1 and 2 percent of all hazmat shipments.

Consequence Analyses for Class 3 Accident Occurring on a Route Segment

There are several possible endpoints that could be used to estimate health effects. Common ones for toxic releases are Emergency Response Planning Guidelines and the Acute Exposure Guideline Levels. For Class 3 accidents, the most common end point considers the thermal radiation from a burning pool. Three end points are commonly used; the distance at which one would receive fatal burns within a minute, second degree burns within a minute and experience pain within a minute. The other endpoint considers the hazard radius from a BLEVE. A BLEVE requires an intact cargo tank and a fire underneath it. The end points from these accidents are based on overpressure generated by the pressure wave from the vessel rupture. Three end points are commonly considered, the distance where the overpressure is sufficient to break glass, cause damage to ear drums, or the maximum distance shrapnel produced by the vessel rupture can be ejected. The latter results in a hazard distance of a half mile. While commonly used, the half-mile distance is very conservative when applied to a BLEVE involving a thin-walled cargo tank carrying gasoline. BLEVEs involving a rail car of Division 2.1 materials, typically a liquefied flammable gas, have resulted in vessel fragments being thrown a half mile. This type of consequence has not been demonstrated for truck cargo tanks containing gasoline. The following paragraphs evaluate the damage radius for two of the more common accidents involving Class 3 flammable liquids.

Pool Fire Gasoline in Bulk. In this scenario, a truck tractor trailer hauling 28 MTs (about 10,000 gallons) of gasoline spills and releases the gasoline at a rate of 20.6 kgs/sec (1,236 kgs/min). The pool is assumed to be on fire. At this discharge rate, it takes approximately 23 minutes for the tank to empty. Based on the National Oceanic and Atmospheric Administration (NOAA) and Areal Location of Hazardous Atmospheres (ALOHA) model, the maximum flame length was 28 meters and the burning pool had a maximum diameter of 16.9 meters (2007). The lethal radius of the fire (death in a minute) is 38 meters. At 55 meters, an individual would receive second degree burns if exposed for longer than a minute and at 88 meters, an individual would experience pain after 60 seconds of exposure. The pool fire continues for over 20 minutes (ALOHA 2007). Most of the injuries and fatalities occur because of vehicle entrapment—individuals who cannot leave their vehicle either because of the severity of their injuries or the absence of an escape route. Figure 19 from ALOHA shows the hazard radii graphically. If one superimposed a six lane expressway onto that diagram, and assuming the accident blocked three lanes in one direction, then within the lethal zone there could be as many as 12 vehicles, four in each lane. Assuming 1.1 occupants per vehicle, there would be 13 individuals in the lethal zone. Expanding the radius out 55 meters would add another six vehicles and eight additional individuals for a total of 21 individuals. Anyone trapped in their vehicles could also receive second degree burns and possibly die. Another 12 vehicles carrying 13 individuals would be in the radius where pain would be experienced after 60 seconds of exposure. Thus there might be as many as 30 vehicles and an estimated 33 individuals within harm's way. For the purposes of this analysis, the 55 meter radius was used. The assumption was made that this large gasoline fire could potentially expose 21 people to fatal burns; assuming 2/3 will escape from danger, a total of seven individuals will be trapped and experience fatal burns.

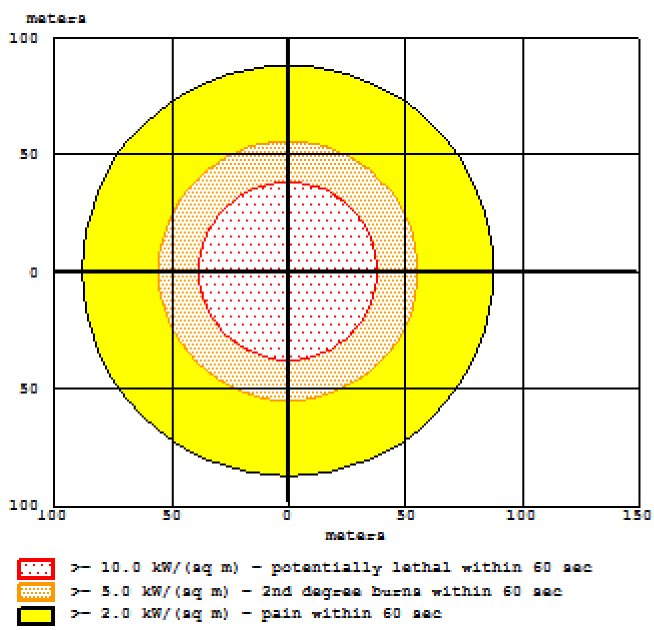


Figure 19: Hazard Radius for a Gasoline Pool Fire

The above paragraph describes a possible scenario. In actuality, from 1998 to mid-2010, there were a total of 427 hazmat transport accidents in the Commonwealth of Massachusetts reported to PHMSA. Of those accidents, 254 or about 54 percent were Class 3 incidents. There were a total of seven fires during that time in Massachusetts and there was one hazmat fatality. There may have been a few non-hazmat fatalities not associated with the hazardous cargo during that time period, but those have not been reported because during most of the 11 year period represented by the data, only hazmat-related fatalities were tabulated. Of the seven fires, five were Class 3 materials and the fatality was as a result of a Class 3 release and fire. Clearly many individuals placed in harms way have been very resourceful when it comes to escaping from danger, something models cannot realistically include because personal behavior is so highly variable and so difficult to model and predict.

From Figure 19, the radius of the fire within which an injury might occur is less than 100 meters (330 feet) from the center of the burning pool and is far less than the half-mile, approximately 800 meter distance suggested for estimating the population risk. Clearly the risk is not associated with a fire scenario. The documentation justifying the half-mile distance for the population risk states that the distance is based on a possible explosion of the vessel carrying the Class 3 material and risk from the shrapnel produced during the explosion. Even this radius for a Class 3 material is conservative because most cargo tanks carrying Class 3 materials are relatively thin-walled aluminum and could not build up the pressure before failure so as to eject a piece of the wall a half mile. The wall of a container for a Division 2.1 flammable gas such as propane is designed to maintain its integrity to a much higher pressure so that when it does fail in a fire, it is capable of ejecting a vessel fragment a half mile.

Vapor Cloud Explosion following a Gasoline Spill. This scenario is similar to previous scenario with the exception that there is no fire. This can also be modeled with ALOHA which shows that there is no sizable plume area that is within 60 percent of the Lower Flammability Limit (LFL) (2007). This limit is used as the lower limit for igniting a flammable gas cloud. There is a total surface area of 6,600 m^2 inside the 10 percent LFL. Since the plume is a small fraction of the LFL, if ignited, the gasoline in the plume would burn but would not flash back to the pool. There would be no vapor cloud explosion (ALOHA 2007).

Establishing a Potential Impact Area

The consequence analyses shown in the previous paragraphs clearly show that the potential impact area for fire and vapor cloud explosions is quite small, less than 100 meters for the dominant class of hazmat being shipped (Class 3 flammable and combustible liquids). In the Hazmat Routing Guidelines document (FHWA 1996), several methods for establishing potential impact areas are described. They range from Method 1, which conservatively establishes a 5 mile potential impact distance, to Method 3, where computer models such as ALOHA shown above are used to establish an impact distance. Method 2 establishes a fixed distance based on the class of hazmat being shipped (FMCSA). For Class 3, the dominant class of hazmat being shipped through Boston, Exhibit 6 in Section III of the Routing Guidelines Document (FHWA 1996), lists a potential impact distance of one half mile on either side of the route. This same distance is recommended for Corrosives, the second most common class of material observed in Boston and also for Flammable Gases, the third most common material observed. This distance is considered very conservative for these types of hazmat. The only scenario that has the potential for causing damage a half mile from an incident would be a BLEVE. Shrapnel generated from a BLEVE of a rail car containing propane, a Division 2.1 material, have occasionally been thrown a half mile. Injury from breaking glass can also occur as far as a half mile from the BLEVE. In this analysis, the potential impact area will be a half mile on either side of the routes being evaluated. The remainder of this report will analyze impacts based a half mile impact area. The next section will show the methods used to estimate the potentially exposed population within a half mile of the routes. The analysis will consider several population types. The base case analyses will consider the number of people residing or employed within a half mile of the routes being evaluated. Sensitivity cases will look at other transient populations that could be present near the routes being analyzed.

Estimating the Population Living Near Alternative Hazmat Routes

In order to estimate the population within a half mile of either side of the alternative routes being evaluated, the following methodology was followed:

- One important element of the population risk is the temporal distribution of the population between night and day. Due to diurnal fluctuations in residential and employment populations, populations were estimated for day (7:00 AM to 7:00 PM) and night (7:00 PM to 7:00 AM).
- The population for the day and night periods were composed of the following elements:
    - Census track data along the routes using traffic analysis zones (TAZs) which provide employment and residential population numbers. These data were obtained from the Central Transportation Planning Staff in 2010. (CTPS 2010)
    - School populations
    - Hospital patients represented by the number of beds in the hospitals along the route and the occupancy rate
    - Patients in nursing homes
    - Hotel guest populations
- A GIS system using Arcinfo software was used to allocate the total population in a TAZ for the day and night periods. The distribution of population along the routes was achieved by first distributing the total population for each of the TAZs located within the half mile boundary on either side of the route. Next the software distributed the population within the TAZ proportional to the percentage of the TAZ found within the half mile zone. For example, if a route had a total daytime population of 2,300 and only 60 percent of the TAZ was located within the half mile zone, then only 1,380 people would be allocated for that route.
- In order to enable the calculation of risk, each route was classified by segments according to their characterization as a particular Massachusetts road class. For example, a route might have one segment classed as a principal arterial and the other as an interstate. Therefore, the population would be allocated for each segment based on a similar approach described above. At the boundaries between segments the population would be allocated based on the proportion of overlapping TAZs located in a particular route segment.
- The final product of the population estimation will be total day and night populations for each road class segment for each route.

The following sections describe in more detail how the various components of the total population were calculated.

Estimating the day and night residential populations: Most people are home during the evening and nighttime hours but a large fraction are away at work or school during the daytime. To estimate the daytime population, the following method was used. The U.S Census Bureau provides estimates of age distributions for the nation, at the State level and for major metropolitan areas every ten years with intermediate updates. The latest census update, prior to the publishing of the 2010 census data, is for 2008. The data for the Boston-Cambridge-Quincy Metropolitan Area is available as at: http://www.census.gov/compendia/statab/cats/population.html (U.S. Census November 2011). Table 6 shows the worksheet used to estimate the fraction of the population that is likely to be home during the day. The source column shows the Table from the Census website or the calculation step used to develop the entry in the Count column. An additional source was data from Suffolk County, https://edis.commerce.state.nc.us/docs/countyProfile/MA/25025.pdf (U.S. Census 2010).

By combining both the census and Suffolk county data, it was estimated that the daytime resident population will be about 30 percent of the nighttime population. The 30 percent estimate represents the fraction that could be home during the day. There are many reasons for leaving home. Those working at home could be on a business trip or visiting with someone at an office in another location. The elderly or the children under five could be at a park or shopping. There is no way to know the exact count of the number of people who might be at home on a particular day. On weekends, it would be reasonable, and conservative to assume all residents are home during both the daytime and nighttime hours.

Table 6: U.S. Bureau 2008 Data for the Boston-Cambridge Quincy Metropolitan Area

Population Category	Count	Source
Total Population	4,822,858	Table 20
Population by Age		
Under 5	384,000	Table 16
5-9	384,000	Table 16
10-14	400,000	Table 16
5 – 19	460,000	Table 16
5 – 19 Total	1,244,000	Total
5 – 18 Total	1,152,000	Prorated
Under 5 or Working age	3,671,000	Total Population minus 5 – 18 Total
Total Employed	2,500,000	Table 581
Unemployment Rate	8.3 %	BOL Statistics for Aug 2010
Unemployed	208,000	Product of last two rows
Work Force	2,292,000	
Work at Home	51,000	Prorated from Suffolk Co. (7,316 of 695,403)
Workers Not Home	2,241,000	Subtract Work at Home from Work Force
Students Not Home	1,152,000	Total Age 5 to 18
Total Not Home	3,393,000	Sum of last two rows
Total at Home	1,430,000	Total Population minus Total Not Home
Percent at Home Day	30%	Percent of Total Population at Home

Estimating the Number of Individuals Employed Near Alternative Hazmat Routes

The methodology for estimating the number employed in vicinity of a hazmat route consisted of two major steps. First, the employment data were obtained from the CTPS allocated by TAZ (CTSP 2010).

In order to allocate the employment data into either daytime or nighttime categories, estimates of about 83 percent of employment occurring during the daytime and about 17 percent during the nighttime were used. To estimate the daytime and nighttime populations of those employed in the Boston area, statistical information was used from the Bureau of Labor Statistics (Beers 2000). In 2000 in the United States, the percentage of workers that worked during the day (from 6:00 AM to 6:00 PM) was 83.2 percent. This was rounded to 83 percent. Therefore, the percentage of the workforce working from 6:00 PM to 6:00 AM would be 16.8 percent. For the purposes of this study, this was rounded to 17 percent.

As described above in the “estimating population” section, the employment data by TAZ was distributed along with the other components of the population along the alternative routes for each road class route segment.

Estimating the School Population

To estimate school population, data were gathered from the Commonwealth of Massachusetts' Office of Geographic Information website (Commonwealth of Massachusetts). GIS software was used to visualize the number of schools and the various types of schools (private, public, special education, charter, etc.). Available Metadata provided enough information to create a document with all Massachusetts schools and a separate document with all Boston-area schools. These documents contained the school name, address, and contact information. The routes being studied were not limited to the Boston area schools so several areas from the Massachusetts area were incorporated, which included: Braintree, Burlington, Cambridge, Chelsea, Concord, Everett, Lexington, Medford, Needham, Quincy, Somerville, and Stoneham. From the Education data from the Massachusetts Open Data Initiative Wiki Space (McKay 2010), specific information about enrollment by school and grade was found. The Massachusetts Department of Elementary and Secondary Education collects enrollment data for all students enrolled in public schools. Regular and Special Education enrollment data by grade, gender, race, language and low income status are available for download (McKay 2010). The school data from the Metadata was cross listed to the population data available through The Massachusetts Department of Elementary and Secondary Education. A table listing the schools used in the analysis is found in Table D-1.

Estimating Hotel Population

In order to estimate the number of people staying in hotels in the areas flanking the alternative routes, two major sources were used. Google Earth was used to search all the hotels in the Boston area. A ruler tool was used in Google Earth to determine the hotels within a half-mile of the alternative routes to be included in the study. In addition, a list of hotels was gathered from a hotel database website (Hotel Guide) from the City of Boston, cities surrounding Boston and cities along the alternative routes. These cities included: Arlington, Belmont, Boston, Braintree, Brockton, Burlington, Canton, Chelsea, Concord, Dedham, Everett, Lexington, Lynn, Medford, Melrose, Milton, Needham, Newton, Norwood, Quincy, Randolph, Reading, Somerville, Stoneham, Stoughton, Wakefield, Waltham, Watertown, Wellesley, Weston, Wilmington and Woburn.[1] Latitude and longitude was calculated for all the hotels located in these cities and was made into a GIS file using TransCAD. This hotel data GIS file was added to the alternative route map in ArcGIS, and a selection query was done to identify the hotels that were within a half-mile radius from the alternative route map.

Hotel population was assumed to be composed of overnight guests and people using the meeting rooms during the day. Hotel employees were assumed to be included in the employment statistics. For each selected hotel, the address, number of bedrooms, number of meeting rooms and total square footage of each meeting room were recorded for each hotel. This information was recorded from the hotel's main website, hotel database websites[2] and by directly contacting the hotel. Some of the data for the total square footage of hotel meeting rooms could not be found, so an estimated number was applied. Using the information from hotels with complete data, an average meeting room size was calculated by dividing the total square footage by the total number of meeting rooms, which was found to be 1,296 square feet.

For the daytime hotel population, an assumption was made that about ten percent of the guests would be at the hotel during the day at any particular time. For most of the large hotels there are usually people in the hotel attending conferences or other events that would contribute to the daytime population. These individuals would likely include both guests and those not staying at the hotel. The total number of people that could fit in a meeting room under conference- or boardroom-style arrangement was obtained from the respective hotel websites. If the information was not available from the website, the total number of people per room was estimated using a meeting space calculator (Venue Chooser 2004), which assigns about 30 square feet of space per person. An occupancy rate equivalent to the hotel occupancy rate was applied to the meeting rooms. This rate was used because there were no available data for the percentage of time that meeting rooms would be typically be used.

For hotels where meeting room data was unavailable, the daytime population was assumed to be ten percent of the number of overnight guests. No allocation was made for meeting attendance. All of these hotels had 150 rooms or less.

During the nighttime, it was assumed that guests would occupy their hotel room. The capacity of each hotel was calculated by multiplying the number of rooms by an assumed average of two occupants per room. This average of two occupants per each hotel room is based on averaging rooms with several or more guests, two guests and those with only one guest. This hotel capacity was multiplied by the most recent hotel occupancy rate for Boston, which is 71.8 percent in 2010 (Urie 2010). This final number is set as the baseline maximum capacity for each hotel because it takes into account average guests per room and hotel occupancy rate. A table listing the hotels used in the analysis is found in Table D-2.

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[1] Not all of these cities ended up having hotels that were close to the alternative routes

[2] Hotel Guide. http://hotelguide.net

[2] Not all of these cities ended up having hotels that were close to the alternative routes

[2] Websites listed in Bibliography

Estimating the Population in Hospitals

For this analysis, hospital populations were assumed to include patients that spend the night in a bed and those at the hospital for outpatient services. The hospital data were gathered from the Commonwealth of Massachusetts Board of Registration in Medicine, which compiles a list of all the licensed hospitals in Massachusetts. Hospitals located in the City of Boston, cities surrounding Boston, and cities along the alternative routes were identified. These cities included: Arlington, Belmont, Boston, Braintree, Brockton, Burlington, Canton, Chelsea, Concord, Dedham, Everett, Lexington, Lynn, Medford, Melrose, Milton, Needham, Newton, Norwood, Quincy, Randolph, Reading, Somerville, Stoneham, Stoughton, Wakefield, Waltham, Watertown, Wellesley, Weston, Wilmington, and Woburn.[3] Latitude and longitude were calculated for all the hospitals located in these cities and made into a GIS file using TransCAD. This hospital data GIS file was added to an alternative route map in ArcGIS and a selection query was done to identify the hospitals that were within a half-mile radius from the alternative route map. In addition to the data provided from the Commonwealth of Massachusetts Board of Registration in Medicine, a search was done with Google Earth for hospitals in the Boston area to see whether there were any hospitals not already accounted for. A ruler tool was used in Google Earth to determine those data points within a half-mile of the alternative routes.

For each of the selected hospitals located within a half mile from the alternative routes, the address, number of beds and number of outpatient visits were recorded. This information was recorded from the hospital's main website, hospital database websites (Hospital Data 2010) and by directly calling the hospital. Some of the data for outpatient visits for specific hospitals could not be found, so an estimated number was applied. Using the information from hospitals with complete data, a ratio of the number of outpatients per day to the total number of beds was calculated, which was found to be 7.86. This ratio was applied to the hospitals with unknown outpatient information to calculate an estimated daily outpatient rate of the hospital.

The daytime population of the hospitals was calculated by adding the number of occupied beds in the hospital to the number of outpatient visits per day. It was assumed that one person would occupy each bed, so the maximum capacity of the hospital would equal the number of beds. This hospital capacity was multiplied by the hospital occupancy rate for Boston, which was 72.8 percent in 2001 (Bazzoli 2003). The number of outpatients per day for each hospital was divided by four, assuming that each outpatient would spend an average of three hours in the hospital. The nighttime population was calculated as the number of beds multiplied by the hospital occupancy rate plus ten percent of twenty five percent of the total outpatients during the day. This figure was used to represent patients visiting the emergency room during the night. A table listing the hospitals used in the analysis is found in Table D-3.

Estimating the Population in Nursing Homes

The data for nursing home and rehabilitation centers, assisted living facilities, and rest homes in the Boston area was gathered first from the Commonwealth of Massachusetts' Office of Geographic Information website. A GIS data layer was downloaded from this website and a selection query was done on all the long term care centers to see which were within a half-mile from the alternative route map. In addition to the data collected from the Massachusetts GIS

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[3] Not all of these cities have hospitals close to the alternative routes.

website, data about long-term care centers were gathered from the American Medicare website (Medicare 2010) from the City of Boston, cities surrounding Boston, and cities along the alternative routes. These cities included: Arlington, Belmont, Boston, Braintree, Brockton, Burlington, Canton, Chelsea, Concord, Dedham, Everett, Lexington, Lynn, Medford, Melrose, Milton, Needham, Newton, Norwood, Quincy, Randolph, Reading, Somerville, Stoneham, Stoughton, Wakefield, Waltham, Watertown, Wellesley, Weston, Wilmington, and Woburn. Latitude and longitude were calculated for all the long-term care centers located in these cities and were made into a GIS file using TransCAD. This care center data GIS file was added to the alternative route map in ArcGIS, and a selection query was done to identify the care centers that were within a half-mile radius from the alternative route map. Lastly, Google Earth was used to search for long-term care centers not already accounted for. A ruler tool was used in Google Earth to determine those data points within a half mile of the alternative routes.

For each of the selected long term care centers, the address, number of beds, and occupancy rate were recorded. This information was recorded from the Massachusetts GIS data, long term care center database websites (Medicare 2010), the care center's main website, and by directly calling the facility. Some of the data for the occupancy rate for specific long term care centers could not be found, so an estimated number was applied. Using the information from care centers with complete data, an average occupancy rate was calculated and found to be 88.9 percent. This average rate was applied to all the centers with unknown information.

The maximum capacity of each center was calculated by assuming one person would occupy each bed or residential unit. The occupancy rate for each center was applied to the number of beds to find the population. This population applies to the daytime and nighttime population because it was assumed that there are not outpatient visits at a long-term care center. A table listing the long-term care facilities used in the analysis is found in Table D-4.

Estimating the Number of Visitors

Sites controlled by the National Park Service attract many thousands of visitors to Boston and the region annually. These visitors were included in the population study because they constitute a significant addition to the other components of population discussed in the paragraphs above. Data were obtained from the National Park Service and used for parks and sites that were closest to the routes chosen for analysis (NPS 2010). The name, address of the sites, and number of visitors were recorded for each park. As there are more visitors during the spring and summer seasons, an average number of visitors per month was calculated from May to September from 2009. Assuming that people can visit the park any day of the month, the average per month was divided by 30 to find an average number of visitors per day. Although this is number is more representative of the summer months, this will ensure that a conservative visitor estimate has been made. Although the number of visitors was applied only to the daytime population, the assumption was made that this number of people would be present at any particular time during the day. The data for the visitors at major National Park Service sites are shown in Table 7.

Table 7: Estimated National Park Visitor Population

Park Name	Address	Daytime Population
Boston National Historic Park Total	Charlestown Navy Yard, Boston, MA 02129	8,849
1. Bunker Hill Monument	Monument Sq, Boston, MA 02129	543
2. USS Cassin Young	Charlestown Navy Yard, Boston, MA 02129	335
3. Faneuil Hall	4 South Market Building, Boston, MA 02109	420
4. Old South Meeting House	310 Washington Street, Boston, MA 02108	135
5. Old State House	206 Washington Street, Boston, MA 02109	205
6. Paul Revere House	19 North Sq, Boston, MA 02113	530
7. Special Event	Monument Sq, Boston, MA 02129	2
8. USS Constitution	Charlestown Navy Yard, Boston, MA 02129	1,148
9. Constitution Museum	Charlestown Navy Yard, Boston, MA 02129	737
10. Charlestown Navy	Charlestown Navy Yard, Boston, MA 02129	2,589
11. Shipyard Galley	1 Pier 7, Boston, MA 02129	106
12. Building 5 Visitor Center	Charlestown Navy Yard, Boston, MA 02129	1,017
13. Old North Church	193 Salem Street, Boston, MA 02113	856
14. Bunker Hill Museum	Monument Sq, Boston, MA 02129	225
Minute Man National Historic Park Total	174 Liberty Street, Concord, MA 01742	3,631
North Bridge Visitor Center	174 Liberty Street, Concord, MA 01742	194
Minute Man Visitor Center	250 North Great Road, Lincoln MA	504
North Bridge Parking Lot	North Bridge, Concord, MA 01742	801
Fiske Hill Parking Lot	Fiske Hill, Lexington, MA 02421	193
Wayside Parking Lot	455 Lexington Road, Concord, MA 01742	150
Meriam	Meriam's Corner, Concord, MA 01742	395
Paul Revere	Paul Revere Capture Site, Concord, MA 01742	317
Hartwell Tavern	Hartwell Tavern, Concord, MA 01742	243
Bus Visitors	Fiske Hill, Lexington, MA 02421	714
Special Event Visitors	Fiske Hill, Lexington, MA 02421	103
Bike Count	Fiske Hill, Lexington, MA 02421	17
Boston African American National Historical Site Total	46 Joy Street, Boston, MA 02114	2,005
African Meeting House	46 Joy Street, Boston, MA 02114	56
Black Heritage Trail	14 Beacon Street, Boston, MA 02108	15
Shaw/5th Memorial (Non-tour)	147 Tremont Street, Boston, MA 02111	1,922
Special Program	46 Joy Street, Boston, MA 02114	13
John Fitzgerald Kennedy National Historic Site Total	83 Beals Street, Brookline, MA 02446	63
	Park Population Total:	**29,033**

POPULATION DENSITY ALONG THE ROUTES

Tables 8 through 10 summarize the total population along each of the alternative routes. Total populations as well as population density are shown in the tables. "Total population" includes all of the population types discussed above including residential, employment and "transient" populations. Population density is defined here as the total population per square mile, Since the analysis is examining the population for one half mile on each side of a route, one square mile is represented by one linear mile of a route.

Table 8: Route Population Characteristics of Through and Alternative Routes – Everett to Quincy

Route Description	Distance Miles	Daytime Population	Nighttime Population	Daytime Pop Density (People /mi^2)	Nighttime Pop Density (People /mi^2)	Night/Day Pop Density Ratio %
Northbound – Quincy to Everett						
Route RA1 – Through Boston	10.7	309,000	173,000	28,900	16,200	56
Route RA2 – Through Cambridge	33.2	245,000	218,000	7,400	6,600	89
Route RA3 – I-93S to I-95N to I-93S	47.0	204,000	173,000	4,300	3,700	86
Southbound – Everett to Quincy						
Route RA1 – Through Boston	10.6	301,000	169,000	28,400	15,900	56
Route RA2 – Through Cambridge	33.8	249,000	223,000	7,400	6,600	89
Route RA3 – I-93N to I-95S to I-93N	47.8	203,000	171,000	4,200	3,600	85

The population data in Table 8 shows that the route through downtown Boston has a higher total population during the day, but the Cambridge route has the highest total nighttime population. At night the total population along Route Alternative 3, which is over 47 miles long, is about the same Route Alternative 1, the through route. This is reflected in the population density along each route. The population density along Route Alternative 1 is much higher than the population density along either of the other routes both during the daytime and nighttime. This difference can be quantified by looking at the ratio of the nighttime population density divided by the daytime population density. This ratio is shown in the last column in Table 9. For RA1, the nighttime population is only 56 percent of the daytime population. For RA2 and RA3, the percentage is 89 and 86 percent respectively. The greater difference in the percentage difference for RA1 shows the dominant influence of daytime employment in downtown Boston. This effect can be stated in another way. The population density during the day is almost the same as the density at night for RA2 and RA3 because, while 70 percent of the residents leave during the day, see Table 6, they are offset by a slightly greater number of people who come into the area to work.

Table 9: Route Population Characteristics of Through and Alternative Routes – Everett to I-95 Exit 12

Route Description	Distance Miles	Daytime Population	Nighttime Population	Daytime Pop Density (People /mi^2)	Nighttime Pop Density (People /mi^2)	Night/Day Pop Density Ratio %
Northbound – I-95 Exit 12 to Everett						
Route RA4 – Through Boston	19.5	334,000	193,000	17,100	9,900	58
Route RA5 – Through Cambridge	24.4	221,000	198,000	9,100	8,100	89
Route RA6 – I-95N to I-93S	38.2	180,000	153,000	4,700	4,000	85
Southbound – Everett to I-95 Exit 12						
Route RA4 – Through Boston	19.7	327,000	190,000	16,600	9,600	58
Route RA5 – Through Cambridge	24.8	224,000	202,000	9,000	8,100	90
Route RA6 – I-93N to I-95S	38.7	178,000	150,000	4,600	3,900	85

The population characteristics of Route Alternatives 4 through 6 are almost the same as Route Alternatives 1 though 3. The biggest difference between Table 8 and Table 9 is that by eliminating from each the portion of the route segment on I-93 near Quincy in Route Alternatives 4, 5, and 6, now the nighttime population density along Route Alternative 4 (which is essentially a shortened Route Alternative 1) is about equal to the day and night population along Route Alternative 5 (which is essentially a shortened Route Alternative 2). Route Alternative 6 (which is essentially a shortened version of Route Alternative 3) has a very low population density along it both day and night, and the day night difference is quite small. The ratios of the nighttime population density to the daytime population density are shown in the last column in Table 9. The same ratio is almost the same as calculated for the values shown in Table 8. The ratios are 58, 89 and 85 percent for RA4, RA5 and RA6 respectively.

Table 10: Route Characteristics for Alternative Surface Routes through Downtown Boston

Route Description	Distance Miles	Daytime Population	Nighttime Population	Daytime Pop Density (People /mi^2)	Nighttime Pop Density (People /mi^2)	Night/Day Pop Density Ratio %
Northbound						
RA7 – HM route through Cambridge to I-90	5.0	133,000	102,000	26,600	20,400	78
RA8 – Cross Street – North Washington	4.8	257,000	120,000	53,500	25,000	47
RA9 – Commercial – North Washington	5.1	321,000	139,000	62,900	27,300	43
RA10 – Land Boulevard – Massachusetts Avenue	7.2	200,000	157,000	27,800	21,800	78
RA11 – Congress – North Washington	4.8	257,000	121,000	53,500	25,200	47
RA12 – Haul Road – Congress – North Washington	5.1	241,000	110,000	47,300	21,600	46
RA13 – Haul Road – Cambridge – Lomasney	5.9	289,000	141,000	49,000	23,900	49
RA14 – Haul Road – Cross – N Washington	5.1	244,000	109,000	47,800	21,400	45
RA15 – Commercial St – Haul Road to I-93S	5.4	309,000	129,000	57,200	23,900	42
RA16 – Lomasney	5.5	291,000	146,000	52,900	26,500	50
Southbound						
RA7 – HM route through Cambridge to I-90	5.2	135,000	105,000	26,000	20,200	78
RA8 – Surface Road – North Washington	4.0	242,000	110,000	60,500	27,500	45
RA9 – Commercial – North Washington	4.3	306,000	129,000	71,200	30,000	42
RA10 – Land Boulevard – Massachusetts Avenue	7.4	203,000	161,000	27,400	21,800	80
RA11 – North Washington – Congress	5.5	282,000	137,000	51,300	24,900	49
RA13 – Lomasney – Congress – Purchase	4.4	267,000	132,000	60,700	30,000	49
RA14 – Lomasney – Congress – Haul Road	5.7	289,000	142,000	50,700	24,900	49
RA15 – Commercial St – Haul Road to I-93S	5.1	337,000	143,000	66,100	28,000	42
RA17 – Surface Road – Haul Road	5.5	262,000	121,000	47,600	22,000	42
RA18 – Congress – Haul Road	5.9	276,000	130,000	46,800	22,000	47

In Table 10, the first route, from Everett to the Turnpike using the posted hazmat route through Cambridge is really not directly comparable to the other routes which all go through Boston and have similar starting and ending points. There are differences among the routes but most are quite similar. One way of showing the similarity is to calculate the ratio of the population density at night to the population density during the day. As shown in the last column of Table 10, for RA7 and RA10 that ratio is 78 percent. All the others, which go through the downtown Boston business section, have ratios between 42 to 50 percent. The greatest percentage difference, 42 percent is for RA9, RA15, and RA17 southbound and RA15 northbound. A segment of Commercial Street is in three of the four routes. These routes have the highest daytime population density among all the routes through the downtown Boston business area. Both RA7 and RA10 have the highest ratio and reflect that the increase in the population along the route during the day is largely compensated for by the people residing along these routes who leave for work elsewhere. For the routes through the downtown business area, the differences point out the dominant importance of employment concentrated in the downtown business area.

Estimating Travel Times on Alternative Routes being Evaluated

Travel times for the alternative routes were conducted by CTPS staff. The primary input for the data was field work conducted by CTPS during the summer of 2010. During this period, CTPS staff drove the routes and recorded actual travel times required to traverse the routes. At least four separate trips were made for each route. Due to some changes in the selection of the alternative routes, CTSP staff updated their travel time estimates to include new route segments. These most recent estimates are shown in Table 11. The travel times provide an estimate of travel differences among the alternatives, and especially between routes that traverse the central Boston area and those that travel over I-90 and 128. If the beltway is used, the non-rush hour trip can take up to 51 minutes to travel from Everett to Milton compared to as little as 22 minutes if the Cross Street route through the center of Boston is followed (CTSP 2010a).

Table 11: Summary of End-to-End Travel Times Hypothetical Corridors by Direction and Endpoints (Travel Time in Minutes) (CTSP 2010a)

Corridor name	Southbound Fellsway to Milton	Fellsway to Willard	Alford to Milton	Alford to Willard
Cross Street	23	26	22	25
Commercial Street	26	29	25	28
Congress Street	28	31	27	30
Lomasney	22	25	25	28
Cross St./Haul Road	28	31	27	30
Commercial St./Haul Road	31	34	30	33
Congress St./Haul Road	33	36	32	35
Lomasney/Haul Road	26	29	29	32
Massachusetts Avenue	40	43	39	42
I-90	54	51	53	50
Route 128	50	47	51	48
	Northbound Milton to Fellsway	Willard to Fellsway	Milton to Alford	Willard to Alford
Cross Street	29	32	27	30
Commercial Street	27	31	25	28
Congress Street	29	32	27	30
Lomasney	25	28	26	29
Cross St./Haul Road	25	28	23	26
Commercial St./Haul Road	23	26	21	24
Congress St./Haul Road	25	28	23	26
Lomasney/Haul Road	21	24	22	25
Massachusetts Avenue	39	42	37	40
I-90	56	52	54	50
Route 128	48	45	49	46

Midday travel times in minutes derived from fieldwork and estimates
Fellsway: Route 28 at I-93 north of Assembly Square
Alford: Route 99 bridge over the Mystic River
Milton: Exit 9 on I-93 near East Milton Square
Willard: Exit 6 on I-93 near South Shore Plaza

Based on discussions with drivers, a modern gasoline cargo tank can be unloaded at about 300 gallons per minute or in about 30 minutes for a cargo tank loaded with 9,000 gallons of gasoline. Assuming an equal time for loading, including preparing the required paper work and the required driver vehicle inspections, a one way travel time of 22 minutes, the minimum shown in Table 11, the total trip time from the start of loading until the return to the loading point would be 1 hour and 44 minutes. Use of the maximum one way travel time shown in Table 11, 52 minutes, the total trip time would be 2 hours and 44 minutes, an increase of almost exactly an hour. These trip times show that if there were no delays, a driver could make 4 trips in an 8 hour day if all the trips used the quickest travel time, and could make 3 trips in an 8 hour day if using the maximum travel time route if one of the trips could be shortened by 12 minutes. A driver frequently experiences long queues during the day at the fuel distribution terminals making it realistic for a driver to make no more than 2 trips on a typical day without overtime. Since the travel times shown in Table 11 are for daytime travel, if a driver worked at night, assuming deliveries at stations can occur at night, it would be realistic to assume that a driver could make at least 3 round trips.

Analysis Methodology Summary

The previous sections have either presented the data or shown the analysis approach that will be used to apply to the routing methodology in 49 CFR Part 397, Subpart C, to alternative hazmat routes being evaluated for consideration in Boston. The truck accident rates by road functional classification have been presented, as has the approach to estimate the number of people that might be present within a half-mile of the routes. The next section of this report focuses on analyzing the routes in a manner that meets the requirements presented in 49 CFR Part 397, Subpart C and especially on determining the relative risk of the alternative routes. This analysis makes the assumption that a driver for a hazmat carrier will travel to a variety of destinations that would require a variety of travel times. They will seldom travel the route with the fastest or slowest travel time twice during a work shift. Thus, on a typical day, considering there will be at least one delay in the loading queue, a driver will be able to make 2 deliveries during an 8 hour day shift and 3 during an 8 hour night shift.

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CHAPTER 3: APPLYING 49 CFR 397 SUBPART C: THE ROUTING OF NON-RADIOACTIVE HAZARDOUS MATERIALS (NRHM)

A State or political subdivision must comply with the Federal standards in 49 CFR 397.71: *The Routing of Non-Radioactive Hazardous Materials* (NRHM) (FMCSA 1994) when establishing specific NRHM routing designations over which NRHM may or may not be transported. In order to confirm any recommendations for routing designations, certain analyses meeting these Federal standards need to be completed. The regulations detail a process that provides a tabulation of the steps that must be followed in order to evaluate the candidate routes comparatively and formulate routing recommendations to the routing authority. Based on these analyses and any recommendations made as a result by the City of Boston, it is anticipated that MassDOT, as routing agency for the Commonwealth, will complete the routing designation process pursuant to the Federal standards and will in time provide the selected routing designations to the FMCSA for inclusion in the National Hazardous Materials Routing Registry.

The following are the federal Standards found in the regulation that must be followed in any routing analysis.

Enhancement of public safety
Ensure public participation
Consult with other jurisdictions
Conduct through routing analysis
If needed, develop agreement with other states
Ensure timeliness (18 months to complete)
Ensure reasonable routes to terminals and other facilities
Resolve disputes between/among jurisdictions

Other Factors to consider include:
Population density
Types of highways
Types and quantities of hazmat
Emergency response capabilities
Results of consultations with affected parties (hearing response)
Exposure and other risk factors (proximity to sensitive areas, e.g., special populations and natural areas)
Terrain considerations
Continuity of routes
Alternative Routes
Effects on Commerce
Delays in Transportation
Climatic Conditions
Congestion and Accident History

To evaluate these Standards and Factors, we applied the approach recommended in the Hazmat Routing Guidelines (FHWA, 1996). The first assessment is for through routing of hazmat. Through highway routing addresses the continuity of movement of NRHM transportation so that it is not impeded or unnecessarily delayed by routing designations. The primary goal of a routing designation is to enhance public safety while not unduly burdening commerce. The through routing criteria provide quantitative measures of these two goals. (FHWA, 1996).

Evaluation of Through Routing Criteria

To apply the through routing criteria, the relative population risk for the current routing and the proposed alternatives must first be determined. Then, the ratio of the relative risk of the current routing to that of the candidate alternative routing is determined.

In 49 CFR 397.71(b)(4) two criteria are presented for evaluating through routes such as the alternative through routes for shipping hazmat through the City of Boston. The two criteria are risk and distance. These criteria would not be applicable for hazmat whose origin or destination is within the City of Boston. The most direct route through the City is designated as the through route, and all other proposed routes are compared to this route.

The through routing risk criteria states that the alternative route may be prescribed (i.e., put into effect) if the most direct route has a risk more than 50 percent higher than the alternative route. Thus, according to the FHWA Guidelines document, "if the ratio of the relative risk of the current routing to that of the proposed alternative is greater than 1.5 – i.e., 'the current routing presents at least 50 percent more risk to the public' – *then the proposed alternative can be designated without further analysis*." (FHWA, 1996). See also 49 CFR 397.71(b)(4)(i).

If the risk of the most direct route is greater than the risk of the alternative route but less than 50 percent greater, *i.e*., the ratio of the relative risks falls between 1.0 and 1.5, then the alternative route may be prescribed if the distance traveled on the alternative route is not more than 25 miles or 25 percent longer, whichever is more restrictive (FHWA, 1996) and 49 CFR 397.71(b)(4)(ii). Thus, only if the ratio of the relative risk between the two routes being compared is between 1.0 and 1.5, does the second criteria, distance, come into play, and then the length of the deviation is examined. Finally, as clearly stated in the rule, no routing with a population risk higher than that of the current routing can be designated. 49 CFR 397.71(b)(4)(iii).

For the through routing analysis, two variants on the through route will be considered. While both will have a terminus in Everett, one through route will have its second terminus at Exit 9 on I-93, the Quincy Exit. The second variant will have its southern terminus at Exit 12 on I-95, the interchange where I-93 begins. For each through route variant, two alternative routes will be considered. The risk for using Route Alternative 1, the first of the through routes considered, is compared with two alternatives that are designated as Route Alternative 2 and Alternative 3. For the second variant, the through route is Route Alternative 4 and it is compared with Route Alternative 5 and Route Alternative 6.

Risk Evaluation of Through and Alternative Routes

In the Hazardous Material Routing Guidelines document, three methods for estimating route risk are given. The methods increase in complexity from the first to the third. The second will be used in this assessment. Using the second method, the average density of people within a selected distance of the route is calculated, multiplied by the accident rate and distance to obtain risk. The equation can be written as follows:

$$Risk = Accident\ Rate * Distance * \frac{Number\ of\ People\ Adjacent\ to\ Route}{Distance * Influence\ Distance * 2}$$

The influence distance from the route is to be determined by the type of hazmat selected for analysis. Since the vast majority of shipments are Class 3 flammable and combustible liquids, the selected distance on either side of the route for these materials of a half mile will be used. As stated previously, this distance was suggested in Exhibit 6 in Section III of the Routing Guidelines document (FHWA 1996). When the half-mile influence distance is placed in the risk equation it can be seen that the risk equation simplifies to:

$$Risk = Accident\ Rate * Number\ of\ People\ Adjacent\ to\ Route$$

The analysis begins with a determination of the risk for the first three routes. It will be then followed by an analysis of the second set of routes using a different second end point further down I-93, at the point where I-93 and I-95 join. This will be followed by looking at the risk associated with using several different alternative surface routes through downtown Boston. Because the focus is on the routes through downtown Boston, the northern terminus of the route will remain on Alford Street at the northern end of the Alford Street Bridge but will have a different terminus, in most cases, the point where the truck traffic would enter or leave the surface portion of I-93 in south Boston.

Route Alternative 1 – The Reference Through Route

For purposes of this analysis, the most direct route is designated as the Cross Street – North Washington Route. As described previously, the route being evaluated begins on Alford Street, Route 99 at the north end of the Alford Street Bridge. The southern terminus is Exit 9 on I-93 near Quincy. The total length of the route is 10.6 miles southbound and 10.7 miles northbound. This route will be compared with Route Alternative 2 and Route Alternative 3 described below. As a sensitivity case, an alternative end point at the southern junction of I-93 and I-95, designated as Exit 12 on I-95, will be used as a through route, called Route Alternative 4. The corresponding alternatives are Route Alternative 5 and Route Alternative 6.

Route Alternative 2 as the Alternative Route

The second alternative route begins at the same point on Alford Street (Route 99) as Route Alternative 1 and ends at the same exit on I-93 south of Boston. Route Alternative 2 uses the signed hazmat route through Cambridge to I-90W, I-95 (Route 128) south to I-93 and then I-93 up to Exit 9 in Quincy. The total distance of this route is 33.8 miles southbound and 33.2 miles northbound. It can be seen from the difference between Route Alternative 1 and Route Alternative 2 that although the route is not 25 miles farther, it is more than 25 percent longer. Therefore it could only be selected as the preferred alternative if Route Alternative 1 had a risk that is more than 1.5 times the risk of Route Alternative 2. The risk ratio will be developed in a subsequent section.

Route Alternative 3 as the Alternative Route

The third alternative route begins and ends at the same points used for Route Alternative 1 and Route Alternative 2. This route goes north on I-93 to the junction of I-95 (Rt 128), goes southward on I-95 to the junction of I-93 and then east and then northward on I-93 to Exit 9.

The total length of this route is 47.8 miles southbound and 47 miles northbound. This route is more than 25 miles longer than Route Alternative 1 so like Route Alternative 2, could only be selected as the preferred alternative if Route Alternative 1 had a risk that is more than 1.5 times the risk of Route Alternative 3.

Route Alternative 4 as the Alternative Route

This route is similar to Route Alternative 1. It begins at the same starting point in Everett on Alford Street but ends on I-95 at the junction of I-93, listed as Exit 12 on I-95. Route Alternative 4 follows the surface streets used by Route Alternative 1 though downtown Boston. The total length of this route is 19.5 southbound and 19.7 northbound. This is considered an alternative through route since it goes through downtown Boston.

Route Alternative 5 as the Alternative Route

This route is similar to Route Alternative 2. Like Route Alternative 2 it begins on Alford Street in Everett, travels through Cambridge to the Massachusetts Turnpike, and at the junction with I-95 takes I-95 south to Exit 12, the junction with I-93. The total length of this route is 24.8 miles southbound and 24.4 miles northbound. When evaluating the routing criteria, this route will be compared to Route Alternative 4. As was the case with Route Alternative 2, when comparing Route Alternative 5 with Route Alternative 4, Route Alternative 5 is not more than 25 miles longer but it is more than 25 percent longer, so for Route Alternative 5 to be preferred as a through route over the most direct route, Route Alternative 4, the risk of traveling on Route Alternative 4 must be more than 1.5 times greater.

Route Alternative 6 as the Alternative Route

This route is similar to Route Alternative 3. Like Route Alternative 3 it begins on Alford Street in Everett, travels up I-93 north to the junction of I-95 (Route 128), and then south on I-95 to Exit 12, the junction with I-93. The total length of this route is 38.7 southbound and 38.2 northbound. Route Alternative 5 is not more than 25 miles longer but it is more than 25 percent longer, so for Route Alternative 5 to be preferred as a through route over the most direct route, Route Alternative 4, the risk of traveling on Route Alternative 4 must be more than 1.5 times greater.

EVALUATION OF THE FIRST THROUGH ROUTE AND ITS ALTERNATIVES

As described in the previous sections, the number of people adjacent to the route is determined by considering the resident population, the number in schools, hospitals, nursing homes and visitors along the route. To this resident population is added the number of employees working within the influence distance. The population estimate is made for both daytime and nighttime travel. The risk comparison of the first three routes is shown in Table 12, first for Northbound travel and then for Southbound travel

Table 12: Risk Summary of Through and Alternative Routes – Everett to Quincy

Route Description	Distance miles	Daytime Population	Nighttime Population	Daytime Risk	Nighttime Risk
Northbound – Quincy to Everett					
Route Alternative 1 – Through Boston	10.7	309,000	173,000	0.29	0.14
Route Alternative 2 – Through Cambridge	33.2	245,000	218,000	0.18	0.14
Route Alternative 3 – I-93S to I-95N to I-93S	47.0	204,000	173,000	0.072	0.063
Southbound – Everett to Quincy					
Route Alternative 1 – Through Boston	10.6	301,000	169,000	0.28	0.14
Route Alternative 2 – Through Cambridge	33.8	249,000	223,000	0.18	0.15
Route Alternative 3 – I-93N to I-95S to I-93N	47.8	203,000	171,000	0.070	0.062

As noted above, the through routing risk criterion for prescribing a route is based on the ratio of the risk of the through route to the risk of the alternatives. From the relative risk values for Route Alternatives 1, 2, and 3, presented in Table 12, it is possible to construct these comparative risk ratios for day and night travel for north and southbound travel for the two alternative routes. The results are shown in Table 13.

Table 13: Risk Ratios for Through and Alternative Routes – Everett to Quincy

Ratio of Risk Between Routes	Northbound		Southbound	
	Day	Night	Day	Night
Route RA1 / Route RA2	1.7	1.0	1.6	0.9
Route RA1 / Route RA3	4.0	2.2	4.0	2.2

For example, to calculate the ratio of the relative daytime risk Northbound, between Route Alternative 1 and Route Alternative 3, we compare the corresponding daytime risk values from Table 12, take 0.29 and divide it by 0.072, which yields a risk ratio of 4.0. This ratio indicates that Route Alternative 1 is approximately 4 times higher risk than Route Alternative 3 during the daytime in the Northbound direction. This risk comparison is from a relative population risk exposure perspective, which is the fundamental concern of any routing designation. In the Southbound direction, the ratio is also 4.0, indicating a consistently higher risk for the use of Route Alternative 1 compared to Route Alternative 3. For nighttime travel, the ratio comparing Route Alternative 1 and Route Alternative 3, Northbound, is 2.2 and for Southbound travel, 2.2, again suggesting that Route Alternative 3 is safer than Route Alternative 1. Note that these nighttime risk ratio values comparing Route Alternatives 1 and 3 are greater than the through routing criteria of 1.5, specified in the regulations at 49 CFR 397.71(b)(4). However, care should also be taken in assigning undue importance to relatively small differences in risk values among routes. In such cases, some consideration should be given to the statistical uncertainty of the underlying data.

Appendix F presents an uncertainty analysis showing that a ratio of less than 2.3 cannot be considered statistically significant at the 95 percent confidence level. Based on the risk ratios in Table 13, the only ratio that is greater than 2.3 is when daytime travel through downtown Boston (Route Alternative 1) is compared to going around the City using I-95 (Route 128) (Route Alternative 3). When the ratio of relative risk is compared for the other route pairing, Route Alternative 2 to Route Alternative 1, the calculated result, is 1.7 (Northbound) and 1.6 (Southbound). This is greater than the though routing risk criteria of 1.5, but less than that significance ratio of 2.3 for daytime travel, and less than 1 for nighttime travel. Thus, based on the through routing risk criteria, Route Alternative 2 would not be picked over Route Alternative 1 at night, even if statistical significance was not considered. During the day, based solely on the through routing risk criteria requiring a risk ratio greater than 1.5, Route Alternative 2 through Cambridge poses lower risk than Route Alternative 1 through Boston. However, this cannot be stated with a degree of certainty reflecting the 95 percent confidence level given the underlying uncertainty in the data. Therefore, the daytime risk ratio between Route Alternatives 1 and 2 is not deemed statistically significant because it is less than 2.3.

It is important to recognize that the purely statistical arguments are being used when any risk acceptance ratio is increased to 2.3 to cover uncertainties in the data. A 95 percent confidence level is difficult to obtain given the inherent uncertainty in accident data. If a decision on routing was made based on a risk ratio of 2, it would just be based on using a confidence interval of less than 95 percent. It is insightful to look at the reasons for the risk ratio differences. During daytime travel, the population on Route Alternative 1 greatly exceeds the population on Route Alternative 3, and Route Alternative 2 has an intermediate population. However at night, Route Alternative 2 maintains its high population whereas Route Alternative 1 and Alternative 3 have almost the same number of potentially affected individuals along the routes, even though Route Alternative 3 is much longer. Basically Route Alternative 2 uses the marked HM routes through Cambridge and the high resident population adjacent to the route balances the modest employment numbers during the day. These differences in population cause the differences in the risk levels and are quite certain. What drives the uncertainty estimate is the uncertainty in accident rate, specifically the uncertainty in truck traffic density that is the denominator of the accident rate equation. Accident rates are difficult to estimate with certainty and accident rate differences between two routes can seldom be supported by accident data. The University of Massachusetts' estimate of accident rates by roadway functional classification is a significant accomplishment. However, any attempt to extend that accident rate analysis down to a specific route for comparison purposes results in a major increase in the accident rate uncertainty. This is because there are too few serious truck accidents, the numerator in the accident rate calculation, and considerable uncertainty in measuring actual truck flows, the denominator of the accident rate calculation.

Sensitivity Case – Use of I-93 / I-95 S as the Through Routing Endpoint

This sensitivity case considers an alternative second end point for the through routing analysis. The routes still have the same origin point in Everett on Alford Street (Route 99) as the northern terminus, but the southern terminus has been moved to Exit 12 on I-95. In this sensitivity case, the through route is Route Alternative 4 and the two alternative routes are Route Alternative 5 and Route Alternative 6. Moving the southern terminus effectively lengthens the through route and shortens the alternative route distances. The alternative routes still have lengths that are more than 25 percent longer than the through route, so like the previous through routing analysis, selecting a different through route, either Route Alternative 5 or Alternative 6, will depend on the risk ratios being higher than 1.5 for the risk of Route Alternative 4 divided by the risk of using either Route Alternative 5 or Alternative 6. The daytime and nighttime risks for these set of routes when using an alternative southern terminus are shown in Table 14.

Table 14: Risk Summary of Through and Alternative Routes – Everett to I-95 Exit 12

Route Description	Distance Miles	Daytime Population	Nighttime Population	Daytime Risk	Nighttime Risk
Northbound – I-95 Exit 12 to Everett					
Route Alternative 4 – Through Boston	19.5	334,000	193,000	0.30	0.15
Route Alternative 5 – Through Cambridge	24.4	221,000	198,000	0.17	0.14
Route Alternative 6 – I-95N to I-93S	38.2	180,000	153,000	0.065	0.057
Southbound – Everett to I-95 Exit 12					
Route Alternative 4 – Through Boston	19.7	327,000	190,000	0.29	0.14
Route Alternative 5 – Through Cambridge	24.8	224,000	202,000	0.17	0.14
Route Alternative 6 – I-93N to I-95S	38.7	178,000	150,000	0.063	0.055

The risk criterion for prescribing a route is based on the ratio of the risk of the through route to the risk of the alternatives. From Table 14 the route risk ratios for day and night travel for north and southbound travel are shown in Table 15.

Table 15: Risk Ratios for Through and Alternative Routes – Everett to I-95 Exit 12

Ratio of Risk Between Routes	Northbound		Southbound	
	Day	Night	Day	Night
Route RA4 / Route RA5	1.7	1.1	1.7	1.0
Route RA4 / Route RA6	4.6	2.6	4.6	2.6

As might be expected, a comparison of the risk ratios in Table 15 with those in Table 13 shows that because the through route, Route Alternative 4, is now longer, its risk will increase and the risk of the alternative routes will decrease, making the risk ratios less favorable for selecting the through route as the prescribed option. In this case, considering the uncertainty in the risk ratio, the Route Alternative 4 / Route Alternative 6 ratio is statistically significant for both day and nighttime travel. This confirms the validity of a routing restriction which would direct hazmat cargoes around Boston where the greater population risk is simply higher than that found along alternative routes that do not go through this densely populated urban area. It is also consistent with current MassDOT signs placed on routes coming into Boston that give notice that hazmat cargoes are prohibited from the Boston tunnels and that direct placarded trucks (at least those that do not have destinations within Route 128) must instead use Route 128/I-95 to go around Boston and the inner suburbs that lie inside Route 128.

Alternative to the Cross-North Washington-Surface Route

The second part of the analysis determines the route risk for a variety of local routing alternatives through downtown Boston using surface roads. While the Cross – North Washington route was used in the through routing analysis as the most direct route, different routes could be selected if they had a significantly lower risk or alternatively the choice could be made on other factors if there is no significant difference in the risk among the many alternatives listed in Table 16.

Of all the routes shown in Table 16, most are comparable in that they begin and end at the same termini. The one exception is the first route though Cambridge, the marked Cambridge hazmat/truck route. The western terminus of this route is the exit onto or off the Massachusetts Turnpike (I-90). Although the day and night risk is similar, the results are really not comparable to the other local routes. The hazmat route through Cambridge to I-90 presents the lowest relative population risk of all of these local surface routes in the evaluation, but this route does not transit through downtown Boston, and as such, could not be used for making "local" deliveries within Boston proper. Accordingly, all that could be said is that the route has similar risks to many of the routes through downtown Boston. The second route, using Cross and North Washington Streets, was used in the through routing analysis and could be considered to be the reference route in this analysis of the surface route alternatives in downtown Boston. In looking at all the remaining routes, the Massachusetts Avenue route which goes through both Cambridge and Boston, is notable. While the daytime risk is similar to the other routes, the nighttime risk remains high while the others drop significantly. This is because the total population remains high along the route for nighttime travel.

The Massachusetts Avenue route is different from the other routes in that it goes through a mainly residential area, which is the reason why the risk remains high at night. The small relative risk difference between day and nighttime travel on this Massachusetts Avenue route could be considered to be representative of local delivery routes in Boston. Clearly, for local deliveries to primarily residential areas in Boston, factors other than shipment risk would have to be used to justify any time of day travel restrictions.

Table 16: Analyses Results for Alternative Surface Routes through Downtown Boston

Route Description	Distance Miles	Daytime Population	Nighttime Population	Daytime Risk	Nighttime Risk
Northbound					
Hazmat route through Cambridge to I-90 [RA7]	5.0	133,000	102,000	0.14	0.11
Cross Street – North Washington [RA8]	4.8	257,000	120,000	0.26	0.12
Commercial – North Washington [RA9]	5.1	321,000	139,000	0.35	0.15
Land Boulevard – Massachusetts Avenue [RA10]	7.2	200,000	157,000	0.21	0.17
Congress – North Washington [RA11]	4.8	257,000	121,000	0.26	0.12
Haul Road – Congress – North Washington [RA12]	5.1	241,000	110,000	0.25	0.11
Haul Road – Cambridge – Lomasney [RA13]	5.9	289,000	141,000	0.28	0.14
Haul Road – Cross – N Washington [RA14]	5.1	244,000	109,000	0.25	0.11
Commercial Street – Haul Road to I-93S [RA15]	5.4	309,000	129,000	0.33	0.14
Lomasney [RA16]	5.5	291,000	146,000	0.29	0.14
Southbound					
Hazmat Route through Cambridge to I-90 [RA7]	5.2	135,000	105,000	0.15	0.11
Surface Road – North Washington [RA8]	4.0	242,000	110,000	0.25	0.11
Commercial – North Washington [RA9]	4.3	306,000	129,000	0.28	0.11
Land Boulevard – Massachusetts Avenue [RA10]	7.4	203,000	161,000	0.21	0.17
North Washington – Congress [RA11]	5.5	282,000	137,000	0.29	0.14
Lomasney – Congress – Purchase [RA13]	4.4	267,000	132,000	0.26	0.13
Lomasney – Congress – Haul Road [RA14]	5.7	289,000	142,000	0.29	0.14
Commercial St – Haul Road [RA15]	5.1	337,000	143,000	0.36	0.15
Surface Road – Haul Road [RA17]	5.5	262,000	121,000	0.27	0.12
Congress – Haul Road [RA18]	5.9	276,000	130,000	0.28	0.13

A sensitivity analysis, shown in Appendix F, on the downtown segment of the Cross – North Washington Street through route estimates that the standard deviation of the risk number is 14.8 percent, meaning that ± 1.64 *0.148 would be the 95 percent confidence level, ± 0.242. Thus since the Cross – North Washington Street route has a daytime risk of 0.26 and a nighttime risk of 0.12, it follows that the range of uncertainty on those two values are ± 0.26* 0.242 and ± 0.12 * 0.242 respectively. When multiplied out the uncertainty band for daytime travel is 0.26 ±0.064 and for nighttime travel 0.12 ± 0.029. When converted into ranges, any route falling outside the range of 0.20 to 0.33 would be considered to have a risk that is statistically significant from the daytime risk of using the Cross – North Washington route and any route falling outside the range of 0.09 to 0.15 would have a risk that is statistically different from nighttime travel on the Cross – North Washington route. It will be shown that the only risk differences derived from the values in Table 16 that are significant are the nighttime travel on Massachusetts Avenue (0.17), which is considered significantly higher than the risks for the other routes and the daytime travel on Commercial-North Washington Street northbound (0.35).

The sensitivity analysis performed in the Cross – North Washington route showed that the uncertainty is primarily driven by the uncertainty in the accident rate, which in turn is driven by the uncertainty in the truck flows. Had the uncertainty analysis been performed on the Massachusetts Avenue route, the uncertainty ranges would be similar to those for the Cross-North Washington route, indicating that it would not be possible to state that there was a significant difference in the shipment risk between day and nighttime shipments on the Massachusetts Avenue Route. Starting with the 0.21 daytime shipment risk, the 95 percent confidence limit ranges from 0.16 to 0.26. The nighttime risk value of 0.17 falls within that range. Since Massachusetts Avenue is considered typical of local delivery routes within the City of Boston, from purely a risk standpoint, the shipment risk data would not support restricting hazmat deliveries to locations within the City of Boston during the day. Since many current deliveries occur during the day, the risk analysis would not suggest restricting the current delivery practice *to points within* the City of Boston in any way. However, consideration of other factors, such as heavy traffic congestion during peak rush-hour traffic flows, may influence a decision among routes that otherwise present similar risk, or take into consideration other restrictions that reflect community or traffic management priorities.

Additional Sensitivity Assessments

The Routing Guidelines suggests that a sensitivity analysis is conducted by modifying key parameters based on the likely variation in their values. The sensitivity analysis below examines two alternative scenarios that have been selected to show that the results of the analysis are not sensitive to the reasonably expected variation in the parameters.

Alternative Scenario 1

The first alternative scenario changes the fraction of the resident population that is home during the day from 30 to 15 percent, effectively lowering the daytime population along each route. Table 17 shows the resultant relative risk parameters and Table 18 shows the resultant risk ratios.

Table 17: Risk Summary if Fraction of Residents at Home during Day Changed to 15 Percent

Route Description	Distance Miles	Daytime Population	Nighttime Population	Daytime Risk	Nighttime Risk
Northbound – Quincy to Everett					
Route Alternative 1 – Through Boston	10.7	292,000	173,000	0.28	0.14
Route Alternative 2 – Through Cambridge	33.2	219,000	218,000	0.16	0.14
Route Alternative 3 – I-93N to I-95S to I-93N	47.0	184,000	173,000	0.064	0.063
Southbound – Everett to Quincy					
Route Alternative 1 – Through Boston	10.6	284,000	169,000	0.27	0.14
Route Alternative 2 – Through Cambridge	33.8	223,000	223,000	0.16	0.15
Route Alternative 3 – I-93N to I-95S to I-93N	47.8	184,000	171,000	0.063	0.062

Table 18: Risk Ratios if Fraction of Residents at Home during Day Changed to 15 Percent

Ratio of Risk Between Routes	Northbound		Southbound	
	Day (Table 13)	Day (Scen 1)	Day (Table 13)	Day (Scen 1)
Route RA1 / Route RA2	1.7	1.8	1.6	1.6
Route RA1 / Route RA3	4.0	4.3	4.0	4.2

Table 18 compares the risk ratios for Scenario 1 with the ratios for the base case shown in Table 13. Decreasing the fraction of people home during the day from 30 to 15 percent results in daytime risk ratios that are higher or the same. Scenario 1 does not affect the nighttime risk ratios. Since it is thought that the analysis that developed the 30 percent number is conservative, these results show that a change that would lower the fraction of the population that is home during the day would not affect any decision to prescribe an alternative route for daytime travel though downtown Boston.

Alternative Scenario 2

This alternative scenario changes the fraction of workers at night from 17 to 8 percent. This means that more people will be along the route during the day and less at night. The resultant risk and their risk components are shown in Table 19. The resultant risk ratios are shown in Table 20.

Table 19: Risk Summary if Number of Employees at Work during the Day Changed to 92 Percent

Route Description	Distance Miles	Daytime Population	Nighttime Population	Daytime Risk	Nighttime Risk
Northbound – Quincy to Everett					
Route Alternative 1 – Through Boston	10.7	334,000	148,000	0.31	0.12
Route Alternative 2 – Through Cambridge	33.2	263,000	200,000	0.19	0.13
Route Alternative 3 – I-93N to I-95S to I-93N	47.0	220,000	157,000	0.077	0.058
Southbound – Everett to Quincy					
Route Alternative 1 – Through Boston	10.6	326,000	144,000	0.30	0.11
Route Alternative 2 – Through Cambridge	33.8	268,000	205,000	0.19	0.13
Route Alternative 3 – I-93N to I-95S to I-93N	47.8	219,000	155,000	0.076	0.056

Changing the fraction of people working at night from 17 to 8 percent increases the daytime employment population but keeps the resident population unchanged. Table 20 shows that the higher worker population increases the risk rations for northbound travel but actually decreases the ratio for southbound travel, making the through route through downtown Boston less attractive. The ratio for RA1/RA3 is still well above the threshold criteria for making RA3 the prescribed route for daytime travel.

Table 20: Risk Rations for Daytime Travel if Number of Employees at Work During the Day Set at 92 Percent

Ratio of Risk Between Routes	Northbound		Southbound	
	Day Table 13	Day (Scen 2)	Day Table 13	Day (Scen 2)
Route RA1 / Route RA2	1.733	1.744	1.733	1.562
Route RA1 / Route RA3	4.017	4.047	4.017	3.995

Table 21 presents the risk ratio results for nighttime travel. A comparison of the reference ratios from Table 13 to the second sensitivity case results shows that the risk ratios are the same or are made less favorable by decreasing the nighttime employment from 17 to 8 percent. The change is relatively small and clearly shows that the risk ratios are not very sensitive to the assumption regarding the fraction of employment present at night. The 17 percent figure is a national average and considers all economic sectors of employment. The downtown Boston employment is predominately financial and for that economic sector, the 17 percent estimate is probably high. Thus this sensitivity case shows that any reasonable change in the fraction of the total employment present during nighttime and daytime hours will not result in a significant difference in the risk ratios and therefore any routing recommendation based on those ratios.

Table 21: Risk Ratios for Nighttime Travel if Number of Employees at Work during the Day Set at 92 Percent

Ratio of Risk Between Routes	Northbound		Southbound	
	Night Table 13	Night (Scen 2)	Night Table 13	Night (Scen 2)
Route RA1 / Route RA2	1.0	0.9	0.9	0.9
Route RA1 / Route RA3	2.2	2.0	2.2	2.0

Table 21 shows that lowering the number of nighttime workers results in a slight lowering of the risk ratio for the comparison of RA1/RA3 and for RA1/RA2 northbound. The results for RA1/RA2 already make any decision to prescribe the route through Cambridge instead of the route through downtown Boston less favorable. The ratio of RA1/RA3 is also slightly less favorable but still greater than 1.5. Thus, there is still some justification for prescribing RA3 over RA1, the downtown route, for nighttime travel but the decision is less favorable. Because few of the businesses in downtown Boston have large nighttime staffs there is almost no manufacturing, the 17 percent number is a national average, an actual survey of nighttime workers in downtown Boston might be closer to the 8 percent assumption in Scenario 2. Thus, based solely on Scenario 2, there might be less justification for prescribing an alternative route for night time travel in downtown Boston.

Additional Sensitivity Analyses Considered but not Quantified

There are several factors that could be changed in sensitivity analyses that were not formally evaluated and quantified. One was the accident rate. It is well known that there is some under-reporting of accidents, and since the number of accidents is in the numerator of the accident rate calculation, the accident rate could be low. However, as long as the number of accidents for one functional class of highway was not under-reported relative to other functional classes, the under-reporting is uniform. Use of a common factor like 1.2 to account for under-reporting would raise all the risks by 1.2, but the 1.2 would cancel out when the route risk ratios were calculated. Thus no quantification to show no effect was performed.

There were some factors used to include the additional people who might be present at hospitals during the day. They could be visiting patients in hospitals or going to clinics. Many people going to clinics are accompanied by an additional person, further inflating the daytime population at hospitals. In comparing the number of people at hospitals to the resident and employment population along a route, the total number of individuals at a hospital that were not employed by the hospital was very small and the uncertainty not evaluated.

The U.S. Census Bureau counts people and does surveys to estimate employment numbers by census tracks. The U.S. Census estimates the counts of residents are accurate to 0.2 percent and the employment numbers are accurate to about 1 percent at the time the counts and surveys were taken. Changing the daytime and nighttime worker population and the fraction of the people at home during the day did not have a significant impact on the risk ratios, so no sensitivity analysis that reduced or increased these figures to account for errors in the projects after the time the counts and estimates were made.

For the routes through downtown Boston, there were two factors that could affect the already high shipment risk numbers for the downtown routes. One was the estimated size of the visitor population. The second is the presence of many tourist buses along the downtown routes.

The visitor population is highly variable. In the analysis, the visitor population used was almost equal to the number of people along the route that were at home during the day. For the first sensitivity analysis shown above that cut the number of residents at home during the day in half, the effect was small. Doubling or halving the visitor population would have a similar effect as the change in the number of people at home during the day.

The presence of the many hop-on hop-off buses along the downtown streets presents a risk that is very difficult to quantify. In the NRHM Routing Guidelines Document, such a population is not specifically listed as a special population under Exposure and Other Risk Factors. However, one specific class of special populations to be considered are those outdoors. The visitor population certainly meets this criterion and those in a tourist bus would be very close to a placarded vehicle as they travel together along the surface routes in downtown Boston. One Class 3 accident occurred on a mountain pass north of San Paulo Brazil on September 8, 1998. The accident resulted in the death of more than 50 individuals on two buses. They died because the Class 3 material pooled around the buses and ignited, making it impossible for many of the individuals to escape. Bus-truck accidents are rare, only a few occur each year in the United States. It follows that accidents involving a bus and a truck hauling hazmat is even less frequent, occurring perhaps once per decade. The ensuing fire following the crash makes it even less likely to occur somewhere in the United States. Limiting the geographic area to Boston makes it even less likely. Clearly, although this accident is one of those rare accidents that could occur, its likelihood is so small that it is very difficult to quantify.

The sensitivity analyses performed in this section confirm that the risk assessment results are quite robust, and the collection of additional data or performing additional analyses would not change any findings or conclusions regarding route risk.

Estimate of Uncertainty in Route Risk Calculation

The risk is being calculated for 18 routes in the Boston Metropolitan Area. Many are slight variations of other routes, selected for the purpose of seeing whether there are any risk-based advantages to directing placarded hazmat truck shipments from not using the most direct surface route through downtown Boston. While risk is one of the key criteria that can be used to identify the prescribed route, since all routes involve some tradeoffs, it is important to know whether there is a significant difference in the risk among the many routes being evaluated. This information can be factored into any decision-making process, so as to weigh risk with other factors such as traffic volume and travel time. Therefore, a route could be selected that does not show a significantly lower risk level than other routes but has been chosen based primarily on other factors. A determination of what constitutes a significant difference in risk is therefore a useful piece of information to a decision maker. Fortunately there are well-developed error propagation techniques that can be used to determine whether the risk difference among routes is significant. The calculations used to estimate uncertainty are shown in Appendix F. These calculations show that the variations in risk among the alternative local routes that traverse downtown Boston are not statistically significant. Consequently, other factors such as distance traveled or factors that reflect community priorities and values should be used to select a preferred route among these various local downtown routes used for local hazmat cargoes where there is a point of origin or destination within downtown Boston.

Additional Analyses

Although all the factors listed in 49 CFR 397.71(b)(9) must ultimately be considered in the routing designation process, the manner and extent to which they are applied in the routing process is at the discretion of the routing agency. The routing agency has discretion not only in selecting the level of analysis for each factor but also in deciding how to apply the results of the analysis. (FHWA 1996). In this Hazmat Route Evaluation Report we discuss how some of these factors can be taken into consideration and might be applied by the routing agency.

Estimating Emergency Response Times on Routes Being Evaluated

One measure of the relative risk of shipping hazmat is the capability of emergency personnel to respond to incidents involving hazmat. This capability includes: minimally acceptable standards for response time, skill levels, abilities to handle different types of releases, equipment, and training. These hazmat response capabilities in the Boston area are related specifically to the capabilities of the fire departments that serve a particular area. These include the Boston Fire Department, the Cambridge Fire Department and the Massachusetts Department of Fire Services. In addition, agreements are in place to provide cooperation for dealing with major incidents. The following discussion addresses each of the fire departments and discusses their capabilities to effectively respond to hazmat incidents.

The Boston Fire Department serves Boston and has five hazmat companies including three engine and two ladder companies. A specialized Hazmat Operational Unit is located at Engine Company 22, one of the three hazmat engine companies. These are staffed by 130 firefighters trained as hazmat technicians. These technicians are distributed in four shifts and allowing for days off and vacations, at any one time there are twenty-four technicians on duty (Anderson, July 2010). In addition there are another ten engine companies with personnel trained in decontamination. These engine companies have access to specialized decontamination units including a Decon Supply Unit, a Mass Decontamination Response Trailer, and Special Operations Command Equipment Trailer. Mass Decontamination Trailers are also located at eight hospitals located around Boston. Response time assumes that one of the five hazmat response units will arrive on the scene within five to ten minutes. Boston also has a comprehensive operating procedure, Standard Operating Procedure No. 53, "Fires, Spills and Other Emergencies Involving Hazardous Materials," which provides guidelines for all members of the Boston Fire Department for use in response to hazmat incidents. The capability of the Boston Fire Department to respond to a hazmat incident involving a truck is defined in four levels of response. Each level requires a greater degree of response and ranges up to a Level 3 incident requiring evacuation of buildings and use of protective clothing for the responders (Boston Fire Department 2006). The operating procedure specifies personnel and equipment as the steps that would be followed by the Department to handle the incident. The Boston Fire Department has mutual aid agreements with the Cambridge Fire Hazardous Material Task Force, and the Massachusetts Hazardous Material Response Team.

The Massachusetts Department of Fire Services operates the state hazmat system that provides primary hazmat emergency response services to the entire Commonwealth with the exception of

Boston and Cambridge. Route 128 (I-95) traverses three hazmat districts; each district is staffed by 45 firefighters trained as hazmat technicians. These firefighters serve on an "on-call basis" as members of the hazmat team in each district. These districts include the: southeast, northeast and metro Boston. The Department of Fire Services maintains three types of units. These include the Technical Operations Modules (TOMs), Hazmat Squads, Operational Response Units (ORUs) and Tactical Support Units (TSUs). The TOMs are primarily responsible for detection and can detect the gamut of hazmat through the use of a large number of detection equipment. The ORUs are the source of mitigation equipment although they can perform rescues. They are trained and have equipment to stop a release and prepare a site for clean-up. The TSUs carry both detection and mitigation equipment. One TSU is located in Natick to the west of the 128 alternative hazmat route. The hazmat teams can have detection equipment on the scene of an incident within thirty minutes and have a team operational within sixty minutes (Ladd, July 2010). TOMs and Hazmat Squads can be in a high population area of the state within 30 minutes. This would include all of the hazmat routes under consideration outside of Boston and Cambridge.

As in Boston, the Commonwealth has mass contamination units that would be assigned to hospitals and 17 units statewide that would be assigned to the scene of an incident.

Cambridge, in addition to Boston, is the only community that has a dedicated hazmat team or teams. Cambridge operates a Hazardous Materials/Special Operations unit as part of a professional department that includes 274 uniformed firefighters and five civilians (Cambridge Fire Department. 2010). HazMat 1 is deployed from the Cambridge Fire Department Headquarters which provides a centralized location for responding to hazmat incidents in the City. In addition, the City has two hazmat trailers deployed at the Engine 2/Ladder 3 and the Engine 8/Ladder4 firehouses. Cambridge has mutual aid agreements with both Boston and the Metrofire mutual aid network. Response time for hazmat incidents is currently unavailable but based on the location of the HazMat 1, response time anyplace in Cambridge is unlikely to exceed fifteen minutes.

Conclusion

Based on the analysis of emergency response to any hypothetical release on any of the alternative routes, the emergency response capabilities were assessed to be adequate for handling the hazmat release and not as a differentiator that would be used to distinguish among or between the hazmat routes and conclude that one route was safer than another.

Boston Climate's Influence on Driving Safety

Boston has a humid continental climate characterized by cold winters and warm summers. However, because of its proximity to the ocean, the temperature extremes are moderated by the influence of the more stable water temperatures when compared to those of the land. The months of December, January, February and March all experience average daily low temperatures below freezing. Precipitation ranges between three and four inches for each month with a total of 42.5 average inches of rain and 42.6 inches of snow. Of course, climatic averages can fluctuate widely and some years may experience extreme snowfalls such as the winter of 2010 to 2011. Major potential climatic hazards for truck transportation include icy and or snow-covered roadways, fog, strong winds, and rain such as those accompanying northeasters and severe summer thunderstorms.

Although these hazards to safe driving inevitably will occur on an annual basis, many of the dangers associated with them can often be avoided through careful attention to meteorological forecasts and when encountered on the roadways, through slower and more cautious driving and imposition of speed restrictions. None of the alternative routes investigated for this analysis were identified as experiencing significant episodes or duration of hazardous weather that would distinguish them from any other routes. Because hazardous weather conditions may occur on any of the alternative routes, the presence of hazardous weather-related road conditions was not judged to be a discriminating factor among the alternative through hazmat routes analyzed.

Identifying Sensitive Environments near Routes being Evaluated

In addition to the human population that may be at risk from exposure to hazmat, there may also be a risk to the natural environment. To determine whether any components of the natural environment would be at risk from a hazmat release, sites along the alternative routes were deemed to be potentially vulnerable to a hazmat spill. The types of sites that were included were of the following general characteristics:

- Areas of ecological importance such as wetlands and habitats of threatened or endangered species.
- Watersheds, major aquifers and reservoirs that serve as water sources for drinking water or critical habitats.
- Natural areas of exceptional recreational value such as scenic rivers and wilderness areas.

The information for these environmental areas was obtained from compiled datalayers from the Commonwealth of Massachusetts GIS website. Natural areas that are of critical preservation value, protected status, or at risk for endangerment were selected to be studied. Specifically, site information was gathered from the following environmental databases identified by the Commonwealth of Massachusetts, Geographic office:

1. Protected and Recreational Open Space – This map contains boundaries of conservation lands and outdoor recreational facilities that are under some level of land protection. As some of the areas in this database were not necessarily of critical environmental concern, the areas were selected for based on their primary purpose. If the primary purpose of the area was “C” (conservation areas that are non-facility based), “W” (water supply protection) or “Q” (habitat protection), then they were chosen from this datalayer (Commonwealth of Massachusetts 2010)
2. Areas of Critical Environmental Concern – This map contains boundaries for areas given special importance because the natural area possesses a quality, uniqueness and significance. These areas are nominated at the community level and are designated by the Secretary of Energy and Environmental Affairs (EEA) (Commonwealth of Massachusetts 2010).
3. NHESP Priority Habitats of Rare Species – This map contains boundaries of habitats with state-listed rare species as identified by the Natural Heritage and Endangered Species Program (NHESP). These areas must also be compliant with the Massachusetts

Endangered Species Act (MESA). Wetlands, uplands and marine habitats constitute a large portion of the areas in this datalayer (Commonwealth of Massachusetts 2010).

4. Estimated Habitats of Rare Wildlife – This database contains boundaries that are a subset of the Priority Habitats of Rare Species and are based on rare wetland wildlife observed by the NHESP. They do not include areas marked for rare plant or wildlife with strict upland habitats. Estimated habitats must follow regulations of the Wetlands Protection Act (Commonwealth of Massachusetts 2010).
5. Certified Vernal Pools – This database contains locations of vernal pools certified by the NHESP. These areas must also be compliant with MESA. Vernal pools habitats are important for the life cycles of many wildlife species, including the function of breeding and feeding. Also, these pools maintain biological activity and are not a resource area protected by the Wetlands Protection Act (Commonwealth of Massachusetts 2010).
6. NHESP Living Waters Critical Supporting Watersheds – This database contains areas with strong hydrologic contributions to lakes, ponds, rivers and streams that are important for freshwater biodiversity. These areas have the highest ability to either sustain or degrade these lakes, ponds, rivers and streams. These watersheds were identified in a study done by the Natural Heritage Program and University of Massachusetts' Landscape Ecology Program. The threat metrics that were considered for each critical supporting watershed includes impervious surfaces, road density, road crossings, potential point sources, agricultural intensity, dam intensity, and public water withdrawals (Commonwealth of Massachusetts 2010).
7. NHESP Natural Communities – This database contains areas of natural communities that are identified for biodiversity conservation as observed by NHESP. Aquatic communities are not included in this datalayer. The natural communities themselves are not protected themselves under MESA, but may contain rare species that are (Commonwealth of Massachusetts 2010).
8. Priority Natural Vegetation Communities – This database contains eight natural communities identified by NHESP as critical conservation areas for biodiversity. Only six of the eight communities were found to be along the alternative routes, which include: coastal communities, vernal pools, acidic peatlands, riverines, maritime sandplains, and pine barrens (Commonwealth of Massachusetts 2010).
9. Outstanding Resource Waters – This database contains watershed areas that are considered an outstanding resource due to their socioeconomic, recreational, ecological, and or aesthetic values. These watersheds were classified as outstanding by the Massachusetts Surface Water Quality Standards of 2007 (Commonwealth of Massachusetts 2010).
10. Surface Water Supply Watersheds – This database contains watersheds for all surface water supplies including active, inactive, emergency, sources outside of Massachusetts, watersheds that extend into other states and watersheds from other states that extend into Massachusetts (Commonwealth of Massachusetts 2010).
11. Non-Potential Drinking Water Source Areas – This database contains areas that are used in considering when ground water should be cleaned in case there is a release of a hazmat. These areas are not based on existing water quality and do not indicate poor conditions (Commonwealth of Massachusetts 2010).

All the critical sites were mapped using Arcinfo GIS software to determine which sites were located within the half-mile zone flanking an alternative route. The critical sites that were in proximity to the alternative routes were marked with a particular symbol or color to indicate the general location of the site. As these sites are actually polygons, they extend around the symbol that it was labeled with on the map. Finally, a qualitative analysis was conducted to determine whether a potential hazmat release would result in negative consequences that could not be mitigated by clean-up crews. Figure 20 shows the major sensitive environmental areas located within a half-mile of the alternative routes. Appendix E provides a listing of the specific sites that are mapped in the figure and includes the estimated acreage for each site. The Guidance document (FHWA, 1996), Section IV, pp. 30-32, presents a method for quantifying the relative risk to sensitive environments based on measuring the area of each type of sensitive environment within the impact area and summing to determine the total area. This method could not be used because many of the sensitive areas associated with one environmental category overlap with another. The method used first estimated the area within the half mile buffer on either side of a route with no environmental sensitivity and then subtract that area from the total area within the buffer. The guidance document was followed after the total acreage of sensitive area was identified. That total sensitive environment area within each route is then multiplied by the appropriate accident rate, and summed to determine the relative route sensitive environment risk. This quantitative analysis highlights potential risk differences among the alternative routes and Table 22 summarizes these relative environmental risk differences.

Table 22: Environmental Risk Results for the Alternative Routes RA1 Through RA6

Route	Distance	Acres	Environmental Risk $*10^6$
Everett to Quincy (Exit 9 on I-93)			
Route Alternative 1 – Through Boston	10.7	920	0.47
Route Alternative 2 – Through Cambridge	33.2	4,583	2.9
Route Alternative 3 – I-93S to I-95N to I-93S	47.0	14,500	6.8
Everett to Exit 12 on I-95			
Route RA4 – Through Boston	19.5	6,969	2.2
Route RA5 – Through Cambridge	24.4	2,606	1.3
Route RA6 – I-95N to I-93S	38.2	10,898	5.1

From the environmental risk point of view, the route through Boston has the lowest environmental risk because there is limited open space, most of the land is occupied by homes and business or governmental office space. The alternative routes have much more open space, one of the sensitive environments considered. The results show that the beltway routes, even though the accident rate is much lower, by about a factor of three, present higher environmental risk. What was unexpected was that the differences were not larger. Slightly more than an order of magnitude separates the downtown route, RA1 from the route with the highest environmental risk, RA3. The sensitivity case, RA4 through RA6 shows a much more balanced environmental risk because more of RA4 is an extension of RA1 and the added segment has more environmentally sensitive areas. The difference between the through route, RA4 and the longest route, RA6 now differs by a factor of 2.4. Since that the risk assessment methodology assumes that any spill on a roadway in an environmentally sensitive area causes the same damage as any other accident, these differences are not considered significant.

For protection of people and the environment, the U.S. DOT regulations clearly place the major responsibility for protection on the design of the packaging, the maintenance of the vehicle, and the qualifications of the driver. The drivers of vehicles carrying hazardous materials must be specifically trained on the handling of these materials and must have a hazardous material endorsement on their license indicating that they understand the nature of the cargo they are carrying the procedures involved for protecting the public and the environment should as spill occur. Furthermore the packaging must meet DOT standards, which reduces the probability of a spill should the vehicle be involved in an accident. DOT has determined that the driver, vehicle and packaging requirements for transporting hazardous materials are adequate to protect people and the environment. Thus, even though the environmental risk is higher for some of the routes, the DOT requirements are thought to provide adequate protection and therefore need not be a determiner in any routing selection. Nevertheless, a spill can occur and sensitive environments as well as people can be affected. This analysis follows specific routing criteria that have been promulgated to ensure public safety. Consequently, population risk is judged to be more important than environmental risk. The environmental risk is presented but will not determine any routing recommendation.

Conclusion

There were several natural areas of critical or protected status that were located nearby the alternative routes and may suggest some areas for consideration. A spill along an alternative route to a surface water supply reservoir is potentially a significant environmental impact. A reservoir cannot necessarily be shut off if it is critical for supplying drinking water. Although the impacts may be attenuated downstream or down gradient via dilution, etc. it may not be possible to quickly clean up a major spill within a roadside reservoir (e.g., 10,000 gallons of gasoline into the water body). A shutdown of the reservoir pending cleanup could be a significant issue for a community. However, with respect to the impacts from a less catastrophic spill, there was no indication that these areas were strongly at risk since there are regulated safety mechanisms in place to control and clean up a hazmat accident. For example, deployment of cleanup measures such as booms and absorbent materials would help mitigate an accidental petroleum spill. Also, since these areas extend further than the half-mile impact zone on each side adjacent to the alternative routes, it is likely that there are protected areas or threatened species not immediately next to the alternative routes by which freight carriers will be transporting hazmat. Therefore, although there are some significant sensitive environmental areas along the routes, selection of any of the alternative routes as the through hazmat route would not substantially increase the risk of environmental damage.

In the less likely case of a serious hazmat accident, the data presented may be useful in identifying the habitats or sensitive receptors that may need extra concern or more thorough clean-up. For instance, areas that contain threatened or endangered species could be attended to first and then watershed areas that provide water for specific populations. Although this prioritization again depends on the severity of the accident, hazmat spills could have a more direct effect on critical habitats due to direct contact. On the other hand, hazmat spills could have an attenuated indirect affect on watershed areas, as these areas can be blocked from providing water and cleaned up before they serve their purpose again.

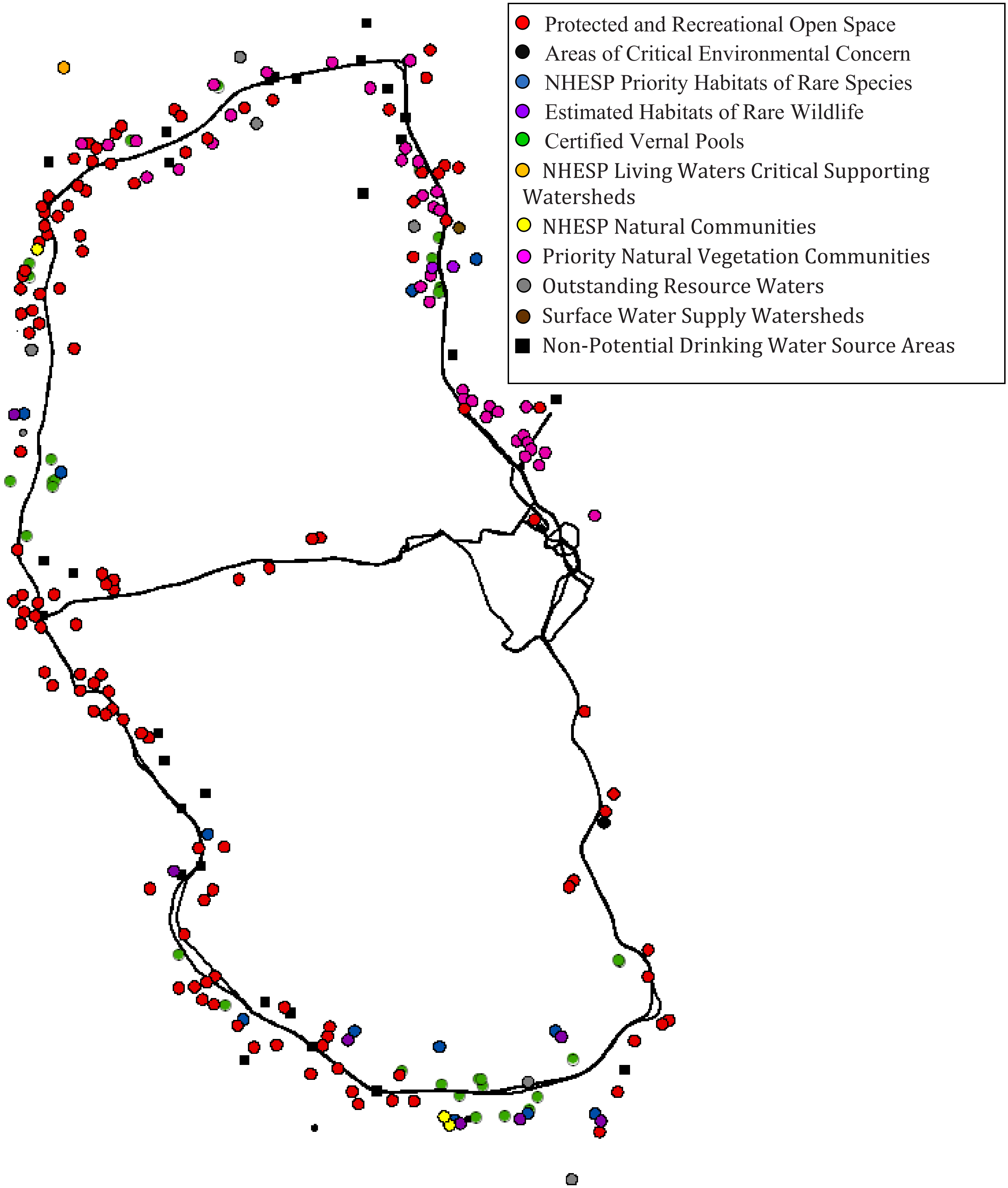

Figure 20: Major Sensitive Environmental Areas Located Within One Half Mile of the Routes

Burden on Commerce [49 CFR 397.71(b)(5)(i) and 397.71(b)(9)(x)]

As required in the Federal NRHM Routing Regulations, Sections 397.71(b)(5) and (9)(x), the "burden on commerce" of any alternative routing must be evaluated. According to the routing Guidelines (FHWA, 1996), p. 33: "[u]nderstanding and evaluating the likelihood of burden on commerce is an intrinsic part of the selection process, but not one that requires additional steps or actions. If steps in the Guide are followed, burden on commerce should not become an issue." (FHWA, 1996). The term "burden on commerce" is defined in the glossary of the Guidelines (FHWA, 1996) as "an effect that creates additional shipment costs arising from such things as routing restrictions that create circuitous routes that in turn may create shipment delays." Any routing designation made in accordance with Subpart C of Part 397 shall not create an "unreasonable burden" on interstate or intrastate commerce [§ 397.71(b)(9)(x)]. Thus, as with many decisions, the impact on commerce is one of the factors to consider when recommending an alternative route or placing restrictions on a through route.

In order to evaluate the potential burden on commerce associated with potential candidate route alternatives effectively, some specific routing restrictions need to be considered. The through routing analyses identified route population risks for the through route from Everett to Quincy using the surface streets of downtown Boston (RA1) and as required in the regulations compared that route with an alternative route that avoided downtown Boston. Two alternative routes were evaluated, The route designated RA2, used the existing hazmat route through Cambridge to the Massachusetts Turnpike then used I-95S (MA 128) to Exit 12 and then went north on I-93N to Exit 9, the Quincy Exit. The next, denoted (RA3) went north on I-93N to I-95 (MA 128) took I-95 south to Exit 12 and then went north on I-93N to Exit 9. Table 13, showed that RA3 met the risk criteria for being selected as a prescribed route for both day and nighttime travel and RA2 met the *through routing criteria* of 49 CFR 397.71(b)(4) for being selected as a prescribed route for daytime travel. Subsequent sensitivity and uncertainty analyses showed that the population risk differences were sufficient for designating RA3 as the prescribed through route for daytime travel, effectively prohibiting through route transportation of NRHM (but not local deliveries within Boston) on downtown Boston streets (using RA1) during daytime hours – 7:00 AM to 7:00 PM because continuity of movement could be ensured by using an alternative through route that presents a significantly lower risk to the public (i,e, RA3). Further evaluation and clarifications may be useful here to determine if such a restriction may present an unreasonable burden on commerce. First of all, such a restriction would not be a complete denial of any deliveries or pickups to any point in the Boston area, something that would clearly be a burden on commerce. Secondly, the restriction would not be for local deliveries within the City of Boston because these pickups or deliveries would not necessarily need to use the Route Alternative 1 surface streets such as Cross and North Washington to make these local deliveries. If necessary, the City could make exceptions for those carriers that documented the need for using the downtown routes. Since, most of Boston's area is west of Massachusetts Avenue, that route is probably a more direct route to many hazmat pickup and delivery points, thereby avoiding the need to use the downtown City streets.

One element that may be considered when evaluating potential burden on commerce is to consider the economic impact of such a proposed daytime restriction.

For this analysis, the monetary burden on commerce can be assessed by looking at the additional costs that could be incurred by a carrier if required to change the currently designated hazmat route used for transporting hazmat through Boston. The approach used was to apply an hourly cost for truck operation to estimate the additional time required to travel the alternative routes. Tables 23 and 24 show comparative costs for selected alternative routes based on travel time and an hourly cost for operating a truck. The analysis in the travel time section showed that it was reasonable to assume a truck driver would make two trips each work day. Assuming a 40 hour work week, the driver would make 10 roundtrips per week for a maximum of 520 trips per year. Hourly costs for operating a truck were estimated by the American Transportation Research Institute (ATRI) http://www.atrionline.org/research/results/economicanalysis/Operational_Costs_OnePager.pdf Accessed on 12/28/2010 (ATRI 2010) to be 83.68 dollars per hour or 1.39 dollars per minute.

Table 23: Estimated Costs Based on Travel Time Differentials with Route Alternative 1 or 4 (Northbound)

Route Number	Corridor Name	Drive Time from Quincy to Alford	Time Difference from Cross St	Additional Cost per Day	Additional Cost per Year
Route RA1	Cross Street	27	0	$0.00	$0.00
Route RA2	I-90	54	27	$75.31	$19,581.12
Route RA3	Route 128	49	22	$61.37	$15,954.99
Route RA4	Cross Street to I-95	36	0	$0.00	$0.00
Route RA5	I-90 to I-95	45	9	$24.04	$6,250.35
Route RA6	Alford to I-95	40	4	$10.09	$2,624.22

Table 24: Estimated Costs Based on Travel Time Differentials with Route Alternative 1 or 4 (Southbound)

Route Number	Corridor Name	Drive Time from Alford to Quincy	Time Difference from Cross St	Additional Cost per Day	Additional Cost per Year
Route RA1	Cross Street	22	0	$0.00	$0.00
Route RA2	I-90	53	31	$86.47	$22,482.03
Route RA3	Route 128	51	29	$80.89	$21,031.57
Route RA4	Cross Street to I-95	32	0	$0.00	$0.00
Route RA5	I-90 to I-95	43	12	$32.46	$8,439.83
Route RA6	Alford to I-95	41	10	$26.88	$6,989.38

Since each carrier must make a round trip, the total costs shown in Table 23 must be added to the costs shown in Table 24. The total distance, time and cost impacts for the use of RA1 though RA6 are shown in Table 25. When RA1 (direct route through Boston) is compared to RA3 (using Rt 128), the incremental cost increase per driver, a reasonable measure of the impact on a carrier for requiring the use of RA3 instead of RA1, is almost 37 thousand dollars per year. As would be expected, the use of another end point further down I-93 reduces the cost impact. This can be seen by comparing RA4 with RA5 or RA6. The cost impact is about half that shown in the comparison of RA4 with RA5 or RA6. This shows that the 42 thousand dollars can be consider as the maximum additional cost that would be experienced by a carrier.

Table 25: Estimated Round Trip Costs Based on Travel Time Differentials

Route Number	Corridor Name	Drive Time from Alford to Quincy	Time Difference from Cross St	Additional Cost per Day	Additional Cost per Year
Route RA1	Cross Street	49	0	$0.00	$0.00
Route RA2	I-90	107	58	$161.78	$42,063.15
Route RA3	Route 128	100	51	$142.26	$36,986.56
Route RA4	Cross Street to I-95	68	0	$0.00	$0.00
Route RA5	I-90 to I-95	88	20	$56.50	$14,690.18
Route RA6	Alford to I-95	81	13	$36.98	$9,613.59

This cost increase shown in Table 25 needs to be put in perspective. Assuming the fuel oil and gasoline sales are distributed in the Boston Metropolitan area based on population, a tabulation of the populated areas within or near Rt 128 shows that much of the population is north of Interstate 90, the Massachusetts Turnpike. In addition, as shown in Table 26, eight of the nine terminals are also located north of downtown Boston. These two facts tend to reduce the effects of any travel restrictions through downtown Boston.

Table 26: Listing of Terminals in Greater Boston Area in 2009

Facility Name	Location	Address
Global Revco Terminal	Revere	101/201 Lee Burbank Highway
Global Petroleum Terminals	Revere	71 & 140 Lee Burbank Highway
Global South Terminal LLC	Revere	49/96 Lee Burbank Highway
Irving Oil Terminals, Inc.	Revere	41 Lee Burbank Highway
Gulf Oil Terminal	Chelsea	281 Eastern Avenue
Chelsea Sandwich Petroleum Storage Facility	Chelsea	11 Broadway
Exxon Mobile Corp. Everett Terminal	Everett	52 Beacham Street
Conoco Phillips East Boston Terminal	East Boston	467 Chelsea Street
Deepwater Oil Terminals, Inc.	Quincy	728 Southern Artery

In an effort to quantify the fraction of the shipments that might be effected by any restrictions on travel through downtown Boston, the latest census figures for Cities, Towns and Places having more than 15,000 inhabitants was downloaded from the Census Bureau website (http://www.citypopulation.de/USA-Massachusetts.html) Any population centers within or adjacent to Route 128 were tabulated. The total number of inhabitants within these population centers totaled 2.153 million inhabitants. It was assumed that populated area south and east of Exit 15 on I-95 (Rt 128), would be serviced by gasoline or fuel oil trucks that would travel through downtown Boston if there were no travel restrictions. The population of those Cities, Towns or Places totaled 347 thousand inhabitants, about 16 percent of the total population within or near Route 128. Since many of the shipments from the oil terminals located north of downtown Boston would see the effects of any travel restrictions through downtown Boston, it is reasonable to reduce the impact of any restriction to that fraction of the estimated population south of the City. Consequently, only 16 percent of the trips, implying 16 percent of the total dollar impact ($42,000), would be realized by a carrier's driver. Thus, the annual total impact, is estimated at about 6,730 dollars per year. If there are 520 shipments per year for each vehicle and each shipment holds 10,000 gallons, at 3 dollars per gallon the total revenue stream is in excess of 15 million dollars and from Table 5, the total value of all Class 3 truck shipments in the Boston, Worcester, Manchester region in the Commonwealth of Massachusetts is in excess of 15 billion dollars. Even if the company profit is only 1 percent of revenue, the 6,730 dollars is only 4.3 percent of the profit, a cost easily passed onto the customer through increased delivery cost of less than 0.1 cents per gallon. If the cost were entirely passed onto the people south of Boston, the cost would be less than .about .8 cent a gallon.

The impact on the carriers transporting fuel oil and gasoline from the single terminal in Quincy is larger. For analysis purposes, it was assumed that all the populated areas located within or near Route 128 and north of Exit 32 would use routes through downtown Boston if there were no downtown travel restrictions. A total of 839 thousand inhabitants are potentially affected. This represents 39 percent of the total population. This would be a significant impact but clearly this single terminal could not supply 39 percent of the total fuel needs for 2.153 million inhabitants residing in or near Route 128. If a daytime travel restriction through downtown Boston were imposed, this terminal would probably focus on meeting the needs of the inhabitants south and west of Quincy, while at the same time attempting to meet some of the fuel requirements of the other 61 percent of the residents. Carriers using the Quincy terminal can clearly supply numerous customers in these regions without any cost penalty and perhaps, depending on the cost charged by the terminal, at a cost advantage.

This analysis of the potential burden on commerce did not consider that at the present time there are numerous hazmat carriers traveling through downtown Boston at night. The City of Boston Traffic Department provided 24 hour traffic cam video tapes for several locations in downtown Boston. While it was not possible to see the placard on any cargo tank, it was possible to count cargo tanks with a placard holder. There was one traffic cam that was particularly easy to observe, the southbound traffic on the North Washington Street Bridge from the intersection at Commercial Street. The totals for one day are shown in Table 27 It can be seen that about 30 percent of the cargo tanks are currently using the downtown surface streets during the day. If this factor were included in the estimated cost increase from restricting hazardous material transport during the day, the burden on commerce would be reduced to 30 percent of the already small impact.

Table 27: Daily Cargo Tank and Bus Counts on North Washington Street Bridge Southbound

Time\Vehicle Type	Truck Cargo Tank	Tour Buses	Ducks	School Buses	City Buses	Health Care Vans	Bus Van Total
7 AM to 6 PM	26	259	82	13	255	53	662
6 PM to 7 AM	63	35	10	4	131	15	195
Total for 24 hrs	89	294	92	17	386	68	857
Day Fraction %	29%	88%	89%	76%	66%	78%	77%

Conclusion

The requirement that a routing designation impose no unreasonable burden on commerce is derived from the Commerce Clause of the U.S. Constitution which prohibits States from erecting barriers to the free flow of interstate commerce (FHWA 1996). Any added burden on commerce associated with designating a prescribed hazmat route from among the alternative routes evaluated here would apply to all shippers, carriers and end users of hazmat. Despite the differences among the alternatives, any routing decision that is made will apply equally to all shippers and carriers, whether engaged in interstate commerce or intrastate commerce. There is no discrimination against interstate commerce *vis a vis* intrastate commerce in designating a prescribed hazmat route through Boston that attains the primary objective of enhancing public safety. Carriers would not be prevented from reaching any destination for their deliveries or pickups. None of the destinations would be off-limits. Furthermore, since through shipments are likely to be approved for a designated route for nighttime shipments, based on the comparable risk assessment results for the routing alternatives studied, a carrier would be able to make a shipment through Boston by adjusting its schedule for hazmat deliveries and pickups. This is also true under current City of Boston ordinance that imposes no nighttime restrictions are imposed on through shipments of flammable liquids during the overnight hours (8:00 PM – 6:00 AM). If the data shown in Table 27 is representative, the majority of the shipments could occur at night and there would be no significant economic penalty for these carriers

In the analysis shown above, since only one of nine terminals (11 percent) of the terminals, is located south of Boston and 16 percent of the population near or within Route 128 is located south of Boston, any restrictions on travel through downtown Boston would result in a relative small transportation cost increase, about a tenth of a cent per gallon if passed onto all customers and less than a penny a gallon if it were passed onto to service stations south of Boston who receive gasoline from the terminals north of the City. There would be no cost penalty and probably a reduced shipment cost if the gas stations in south Boston received their fuel from Quincy.

The analyses in this Section present a rational basis for limiting the transport of hazmat to certain routes is the reduction of risk to public health and safety. A hazmat routing designation would achieve its goals by restricting the hazmat route to the alternative deemed safest in the analysis provided it does not create an “undue burden on commerce.” If we assume the current hazmat truck route, Route Alternative 1, as the designated NRHM route, then Alternative Route 3 (Route 128 beltway) poses no unreasonable burden on commerce through cost or impairment of efficiency. Some delay to transportation of hazmat may be deemed reasonable in the interest of increased public safety. Alternative Route 3 does impose additional travel time costs to carriers compared with Alternative Route 1, the most direct through route, given that most of hazmat terminals for fuels are located to the north of the City, and thus using the Route 128 beltway is more circuitous than via the most direct route through downtown Boston. The limitations in the routing for Alternative 2 or 3 should not represent an unreasonable burden on commerce based on the maximum forecasted increase in the round trip travel time of approximately 58 minutes estimated by comparing RA1 with RA2. Note that if RA3 is used, the estimated cost impact is less. As shown in Table 25, this increased travel time of 58 minutes associated with use of Route Alternative 2, for example, is estimated to add approximately $162 per day or $42,100 per year in operating costs. This added cost, if passed onto all the residents within or near Route 128 would be less than 0.1 cents per gallon or if passed on to just those stations located south of Boston, less than a penny a gallon. As supported by the risk analyses, this is not considered an unreasonable burden on commerce in relation to the increased public safety associated with the use of alternative through routes RA2 or RA3.

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CHAPTER 4: CONCLUSIONS

This analysis has compared alternative routes for their suitability as through routes for the shipment of hazmat through Boston. The analysis evaluated a number of variables including the characteristics of the infrastructure composing the alternative routes, the risk to populations from a hazmat spill, the capabilities of emergency response available along the routes, the vulnerability of sensitive environmental areas to a hazmat spill, the affect of climate and related meteorological conditions on truck safety and the burden on commerce from the selection of a particular routing alternative. With the exception of limitations posed by the narrow Pleasant Street on the Cambridge route (Route Alternative 2 in Table 12), the significant differentiating variable is route risk related to the potential exposure of populations along a route as a consequence of a hazmat spill.

Major report conclusions include the following:

- Based on the differences in route risk, the routes through downtown Boston are significantly higher in risk than travel on the beltway (Route 128). Table 28 summarizes the day and nighttime risks for the first six alternative through hazmat routes.
- Route 128 should be the leading candidate for designation as a through hazmat route. Applying the federal through routing criteria and comparing Route Alternative 1 (through Boston) with Route Alternative 3 (which uses Route 128) demonstrates the significantly increased risk posed by hazmat cargoes coming through Boston. Because Route Alternative 1 poses more than 50 percent greater risk than Route Alternative 3, Alternative 3 may become the designated hazmat route, if selected, regardless of its length and circuitry relative to the other alternatives. Sensitivity and uncertainty analyses were performed on these shipment route risk results.
- Factors besides risk such as emergency response capabilities, the location of sensitive environmental features, climate and the burden to commerce – while worthy of consideration – do not represent factors that can be used to effectively discriminate among the alternative through routes.
- There is ample justification to monitor, control and even restrict daytime through hazmat shipments through downtown Boston.
- If downtown shipment routes are allowed, the selection of any downtown through shipment route should be made based on factors other than risk and made by transportation officials using such factors as traffic flow and distance. If these factors are judged to not be significant, then the routing regulations state that the most direct route be selected.
- Nothing in this report is intended to lead to recommendations for further restricting the local delivery of gasoline, diesel fuel and fuel oil within the City of Boston, beyond those otherwise reasonable restrictions currently in place as implemented by permits issued under the City's existing regulations.
- The risk analysis conducted for this report focused on the transport of Class 3 (flammable liquids) materials. There is nothing in the analysis that would result in a different finding

had another Class or Division of Hazardous Material been chosen for as the reference shipment in the risk assessment.

The risk determinations were made using one of the methodologies suggested in the Highway Routing of Hazardous Materials Guidelines Book. The methodology chosen is intermediate to a very simple calculation and a more complex analysis. The use of either of the other methodologies is unlikely to alter the results significantly enough to affect the conclusions. The more complex analysis might be warranted if there were numerous shipments of Division 2.3 Poisonous Gases, Division 6.1 Liquid Poisons or Class 1 Explosives where the impact area could extend beyond a half mile on either side of the roadway. If the less detailed analysis had been performed, it would have been much more difficult to perform meaningful sensitivity and uncertainty analyses.

Because there are uncertainties in any risk assessment, sensitivity and uncertainty assessments were performed. Those analyses show that the results obtained are robust for restricting hazmat transport through downtown Boston during the day. No reasonable change in the route parameters would change the routing conclusions based on the daytime analysis of risk. The results for nighttime transport are less robust. Based on a propagation of errors analysis, that considered randomness in the data, the night time risk ratio of Route Alternative 1 [RA1] over Route Alternative 3 [RA3] is still significant at a little less than the 95 percent confidence level (approximately 92 percent). However, as shown in the sensitivity analyses, which were performed to address systematic error or biases, there are factors, such as the fraction of the workforce that are at work at night, that could materially lower the statistical significance level associated with the night time risk ratio. Thus, while any reasonable estimation and selection of population and accident rate data would keep the night time risk ratio [RA1]/[RA3] above 1.5, the confidence level in the ratio is lower.

For through shipments where both the origin and destination are outside Route 128, the risk ratios would be higher than those shown in Table 15 (Risk Ratios for Through and Alternative Routes – Everett to I-95 Exit 12); there is no risk-based justification for using the surface streets of downtown Boston or the I-93 links to those streets for such shipments. Thus, the risk assessment results justify the directions posted on the highway signs outside Route 128 directing traffic approaching Boston to use Route 128/I-95 instead in order to avoid traveling through the hazmat restricted tunnels in central Boston or through downtown Boston itself.

When the significance difference is applied to the risks for the many alternative surface routes (see Table 16: Analyses Results for Alternative Surface Routes through downtown Boston), the only routes with a statistically significant risk difference, were the Massachusetts Avenue route, [RA10], during nighttime hours, the daytime travel on Commercial – North Washington Street northbound, [RA9] and Commercial Street-Haul Road southbound, RA15]. Because of the high resident population along the Massachusetts Avenue route, there is justification for not using it at night for through shipments if through shipments through downtown Boston are allowed. While the risk difference is somewhat less clear cut concerning the use of the two local routes which use Commercial Street through downtown Boston, there is some risk-based indication that use of that roadway in Route Alternative 9 [RA9] and Route Alternative 15 [RA15] presents a higher population exposure risk, compared to the other local surface route alternatives.

Regarding deliveries or pickups within the City of Boston, there are large areas of the City that are not in close proximity to expressways. While not analyzed for this report, the risks for those routes would likely be similar to the results for the Massachusetts Avenue route. When a carrier must travel on an undesignated hazmat route for such deliveries or pickups, the carrier must still meet the requirements of 397.67(b) when picking routes. Because the results show that the per mile risk on expressways is lower than on major thoroughfares, this analysis would suggest that the carrier select routes that give preference to expressways and then use the most direct route from an expressway to the pickup or delivery point, thereby minimizing transport on the surface streets of the City of Boston. Such pickups and deliveries within the City of Boston should not be banned or otherwise restricted unnecessarily.

The carrier should not consider its routing decisions made in accordance with 49 CFR 397.67(b) to allow shipments through downtown Boston during the day. The through routing analyses show that there is ample justification for prohibiting such through shipments during the day, and such quantitative risk analysis findings should take precedence over routes picked using carrier judgment. The important points are: (1) that based on comparable relative risks for the local downtown routes, there is no strong differential risk-based need to designate prescribed hazmat routes for all shipments to destinations or from origins *within the city of Boston*, provided that major thoroughfares are used to the point as close as possible to the destination before using non-major thoroughfare routes (although consideration of other factors and good transportation planning may strongly recommend designating a primary downtown local hazmat route); and (2) there is no justification for using the surface streets in downtown Boston for hazmat through shipments during the day.

There is one benefit of restricting hazmat shipments through downtown Boston that has not been analyzed. Some of the most severe hazmat truck accidents have been with buses. Data in Table 27 show that almost 80 percent of the buses are on the surface roads during the day. Restricting hazardous material truck transport on Boston's downtown streets during the day will reduce the probability of a severe hazmat truck-bus crash during the daytime hours.

Table 28: Risk Summary of Six Alternative Through Hazmat Routes

Route Description	Distance miles	Daytime Population	Nighttime Population	Daytime Risk	Nighttime Risk
Northbound – Quincy to Everett					
Route RA1 – Through Boston	10.7	309,000	173,000	0.29	0.14
Route RA2 – Through Cambridge	33.2	245,000	218,000	0.18	0.14
Route RA3 – I-93S to I-95N to I-93S	47.0	204,000	173,000	0.072	0.063
Southbound – Everett to Quincy					
Route RA1 – Through Boston	10.6	301,000	169,000	0.28	0.14
Route RA2 – Through Cambridge	33.8	249,000	223,000	0.18	0.15
Route RA3 – I-93N to I-95S to I-93N	47.8	203,000	171,000	0.070	0.062
Northbound – I-95 Exit 12 to Everett					
Route RA4 – Through Boston	19.5	334,000	193,000	0.30	0.15
Route RA5 – Through Cambridge	24.4	221,000	198,000	0.17	0.14
Route RA6 – I-95N to I-93S	38.2	180,000	153,000	0.065	0.057
Southbound – Everett to I-95 Exit 12					
Route RA4 – Through Boston	19.7	327,000	190,000	0.29	0.14
Route RA5 – Through Cambridge	24.8	224,000	202,000	0.17	0.14
Route RA6 – I-93N to I-95S	38.7	178,000	150,000	0.063	0.055

APPENDIX A: REFERENCES

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APPENDIX B: ROUTE CHARACTERISTICS

Both bridge and road data were obtained from MA DOT websites. The bridge data for alternative routes is combined in a single table. Table B-1 includes a key parameter for bridges: the bridge condition. Three bridges, the Alford street Bridge, the Huntington Avenue Bypass and Memorial Drive Bridges are rated as a 3 indicating that substantial repairs were required. One bridge, the North Washington Bridge is rated 4 (FHWA 1995). Repairs on the Alford street Bridge began in November and repairs for the north Washington are scheduled to begin in of 2011.

For each road on each route, specific road attributes were identified and described as follows:

Number of Lanes: Number of travel lines on a given road and the number of travel lines in the opposite direction of a divided highway

Lane Width: Width of the lanes in feet, which excludes shoulders and auxiliary lanes

Type of Lane Separation: Type of median on divided highways; either none, curbed, unprotected, unspecified, rigid and semi-rigid positive barrier.

Shoulder Type: Type of shoulder on the right or left side of the road; either no shoulder, stable unruttable compacted sub grade or hardened bituminous mix or penetration.[4]

[4] Information retrieved from Road Inventory Data Dictionary

Table B-1: Characteristics of Bridges on the Roads Comprising the Alternative Routes

Bridge ID	Carries	Over	Route	Roadway width	Under Clearance		Condition Rating
				(in meters)	Type	Meters	
B-16-689	Albany Street	I-90 & RR Tracks	7,17,2,3,5	No data	No data	No data	7
B-16-675	Albany Street	I-93 SB Ramps	7,17,2,3,5	8.53	No restriction	No restriction	7
B-16-674	Albany Street	I-93 Ramps	7,17,2,3,5	15.57	No restriction	No restriction	7
B-16-006	Cambridge Street	Charles River	1,10,18	12.20	No restriction	No restriction	5
B-16-377	Cambridge Street	Soldiers Field Road	1,10,18	18.30	Highway	3.05	5
B-16-351	Charlestown Avenue	New Rutherford Avenue	7,8,1,4,10,14,18	32.00	Highway	4.67	5
B-16-179	Charlestown Avenue/Land Boulevard	B&M Yard	7,8,1,4,10,14,18	15.20	Railroad	7.01	5
B-16-881-A	Frontage Road	I-90 & RR Tracks	3,4,5,12	9.10	Railroad	6.00	7
B-16-657	Frontage Road NB	I-93 Ramp to South Station	3,4,5,12	12.20	Highway	4.41	6
B-16-647	Frontage Road NB	I-93 Ramps	3,4,5,12	12.20	No restriction	No restriction	6
B-16-646	Frontage Road NB	I-93 Ramps	3,4,5,12	13.60	No restriction	No restriction	7
B-16-648	Frontage Road Southbound	I-93	4,5,12	23.90	No restriction	No restriction	7
B-16-660	Frontage Road/Mass Avenue Connector Intersection	I-93 Ramps	4	12.40	No restriction	No restriction	7
B-16-681	Frontage Road/S Boston Haul Road Intersection	I-93 Ramps	6,7,8	17.20	No restriction	No restriction	6
C-01-001	Land Boulevard	Lechmere Canal	1,4,10,18	13.70	Other	0.00	7
B-16-660	Massachusetts Avenue Connector	I-93	4	19.20	Highway	4.80	6
B-16-012	Massachusetts Avenue	Charles River & Storrow Drive	4	15.80	Highway	3.81	7
B-16-051	Massachusetts Avenue	I-90	4	21.90	Highway	4.34	5
B-16-087	Massachusetts Avenue	MBTA Southwest Corridor	4	30.50	No restriction	No restriction	7
B-16-237	Massachusetts Avenue	Commonwealth Avenue Bypass	4	18.30	Highway	4.03	5
B-16-238	Massachusetts Avenue	Huntington Avenue Bypass	4	29.00	Highway	4.03	3
C-01-023	Massachusetts Avenue	Memorial Drive	4	24.70	Highway	2.74	3
B-16-649	Massachusetts Avenue Connector	I-93	4	18.60	No restriction	No restriction	6
B-16-016	North Washington Street	Charles River	2,3,5,6,8,12,13,14,15,16,17	22.60	No restriction	No restriction	4
B-16-029	Route 99 (Alford Street)	Mystic River	All routes	23.20	No restriction	No restriction	3
B-16-223	Seaport Boulevard	Fort Point Channel	8,13	21.40	No restriction	No restriction	7
B-16-644	South Boston Haul Road	Widett Circle	6,7,8,13,15,16	17.50	No restriction	No restriction	6
B-16-645	South Boston Haul Road	MBTA Yard	6,7,8,13,15,16	9.70	Highway/Railroad	4.50	7
B-16-010	Western Avenue	Charles River	1,10,18	12.20	No restriction	No restriction	5
B-16-400	Western Avenue	Soldiers Field Road	1,10,18	20.70	Highway	3.63	5

Table B-2: Road Attributes of Alternate Route: Quincy to Everett – Route Alternative 1 (I-93S to I-95N to I-93S) NB & SB in Boston, Massachusetts

Road	Number of Lanes		Surface Width (Feet)	Lane Width (Feet)	Type of Lane Separation	Type of Breakdown Lanes	
	Travel	Opposite				Right	Left
I-93 Frontage Road	2-3	0	36	12	None	Hardened bituminous mix or penetration	No shoulder
Albany Street	2-3	0	60	20	None	No shoulder	No shoulder
Alford Street	2-4	0-2	38-60	12	None or curbed	No shoulder	No shoulder
Atlantic Avenue	3	0	35-62	12-21	None	Hardened bituminous mix or penetration	No shoulder
Causeway Street	2	2	45	23	Curbed	No shoulder	No shoulder
Cross Street	2-3	0	40	13-20	None	No shoulder	No shoulder
John F. Fitzgerald Surface Road	3	0	32-34	11	None	No shoulder	No shoulder
New Rutherford Avenue	2-3	0-3	24-52	12-17	None or curbed	No shoulder*	No shoulder
North Washington Street	2-3	2-3	32-36	12-16	Curbed or unprotected	No shoulder	No shoulder
Purchase Street	2-3	0	34-40	13-17	None	No shoulder	No shoulder
Surface Road	3	0	33	11	None	No shoulder	No shoulder
I-93	4	4	48**	12	Rigid positive barrier	Hardened bituminous mix or penetration	No shoulder

* In the southbound direction, there is one unruttable compacted subgrade stable right breakdown lane.

Table B-3: Road Attributes of Alternate Route: Quincy to Everett – Route Alternative 2 (I-93S to I-95N to I-93S) NB & SB in Boston, Massachusetts

Road	Number of Lanes		Surface Width (Feet)	Lane Width (Feet)	Type of Lane Separation	Type of Breakdown Lanes	
	Travel	Opposite				Right	Left
Alford Street	2-4	0-2	26-60	12	None or curbed	No shoulder	No shoulder
Allston Toll Plaza	1	0	12***	12	None	No shoulder	No shoulder
Austin Street/Charlestown Avenue	2-4	2	26-42	11-13	None or curbed	Hardened bituminous mix or penetration	No shoulder
Binney Street	2	2	20	10	Curbed	No shoulder	No shoulder
Edwin H. Land Boulevard	2	2	24***	12	Curbed	No shoulder	No shoulder
Galileo Galilei Way	2	0-2	20-24	10-12	None or curbed	No shoulder	No shoulder
I-90	3-4	3-4	36-48**	12	Rigid positive barrier	Hardened bituminous mix or penetration	Hardened bituminous mix or penetration
I-95	3-4	3-4	36-60	12-15	Rigid, semi-rigid or unspecified positive barrier	Hardened bituminous mix or penetration	Hardened bituminous mix or penetration
Main Street	0	2	50	25	None	No shoulder	No shoulder
Massachusetts Avenue	4	0	60	15	None	No shoulder	No shoulder
Mystic Avenue	2	0	30-46	15-23	None	No shoulder	No shoulder
New Rutherford Avenue	2-3	0-3	24-52	12-17	None or curbed	No shoulder*	No shoulder
Pleasant Street	2	0	27	14	None	No shoulder	No shoulder
River Street	2	0	34	17	None	No shoulder	No shoulder
Sidney Street	1	0	16	16	None	No shoulder	No shoulder
Soldiers Field Road	1	0	20	20	None	No shoulder	No shoulder
Western Avenue	4	0	40-45	10-11	None	No shoulder	No shoulder
I-93	2-4	0-4	24-48	12	Unspecified, semi-rigid and rigid positive barrier	Hardened bituminous mix or penetration	Hardened bituminous mix or penetration or no shoulder

* In the southbound direction, there is one unruttable compacted subgrade stable right breakdown lane.
**In the eastbound direction, the Lane width is between 34 and 48 feet.
*** Google earth measured surface width.

Table B-4: Road Attributes of Alternate Route: Quincy to Everett – Route Alternative 3 (I-93S to I-95N to I-93S) NB & SB in Boston, Massachusetts

Road	Number of Lanes		Surface Width (Feet)	Lane Width (Feet)	Type of Lane Separation	Type of Breakdown Lanes	
	Travel	Opposite				Right	Left
I-93	2-4	2-4	24-48	12	Rigid, semi-rigid or unspecified positive barrier	Hardened bituminous mix or penetration	Hardened bituminous mix or penetration or no shoulder
I-95	3-4	3-4	36-60	12-15	Rigid, semi-rigid or unspecified positive barrier	Hardened bituminous mix or penetration	Hardened bituminous mix or penetration
I-95 to I-93 Ramp	2	0	20	10	None	No shoulder	No shoulder
I-93 to Mystic Avenue Ramp	2	0	20	10	None	No shoulder	No shoulder
Mystic Avenue	2	0	28-40	14-20	None	No shoulder	No shoulder
Alford Street	2-4	0-2	26-60	13-15	None or curbed	No shoulder	No shoulder

Table B-5: Road Attributes of Alternate Route: I-95 Exit 12 to Everett – Route Alternative 4 (I-95N to I-93S) NB & SB in Boston, Massachusetts

Road	Number of Lanes		Surface Width (Feet)	Lane Width (Feet)	Type of Lane Separation	Type of Breakdown Lanes	
	Travel	Opposite				Right	Left
I-93 Frontage Road	2-3	0	36	12	None	Hardened bituminous mix or penetration	No shoulder
Albany Street	2-3	0	60	20	None	No shoulder	No shoulder
Alford Street	2-4	0-2	38-60	12	None or curbed	No shoulder	No shoulder
Atlantic Avenue	3	0	35-62	12-21	None	Hardened bituminous mix or penetration	No shoulder
Causeway Street	2	2	45	22.5	Curbed	No shoulder	No shoulder
Cross Street	2-3	0	40	13-20	None	No shoulder	No shoulder
I-93	2-4	0-4	24-48	12	Unspecified, semi-rigid and rigid positive barrier	Hardened bituminous mix or penetration	Hardened bituminous mix or penetration or no shoulder
John F. Fitzgerald Surface Road	3	0	32-34	11	None	No shoulder	No shoulder
Mystic Avenue	2	0	30-46	15-23	None	No shoulder	No shoulder
New Rutherford Avenue	2-3	0-3	24-52	12-17	None or curbed	No shoulder*	No shoulder
North Washington Street	2-3	2-3	32-36	12-16	Curbed or unprotected	No shoulder	No shoulder
Purchase Street	2-3	0	34-40	13-17	None	No shoulder	No shoulder
Surface Road	3	0	33	11	None	No shoulder	No shoulder

* In the southbound direction, there is one unruttable compacted subgrade stable right breakdown lane.

Table B-6: Road Attributes of Alternate Route: I-95 Exit 12 to Everett – Route Alternative 5 (Through Cambridge) NB & SB in Boston, Massachusetts

Road	Number of Lanes		Surface Width (Feet)	Lane Width (Feet)	Type of Lane Separation	Type of Breakdown Lanes	
	Travel	Opposite				Right	Left
Alford Street	2-4	0-2	26-60	12	None or curbed	No shoulder	No shoulder
Allston Toll Plaza	1	0	12***	12	None	No shoulder	No shoulder
Austin Street/Charlestown Avenue	2-4	2	26-42	11-13	None or curbed	Hardened bituminous mix or penetration	No shoulder
Binney Street	2	2	20	10	Curbed	No shoulder	No shoulder
Edwin H. Land Boulevard	2	2	24***	12	Curbed	No shoulder	No shoulder
Galileo Galilei Way	2	0-2	20-24	10-12	None or curbed	No shoulder	No shoulder
I-90	3-4	3-4	36-48**	12	Rigid positive barrier	Hardened bituminous mix or penetration	Hardened bituminous mix or penetration
I-95	3-4	3-4	36-60	12-15	Rigid, semi-rigid or unspecified positive barrier	Hardened bituminous mix or penetration	Hardened bituminous mix or penetration
Main Street	0	2	50	25	None	No shoulder	No shoulder
Massachusetts Avenue	4	0	60	15	None	No shoulder	No shoulder
Mystic Avenue	2	0	30-46	26	None	No shoulder	No shoulder
New Rutherford Avenue	2-3	0-3	24-52	12-17	None or curbed	No shoulder*	No shoulder
Pleasant Street	2	0	27	14	None	No shoulder	No shoulder
River Street	2	0	34	17	None	No shoulder	No shoulder
Sidney Street	1	0	16***	16	None	No shoulder	No shoulder
Soldiers Field Road	1	0	20	20	None	No shoulder	No shoulder
Western Avenue	4	0	40-45	10-11	None	No shoulder	No shoulder

* In the southbound direction, there is one unruttable compacted subgrade stable right breakdown lane.
**In the eastbound direction, the Lane width is between 34 and 48 feet.
*** Google earth measured surface width.

Table B-7: Road Attributes of Alternate Route: I-95 Exit 12 to Everett – Route Alternative 6 (I-95N to I-93S) NB & SB in Boston, Massachusetts

Road	Number of Lanes		Surface Width (Feet)	Lane Width (Feet)	Type of Lane Separation	Type of Breakdown Lanes	
	Travel	Opposite				Right	Left
I-93	4	4	48	12	Rigid or semi-rigid positive barrier	Hardened bituminous mix or penetration	Hardened bituminous mix or penetration
I-95	3-4	3-4	36-60	12-15	Rigid, semi-rigid or unspecified positive barrier	Hardened bituminous mix or penetration	Hardened bituminous mix or penetration
I-95 to I-93 Ramp	2	0	20	10	None	No shoulder	No shoulder
I-93 to Mystic Avenue Ramp	2	0	20	10	None	No shoulder	No shoulder
Mystic Avenue	2	0	28-40	14-20	None	No shoulder	No shoulder
Alford Street	2-4	0-2	26-60	13-15	None or Curbed	No shoulder	No shoulder

Table B-8: Road Attributes of Alternate Route: Cambridge to I-90 EB & WB (Route Alternative 7) in Boston, Massachusetts

Road	Number of Lanes		Surface Width (Feet)	Lane Width (Feet)	Type of Lane Separation	Type of Breakdown Lanes	
	Travel	Opposite				Right	Left
Alford Street	2	0-2	38	12	None or curbed	No shoulder	No shoulder
Allston Toll Plaza	1	0	12*	12	None	No shoulder	No shoulder
Austin Street/Charlestown Avenue	2-4	0-2	26-42	11-13	None or curbed	Hardened bituminous mix or penetration	No shoulder
Binney Street	2	2	20-34	10-17	Curbed	No shoulder	No shoulder
Edwin H. Land Boulevard	2	2	45	12	Curbed	No shoulder	No shoulder
Galileo Galilei Way	2	0-2	20-24	10-12	None or curbed	No shoulder	No shoulder
I-90	4	4	48	12	Rigid positive barrier	Hardened bituminous mix or penetration	Hardened bituminous mix or penetration
Main Street	0	2	42-50	25-42	None	No shoulder	No shoulder
Massachusetts Avenue	4	0	60	15-60	None	No shoulder	No shoulder
Mystic Avenue	1-2	0	20-46	20-23	None	No shoulder	No shoulder
New Rutherford Avenue	0-2	0	24	12	None or curbed	No shoulder**	No shoulder
Pleasant Street	2	0	20	10	None	No shoulder	No shoulder
River Street	2	0	34	17	None	No shoulder	No shoulder
Sidney Street	1	0	16***	16	None	No shoulder	No shoulder
Soldiers Field Road	1	0	20	20	None	No shoulder	No shoulder
Sullivan Square	2	0	26-56	13-28	None	No shoulder	No shoulder
Western Avenue	4	0	40-45	10-11	None	No shoulder	No shoulder

* Standard lane width
** In the southbound direction, there is one unruttable compacted subgrade stable right breakdown lane.
*** Google earth measured surface width.

Table B-9: Road Attributes of Alternate Route: Cross/North Washington NB & SB (Route Alternative 8) in Boston, Massachusetts

Road	Number of Lanes		Surface Width (Feet)	Lane Width (Feet)	Type of Lane Separation	Type of Breakdown Lanes	
	Travel	Opposite				Right	Left
I-93 Frontage Road	2-3	0	60	12	None	Hardened bituminous mix or penetration	No shoulder
Albany Street	2-3	0	60	20	None	No shoulder	No shoulder
Alford Street	2	0-2	38	12	None or curbed	No shoulder	No shoulder
Atlantic Avenue	3	0	35-62	12-21	None	Hardened bituminous mix or penetration	No shoulder
Causeway Street	2	2	45	23	Curbed	No shoulder	No shoulder
Cross Street	2-3	0	40	13-20	None	No shoulder	No shoulder
John F. Fitzgerald Surface Road	3	0	32-34	11	None	No shoulder	No shoulder
Mystic Avenue	2	0	28-46	14-23	None	No shoulder	No shoulder
New Rutherford Avenue	2-3	0-3	24-42	12-14	None or curbed	No shoulder*	No shoulder
North Washington Street	2-3	2-3	32-36	12-16	Curbed or unprotected	No shoulder	No shoulder
Purchase Street	2-3	0	34-40	17-13	None	No shoulder	No shoulder
Sullivan Square	2	0	56	28	None	No shoulder	No shoulder
Surface Road	3	0	33	11	None	No shoulder	No shoulder

* In the southbound direction, there is one unruttable compacted subgrade stable right breakdown lane.

Table B-10: Road Attributes of Alternate Route: Commercial/North Washington NB & SB (Route Alternative 9) in Boston, Massachusetts

Road	Number of Lanes		Surface Width (Feet)	Lane Width (Feet)	Type of Lane Separation	Type of Breakdown Lanes	
	Travel	Opposite				Right	Left
I-93 Frontage Road	2-3	0	36	12	None	Hardened bituminous mix or penetration	No shoulder
Albany Street	2-3	0	60	20	None	No shoulder	No shoulder
Alford Street	2-4	0-2	38-60	12	None or curbed	No shoulder	No shoulder
Atlantic Avenue	3	0	35-62	12-21	None	Hardened bituminous mix or penetration	No shoulder
Commercial Street	2	0	44-48	22-24	None	No shoulder	No shoulder
John F. Fitzgerald Surface Road	3	0	32-34	11	None	No shoulder	No shoulder
Mystic Avenue	2	0	30-46	15-23	None	No shoulder	No shoulder
New Rutherford Avenue	2-3	0-3	24-52	12-17	None or curbed	No shoulder*	No shoulder
North Washington Street	2-3	2-3	32-36	12-16	Curbed or unprotected	No shoulder	No shoulder
Purchase Street	2-3	0	34-40	13-17	None	No shoulder	No shoulder
Sullivan Square	2	0	56	28	None	No shoulder	No shoulder
Surface Road	3	0	33	11	None	No shoulder	No shoulder

* In the southbound direction, there is one unruttable compacted subgrade stable right breakdown lane.

Table B-11: Road Attributes of Alternate Route: Land Boulevard/Massachusetts Ave NB & SB (Route Alternative 10) in Boston, Massachusetts

Road	Number of Lanes		Surface Width (Feet)	Lane Width (Feet)	Type of Lane Separation	Type of Breakdown Lanes	
	Travel	Opposite				Right	Left
I-93 Frontage Road	2-3	0	36	12	None	Hardened bituminous mix or penetration	No shoulder
Alford Street	2-4	0-2	38-60	12	None or curbed	No shoulder	No shoulder
Binney Street	2	2	20	10	Curbed	No shoulder	No shoulder
Edwin H. Land Boulevard	2	2	24**	12	Curbed	No shoulder	No shoulder
Galileo Galilei Way	2	0-2	20-24	10-12	None or curbed	No shoulder	No shoulder
Main Street	0	2	50	25	None	No shoulder	No shoulder
Massachusetts Avenue	4-2	2	33-60	15-17	Curbed	No shoulder	No shoulder
Massachusetts Avenue Connector	2	2	30	15	Curbed	No shoulder	No shoulder
Melnea Cass Boulevard	2	0-2	26	13	None or unprotected	No shoulder	No shoulder
Mystic Avenue	2	0	30-46	15-23	None	No shoulder	No shoulder
New Rutherford Avenue	2-3	0-3	24-52	12-17	None or curbed	No shoulder*	No shoulder
Sidney Street	1	0	16**	16	None	No shoulder	No shoulder
Sullivan Square	2	0	56	28	None	No shoulder	No shoulder
Surface Road	3	0	33	11	None	No shoulder	No shoulder
Washington Street	2	0	40**	20	None	No shoulder	No shoulder

* In the southbound direction, there is one unruttable compacted subgrade stable right breakdown lane.
** Google earth measured surface width.

Table B-12: Road Attributes of Alternate Route: Congress/North Washington NB & SB (Route Alternative 11) in Boston, Massachusetts

Road	Number of Lanes		Surface Width (Feet)	Lane Width (Feet)	Type of Lane Separation	Type of Breakdown Lanes	
	Travel	Opposite				Right	Left
I-93 Frontage Road	2-3	0	36	12	None	Hardened bituminous mix or penetration	No shoulder
Albany Street	2-3	0	60	20	None	No shoulder	No shoulder
Alford Street	2-4	0-2	38-60	12	None or curbed	No shoulder	No shoulder
Cambridge Street	2	2	33	17	Curbed	No shoulder	No shoulder
Causeway Street	2	2	34-45	17-23	Curbed	No shoulder	No shoulder
Congress Street	2-3	0-3	32-35	12-16	None or curbed	No shoulder	No shoulder
Cross Street	2	0	40	20	None	No shoulder	No shoulder
Mystic Avenue	2	0	30-46	15-23	None	No shoulder	No shoulder
New Rutherford Avenue	2-3	0-3	24-52	12-17	None or curbed	No shoulder*	No shoulder
New Sudbury Street	3	0	56	19	None	No shoulder	No shoulder
North Washington Street	2-3	2-3	32-80	16-27	Curbed or unprotected	No shoulder	No shoulder
Pearl Street	2	0	36-40	18-20	None	Hardened bituminous mix or penetration or no shoulder	No shoulder
Purchase Street	2-3	0	34-40	13-17	None	No shoulder	No shoulder
Staniford Street	2	2	30	15	Curbed	No shoulder	No shoulder
Sullivan Square	2	0	56	28	None	No shoulder	No shoulder
Surface Road	3	0	33	11	None	No shoulder	No shoulder

* In the southbound direction, there is one unruttable compacted subgrade stable right breakdown lane.

Table B-13: Road Attributes of Alternate Route: Haul Road/Congress/North Washington NB (Route Alternative 12) in Boston, Massachusetts

Road	Number of Lanes		Surface Width (Feet)	Lane Width (Feet)	Type of Lane Separation	Type of Breakdown Lanes	
	Travel	Opposite				Right	Left
I-93 Frontage Road	2-3	0	36	12	None	Hardened bituminous mix or penetration	No shoulder
Alford Street	2-4	0-2	38-60	12	None or curbed	No shoulder	No shoulder
Congress Street	2-4	0-3	32-55	14-16	None or curbed	No shoulder	No shoulder
Cross Street	2	0	40	20	None	No shoulder	No shoulder
Haul Road	2	0	26-40	13-20	None	Hardened bituminous mix or penetration	No shoulder
Mystic Avenue	2	0	30-46	15-23	None	No shoulder	No shoulder
New Rutherford Avenue	2-3	0-3	24-52	12-17	None or curbed	No shoulder*	No shoulder
New Sudbury Street	3	0	56	19	None	No shoulder	No shoulder
North Washington Street	2-3	2-3	32-36	12-16	Curbed or unprotected	No shoulder	No shoulder
Pearl Street	2	0	36-40	18-20	None	Hardened bituminous mix or penetration or no shoulder	No shoulder
Purchase Street	2-3	0	34-40	13-17	None	No shoulder	No shoulder
Sullivan Square	2	0	56	28	None	No shoulder	No shoulder
West Service Road	2	0	40	20	None	No shoulder	No shoulder

* In the southbound direction, there is one unruttable compacted subgrade stable right breakdown lane.

Table B-14: Road Attributes of Alternate Route: Haul Road/Cambridge/Lomasney NB and Lomasney/Congress/Purchase SB (Route Alternative 13) in Boston, Massachusetts

Road	Number of Lanes		Surface Width (Feet)	Lane Width (Feet)	Type of Lane Separation	Type of Breakdown Lanes	
	Travel	Opposite				Right	Left
I-93 Frontage Road	2-3	0	36	12	None	Hardened bituminous mix or penetration	No shoulder
Albany Street	2-3	0	60	20	None	No shoulder	No shoulder
Atlantic Avenue	3	0	35-62	12-21	None	Hardened bituminous mix or penetration	No shoulder
Austin St/Charlestown Avenue	2-4	2	26-42	11-13	None or curbed	Hardened bituminous mix or penetration	No shoulder
Cambridge Street	2	2	33-34	17	Curbed	No shoulder	No shoulder
Congress Street	2-4	0-3	32-55	14-16	None or curbed	No shoulder	No shoulder
Haul Road	2	0	26-40	13-20	None	Hardened bituminous mix or penetration	No shoulder
John F. Fitzgerald Surface Road	3	0	32-34	11	None	No shoulder	No shoulder
Leverett Connector	2	2	24**	12	None	No shoulder	No shoulder
Lomasney Way/Nashua Street	2	2	34-70	17-35	Curbed	No shoulder	No shoulder
Merrimac Street	2	2	68	34	Curbed	No shoulder	No shoulder
Monsignor Obrien Highway	6	0	66-72	11-12	None	No shoulder	No shoulder
New Chardon Street	4	0	24-56	6-14	None or curbed	No shoulder	No shoulder
New Rutherford Avenue	2-3	0-3	24-33	11-12	None	No shoulder*	No shoulder
Purchase Street	2-3	0	34-40	13-17	None	No shoulder	No shoulder
Staniford Street	2	2	30	15	Curbed	No shoulder	No shoulder
State Street/Court Street	2	0	28-65	14-33	None	No shoulder	No shoulder
Surface Road	3	0	33	11	None	No shoulder	No shoulder
West Service Road	2	0	40	20	None	No shoulder	No shoulder

* In the southbound direction, there is one unruttable compacted subgrade stable right breakdown lane.
** Google earth measured surface width.

Table B-15: Road Attributes of Alternate Route: Haul Road/ Cross/North Washington NB and Lomasney/Congress/Haul SB (Route Alternative 14) in Boston, Massachusetts

Road	Number of Lanes		Surface Width (Feet)	Lane Width (Feet)	Type of Lane Separation	Type of Breakdown Lanes	
	Travel	Opposite				Right	Left
I-93 Frontage Road	2-3	0	36	12	None	Hardened bituminous mix or penetration	No shoulder
Alford Street	2-4	0-2	38-60	12	None or curbed	No shoulder	No shoulder
Atlantic Avenue	3	0	35-62	12-21	None	Hardened bituminous mix or penetration	No shoulder
Austin Street/ Charlestown Avenue	2-4	2	26-42	11-13	None or curbed	Hardened bituminous mix or penetration	No shoulder
Cambridge Street	2	2	33	17	Curbed	No shoulder	No shoulder
Congress Street	2-3	0-3	32-35	12-16	None or curbed	No shoulder	No shoulder
Cross Street	2-3	0	40	13-20	None	No shoulder	No shoulder
Haul Road	2	0	26-40	13-20	None	Hardened bituminous mix or penetration	No shoulder
Leverett Connector	2	2	24**	12	None	No shoulder	No shoulder
Lomasney Way/Nashua Street	2	2	34-70	17-35	Curbed	No shoulder	No shoulder
Monsignor Obrien Highway	6	0	66-72	11-12	None	No shoulder	No shoulder
Mystic Avenue	2	0	30-46	15-23	None	No shoulder	No shoulder
New Rutherford Avenue	2-3	0-3	24-52	12-17	None or curbed	No shoulder*	No shoulder
New Sudbury Street	3	0	56	19	None	No shoulder	No shoulder
North Washington Street	2-3	2-3	32-36	12-16	Curbed or unprotected	No shoulder	No shoulder
Seaport Boulevard	2-4	0-2	24-48	12	None or curbed	Hardened bituminous mix or penetration	Hardened bituminous mix or penetration or no shoulder
Staniford Street	2	2	30	15	Curbed	No shoulder	No shoulder
Sullivan Square	2	0	56	28	None	No shoulder	No shoulder
West Service Road	2	0	40	20	None	No shoulder	No shoulder

* In the southbound direction, there is one unruttable compacted subgrade stable right breakdown lane.

Table B-16: Road Attributes of Alternate Route: Commercial St/Haul Rd NB & SB (Route Alternative 15) in Boston, Massachusetts

Road	Number of Lanes		Surface Width (Feet)	Lane Width (Feet)	Type of Lane Separation	Type of Breakdown Lanes	
	Travel	Opposite				Right	Left
Alford Street	2-4	0-2	38-60	12	None or curbed	No shoulder	No shoulder
Atlantic Avenue	3	0	35-62	12-21	None	Hardened bituminous mix or penetration	No shoulder
Commercial Street	2	0	44-48	22-24	None	No shoulder	No shoulder
Congress Street	2-4	0-3	32-55	14-16	None or curbed	No shoulder	No shoulder
Haul Road	2	0	26-40	13-20	None	Hardened bituminous mix or penetration	No shoulder
I-93 Frontage Road	2-3	0	36	12-18	None	Hardened bituminous mix or penetration	No shoulder
Mystic Avenue	2	0	30-46	15-23	None	No shoulder	No shoulder
New Rutherford Avenue	2-3	0-3	24-52	12-17	None or curbed	No shoulder*	No shoulder
North Washington Street	2-3	2-3	32-36	12-16	Curbed or unprotected	No shoulder	No shoulder
Seaport Boulevard	2-4	0-2	24-48	12	None or curbed	Hardened bituminous mix or penetration	Hardened bituminous mix or penetration or no shoulder
Sullivan Square	2	0	56	28	None	No shoulder	No shoulder
West Service Road	2	0	40	20	None	No shoulder	No shoulder

* In the southbound direction, there is one unruttable compacted subgrade stable right breakdown lane.

Table B-17: Road Attributes of Alternate Route: Lomasney NB (Route Alternative 16) in Boston, Massachusetts

Road	Number of Lanes		Surface Width (Feet)	Lane Width (Feet)	Type of Lane Separation	Type of Breakdown Lanes	
	Travel	Opposite				Right	Left
Austin St/ Charlestown Avenue	2-4	2	26-42	11-13	None or curbed	Hardened bituminous mix or penetration	No shoulder
Atlantic Avenue	3	0	35-62	12-21	None	Hardened bituminous mix or penetration	No shoulder
Cambridge Street	2	2	33-34	17	Curbed	No shoulder	No shoulder
I-93 Frontage Road	2-3	0	36	12-18	None	Hardened bituminous mix or penetration	No shoulder
Leverett Connector	2	2	24*	12	None	No shoulder	No shoulder
Lomasney Way/Nashua Street	2	2	34-70	17-35	Curbed	No shoulder	No shoulder
Monsignor Obrien Highway	6	0	66-72	11-12	None	No shoulder	No shoulder
New Rutherford Avenue	2-3	0-3	24-33	11-12	None	No shoulder*	No shoulder
Staniford Street	2	2	30	15	Curbed	No shoulder	No shoulder
State Street/Court Street	2	0	28-65	14-33	None	No shoulder	No shoulder

* In the southbound direction, there is one unruttable compacted subgrade stable right breakdown lane.

Table B-18: Road Attributes of Alternate Route: Surface Road/Haul Rd SB (Route Alternative 17) in Boston, Massachusetts

Road	Number of Lanes		Surface Width (Feet)	Lane Width (Feet)	Type of Lane Separation	Type of Breakdown Lanes	
	Travel	Opposite				Right	Left
Alford Street	2-4	0-2	38-60	12	None or curbed	No shoulder	No shoulder
Congress Street	2-4	0-3	32-55	14-16	None or curbed	No shoulder	No shoulder
Haul Road	2	0	26-40	13-20	None	Hardened bituminous mix or penetration	No shoulder
I-93 Frontage Road	2-3	0	36	12	None	Hardened bituminous mix or penetration	No shoulder
Mystic Avenue	2	0	30-46	15-23	None	No shoulder	No shoulder
New Rutherford Avenue	2-3	0-3	24-52	12-17	None or curbed	No shoulder*	No shoulder
North Washington Street	2-3	2-3	32-80	16-27	Curbed or unprotected	No shoulder	No shoulder
Purchase Street	2-3	0	34-40	13-17	None	No shoulder	No shoulder
West Service Road	2	0	40	20	None	No shoulder	No shoulder

* In the southbound direction, there is one unruttable compacted subgrade stable right breakdown lane.

Table B-19: Road Attributes of Alternate Route: Congress/Haul Rd SB (Route Alternative 18) in Boston, Massachusetts

Road	Number of Lanes		Lane Width (Feet)	Lane Width (Feet)	Type of Lane Separation	Type of Breakdown Lanes	
	Travel	Opposite				Right	Left
Alford Street	2-4	0-2	38-60	12	None or curbed	No shoulder	No shoulder
Cambridge Street	2	2	33	17	Curbed	No shoulder	No shoulder
Causeway Street	2	2	34-45	17-23	Curbed	No shoulder	No shoulder
Mystic Avenue	2	0	30-46	15-23	None	No shoulder	No shoulder
New Rutherford Avenue	2-3	0-3	24-52	12-17	None or curbed	No shoulder*	No shoulder
New Sudbury Street	3	0	56	19	None	No shoulder	No shoulder
North Washington Street	2-3	2-3	32-80	16-27	Curbed or unprotected	No shoulder	No shoulder
Staniford Street	2	2	30	15	Curbed	No shoulder	No shoulder
I-93 Frontage Road	2-3	0	36	12	None	Hardened bituminous mix or penetration	No shoulder
Congress Street	2-3	0-3	32-35	12-16	None or curbed	No shoulder	No shoulder
Haul Road	2	0	26-40	13-20	None	Hardened bituminous mix or penetration	No shoulder
West Service Road	2	0	40	20	None	No shoulder	No shoulder

* In the southbound direction, there is one unruttable compacted subgrade stable right breakdown lane.

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APPENDIX C: HAZMAT SURVEY FORMS

Questionnaire to Carriers and Shippers who transport or schedule shipments of Hazardous Materials in the Boston area 6/4/2010

In consultation with the Massachusetts Department of Transportation ("MassDOT") which is the routing agency for the Commonwealth, the City of Boston has contracted with **Battelle Memorial Institute** of Columbus Ohio ("Battelle") to perform an unbiased, comprehensive and accurate assessment of potential hazmat routes through downtown Boston and the surrounding Greater Boston region. Battelle is seeking basic information from the transportation community and will perform the analyses using the aggregated results from all the submissions provided by carriers and shippers. Your responses to these questions will be confidential. Persons or companies listing routing alternatives will not be identified and in the final analysis, it will not be possible to tie the information shown in the report back to any information provided by a specific carrier or shipper.

Federal routing regulations, specifically 49 CFR Part 397, Subpart C specify the procedure to be followed in evaluating hazmat routes. Battelle seeks information pertinent to the factors identified in the federal regulations at 49 C.F.R. §397.71 that must be considered when a state or political subdivision seeks to establish a new routing designation for the transportation of Non-Radioactive Hazardous Materials (NRHM). Battelle seeks your voluntary participation and assistance in providing information useful to Battelle's comprehensive analysis of potential hazmat routing in the region.

Prior to establishing any routing regulation, affected parties, such as shippers and carriers must be consulted. Your participation in this Battelle questionnaire, prior to the routing agency identifying specific routing alternatives to be analyzed as part of the study, will help ensure that thorough consideration is given to identifying a range of potential route alternatives, when developing the basis for any proposed routing designations.

In addition to the requirement for *consultation with others,* the federal standards in 397.71 request that the evaluation consider *(7) Reasonable routes to terminals and other facilities, (9)(iii) Types and quantities of NRHM, (9)(ix) Alternative routes, (9)(x) Effects on commerce (9)(xi) delays in transportation* and lastly, *(9)(xiii) Congestion and Accident History.* While carriers and drivers may contribute information to other evaluation criteria, these are called out because a carrier might have valuable information regarding how these criteria can be applied to the routes to be considered when evaluating hazmat transport in downtown Boston and the Greater Boston region.

The Massachusetts Department of Transportation will be coordinating the required formal public notice and participation process, including the scheduling of future public meetings associated with this routing designation process. This questionnaire represents a preliminary opportunity for your early participation and input to the routing analysis process. By receiving your input now, we will best be able to factor in your views early in the process. Of course you will be able to comment on the results developed during this analysis at later stages in the public process.

The following information is requested: Note, this information will be confidential and names of carriers and/or shippers will not be used for the routing analysis. Complete either Form "A" (Carriers) or Form "B" (Shippers), as appropriate. Please submit your responses by June 25, 2010 to: Arthur Greenberg, Ph.D., Battelle, 505 King Avenue, Columbus, OH 43201-2693. Or email to greenbea@battelle.org

FORM "A"
QUESTIONS FOR CARRIERS

1) Please provide the following information
   a) Company Name ____________________
   b) Name of Contact Person ____________________
   c) Telephone Number ____________________
   d) Address ____________________
   e) E-mail address ____________________

2) Do you deliver, pickup or ship placarded quantities of hazardous materials (hazmat) through the City of Boston or the Boston Region (including and within the I-95 (Route 128) beltway?

   Yes_______ No______

3) What are the origin cities that you ship from?

   ____
   ____

4) What destination cities within I-95 (Route 128) do you ship to?

   ____
   ____

   Within Boston, please circle the applicable districts using the list below.

   East Boston, Charlestown, North End, Downtown Boston, South Boston, Roxbury, Jamaica Plain, Beacon Hill, Back Bay, Fenway, Forest Hills, Dorchester, Neponset, Rosendale, West Roxbury, Hide Park, Mattapan

5) What types of hazardous materials do you ship? Per §397.71((9)(iii) *Types and quantities of NRHM....*

HM Class or Division	Shipment Quantity (gal or lbs)	Origin City	Destination City within Route 128	Shipments per Month

6) If applicable, from what terminal(s) do you obtain the hazardous material? (Per §397.71(7) *Reasonable routes to terminals and other facilities)*

   a. Please provide terminal names and addresses and if readily available a contact person.

      ____
      ____
      ____

   b. What routes do you use to travel from the terminal(s) to major thoroughfares such as I-93, a US Route such as US 1, or a major State Route such as 99, 3 or 128?

      ____
      ____

7) What fraction of your shipments do not travel through Boston because shorter, more direct routes are available? Per §397.71(4) *Through routing.* ________________________________

8) Do you use any non-expressway routes through Braintree, Quincy, Cambridge or Somerville to access an interstate? Per 397.71(9)(ix) *Alternative Routing.* Please list these routes.

   ____
   ____

9) To what extent do you try to avoid scheduling shipments during congested periods?

   ____

   a. When you have used the surface route through downtown Boston during congested periods, on average, how much longer does it take (you can use percentages)?

      ____

   b. How often are you delayed because of accidents? A rough percentage estimate is acceptable. ____

10) What are your hours of operation? Per §397.71(1) *Enhancement of Public Safety.*

   ____

   a. What would be the cost implications of day time restrictions for your company?

      ____

   b. What are the cost implications of a requirement to schedule shipments between 8PM and 6 AM? ____

11) Since federal regulations instruct that you are to avoid tunnels even in the absence of any routing restriction, for destinations where I-93 through downtown Boston would be the most direct route, do you have any alternative surface roadway routes you would like to see evaluated as part of the assessment of hazmat routing in Boston and the Boston region? Per §397.71(9(ix), *Alternative Routes…*

____
____
____
____

a. Considering all the route parings, origins and destinations, listed above, are there any where factors such as cost, access, traffic signal controls, traffic conditions, pedestrians, safety issues, continuity, prevailing roadway vehicle weight and size limits, etc., would suggest using a route other than the most direct route? (Please list route, the alternative you might use, and the reasons)

____
____
____

Your responses to these questions will be completely confidential. If requested by the routing agency, we may share the submissions provided by carriers and shippers with MassDOT only with the understanding and agreement that the information be considered confidential. We also reserve the right to compile a list of responders and non-responders and make those lists part of the route assessment documentation and also provide those lists to the routing agency.

FORM "B"
QUESTIONS FOR SHIPPERS/RECEIVERS

1) Do you or your carrier deliver, pickup or ship placarded quantities of hazardous materials (hazmat) through the City of Boston or the Boston Region (including and within the I-95 (Route 128) beltway?

   Yes_______ No______

2) What are the origin cities that you ship from?
   ____
   ____
   ____

3) If you are a receiver of hazmat, what are the origin cities for your receipts?
   ____
   ____

   If you are a shipper of hazmat, to which cities/communities do you ship?
   ____
   ____
   ____ If Within the City of Boston, please also circle the applicable districts.

   East Boston, Charlestown, North End, Downtown Boston, South Boston, Roxbury, Jamaica Plain, Beacon Hill, Back Bay, Fenway, Forest Hills, Dorchester, Neponset, Rosendale, West Roxbury, Hide Park, Mattapan

4) What types of hazmat do you or your carrier ship? Per §397.71((9)(iii) *Types and quantities of NRHM....*

HM Class or Division	Shipment Quantity (gal or lbs)	Origin City	Destination City within Route 128	Shipments per Month

5) Please complete if you ship from more than one terminal or facility, (Per §397.71(7) *Reasonable routes to terminals and other facilities)*

   a. Please provide terminal names and addresses and if readily available a contact person.

      ____
      ____
      ____
      ____

   b. Do you instruct your carrier to travel from the terminal on specific access routes to limited access highways such as I-93, US Routes such as US 1 or major State Routes such as 3, or 99?

      ____
      ____
      ____
      ____

6) What fraction of the shipments do not travel through Boston because shorter, more direct routes are available? Per §397.71(4) *Through routing.*______________________________

7) Do you or your carrier use any non-expressway routes through Braintree, Quincy, Cambridge or Somerville to access interstates? Per 397.71(9)(ix) *Alternative Routing.* Please list these routes.

   ____
   ____

8) To what extent do you or your carrier try to avoid scheduling shipments during congested periods?

   ____

   a. When you or your carrier have used the surface route through downtown Boston during congested periods, on average, how much longer does it take (you can use percentages)?

      ____

   b. How often are you or carrier delayed because of accidents? A rough percentage estimate is acceptable.

      ____

9) What are your hours of operation? Per §397.71(1) *Enhancement of Public Safety.*

____

a. What would be the cost implications of day time restrictions for your company?

____

b. What are the cost implications of a requirement to schedule shipments between 8PM and 6 AM?

____

10) Since federal regulations instruct that you are to avoid tunnels even in the absence of any routing restriction, for destinations where I-93 through downtown Boston would be the most direct route, <u>do you or your carrier have any alternative surface roadway routes you would like to see evaluated</u> as part of the assessment of hazmat routing in Boston and the Boston region? Per §397.71(9(ix), *Alternative Routes…*

____
____
____
____

a. For <u>each distinct point of origin/destination pairing</u>, how would you or your carrier's <u>preferred route differ from the most direct route</u> after considering all factors such as cost, access, traffic signal controls, traffic conditions, pedestrians, safety issues, continuity, prevailing roadway vehicle weight and size limits, etc.?

____
____
____
____
____
____
____

Your responses to these questions will be completely confidential. If requested by the routing agency, we may share the submissions provided by carriers and shippers with MassDOT only with the understanding and agreement that the information be considered confidential. We also reserve the right to compile a list of responders and non-responders and make those lists part of the route assessment documentation and also provide those lists to the routing agency.

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APPENDIX D: SELECTED FACILITIES RELATED TO POPULATION

Table D-1: Schools Used in the Analysis

School Names	Latitude	Longitude	Day	Night
Boston	42.35904	71.058789		N/A
Boston Renaissance Charter Public (District)	42.3502	71.069456	1206	N/A
Edward M. Kennedy Academy for Health Careers (Horace Mann Charter School)	42.3502	71.089547	211	N/A
MATCH Charter Public School (District)	42.35224	71.120947	382	N/A
Smith Leadership Academy Charter Public (District)	42.30142	71.058747	165	N/A
Agassiz	42.3073	71.113747	492	N/A
Another Course To College	42.35034	71.14555	207	N/A
Baldwin ELC	42.34195	71.140567	140	N/A
Beethoven	42.26315	71.156442	285	N/A
Blackstone	42.33965	71.073561	569	N/A
Boston Adult Academy	42.28357	71.082936	220	N/A
Boston Arts Academy	42.34629	71.095131	430	N/A
Boston Community Leadership Academy	42.35034	71.145553	431	N/A
Boston International High School	42.30892	71.103675	202	N/A
Boston Latin	42.30892	71.103675	2395	N/A
Boston Latin Academy	42.31621	71.084533	1759	N/A
Boston Middle School Academy	42.30125	71.085692	12	N/A
Boston Teachers Union School	42.29466	71.116	142	N/A
Brighton High	42.3492	71.145461	1208	N/A
Brook Farm Business and Service Career Academy	42.28215	71.174833	342	N/A
Carter Developmental Center	42.34046	71.083044	24	N/A
Charles H Taylor	42.27741	71.077606	476	N/A
Charles Sumner	42.28641	71.126881	503	N/A
Charlestown High	42.38008	71.061094	901	N/A
Clarence R Edwards Middle	42.37864	71.067397	496	N/A
Community Academy	42.32443	71.070894	53	N/A
Community Academy of Science and Health	42.26279	71.117919	378	N/A
Curley K-8 School	42.31862	71.113606	667	N/A
Curtis Guild	42.3886	71.004233	297	N/A
Dante Alighieri	42.37156	71.037611	130	N/A
David A Ellis	42.31691	71.092203	315	N/A
Dearborn	42.32645	71.080922	287	N/A
Dennis C Haley	42.28638	71.107825	276	N/A
Donald Mckay	42.36873	71.034256	711	N/A
Dorchester Academy	42.28778	71.076611	40	N/A

School Names	Latitude	Longitude	Day	Night
Dr. Catherine Ellison-Rosa Parks Early Ed School	42.27163	71.091575	188	N/A
Dr. William Henderson	42.29372	71.062108	228	N/A
ELC – East Zone	42.3112	71.071392	124	N/A
ELC – West Zone	42.32603	71.106822	94	N/A
East Boston ECC	42.39145	71.027389	167	N/A
East Boston High	42.38054	71.035356	1385	N/A
Edison K-8	42.34533	71.160147	704	N/A
Edward Everett	42.31453	71.060083	260	N/A
Egleston Comm High School	42.31422	71.099092	93	N/A
Elihu Greenwood	42.26523	71.117425	347	N/A
Eliot Elementary	42.36628	71.053458	277	N/A
Ellis Mendell	42.31659	71.101661	186	N/A
Emily A Fifield	42.28679	71.072711	303	N/A
Excel High School	42.3329	71.0444	392	N/A
Farragut	42.33412	71.106211	216	N/A
Fenway High School	42.34629	71.095131	289	N/A
Franklin D Roosevelt	42.24259	71.12335	406	N/A
Gardner Pilot Academy	42.36078	71.133958	344	N/A
George H Conley	42.27461	71.127317	201	N/A
Harbor School	42.30085	71.060283	287	N/A
Harvard-Kent	42.37666	71.056933	456	N/A
Haynes Early Education Center	42.31522	71.078519	182	N/A
Henry Grew	42.25664	71.126967	255	N/A
Higginson/Lewis K-8	42.32054	71.086581	383	N/A
Horace Mann School for the Deaf	42.35235	71.138197	138	N/A
Hugh Roe O'Donnell	42.37823	71.038122	268	N/A
Jackson Mann	42.35235	71.138197	700	N/A
James Condon Elem	42.33736	71.052578	695	N/A
James J Chittick	42.26726	71.105242	291	N/A
James Otis	42.37525	71.033872	316	N/A
James P Timilty Middle	42.33056	71.091178	668	N/A
James W Hennigan	42.32603	71.106822	479	N/A
Jeremiah E Burke High	42.30708	71.081106	779	N/A
John D Philbrick	42.28539	71.117692	137	N/A
John F. Kennedy	42.32193	71.106275	352	N/A
John Marshall	42.29998	71.071031	711	N/A
John P. Holland	42.30549	71.072828	658	N/A
John W McCormack	42.31783	71.044414	620	N/A
John Winthrop	42.31832	71.076308	322	N/A

School Names	Latitude	Longitude	Day	Night
Joseph J Hurley	42.33934	71.077944	324	N/A
Joseph Lee	42.29265	71.080292	343	N/A
Joseph P Manning	42.30546	71.131447	153	N/A
Joseph P Tynan	42.33476	71.037828	325	N/A
Josiah Quincy	42.34799	71.064983	781	N/A
Joyce Kilmer	42.27147	71.162861	421	N/A
King K-8	42.31106	71.076481	411	N/A
Lee Academy	42.29265	71.080292	281	N/A
Lilla G. Frederick Middle School	42.30826	71.075283	651	N/A
Lyndon	42.28293	71.158664	513	N/A
Lyon K-8	42.35106	71.161614	123	N/A
Lyon Upper 9-12	42.35207	71.160742	18	N/A
Madison Park High	42.32988	71.086542	1,415	N/A
Manassah E Bradley	42.39147	71.005947	282	N/A
Mario Umana Middle School Academy	42.37856	71.040031	488	N/A
Mather	42.30799	71.062583	549	N/A
Mattahunt	42.27452	71.105825	559	N/A
Maurice J Tobin	42.27452	71.105825	452	N/A
Media Communications Technology High School	42.28215	71.174833	353	N/A
Michael J Perkins	42.33098	71.050631	201	N/A
Mildred Avenue K-8	42.27554	71.092281	757	N/A
Mission Hill School	42.3305	71.099292	165	N/A
Monument High School	42.33279	71.044797	338	N/A
Mozart	42.2812	71.141042	149	N/A
Nathan Hale	42.32518	71.091153	171	N/A
New Mission High School	42.33086	71.100256	256	N/A
O W Holmes	42.29669	71.074897	279	N/A
O'Bryant Sch Math/Science	42.33195	71.088397	1,212	N/A
Odyssey High School	42.3329	71.044958	350	N/A
Oliver Hazard Perry	42.33237	71.030225	239	N/A
Orchard Gardens	42.3303	71.078408	700	N/A
Parkway Academy of Technology and Health	42.28215	71.174833	320	N/A
Patrick F Gavin Middle	42.33344	71.050206	465	N/A
Patrick J Kennedy	42.37871	71.030683	257	N/A
Paul A Dever	42.31727	71.042942	480	N/A
Phineas Bates	42.27769	71.1351	296	N/A
Quincy Upper School	42.34818	71.069203	500	N/A
Rafael Hernandez	42.31381	71.098328	411	N/A
Ralph Waldo Emerson	42.32364	71.073133	243	N/A

School Names	Latitude	Longitude	Day	Night
Richard J Murphy	42.29329	71.048997	868	N/A
Roger Clap	42.32302	71.058342	161	N/A
Samuel Adams	42.36574	71.034839	275	N/A
Samuel W Mason	42.32623	71.070769	208	N/A
Sarah Greenwood	42.29667	71.080589	374	N/A
Snowden Int'l High	42.35057	71.077975	398	N/A
Social Justice Academy	42.26279	71.117919	309	N/A
TechBoston Lower Academy	42.27094	71.069753	462	N/A
TechBoston Upper Academy	42.28778	71.076611	284	N/A
The Engineering School	42.26279	71.117919	325	N/A
The English High	42.30636	71.108817	791	N/A
Thomas J Kenny	42.28673	71.053333	249	N/A
Urban Science Academy	42.28215	71.174833	313	N/A
Warren-Prescott	42.37795	71.064294	452	N/A
Washington Irving Middle	42.28326	71.125278	603	N/A
William E Russell	42.31807	71.05695	385	N/A
William Ellery Channing	42.25155	71.133339	323	N/A
William H Ohrenberger	42.26126	71.148731	537	N/A
William McKinley	42.34456	71.0731	410	N/A
William Monroe Trotter	42.31586	71.087336	355	N/A
Winship Elementary	42.34783	71.155333	265	N/A
Wm B Rogers Middle	42.25801	71.12205	582	N/A
Young Achievers	42.28198	71.0939	531	N/A
Boston Renaissance Charter Public (District): Boston Renaissance Charter Public School	42.3502	71.069456	1206	N/A
Edward M. Kennedy Academy for Health Careers (Horace Mann Charter School): Edward M. Kennedy Academy for Health Careers (Horace Mann Charter School)	42.33993	71.089547	211	N/A
MATCH Charter Public School (District): MATCH Charter Public School	42.35224	71.120947	382	N/A
Smith Leadership Academy Charter Public (District): Smith Leadership Academy Charter Public School	42.30142	71.058747	165	N/A
ABCD University High School	42.35207	71.064622		N/A
ABCD University High School	42.35207	71.064622		N/A
Boston Renaissance Charter Public School Discovery Academy	42.3502	71.069456		N/A
EDCO Youth Alternative	42.34943	71.095783		N/A
Suffolk County Juvenile Resource Center	42.35883	71.061511		N/A
William J. Ostiguy High School	42.35534	71.062336		N/A
EDCO Collaborative: EDCO YOUTH ALT	42.34943	71.095786		N/A

School Names	Latitude	Longitude	Day	Night
Advent	42.35817	71.071836		N/A
Boston Trinity Academy	42.25956	71.128958		N/A
Boston University Academy	42.35097	71.109764		N/A
Cathedral Grammar	42.34041	71.068831		N/A
Cathedral High	42.34387	71.072625		N/A
Children's Hospital	42.33744	71.105447		N/A
Commonwealth	42.35235	71.078153		N/A
Dr. Solomon Carter Fuller	42.33637	71.070619		N/A
Newman School	42.3522	71.082083	759	N/A
Park Street School	42.35638	71.071592	131	N/A
St John Elementary	42.36388	71.052992		N/A
The Kingsley	42.3503	71.082308		N/A
The Learning Project	42.3503	71.082308		N/A
The Winsor	42.33987	71.107914		N/A
Manville School	42.33108	71.109711		N/A
Boston	42.35902	71.0588		N/A
Archie T Morrison	42.2104	70.978583	441	N/A
Braintree High	42.20592	71.019875	1,590	N/A
Donald Ross	42.22848	70.986556	300	N/A
East Middle School	42.22091	70.989761	723	N/A
Highlands	42.17778	71.005144	423	N/A
Hollis	42.21603	71.002714	504	N/A
Liberty	42.18743	70.993697	479	N/A
Mary E Flaherty School	42.22078	71.017364	399	N/A
South Middle School	42.184	70.997731	518	N/A
Burlington High	42.49694	71.197308	1,101	N/A
Fox Hill	42.53025	71.190408	495	N/A
Francis Wyman Elem	42.50181	71.215397	602	N/A
Marshall Simonds Middle	42.5012	71.181447	859	N/A
Memorial	42.49982	71.183944	264	N/A
Pine Glen Elementary	42.52176	71.205331	390	N/A
Amigos School	42.3677	71.1133	295	N/A
Cambridge Rindge and Latin	42.37359	71.111831	1,583	N/A
Cambridgeport	42.36925	71.097614	295	N/A
Fletcher/Maynard Academy	42.36668	71.095636	249	N/A
Graham and Parks	42.38294	71.123897	418	N/A
Haggerty	42.37871	71.152556	296	N/A
John M Tobin	42.38426	71.139775	363	N/A
Kennedy-Longfellow	42.36982	71.086722	368	N/A

School Names	Latitude	Longitude	Day	Night
King Open	42.37104	71.091539	498	N/A
Maria L. Baldwin	42.38238	71.116647	383	N/A
Martin Luther King Jr.	42.36681	71.1131	263	N/A
Morse	42.35538	71.111719	419	N/A
Peabody	42.39147	71.128336	520	N/A
Chelsea High	42.39989	71.039742	1,369	N/A
Clark Avenue School	42.39571	71.030428	604	N/A
Edgar A Hooks Elem	42.39931	71.016894	449	N/A
Eugene Wright School	42.394	71.037	507	N/A
Frank M Sokolowski Elem	42.39922	71.018289	439	N/A
George F. Kelly Elem	42.39931	71.016892	508	N/A
Joseph A. Browne School	42.39398	71.036997	442	N/A
Shurtleff Early Childhood	42.3899	71.0354	872	N/A
William A Berkowitz Elem	42.39931	71.016892	448	N/A
Community Charter School of Cambridge	42.36743	71.084517	279	N/A
Alcott	42.45335	71.346394	432	N/A
Concord Middle	42.43954	71.395608	626	N/A
Thoreau	42.45223	71.397139	450	N/A
Willard	42.43009	71.382283	386	N/A
Everett High	42.41432	71.043711	1,763	N/A
George Keverian School	42.4089	71.0449	823	N/A
Lafayette School	42.42169	71.050994	874	N/A
Madeline English School	42.41349	71.0691	797	N/A
Parlin School	42.4101	71.051439	699	N/A
Sumner G. Whittier School	42.40413	71.057603	475	N/A
Webster School	42.41229	71.039553	486	N/A
Bowman	42.42361	71.218389	483	N/A
Bridge	42.43843	71.244842	451	N/A
Fiske	42.46888	71.213231	486	N/A
Harrington	42.44596	71.197167	460	N/A
Jonas Clarke Middle	42.42903	71.229858	751	N/A
Joseph Estabrook	42.47633	71.239439	440	N/A
Lexington High	42.44286	71.233314	1,955	N/A
Maria Hastings	42.44669	71.252767	423	N/A
Wm Diamond Middle	42.46404	71.228797	733	N/A
Brooks School	42.42065	71.127275	589	N/A
Christopher Columbus	42.40125	71.102594	491	N/A
Curtis-Tufts	42.4022	71.106528	36	N/A
John J McGlynn Elementary School	42.41595	71.108025	598	N/A

School Names	Latitude	Longitude	Day	Night
John J. McGlynn Middle School	42.41593	71.107994	591	N/A
Madeleine Dugger Andrews	42.41598	71.108056	490	N/A
Medford High	42.42841	71.125914	1,223	N/A
Medford Voc Tech High	42.42841	71.125914	232	N/A
Milton Fuller Roberts	42.42204	71.099497	65	N/A
Minuteman Regional High	42.44592	71.269031	583	N/A
Broadmeadow	42.27982	71.208678	622	N/A
High Rock School	42.27426	71.244606	422	N/A
Hillside Elementary	42.29538	71.240333	425	N/A
John Eliot	42.30554	71.240528	402	N/A
Needham High	42.2846	71.231703	1,434	N/A
Newman Elem	42.28209	71.254889	759	N/A
Pollard Middle	42.27649	71.226722	761	N/A
William Mitchell	42.28803	71.222378	486	N/A
C C Burr	42.35217	71.242017	379	N/A
Williams	42.34204	71.249778	275	N/A
Phoenix Charter Academy	42.39686	71.028019	164	N/A
Pioneer Charter School of Science	42.40808	71.051258	235	N/A
Atherton Hough	42.26677	70.957825	253	N/A
Atlantic Middle	42.27788	71.024494	455	N/A
Beechwood Knoll Elem	42.26939	71.006428	346	N/A
Broad Meadows Middle	42.2601	70.985053	336	N/A
Central Middle	42.25723	71.007525	563	N/A
Charles A Bernazzani Elem	42.25567	71.021761	350	N/A
Clifford H Marshall Elem	42.24339	70.980622	535	N/A
Francis W Parker	42.27602	71.021467	294	N/A
Lincoln-Hancock Comm Sch	42.24316	71.011992	612	N/A
Merrymount	42.26471	70.994208	321	N/A
Montclair	42.2707	71.032142	363	N/A
North Quincy High	42.27707	71.028328	1,518	N/A
Point Webster Middle	42.2376	70.991164	373	N/A
Quincy High	42.25336	70.999911	1,299	N/A
Reay E Sterling Middle	42.24038	71.015597	316	N/A
Snug Harbor Comm School	42.25538	70.966161	401	N/A
Squantum	42.29764	71.011569	337	N/A
Wollaston School	42.26343	71.023383	297	N/A
Albert F. Argenziano School at Lincoln Park	42.37844	71.099583	497	N/A
Arthur D Healey	42.39725	71.095753	562	N/A
Benjamin G Brown	42.39731	71.114178	255	N/A

School Names	Latitude	Longitude	Day	Night
Capuano ECC	42.38284	71.086939	397	N/A
E Somerville Community	42.38528	71.098639	546	N/A
Full Circle High School	42.38787	71.087008	39	N/A
John F. Kennedy	42.38787	71.087008	461	N/A
Next Wave Junior High	42.3877	71.087022	20	N/A
Somerville High	42.38706	71.097119	1,315	N/A
West Somerville Neighborhood	42.40099	71.116656	323	N/A
Winter Hill Community	42.39221	71.098722	427	N/A
Central	42.48352	71.095572	369	N/A
Colonial Park	42.46815	71.085886	270	N/A
Robin Hood	42.49327	71.107575	342	N/A
South	42.47413	71.099708	334	N/A
Stoneham High	42.4726	71.088942	740	N/A
Stoneham Middle School	42.48503	71.097456	595	N/A

Table D-2: Hotels Used in the Analysis

Name	Address	Latitude	Longitude	Night	Day
15 Beacon Hotel	15 Beacon Street, Boston, MA 02108	42.358244	-71.061925	88	30
30 Claremont Park	30 Claremont Park, Boston, MA 02118	42.34234	-71.08174	4	0
463 Beacon Street Guest House	463 Beacon Street, Boston, MA 02115	42.351147	-71.088375	29	3
Abercrombie's Farrington Inn	23 Farrington Avenue, Allston, MA 02134	42.354233	-71.130903	46	5
Ames Hotel – Boston	1 Court Street, Boston, MA 02108	42.358992	-71.058119	164	25
Anthony's Town House	1085 Beacon Street, Brookline, MA 02446-5610	42.345036	-71.110319	20	2
Beacon Hill Hotel	25 Charles Street, Boston, MA 02114	42.356817	-71.069628	19	24
Berkeley Residence	40 Berkeley Street, Boston, MA 02116-6316	42.345939	-71.070822	101	10
Best Western	1 Rainin Rd, Woburn, MA 01801	42.48125	-71.118569	142	158
Best Western Adams Inn	29 Hancock Street, Quincy, MA 02171	42.283	-71.038028	142	36
Best Western Roundhouse Suites	891 Massachusetts Avenue, Boston, MA 02118	42.331739	-71.07135	132	66
Best Western Tlc	477 Totten Pond Rd, Waltham, MA 02451	42.397406	-71.257919	144	185
Boston Copley Square Hotel	47 Huntington Avenue, Boston, MA 02116	42.349733	-71.076558	205	21
Boston Guest House	261 Newbury Street, Boston, MA 02116	42.349553	-71.083253	46	5
Boston Harbor Hotel	70 Rowes Wharf, Boston, MA 02110	42.356364	-71.050522	330	455
Boston Hotel Buckminster	645 Beacon Street, Boston, MA 02215	42.348522	-71.097922	135	58
Boston Marriott Burlington Hotel	1 Mall Rd (Rt 128 & 3A), Burlington, MA 01803	42.490047	-71.194758	602	494
Boston Marriott Copley Place	110 Huntington Avenue, Boston, MA 02116	42.347061	-71.079667	1580	2121
Boston Marriott Long Wharf	296 State Street, Boston, MA 02109	42.360025	-71.050258	559	411
Boston Park Plaza Hotel	130 Columbus Avenue, Boston, MA 02116	42.35095	-71.069242	1351	1045
Bulfinch Hotel	107 Merrimac Street, Boston, MA 02114	42.363897	-71.062447	113	22
Cambridge Bed and Muffin	267 Putnam Avenue, Cambridge, MA 02139	42.362675	-71.113675	4	0
Candlewood Suites Extended Stay Hotel Boston Braintree	235 Wood Rd, Braintree, MA 02184	42.220622	-71.039106	191	19
Candlewood Suites Extended Stay Hotel Boston Burlington	130 Middlesex Turnpike, Burlington, MA 01803	42.484683	-71.223364	214	21
Chandler Inn Hotel	26 Chandler Street, Boston, MA 02116	42.347125	-71.0706	79	8
Charlesmark Hotel LLC	655 Boylston Street, Boston, MA 02116	42.349814	-71.078458	57	6
Clarendon Square Inn Bed and Breakfast	198 West Brookline Street, Boston, MA 02118	42.343328	-71.076772	4	0
Club Quarters Boston	161 Devonshire Street, Boston, MA 02110	42.35625	-71.057303	256	77
Colonnade Boston Hotel	120 Huntington Avenue, Boston, MA 02116	42.345825	-71.080983	409	388
Comfort Inn	14 Hill Street, Woburn, MA 01801	42.478972	-71.115722	93	9

Name	Address	Latitude	Longitude	Night	Day
Comfort Inn	1374 North Main Street, Randolph, MA 02368	42.201508	-71.063308	227	48
Comfort Inn Boston	900 Morrissey Boulevard, Boston, MA 02122	42.29187	-71.04723	190	104
Commonwealth Court Guest House	284 Commonwealth Avenue # A1, Boston, MA 02115	42.349725	-71.0846	24	2
Constitution Inn	150 3rd Avenue, Boston, MA 02129	42.376447	-71.053428	211	88
Constitution Yacht Charters	28 Constitution Rd, Boston, MA 02129	42.371219	-71.060372	16	2
Copley House	239 W Newton Street, Boston, MA 02116	42.344606	-71.080197	56	6
Copley Inn	19 Garrison Street, Boston, MA 02116	42.345906	-71.0798	30	3
Courtyard Boston Cambridge	777 Memorial Dr, Cambridge, MA 02139	42.358917	-71.115022	292	101
Courtyard Boston Downtown/Tremont	275 Tremont Street, Boston, MA 02116	42.349936	-71.065158	461	317
Courtyard Boston Waltham	387 Winter Street, Waltham, MA 02451	42.397975	-71.259075	164	38
Courtyard Boston-South Boston	63 R Boston Street, Boston, MA 02125	42.3266	-71.0604	236	42
Courtyard by Marriott North Woburn-Stoneham	700 Unicorn Park Dr, Woburn, MA, 01801	42.48856	-71.11597	276	126
Courtyard by Marriott Woburn	240 Mishawum Rd, Woburn, MA, 01801	42.50356	-71.13916	169	42
Courtyard Marriott Hotel Boston Copley Square	88 Exeter Street, Boston, MA 02116	42.348567	-71.078897	116	12
Crowne Plaza Boston/Newton	320 Washington Street, Newton, MA 02458	42.356767	-71.186739	388	113
Days Inn Boston – Harvard Fenway MA	1234 Soldiers Field Rd, Boston, MA 02135	42.364158	-71.136586	162	31
Doubletree Boston Regional	821 Washington Street, Boston, MA 02111	42.34884	-71.06427	383	133
Doubletree Club Boston Hotel – Bayside	240 Mt. Vernon Street, Boston, MA 02125	42.320397	-71.046014	280	35
Doubletree Downtown Boston Hotel	821 Washington Street, Boston, MA 02111	42.349056	-71.063894	372	162
Doubletree Guest Suites	400 Soldiers Field Rd, Boston, MA 02134	42.360153	-71.118492	442	390
Doubletree Guest Suites Boston Hotel – Waltham	550 Winter Street, Waltham, MA 02451	42.397008	-71.266347	395	343
Element Lexington Inn	727 Marrett Rd, Lexington, MA 02421	42.4452	-71.26031	168	103
Eliot Hotel	370 Commonwealth Avenue, Boston, MA 02215	42.348636	-71.088717	136	54
Embassy Suites Boston – Logan Airport	207 Porter Street, Boston, MA 02128	42.370533	-71.031658	392	129
Encore Bed and Breakfast	116 West Newton Street, Boston, MA 02118	42.34159	-71.07702	6	1
Extended Stay America Hotel Boston – Braintree	20 Rockdale Street, Braintree, MA 02184	42.225925	-71.030567	148	15
Extended Stay America Hotel Boston – Braintree	20 Rockdale Street, Braintree, MA 02184	42.225886	-71.030589	148	15
Extended StayAmerica Boston Woburn	831 Main Street, Woburn, MA 01801	42.50307	-71.15869	144	14
Extended StayAmerica Deluxe Boston Waltham	32 Fourth Avenue, Waltham, MA 02451	42.39366	-71.25995	195	20
Fairfield Inn by Marriott Boston	235 Elm Street, Dedham, MA 02026	42.22812	-71.17749	215	22
Fairfield Inn by Marriott Boston Woburn	285 Mishawum Rd, Woburn, MA 01801	42.502931	-71.135867	185	19
Fairmont Battery Wharf Hotel	3 Battery Wharf, Boston, MA 02109	42.366933	-71.050689	215	177

Name	Address	Latitude	Longitude	Night	Day
Fireside Bed and Breakfast of Lexington	24 Eldred St., Lexington, MA 02420	42.47535	-71.24712	4	0
Four Points by Sheraton Barcelo	30 Wheeler Rd, Burlington, MA 01803	42.47764	-71.20866	258	163
Four Seasons Hotel Boston	200 Boylston Street, Boston, MA 02116	42.352056	-71.068317	392	351
Hampton Inn	191 Monsignor O'Brien Highway, Cambridge, MA 02141	42.372075	-71.0785	164	16
Hampton Inn & Suites Boston Crosstown Center	811 Massachusetts Avenue, Boston, MA 02118	42.332906	-71.072628	251	68
Hampton Inn Boston/Braintree	215 Wood Rd, Braintree, MA 02184	42.221953	-71.036281	148	32
Hampton Inn/Boston Woburn	315 Mishawum Rd, Woburn, MA 01801	42.503692	-71.131128	142	14
Harborside Inn	185 State Street, Boston, MA 02109	42.359414	-71.052914	78	8
Hilton Boston Back Bay	40 Dalton Street, Boston, MA 02115	42.346511	-71.085303	560	314
Hilton Boston Financial District	89 Broad Street, Boston, MA 02110	42.357353	-71.053139	520	484
Hilton Boston Logan Airport	1 Hotel Dr, Boston, MA 02128	42.370533	-71.031658	860	577
Hilton Boston Woburn North	2 Forbes Rd, Woburn, MA 01801	42.49638	-71.12083	494	485
Hilton Dedham	25 Allied Dr, Dedham, MA 02026	42.22481	-71.17017	368	379
Hilton Garden Inn / Boston Burlington	5 Wheeler Rd, Burlington, MA 01803	42.476933	-71.211669	257	207
Hilton Garden Inn Aaltham	420 Totten Pond Rd, Waltham, MA 02451	42.39719	-71.25579	213	158
Holiday Inn	30 Washington Street, Somerville, MA 02143	42.381803	-71.081803	253	258
Holiday Inn Boston – Brookline	1200 Beacon Street, Brookline, MA 02446	42.343628	-71.116486	287	132
Holiday Inn Boston at Beacon Hill	5 Blossom Street, Boston, MA 02114	42.361886	-71.066556	435	166
Holiday Inn Express	250 Monsignor O Brien Highway, Cambridge, MA 02141	42.373361	-71.081622	161	16
Holiday Inn Express & Suites	280 Friend Street, Boston, MA 02114	42.364892	-71.061511	103	10
Holiday Inn Express Hotel Boston	69 Boston Street, Boston, MA 02125	42.327017	-71.059108	169	42
Holiday Inn Express Hotel Boston-Waltham	385 Winter Street, Waltham, MA 02451	42.397561	-71.258997	155	16
Holiday Inn Express Hotel Braintree	190 Wood Rd, Braintree, MA 02184	42.221106	-71.036011	148	15
Holiday Inn Hotel Boston-Dedham Htl & Conf Ctr	US 1a &I 95/ 128, 55 Ariadne Rd, Dedham, MA 02026	42.231431	-71.182797	290	265
Holiday Inn Select Boston – Woburn	15 Middlesex Canal Park Rd, Woburn, MA 01801	42.496497	-71.157994	280	190
Home Suites Inn	455 Totten Pond Rd, Waltham, MA 02451	42.39694	-71.2582	168	17
Homestead Studio Suites Boston – Burlington	40 South Avenue, Burlington, MA 01803	42.480797	-71.219742	204	20
Homestead Studio Suites Boston – Waltham	52 Fourth Avenue, Waltham, MA 02451	42.393542	-71.259575	201	20
Hotel 140	140 Clarendon Street, Boston, MA 02118	42.348589	-71.074214	78	47
Hotel Commonwealth	500 Commonwealth Avenue, Boston, MA 02215	42.3487	-71.095267	215	150
Hotel Indigo Riverside	399 Grove Street, Newton, MA 02462	42.333953	-71.254314	274	200

Name	Address	Latitude	Longitude	Night	Day
Hotel Marlowe	25 Edwin H. Land Boulevard, Cambridge, MA 02141	42.367953	-71.074739	339	233
Howard Johnson Hotel Boston	1271 Boylston Street, Boston, MA 02215	42.344936	-71.096419	135	13
Hyatt Harborside Bostons Logan Airport	101 Harborside Dr, Boston, MA 02128	42.356808	-71.019917	388	257
Hyatt Place	116 Riverside Avenue, Medford, MA 02155	42.416661	-71.104886	225	38
Hyatt Regency Boston	1 Avenue De Lafayette, Boston, MA 02111	42.353453	-71.061158	718	526
Hyatt Regency Cambridge	575 Memorial Dr, Cambridge, MA 02139	42.354053	-71.105131	673	1201
Hyatt Summerfield Suites Boston/Burlington	2 Van De Graaff Dr, Burlington, MA 01803	42.483169	-71.195197	215	22
Hyatt Summerfield Suites Boston/Waltham	54 Fourth Avenue, Waltham, MA 02451	42.393669	-71.259853	194	77
InterContinental Boston	510 Atlantic Avenue, Boston, MA 02210	42.353953	-71.052978	609	169
John Hancock Hotel & Conf Center	40 Trinity Pl, Boston, MA 02116	42.348522	-71.075369	92	235
John Jeffries House	14 David G Mugar Way, Boston, MA 02114	42.360672	-71.071058	66	7
La Quinta Inn & Suites	23 Cummings Street, Somerville, MA 02145	42.394583	-71.08395	211	32
Mandarin Oriental, Boston	776 Boylston Street, Boston, MA 02199	42.348806	-71.08175	213	280
Marriott Boston/Quincy	1000 Marriott Dr, Quincy, MA 02169	42.22914	-71.01762	666	444
Marriott Newton	2345 Commonwealth Avenue, Newton, MA 02466	42.346	-71.25711	617	406
Marriott's Custom House	3 McKinley Sq, Boston, MA 02109	42.358964	-71.053189	121	12
Midtown Hotel	220 Huntington Avenue, Boston, MA 02115	42.343403	-71.083975	228	154
Millennium Bostonian Hotel Boston	Faneuil Hall Marketplace, 26 North Street, Boston, MA 02109	42.360969	-71.055964	289	162
Milner Hotel	78 Charles St S, Boston, Massachusetts 02116	42.350453	-71.066731	92	9
Newbury Guest House	261 Newbury Street, Boston, MA 02116	42.34944	-71.0832	46	5
Nine Zero Hotel	90 Tremont Street, Boston, MA 02108	42.357433	-71.061033	271	89
Oasis Guest House	22 Edgerly Rd, Boston, MA 02115-3007	42.345822	-71.087883	45	4
Omni Parker House Boston	60 School Street, Boston, MA 02108	42.357903	-71.060061	791	409
Onyx Hotel	155 Portland Street, Boston, MA 02114	42.363856	-71.061164	161	27
Quality Inn & Suites by Choice Hotels	440 Bedford Street, Lexington, MA 02420	42.473467	-71.249247	293	65
Radisson Hotel Boston	200 Stuart Street, Boston, MA 02116	42.350833	-71.0672	511	333
Ramada Inn Boston	800 Willim T Morrissey Boulevard, Dorchester, MA 02122	42.294872	-71.0473	445	179
Ramada Inn Logan Airport	75 Service Rd, Boston, MA 02128	42.3587	-71.1559	741	264
Red Roof Inn	19 Commerce Way, Woburn, MA 01801	42.506814	-71.130617	228	23
Renaissance Boston Waterfront Hotel	606 Congress Street, Boston, MA 02301	42.347869	-71.040061	655	460

Name	Address	Latitude	Longitude	Night	Day
Residence Inn Boston Harbor	34-44 Charles River Avenue, Boston, MA 02129	42.370453	-71.060242	241	33
Residence Inn by Marriott Dedham	259 Elm Street, Dedham, MA 02026	42.227169	-71.177211	116	12
Seaport Boston Hotel and Seaport World Trade Center Boston	1 Seaport Lane, Boston, MA 02210	42.349225	-71.041794	615	1785
Shawmut Guest House	332 Shawmut Avenue, Boston, MA 02118	42.34166	-71.07101	3	0
Sheraton Boston Hotel	39 Dalton Street, Boston, MA 02199	42.346328	-71.084781	1696	2060
Sheraton Braintree	37 Forbes Rd, Braintree, MA 02184-2602	42.220569	-71.029153	514	396
Sheraton Needham Hotel	100 Cabot Street, Needham, MA 02494	42.303342	-71.219278	355	448
Staybridge Suites Extended Stay Hotel Boston-Burlington	11 Old Concord Rd, Burlington, MA 01803	42.4752	-71.210919	202	26
Super 8 Watertown	100 N. Beacon Street, Watertown, MA 02472	42.364103	-71.178903	63	6
Taj Boston	15 Arlington Street, Boston, MA 02116	42.352808	-71.0716	392	542
The Back Bay Hotel	350 Stuart Street, Boston, MA 02116	42.349497	-71.072242	319	119
The Boston Christopher	476 Columbus Avenue, Boston, MA 02118	42.342972	-71.078594	13	1
The Charles Street Inn	94 Charles Street, Boston, MA 02114	42.358481	-71.070881	13	1
The College Club of Boston	44 Commonwealth Avenue, Boston, MA 02116	42.352714	-71.073294	16	27
The Fairmont Copley Plaza Hotel Boston	138 St. James Avenue, Boston, MA 02116	42.349303	-71.076286	550	402
The Gryphon House Bed and Breakfast	9 Bay State Rd Boston, Ma 02215	42.35001	-71.09324	11	1
The Inn at St. Botolph	99 St Botolph Street, Boston, MA 02116	42.344872	-71.081025	23	2
The Langham Boston Hotel	250 Franklin Street, Boston, MA 02110	42.356328	-71.054519	457	287
The Lenox Hotel	61 Exeter Street, Boston, MA 02116	42.349194	-71.079592	304	104
The Liberty Hotel	215 Charles Street, Boston, MA 02114	42.361611	-71.070711	428	303
The Ritz-Carlton Residences, Boston Common	10 Avery Street, Boston, MA 02111	42.353217	-71.063236	277	301
The Westin Copley Place	10 Huntington Avenue, Boston, MA 02116	42.348461	-71.077422	1153	1283
The Westin Waltham-Boston	70 Third Avenue, Waltham, MA 02451	42.395033	-71.259528	497	737
W Boston	100 Stuart Street, Boston, MA 02116	42.350939	-71.065261	337	174
Westin Boston Waterfront	425 Summer Street, Boston, MA 02210	42.346189	-71.043239	1139	1394
Whitman House Non for Profit – Bed and Breakfast	17 Worcester Street, Cambridge, MA 02139	42.376447	-71.053428	4	0

Table D-3: Hospitals Used in the Analysis

Name	Address	Lat	Long	Night	Day
Spaulding Rehabilitation Hospital	125 Nashua Street, Boston, MA 02114	42.3678	-71.064911	143	282
Massachusetts General Hospital	55 Fruit Street, Boston, MA 02114	42.362408	-71.068942	740	1498
Erich Lindemann Mental Health	25 Staniford Street, Boston, MA 02114	42.363625	-71.063444	44	162
Shriner's Hospital for Children	51 Blossom Street, Boston, MA 02114	42.363086	-71.066506	23	29
Massachusetts Eye and Ear Infirmary	243 Charles Street, Boston, MA 02114	42.362344	-71.069314	52	246
Tufts Medical Center	800 Washington Street, Boston, MA 02111	42.349517	-71.063308	339	672
Boston Medical Center	1 Boston Medical Center Place, Boston, MA 02118	42.349517	-71.073672	560	1412
Caritas Carney Hospital	2100 Dorchester Avenue, Dorchester, MA 02124	42.277289	-71.065097	145	230
Beth Israel Deaconess Medical Center	330 Brookline Avenue, Boston, MA 02215	42.340244	-71.105856	513	988
Dana Farber Cancer Institute	44 Binney Street, Boston, MA 02115	42.338011	-71.107169	20	248
Brigham and Womens Hospital	75 Francis Street, Boston, MA 02115	42.335908	-71.107389	619	1271
Children's Hospital Boston	300 Longwood Avenue, Boston, MA 02115	42.336911	-71.1054	343	855
Franciscan Children's Hospital & Rehabilitation Center	30 Warren Street, Brighton, MA 02135	42.349867	-71.145106	73	270
Caritas St Elizabeth Medical Center	736 Cambridge Street, Boston, MA 02135	42.34835	-71.149644	244	364
Kindred Hospital of Boston	1515 Commonwealth Avenue, Brighton, MA 02135	42.346325	-71.141997	55	159
City of Cambridge: Cambridge Health Alliance	1493 Cambridge Street, Cambridge, MA 02139	42.374783	-71.104781	156	513
Newton-Wellesley Hospital	2014 Washington Street, Newton, MA 02464	42.33151	-71.2457	201	695
Arbour-HRI Hospital	227 Babcock Street, Brookline, MA 02446	42.35104	-71.12144	63	184
Hallmark Health System – Lawrence Memorial Hospital	170 Governors Avenue, Medford MA 02155	42.42642	-71.11026	124	362
M.I.T. Medical Department	25 Carleton Street, Cambridge, MA 02139	42.36045	-71.08725	17	49
Solomon Mental Health Center	85 East Newton Street, Boston, MA 02118	42.33637	-71.07062	23	86
Lahey Clinic Hospital	41 Mall Road, Burlington, MA 01805	42.48667	-71.20516	305	975

Table D-4: Long Term Care Facilities Used in the Analysis

Type	Name	Address	Lat	Long	Night	Day
Nursing Home	Arnold House Nursing Home	490 William Street, Stoneham, MA 02180	42.488594	-71.114269	20	20
Assisted Living	Atria Longmeadow Place	42 Mall Rd, Burlington, MA 01803	42.487653	-71.206781	98	98
Nursing/Rehab	Bostonian Nursing Care & Rehabilitation Center	337 Neponset Avenue, Dorchester, MA 02122	42.287639	-71.047186	119	119
Nursing Home	Brighton House	170 Corey Rd, Brighton, MA 02135	42.343189	-71.139508	69	69
Nursing Home	Chetwynde Health & Rehab Center	1650 Washington Street, West Newton, MA 02465	42.341858	-71.237733	67	67
Nursing Home	Clark House Nursing Center	30 Longwood Dr, Westwood, MA 02090	42.236908	-71.209094	63	63
Nursing Home	Corey Hill Nursing Home Inc	249 Corey Rd, Brighton, MA 02135	42.344756	-71.137083	40	40
Nursing Home	Courtyard Nursing Care Center	200 Governors Avenue, Medford, MA 02155	42.427492	-71.110331	206	206
Rest Home	Elder Residence of Stone Institute	277 Elliot Street, Newton, MA, 02464	42.313392	-71.220694	24	24
Nursing Home	Epoch Senior Health Care	75 Norumbega Rd, Weston, MA 02493	42.349403	-71.261914	99	99
Assisted Living	Evans Park at Newton Corner	430 Centre Street, Newton, MA 02458	42.35549	-71.18603	102	102
Rehab	Franciscan Children's Hospital & Rehabilitation Center	30 Warren Street, Brighton, MA 02135	42.349864	-71.145136	53	53
Nursing Home	Golden Living Center-Dedham	1007 East Street, Dedham, MA 02026	42.228322	-71.162736	106	106
Nursing Home	Golden Livingcenters: Chetwynde	1650 Washington Street, Newton, MA 02465	42.341789	-71.237794	67	67
Nursing Home	Golden Livingcenters: West Newton	25 Armory Street, West Newton, MA 02465	42.350125	-71.220033	109	109
Nursing Home	Hale-Barnard Services-Older People	273 Clarendon Street, Boston, MA 02116	42.353472	-71.076533	51	51
Nursing Home	Highgate Manor Center For Health	10 Carematrix Dr, Dedham, MA 02026	42.227042	-71.171889	125	125
Rehab	Hope House, Inc.	8 Farnham Street, Boston, MA 02119	42.330642	-71.074306	71	71
Nursing Home	Lasell House At Lasell Village	120 Seminary Avenue, Auburndale, MA 02466	42.338908	-71.251472	30	30
Nursing Home	Life Care Center of Stoneham	25 Woodland Rd, Stoneham, MA 02180	42.450842	-71.090008	87	87
Nursing Home	Marian Manor Nursing Home	130 Dorchester Street, South Boston, MA 02127	42.334686	-71.046917	267	267
Nursing Home	Mt Ida Rest Home	32 Newtonville Avenue, Newton, MA 02458	42.352178	-71.187297	16	16
Nursing Home	Newton Health Care Center	2101 Washington Street, Newton, MA 02462	42.329133	-71.251058	152	152
Nursing Home	North End Community Nursing Home	70 Fulton Street, Boston, MA 02109	42.362508	-71.053536	124	124
Assisted Living	Norumbega Point	99 Norumbega Rd, Weston, MA 02493	42.349733	-71.260564	83	83
Nursing Home	Presentation Nursing Rehabilitation Ctr	10 Bellamy Street, Brighton, MA 02135	42.354947	-71.168217	120	120
Assisted Living	Ruggles Assisted Living	25 Ruggles Street, Roxbury, MA 02119	42.331814	-71.083211	38	38
Rehab	Seton Manor	200 Corey Rd, Brighton, MA 02135	42.343725	-71.138794	21	21

Type	Name	Address	Lat	Long	Night	Day
Nursing Home	South Cove Manor Nursing Home	120 Shawmut Avenue, Boston, MA 02118	42.346217	-71.065664	99	99
Nursing Home	Stone Institute	277 Elliot Street, Newton, MA 02464	42.313211	-71.220967	78	78
Assisted Living	Sunrise of Burlington	24 Mall Rd, Burlington, MA 01803	42.490283	-71.1987	70	70
Assisted Living	Susan S. Bailis Assisted Living Community	352 Massachusetts Avenue, Boston, MA 02115	42.342167	-71.084022	73	73
Assisted Living	The Falls at Corderly Dam	2300 Washington Street, Newton, MA 02462	42.325961	-71.255767	71	71
Nursing Home	Tidd Home Inc	74 Elm Street, Woburn, MA 01801	42.506331	-71.162369	14	14
Assisted Living	Traditions of Dedham	735 Washington Street, Dedham, MA 02026	42.2375	-71.1825	84	84
Nursing Home	Vernon Hall Nursing Home	8 Dana Street, Cambridge, MA 02138	42.369592	-71.110433	78	78
Assisted Living	Waltham Crossings	126 Smith Street, Waltham, MA, 02451	42.414561	-71.253514	79	79
Nursing Home	West Newton Health and Rehab Center	25 Armory Street, Newtonville, MA 02460	42.350061	-71.219997	109	109
Nursing Home	Wingate at Brighton Rehab and Sn Residence	100 N Beacon Street, Boston, MA 02134	42.354597	-71.143067	113	113
Nursing Home	Wingate At Needham	589 Highland Avenue, Needham, MA 02494	42.299919	-71.229961	131	131
Nursing Home	Wingate: Skilled Nursing & Rehabilitation Residence	100 North Beacon Street, Allston, MA 02134	42.354606	-71.143042	113	113
Nursing Home	Woburn Nursing Center	18 Frances Street, Woburn, MA 01801	42.487631	-71.151536	134	134
Assisted Living	Zelma Lacey House	9 West School Street, Charlestown, MA 02129	42.376208	-71.066208	59	59

APPENDIX E: ENVIRONMENTAL TABLES

Table E-1: Protected and Recreational Open Space

Site Name	Fee Owner	Primary Purpose	Public Access
N/A	Sun Life of Canada	Conservation	Yes
N/A	DCR - Division of Urban Parks and Recreation & Water Supply Protection	Conservation & Water Supply	Yes
N/A	DCR - Division of Urban Parks and Recreation	Conservation	Unknown
N/A	City of Newton	Conservation	Yes
N/A	Town of Winchester	Conservation	Yes
N/A	Habitat for Humanity	Conservation	Unknown
N/A	Town of Wellesley	Conservation	Unknown
N/A	Town of Reading	Conservation	Yes
N/A	Milton Land Conservation Trust	Conservation	Unknown
N/A	Town of Dedham	Conservation	Yes
N/A	Town of Dedham	Conservation	Yes
N/A	Town of Braintree	Water Supply	Unknown
N/A	Dedham Land Trust	Conservation	Unknown
Auburndale Yard	City of Newton	Conservation	Yes
Bates Road Conservation Land	Town of Lexington	Conservation	Yes
Blue Hill Vista	Town of Westwood	Conservation	Yes
Blue Hills Reservation	Vickerson & Pedrotti	Conservation	Unknown
Blue Hills Reservation	Homans	Conservation	Unknown
Boston Edison Easement	Town of Lexington	Conservation	Yes
Bradley Reservation	The Trustees of Reservations	Conservation	Yes
Brodeur Gift	Town of Braintree	Conservation	Yes
Burlington Strip	Town of Lexington	Conservation	Yes
Cambridge Reservoir	City of Cambridge	Water Supply	Yes
Cambridge Water Basin	City of Cambridge	Water Supply	Unknown
Charles River Pathway	City of Newton & United States	Conservation	Yes
Charles River Pathway	Oak Park Realty	Conservation	Yes
Cochituate Aqueduct	City of Newton	Water Supply	Unknown
Conservation Land/Meadow Rd	Town of Stoneham	Conservation	Yes
Conservation Land/North & Erikso	Town of Stoneham	Conservation	Yes
Crabberry Hill	Town of Lexington	Water Supply	Unknown
Cranberry Bog Conservation Area	City of Woburn	Conservation	Yes
Cranberry Hill	Town of Lexington	Water Supply	Unknown
Currier/Anderson	Town of Westwood	Conservation	Yes

Site Name	Fee Owner	Primary Purpose	Public Access
Cutler Park	DCR - Division of Urban Parks and Recreation	Conservation	Yes
Cutters Bluff Parkway	Weston Forest and Trail Association	Conservation	Unknown
Dedham Town Forest	Town of Dedham	Conservation	Yes
Dikes Pond	Town of Stoneham	Conservation	Yes
Dolan Pond Conservation Area	City of Newton	Conservation	Yes
Dolan Pond Wetland Area	City of Newton	Conservation	Yes
Doublet Hill Conservation Area	Town of Weston	Conservation	Yes
Fiske Hill	Town of Lexington	Conservation	Yes
Flatley Property	Town of Braintree	Conservation	Yes
Former Howard Johnsons Site	City of Quincy	Conservation	Yes
Furnace Brook Parkway	DCR - Division of Urban Parks and Recreation	Conservation	Yes
Great Pond Area	Town of Braintree	Water Supply	Yes
Great Pond Watershed	M040/M244/M133	Water Supply	Unknown
Haslam Pond	Town of Westwood	Conservation	Yes
Heath Cr	Heath Nancy F	Conservation	Unknown
Hobbs Brook	Town of Lexington	Conservation	Yes
Hobbs Brook Reservation	City of Cambridge	Conservation & Water Supply	Yes
Hultman Aqueduct	Massachusetts Water Resources Authority	Water Supply	Unknown
Hunnewell Woods	City of Newton	Conservation	Yes
Idywilde Conservation Area	Town of Lexington	Conservation	Yes
Island	City of Cambridge	Water Supply	Unknown
Ivan St. Conservation Land	Town of Lexington	Conservation	Yes
Juniper Hill Conservation Area	Town of Lexington	Conservation	Yes
Justin/Bernard Cons Land	Town of Lexington	Conservation	Yes
Katahdin Wood	Town of Lexington	Conservation	Yes
Landlocked Land	Town of Burlington	Water Supply	Yes
Lasell Pond	Lasell College	Conservation	Unknown
Laura Estates	Laura Estates	Conservation	Unknown
Legion Road Property	Town of Weston	Conservation	Yes
Long Meadow Brook	Town of Burlington	Conservation	Yes
Lowell Woods	Town of Westwood	Conservation	Yes
Meagherville	Town of Lexington	Conservation	Yes
Middlesex Falls Reservation	DCR - Division of Urban Parks and Recreation & Water Supply Protection	Conservation & Water Supply	Yes

Site Name	Fee Owner	Primary Purpose	Public Access
Mountain Area Cons Area	Town of Burlington	Conservation	Yes
Mulvehill Conservation	Town of Westwood	Conservation	Yes
Mystic River Reservation	DCR - Division of Urban Parks and Recreation	Conservation	Yes
Neponset Conservation Land	Town of Dedham	Conservation	Yes
Neponset River Reservation	DCR - Division of Urban Parks and Recreation	Conservation	Yes
Neponset River Reservation	DCR - Division of Urban Parks and Recreation	Conservation	Yes
Nickerson Well	Town of Weston	Water Supply	Unknown
Norumbega Park	City of Newton	Conservation	Yes
Old Country Rd Cr	Hagman Barry R and Robert B	Conservation	Limited
Old RR R.O.W. by Grossmans	Town of Wellesley	Conservation	Yes
Old Town Quarry	Town of Stoneham	Conservation	No
Otoole	Town of Westwood	Conservation	Yes
Paint Mine Conservation Area	Town of Lexington	Conservation	Yes
Pakeen Farm Cr	Bihldorff and Lyman Trust	Conservation	No
Parker School	Town of Lexington	Conservation	Yes
Parkland	Town of Needham	Conservation	Yes
Pattens Cove	DCR - Division of Urban Parks and Recreation	Conservation	Yes
Pine Meadows Golf Course	Town of Lexington	Conservation	Yes
Pomry House	Newton Community Service Centers Inc	Conservation	Yes
Poor Farm	Town of Lexington	Conservation	No
Revere Beach Parkway	DCR - Division of Urban Parks and Recreation	Conservation	Unknown
River Street	DCR - Division of Urban Parks and Recreation	Conservation	Unknown
Rossi Cr	Rossi Ricardo Land Marcela C	Conservation	No
Sandy Valley	Town of Westwood	Conservation	Yes
Sawins Pond	Unknown	Water Supply	No
Sears Cr # 2 & 3	Sears Zilla M	Conservation	No
Shuttleworth Land	Town of Westwood	Conservation	Yes
Simonds Brook Conservation Area	Town of Lexington	Conservation	Yes
South Bedford St Conservation Area	Town of Burlington	Conservation	Yes
South Reservoir	Town of Winchester	Water Supply	No
Stand Pipe	Town of Burlington	Water Supply	Yes
Stony Brook Reservoir	City of Cambridge	Water Supply	Unknown
Sudbury Aqueduct	DCR - Division of Water Supply Protection	Water Supply	Yes

Site Name	Fee Owner	Primary Purpose	Public Access
Sunlife Assurance Corp Land	Sun Life Assurance	Conservation	No
Tophet Swamp	Town of Lexington	Conservation	Yes
Town Forest	Town of Wellesley	Conservation	Yes
Turning Mill Pond	Town of Lexington	Conservation	Yes
Valley Road	Town of Lexington	Conservation	Yes
Walnut St Property	Town of Wellesley	Conservation	Yes
Weld Pond	Massachusetts Audubon Society	Conservation	Unknown
Wellesley Office Park Cr	Amica Mutual Insurance Company	Conservation	No
Wentworth Area	Town of Westwood	Conservation	Yes
Weston Reservoir	Massachusetts Water Resources Authority	Water Supply	Unknown
Weston Water Department	Town of Weston	Water Supply	Limited
Wetlands	Town of Dedham	Conservation	Yes
Wheeler Road Cr	Seven Springs Residential Llc	Conservation	Limited
Williard Woods Conservation Area	Town of Lexington	Conservation	Yes
Williams Pond	City of Watertown	Water Supply	No
Wilson Mountain Reservation	DCR - Division of Urban Parks and Recreation	Conservation	Yes
Winchester Reservoir	Town of Winchester	Water Supply	No
Windmere Well Field	Town of Burlington	Water Supply	No
Wood St. Conservation Land	Town of Lexington	Conservation	Yes

Table E-2: Areas of Critical Environmental Concern

Site Name	Region
Neponset River Estuary	Coastal
Fowl Meadow And Ponkapoag Bog	Inland
Fowl Meadow And Ponkapoag Bog	Inland

Table E-3: NHESP Natural Communities

Community Name	Description
Kettlehole wet meadow	Small but excellent condition, with good species diversity and a minimum of exotic invasive species.
Atlantic white cedar bog	Good condition and is fairly well buffered by natural vegetation.
Level bog	Most significant level bog in eastern Massachusetts. Densely developed setting, nearly pristine condition, good species and structural diversity and part of a larger complex of acidic wetlands.

Table E-4: Outstanding Resource Waters

Name	Type	Major Basin	Status
Farm River	Public Water Supply Watershed	Boston Harbor	Active
Great Pond	Public Water Supply Watershed	Boston Harbor	Active
Hobbs Brook	Public Water Supply Watershed	Charles	Active
Horn Pond	Public Water Supply Watershed	Boston Harbor	Active
Middle Reservoir	Public Water Supply Watershed	Boston Harbor	Active
Mill Pond Reservoir	Public Water Supply Watershed	Ipswich & Boston Harbor	Active
Stony Brook Reservoir	Public Water Supply Watershed	Charles	Active

Table E-5: Priority Natural Vegetation Communities

ID	Community	General Type	Description
1	Coastal	Tidal & Non-Tidal	Coastal bank bluff/sea cliff, tidal flat and salt marsh
2	Coastal	Tidal & Non-Tidal	Coastal bank bluff/sea cliff and tidal flat
3	Coastal	Tidal & Non-Tidal	Coastal bank bluff/sea cliff, tidal flat, maritime oak-holly forest and non-coastal
4	Coastal	Tidal	Tidal Flat
5	Coastal	Tidal & Non-Tidal	Coastal bank bluff/sea cliff and tidal flat
6	Coastal	Tidal	Tidal Flat
7	Coastal	Tidal & Non-Tidal	Coastal bank bluff/sea cliff, tidal flat and rocky shore
8	Coastal	Tidal	Coastal beach, rocky shore and marine gravel/sand beach
9	Acidic Peatland	Atlantic White Cedar	Atlantic white cedar swamp
10	Riverine	Herbaceous	Shallow emergent marsh
11	Riverine	Herbaceous & Trees	Shallow emergent marsh, wooded swamp deciduous and non-riverine
12	Riverine	Trees	Wooded swamp deciduous
13	Riverine	Trees	Wooded swamp deciduous
14	Riverine	Trees	Wooded swamp deciduous
15	Riverine	Trees	Wooded swamp deciduous
16	Riverine	Herbaceous	Brackish tidal marsh
17	Riverine	Herbaceous	Brackish tidal marsh
18	Riverine	Herbaceous	Brackish tidal marsh
19	Riverine	Herbaceous	Brackish tidal marsh
20	Riverine	Herbaceous	Brackish tidal marsh
21	Riverine	Herbaceous	Brackish tidal marsh
22	Riverine	Herbaceous	Brackish tidal marsh
23	Sandplain	Grassland	Grassy natural field
24	Sandplain	Grassland	Grassy natural field
25	Sandplain	Grassland	Grassland under powerline
26	Sandplain	Grassland	Grassland under powerline
27	Sandplain	Cutural Grassland	Grassy natural field
28	Sandplain	Grassland	Grassland under powerline
29	Sandplain	Grassland	Grassy natural field
30	Sandplain	Grassland	Grassland under powerline
31	Sandplain	Grassland	Grassland under powerline
32	Sandplain	Grassland	Grassy natural field
33	Sandplain	Grassland	Grassy natural field
34	Sandplain	Grassland	Grassy natural field
35	Sandplain	Grassland	Grassy natural field
36	Pine Barrens	Pitch Pine	Ridgetop pitch pine-scrub oak

The following category types did not have enough valuable information to constitute a table, but in some cases a short description is included.

1. Certified Vernal Pools
2. NHESP Priority Habitats of Rare Species
3. Estimated Habitats of Rare Wildlife
4. Surface Water Supply Watersheds: Spot Pond, classified as an emergency resource water source
5. NHESP Living Waters Critical Supporting Watersheds: There was one selected location with high and low threat ratings. A high threat rating (greater than 75 percent of the area at risk) was assigned to impervious surfaces, road density, road crossings, potential point sources and public water withdrawals. A low threat rating (between 0 percent and 25 percent of the area at risk) was assigned to agricultural intensity and dam intensity.
6. Non-Potential Drinking Water Source Areas: All selected locations were of medium to high yield aquifiers.

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APPENDIX F: UNCERTAINTY CALCULATIONS

The following paragraphs will first summarize the mathematical basis for the error propagation equations and then apply the equations to the risk equation for one of the routes through downtown Boston. The risk equation contains many parameters and each has its own uncertainty. The propagation of these uncertainties is based on the form of the equation and can be specified with precision. The basic equation for propagation of errors can be found in numerous text books. The error propagation is governed by the following equations:

Let:

$$X = f(x_1, x_2, x_3, x_4, \ldots)$$

Designating σ as the standard deviation, then the square of σ, denoted as σ^2, is defined as the variance of the parameter. The variance of *X*, denoted as $\sigma^2(X)$, can be determined using the following equation:

$$\sigma^2(X) = \left(\frac{\partial X}{\partial x_1}\right)^2 \sigma^2(x_1) + \left(\frac{\partial X}{\partial x_2}\right)^2 \sigma^2(x_2) + \left(\frac{\partial X}{\partial x_3}\right)^2 \sigma^2(x_3) + \left(\frac{\partial X}{\partial x_4}\right)^2 \sigma^2(x_4) + \cdots$$

The term in the brackets is the partial derivative of X with respect to each parameter that is uncertain. If the parameter can be specified exactly then the standard deviation of the parameter is zero, the variance is therefore zero and it follows that the term for that parameter drops out of the above equation. Thus there is no need to propagate the errors associated with terms that can be specified with great precision, for example, time and distance. There is some uncertainty associated with most other parameters. It is useful to use the above equation for a couple of examples. Assume:

$$X = a * x_1 + b * x_2$$

Since the partial derivative of X with respect to x_1 is a and with respect to x_2 is b, it follows form the above equation that:

$$\sigma^2(X) = (a)^2 \sigma^2(x_1) + (b)^2 \sigma^2(x_2)$$

Since a subtraction is just assigning a negative value to b, because b is squared in the variance equation the addition equation is also valid for subtraction. From the form of this equation, if the a is much larger than b or the variance of x_1 is much larger than x_2, some error terms are likely to dominate as the errors are propagated. If the standard deviation σ is best expressed as a fraction or percentage, then the above equation can be rearranged as follows:

$$\sigma^2(X) = a^2 \bar{x}_1^2 \left(\frac{\sigma^2(x_1)}{\bar{x}_1^2}\right) + b^2 \bar{x}_2^2 \left(\frac{\sigma^2(x_2)}{\bar{x}_2^2}\right)$$

Not the terms in the brackets are the variance estimates generated when the standard deviation is expressed as a fraction or percent of the average value of x_1 and x_2. The bar over the parameters signifies that the average value for the parameter is to be used when propagating errors.

The error propagation is quite different for products. Let:

$$X = a * x_1 * x_2$$

The when the partial differentials are performed to determine the coefficients in the variance equation, the equation becomes:

$$\sigma^2(X) = \left(a^2\,\bar{x}_2^2\right)\sigma^2(x_1) + \left(a^2\,\bar{x}_1^2\right)\sigma^2(x_2)$$

Since both x_1 and x_2 are uncertain, by convention, the coefficients in front of the variance terms are average values. The above equation can be arranged to a simpler form:

$$\sigma^2(X) = (a\,\bar{x}_1\bar{x}_2)\frac{\sigma^2(x_1)}{\bar{x}_1^2} + (a\,\bar{x}_1\bar{x}_2)^2\frac{\sigma^2(x_2)}{\bar{x}_2^2}$$

This can be further simplified to:

$$\sigma^2(X) = \bar{X}^2\left[\frac{\sigma^2(x_1)}{\bar{x}_1^2} + \frac{\sigma^2(x_2)}{\bar{x}_2^2}\right]$$

An alternative form is:

$$\frac{\sigma^2(X)}{\bar{X}^2} = \left[\frac{\sigma^2(x_1)}{\bar{x}_1^2} + \frac{\sigma^2(x_2)}{\bar{x}_2^2}\right]$$

The variance equation when the X = x_1/x_2 is the same as the above two equations.

It is often times convenient to use the last two forms of the variance equation because the terms inside the brackets are essentially the square of the standard deviation expresses as a fraction of the average value for the parameter. The standard deviation could also be expressed as a percentage and as long as percentages were used for all the terms, the resultant error for X would be in percentages as well. The use of fractions or percentages is convenient when the size of the error increases as x increases in value. The accuracy of weigh scales over much of their range can often be expressed as a percentage or fraction of the total weight of the item being weighed. The above equation states that if there are two components of error and say if one has a standard deviation of 1 percent and the other 10 percent, then when these percentages are squared, added and then the square root is taken to get the standard deviation of X, the result is 10.04 percent. The term with the smaller error, can essentially be neglected. This behavior can be advantageous in some circumstances and a great disadvantage in others. If one parameter is well defined, it is frequently possible to neglect the error created using that term. Alternatively, if there is one parameter is difficult to specify with great accuracy, the result will suffer from the same large inaccuracy.

With this introduction to the theory of error propagation, it is now possible to turn to the risk equation and evaluate how the parameter uncertainties affect the uncertainty in the risk. The error in the risk value will be used to determine if there is a significant difference among the many routes that are being evaluated as possible HM routes in downtown Boston. If the differences in risk level among the routes is smaller than the uncertainty in the risk evaluation, then there is little confidence to state that one route is much better than any other.

The basic risk equation is:

$$Risk_{day} = [acc_{rate}] * [[total_{residents_{day}}] + [total_{employment_{day}}]]$$

A similar equation is evaluated for night travel. The errors in parameters will be propagated through both equations. Starting first with the accident rate, it has two components; the total number of accidents over a given time period and the total number of truck miles driven on that road functional classification over the same time period. For the freeways, the two terms are:

$$acc_{rate} = \frac{Number_{accidents}}{Total_{truck_{miles}}}$$

For expressway travel

$Number_{accidents\_}$= 1881

The Total_Truck_Miles has several components shown in the following equation

$$[Total_{truck_{miles}}] = [Hours] * [Average_{hourly_{vehicles}}] * FC_{miles} * Truck_{faction}$$

FC_{miles} = the total miles of roadway for the functional class being evaluated.

When estimating the errors in the estimate, there is no error associated with the number of hours or the total miles of roadway for the functional class being considered. However there are errors associated with the $Number_{accidents}$ due to under-reporting and there are also errors associated with the $Average_{hourly\text{-}vehicles}$ and the $Truck_{faction}$.

For years the number of accidents reported in the MCMIS database have been under-reported. One of the reasons is that only serious accidents are to be reported. Sometimes from the Police Accident Report (PAR) is difficult to determine of the accident met the definition of a serious accident. Evaluations show that fatalities are normally reported so those serious accidents are not under-reported or misreported. While the PAR might list the number of injured, the report might not indicate that they were taken to a medical facility away from the accident scene for treatment, one of the criteria for making the incident serious. It might also be difficult to determine if any vehicle was towed from the scene, another criteria for being a serious incident. The reverse can also be true, accidents can be reported that do not meet the serious accident definition. For the first 10 years of accident reporting in MCMIS, the misreporting rate was well above 25 percent. Some states had even higher misreporting rates. Over the last 10 years, significant improvements have been made. Without analysis, it is probably a good assumption that the misreporting rate is about 10 percent.

The uncertainty in the truck fraction can be estimated by assuming that the there is no statistical difference among the truck fraction for the various road functional classifications. For the urban road types, the mean truck fraction is 6.5 percent and the standard deviation is 0.8 percent. The highway traffic density varies significantly by the hour and by the season of the year. Traffic counts are taken intermediately, typically a few days a year. The Commonwealth of Massachusetts maintains records of average traffic volumes by month at over 100 locations around the state. The monthly variation in these counts can be a measure of the accuracy in vehicle flow data. Data for as many as 5 years is available for some recording stations. The average standard deviation of these data, expressed as a percentage we found to be 0.0815 or approximately 8 percent. In terms of error propagation, the uncertainty in the accident rate can be estimated using the following equation.

[illegible]

The variance is the square of the standard deviations and that is the term that can be propagated to estimate the first the variance of the accident rate and then by taking the square root of the variance the standard deviation of the accident rate. The variance in the accident rate is therefore:

$$\sigma(acc_{rate})^2 = \overline{acc_{rate}}^2 \left[(0.1)^2 + \frac{(0.008)^2}{0.065^2} + (0.081)^2\right] = \left(0.5 * 10^{-6}\right)^2 * 0.0218$$

The resultant standard deviation of the accident rate, expressed as a fraction of the accident rate is the square root of 0.0218 or 0.148. In percent the standard deviation is approximately 15 percent.

The uncertainty in the total population and employment terms must also be estimated.

The census bureau estimates the standard deviation of the population count to be about 0.2 percent. Because of uncertainties in the census count, a value of 5 percent will be applied to the number of people in nursing homes, hospitals, and schools. The number of tourists that might be close to the route can probably be estimated to no better than 25 percent. Even if the number could be specified precisely for a specific hour of a day, there are great variations based on the day of the week and time of the year. The fraction that might be at home during the day can probably be estimated by no more than 10 percent.

The resultant uncertainty in the daytime population can be estimated using the following two equations. The first is the error associated with the residents at home during the day and the second estimates the uncertainty for the people at school, in nursing homes, in hospitals and tourists. Designated by S, H, N, and Tour respectively:

$$\sigma(Res_{pop})^2 = Res_{pop}^2 \left[\frac{\sigma(Pop)^2}{Pop^2} + \frac{\sigma(frac_{home})^2}{frac_{home}^2}\right]$$

$$\sigma(Add_{pop})^2 = \left[S^2 \frac{\sigma(S)^2}{S^2} + \frac{\sigma(L)^2}{L^2} + \frac{\sigma(H)^2}{H^2} + N^2 \frac{\sigma(N)^2}{N^2} + \overline{Tour}^2 \frac{\sigma(Tour)^2}{\overline{Tour}^2}\right]$$

In the above equation, the S, H, N and Tour specify the values for School, Lodging, Hospital and Nursing Home and Tourist population. The squared terms could be canceled out in each of the component error estimates. They have not been canceled because the desire is to express the variance in dimensionless terms. Thus as estimated above the $\sigma(Tour)^2/Tour^2$ is 0.25 or 25 percent. For the Cross Street – Washington Street route, the total resident population is 66,825 and the fraction assumed to be home during the day is assumed to be 0.30. The number in hotels based on conference room size is estimated to be 5,154, the number in Hospitals during the day, 1,232, the number in Nursing Homes 282 and the number of tourists, 21,602. The variance of the residents and the additional population can now be calculated to be 11 percent

The final term is the total employment within a half mile of the route. Based on the following census bureau publication, http://www.census.gov/govs/apes/data_processing.html the coefficient of variation of the employment numbers is estimated to be about 1 percent. This will be taken as the standard deviation. When this uncertainty is added to the population uncertainty the resultant uncertainty, expressed as a percent is estimated to be 4.7 percent of the much larger population that includes the residents at home during the day, the tourists and the employed individuals working within a half mile of the route. The total number of people for the approximately 4 mile route segment is 242,000 individuals. To get the uncertainty in the risk estimate the variance associated with the estimate of the number of individuals adjacent to the route segment must be combined with the variance of the accident rate. The equation, since it is a multiplication, is:

$$\frac{\sigma(Risk)^2}{Risk^2} = \left[\frac{\sigma(Pop)^2}{Pop^2} + \frac{\sigma(acc_{rate})^2}{acc_{rate}^2}\right]$$

The two terms inside the brackets are the errors expressed in fractions, squared; 0.14^2 for the accident rate and 0.046^2 for the population term. The resultant risk ratio, obtained by taking the square root of the left side of the above equation is 0.14. Since the risk for the route is 0.25, then the absolute standard deviation of the risk is 0.15 * 0.25 or 0.037. The 95 percent confidence level is therefore 1.96 * 0.037= 0.072. Thus the 95 percent confidence level is 0.25 ±0.07. Thus any route risks between 0.18 and 0.32 would not be considered statistically different from the Cross- North Washington route for daytime travel.

When the same calculation is done for nighttime travel, the uncertainty in the resident population is much lower because the uncertainty associated with the 0.30 term does not enter into the error propagation equation. The large uncertainty regarding the tourist population does not enter either. However there is the assumption that the number of employees at their point of business is 17 percent of the daytime population. This number was found in a referenced report and although it did not estimate the uncertainty in the estimate, it will be assumed to be 5 percent. The hotels, hospitals and nursing homes are assumed to be at 80 percent occupancy, 2 people per room in the case of the hotels. Using the same methodology, the estimated standard deviation of the risk at night estimated as a percentage is estimated to be 3.4 percent. When added the uncertainty in the risk or 14 percent, the uncertainty estimate does not change from the 14 percent value, almost the same as the daytime estimate. This is because the uncertainty in the accident rate estimate dominates the error propagation. The number is dominated by the accident risk uncertainty. The risk value at night is 0.12, about half the daytime risk. The standard deviation, expressed in risk terms is therefore 0.12 * 0.14 or 0.017. The confidence level is therefore 1.96 * 0.017= 0.034. Thus the 95 percent confidence level is 0.12 ±0.034.

Thus any route risks between 0.09 and 0.15 would not be considered statistically different from the Cross- North Washington route for nighttime travel.

The uncertainty estimates will not be estimated for the other routes because it will hold true that for all of the routes uncertainty will similarly be dominated by the uncertainty in the accident rate estimate.

Risk ratios are used to identify when the risk of the through route is more than 1.5 times the risk of one of the alternative routes. The error propagation equation for division is the same as the error propagation equation for multiplication. When the variance is expressed as a fraction, since the fractional error is assumed to be the same for each, the variance of the ratio is twice the variance of the risk term. Thus, the standard deviation of the ratio is the square root of 2 times the standard deviation of the two route risks. Since the standard deviation of the route risk, expressed in fractions, is 0.14, the standard deviation of the route risk ratio is approximately 0.20 and when multiplied by 1.95, the 95 percent confidence level, the uncertainty in the ratio becomes ± 0.40. When this is applied to the ratio, and 1.5 is to be the lower limit, any risk ratio less than 2.3 cannot be considered statistically significant. This ratio and not 1.5 will be used when considering route risk differences.