A Surface Alternative for the Bowker Overpass: Restoring Charlesgate Park

Dixon (Dixian) Qiu, M.S. Civil Engineering student

Peter G Furth, Professor

Northeastern University

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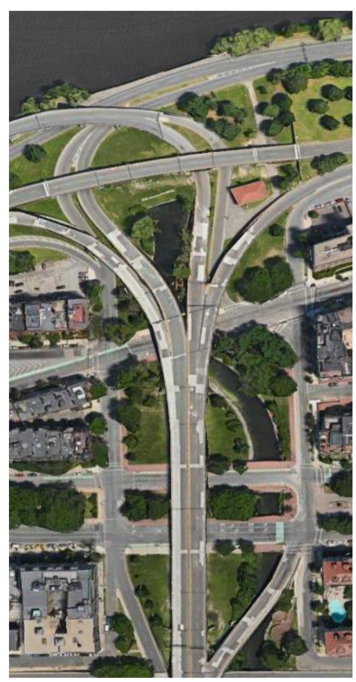

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1. BACKGROUND AND OBJECTIVE

Charlesgate Park, which located at Fenway/Kenmore District as shown in the red box in Figure 1, used to be a fantastic and enjoyable green area. Corresponding with Charles River Esplanade, it comprises a beautiful park system in Boston. However, constructed in 1965, the Bowker overpass, which provides an important connection between northern and western Boston to southern Boston, totally ruined the park. The low elevated overpass and the ramp of Storrow Drive separated the park from neighborhoods entirely. Today, the overpass almost reaches the end of its life. MassDOT is looking for a solution-remove it or repair it. Many professionals and communities are in favor of removing it and have studied and provided several alternatives. However, there is still no feasible solution has been founded so far. This project is goal to find a feasible surface alternative to replace the overpass and restore and reconnect the Parks.

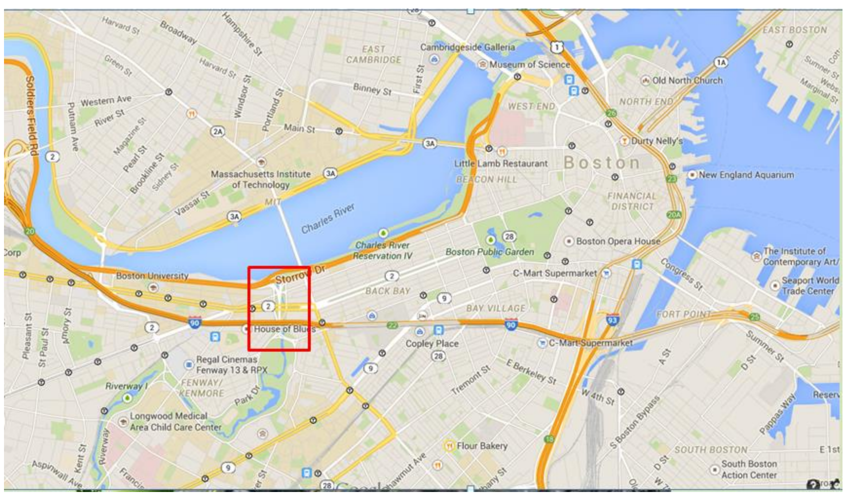


Figure 1 Location of Bowker overpass

This section will introduce background information and objective of this project. The background information includes the history and present of Charlesgate Park, the important role of Bowker overpass from the viewpoint of traffic and alternatives have been studied by MassDOT.

1.1. The History and Present of Charlesgate Park and Charles Esplanade

Charlesgate Park is historically known as the ‘crown jewel’ of ‘Emerald Necklace’. Constructed in 1878, the Charlesgate Park was part of a parkland system, which provides more than 300,000 people good environment and improve the air quality of Boston. The history landscape of this area is as shown in the left picture of Figure 2 and the beautiful scene at that time is as shown in left picture of Figure 3.

As the mid-twentieth century approached, the vehicular traffic dramatically increased in the neighborhood. The Mass. Turnpike and Storrow Drive were constructed to serve the increasing traffic. In, 1965, Bowker Overpass was constructed to connect Storrow Drive to upper Boylston Street and Park Drive. This decision effectively connects the northern and western part of great Boston area to southern part Boston. However, the low elevated overpass and ramps to Storrow Drive also destroyed the parkland.

The landscape of the Charelgate Park nowadays is shown as the right picture in Figure 2. On one hand, Storrow Drive together with its ramps cut Charles River Esplanade, a beautiful quiet path for joggers and bicyclists along the river that comprises part of the Charles River Reservation state park. People used to enjoy the beautiful scenery of MIT and Charles River while running or riding a bike along the Esplanade. On the other hand, the Bowker overpass is just constructed above the Charlesgate Park. The low elevated overpass and the ramps to Storrow Drive separate the neighborhood from the park and ruin the vision of the park. The scene of Charlesgate Park is as shown in right picture of Figure 3. Such an overpass will not be allowed to be built today because of the passage of Section 4f of the DOT Act in 1966 which prohibited constructing any overpass in Park while the Bowker overpass is built just before the legislature of the Law.

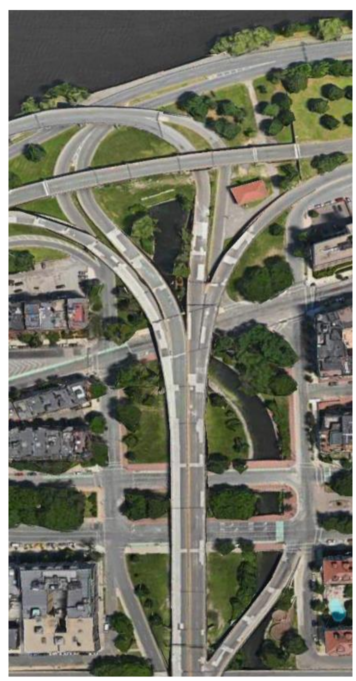


Figure 2 history and present Landscape of Charlesgate park

Figure 3 Histroy and present scene of Charlesgate park

The Charles River Esplanade was once dedicated as the Boston Embankment 1910, which was criticized the lack of shaded trees, visitors and recreation facilities at that time. After a major expansion in from 1928 to 1936, which is aided by a 1 million donation, the recreation facilities and trees are bring to Esplanade. Together with Charlesgate Park, the Esplanade comprises lovely and beautiful neighbors in Charlesgate area. However, in 1949, with the construction of Storrow Drive, Esplanade in Charlesgate area becomes just a small path along the Storrow Drive. Although additional paths including some islands were built to make up the loss of the parkland, the walking experience on Esplanade in Charlesgate River becomes much worse.

Today, the Bowker overpass has reached the end of its life. This is a good chance to right the wrong decision-remove the overpass and bring the traffic back to ground. However, until now there is no feasible surface solution has been found. This project will provide a feasible surface alternative from the viewpoint of traffic improvement and urban landscape design to restore the Charlesgate Park.

1.2. Bowker Overpass in the Transportation Network

The Bowker overpass is located in the target area, which is as shown in the red box in Figure 1. The target area is in Fenway/Kenmore district, Boston, which is adjacent to Back Bay district. The overpass plays an important role in the transportation network in Boston because it provides an important connection between Storrow Dr. and Boylston Street, which enables traffic from northern and western part of great Boston area cross Massachusetts Turnpike. There is limited number of Massachusetts Turnpike crossings. Bowker overpass is the most important crossing between downtown Boston to Brighton. It can provide access to Longwood Medical area and Fenway education/cultural districts which have a lot of jobs.

The overpass serves more than 3000 cars per hour during the peak hours. It enables traffic cross the Charlesgate Park and Massachusetts Turnpike without adding any pressure to local area. Most of the concerns of removing overpass are about whether there is another option to serve the existing demand without adding too much pressure to local traffic and maintain the economic health of this district. One possible option is to divert part of the traffic to the nearby crossings of Turnpike. However, two nearby crossings of Massachusetts Turnpike, Massachusetts Avenue and Brookline Avenue, already operate at or near its capacity so they have no capacity to absorb diverted traffic.

1.3. Alternatives explored by MassDOT

In order to investigate the possibility of removing Bowker Overpass, MassDOT has conducted several studies about the possible alternatives, which are shown in the website http://www.massdot.state.ma.us/bostonramps/Home.aspx. They have investigated the possible alternatives, which is shown as following:

- **Bowker Alternative 0**: Rebuild as it is now with minor improvements.

- **Bowker Alternative 1**: The Bowker Overpass is removed and all movements are accommodated on the Charlesgate Roadways. Rejected because Charlesgate roadways don't have enough capacity to serve the traffic on overpass.

- **Bowker Alternative 2**: The Bowker Overpass is lowered to an at-grade roadway and the Charlesgate roadways are downgraded to provide only local access. Rejected because it just brings a main highway into the park, take up most of the parkland and also create a barrier for pedestrians, which just make things worse.

- **Bowker Alternative 3**: The Bowker Overpass is removed and a new interchange is constructed connecting the Turnpike to Boylston Street with the local connection to Storrow Drive maintained at Charlesgate. Rejected because Mass Turnpike doesn't have capacity to absorb the traffic diversion.

- **Bowker Alternative 4**: The Bowker Overpass is removed and a new interchange is constructed connecting the Turnpike to Boylston Street, with the local connection to Storrow Drive provided by a new interchange with Massachusetts Avenue. Rejected because he the Mass Ave doesn't have capacity to absorb traffic diversion although it can fully restore and reconnect Charlesgate Park and Charlesgate Espnanade.

Preliminary MassDOT study, conducted in 2014, determined that alternative 0 is the best. All of these alternatives seem to fail. However, remove the overpass and use Charlesgate roadways to serve the traffic on the overpass is a good idea. The fail of alternative 1 is because Charlesgate E and W ramp and the exit ramps from Storrow Drive is just two lanes and the network cannot provides enough capacity. The project is inspired by the alternative 1 of MassDOT, proposes special approaches to solve the capacity problem, and restore and reconnect Charlesgate Park and Charles River Esplanade as alternative 4.

1.4. Objective

The objective of this project is to find a feasible surface alternative that has enough capacity to carry all of the existing traffic without relying on traffic diversions, reconnect Charlesgate Park with the Esplanade, and provide a pedestrian and bicycle connection to the park.

2. ROADWAY LAYOUT ALTERNATIVES

The project proposes the surface ramp alternative, which is as shown in Figure 4 in the last page of this section. It is inspired by MassDOT alternative 1 with several approaches to solve the capacity problem and go further to restore the parkland. These approaches deal with three different sites in this area-on Esplanade side, along Charlesgate Park and at the Charlesgate E-Commonwealth Avenue junction. This section will introduce the approaches used in the surface ramp alternative corresponding with other alternatives compare to it, and then the study concerns.

2.1. Alternatives on Esplanade Side

This project investigates two alternatives for traffic circulation assuming that the Bowker Overpass is removed. In one, the ramps connecting Storrow Drive to Charlesgate East and Charlegate West are on the surface; the other retains the existing ramps. Information about each alternative is as shown below.

Retain existing ramps (RER) alternative: this alternative is designed to just solve the capacity problem of MassDOT's Alternataive 1. In order to serve the traffic now using Bowker Overpass, the ramps between Storrow Drive and Charlesgate East / West are widened as needed after removing the overpass and its ramps. Storrow Drive will be the same as existing.

Surface ramps only (SRO) alternative: this alternative is proposed not only to provide sufficient traffic capacity, but also to restore the Esplanade and the park connection between Charlesgate and the Esplanade, as shown in Figure 4. Compared to RER alternative, it provides several changes to restore the Esplanade. Outbound Storrow Drive is moved and elevated to the same level of the inbound Storrow Drive, which restores a large swath of parkland along the Charles River. The ramp from Storrow Drive to Mass Ave. will exit on the right instead of the left. With this change, the distance between the edge of Storrow Drive and the Charles River will be as much as 130 ft and at the pinch point, the distance will reach almost 30 ft where is now nearly 0 space between Storrow Drive and the river.

With this change, the Esplanade will be restored and reconnected to Charlesgate Park. Esplanade will have a 15ft wide path along the river that connects to Charlesgate Park via a path proposed in this project. The ramps to / from Storrow Drive will be changed to surface ramps and meet at a one intersection, with crosswalks that provide pedestrians' access to Esplanade. With these two changes, the Esplanade can be widened and reconnected to Charlesgate Park directly without forcing people to use the ramp from the Mass Ave. bridge.

In this alternative, a pedestrian path is proposed to connect the Charles River Esplanade, Charlesgate Park and Boylston Park, which is also shown in Figure 4. The main path will start from the Back Bay Fens at Boylston Street, go along the west side of Charlesgate W ramp toward Comm Ave, cross Charlesgate W ramp at the newly added signal on that ramp, and then travel in the interior of Charlesgate Park until it reaches and crosses Commonwealth Avenue. There, it will separate into two paths, one of which goes along Charlesgate W while the other one crosses and runs alongside the Muddy River. The two paths will meet before the proposed "X" intersection for the Storrow Drive ramps, and then pass under Storrow Drive and merge into the Esplanade. Path users can enjoy the green area in Charlesgate Park and cross Storrow Drive and easily access the Esplanade. Walking under the high elevated Storrow Drive will not create a barrier for pedestrians.

SRO alternative is a further step beyond the RER alternative. It not only solves the capacity problem of MassDOT alternative 1, it also restores and reconnects the parks as in MassDOT alternative 4. The comparison of them will be discussed in later section.

2.2. Two way alternative

There was a two way alternative we studied last year, where Charlesgate W was a two-way road and carried the traffic that now uses the overpass while Charlesgate E was one way and just allowed local access in order to protect Muddy River.

Information about the two-way on Charlesgate W alternative can be seen in the presentation "Charlesgate-Surface-Alternative-PFurth-Oct-2014". This alternative has many advantages including that it doesn't rely on any traffic diversion, and that Charelsgate E will not be changed. However, many neighbors are against the idea of a-6 lane Charelsgate W because they think it will become a barrier for pedestrians crossing east or west, the three left turn lanes on reversed Beacon Street will create some safety issue and the operation of service road may also cause confusion for drivers. As a result, this alternative will not be discussed in this report.

A one way network was created in this project as an alternative to a single, wide, 2-way road. All the traffic now using the overpass can be accommodated by one way Charlesgate roadways with three through lanes each, as shown in Figure 4. Beacon Street and Commonwealth Ave. will not change.

2.3. Alternatives for Commonwealth Ave-Charlesgate East Junction

There are three alternatives about Commonwealth Ave. and Charlesgate E junction – leave it as is, merge the two northbound roads using a pre-signal before the intersection, or close Newbury Street.

Null alternative: in this alternative, the junction point will not change. Charlesgate E ramp and Newbury Street meets at the intersection Commonwealth Ave. @ Charlesgate E. The cycle for the intersection Charlesgate E @ Commonwealth Avenue splits time 4 ways: NB from Charlesgate E ramp, NB from Newburry Street, EBL from Commonwealth, and WB from Commonwealth.

Pre-signal alternative: in this alternative, the Charlesgate E ramp will merge with Newbury Street before the intersection, using a pre-signal. Signal timing at the intersection will then split time only 3 ways, which can provide more capacity.

Newbury Street dead-end alternative: in this alternative, Newbury Street is just closed at the intersection. Traffic from Newbury Street needs to use other routes, such as Mass Ave. to access to their destination. This diversion can effectively reduce the conflict at the intersection and increase the capacity. However, this may trigger other issue such as finding space for traffic to make a U turn, take up the parking space on Newbury Street, and capacity problem on Mass. Ave.

Of these alternatives, Pre-signal alternative is the one proposed in this project because it provides more capacity without relying on traffic diversion.

2.4. Summary: Preferred Alternative

In a word, the alternative favored by this project is Surface Ramps Only with a Pre-signal at the Comm Ave / Charlesgate East intersection..

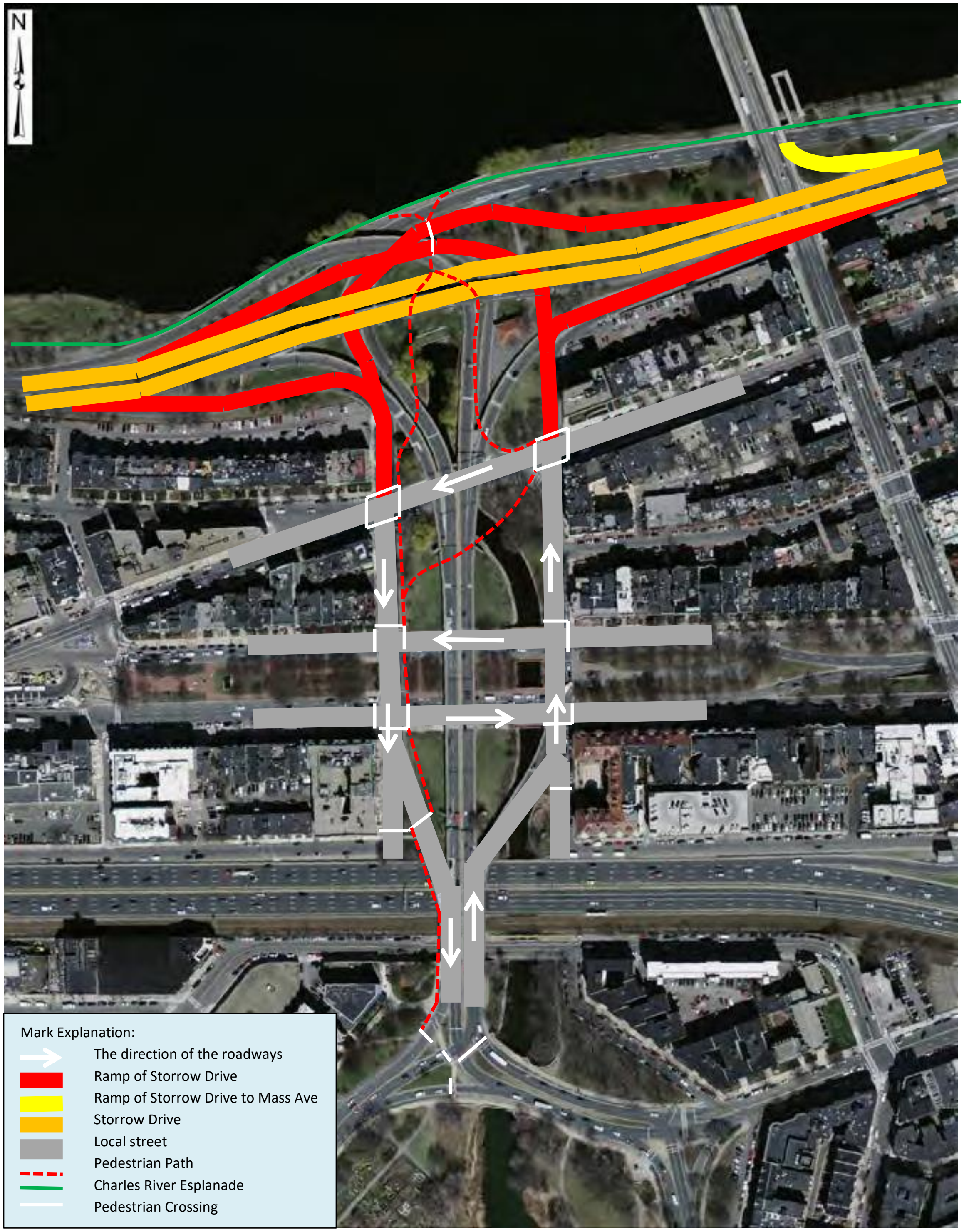


Figure 4 Traffic Circulation of X Intersection Alternative

2.5. Study Concerns

The goal of this project is to find a feasible surface alternative to replace the overpass. The feasibility from the viewpoint of transportation engineering and urban landscape for each alternative needs to be tested. After making the necessary change to the network and redesign the signal plan, the following aspects need to be tested:

- Volume / capacity ratio of each intersection should not be greater than 0.9. That will allow for potential growth and for events that lead to traffic surges.
- Delay to traffic movements that are now signalized should not increase substantially to avoid diversions.
- Delay added to traffic currently using overpass should be less than 90s.
- Queues should not spill back, especially any queue on a ramp coming from Storrow Drive.
- Any space needed to widen the roadways should not encroach on the Muddy River.
- Roads and paths should meet the slope, radius, and width requirement.
- Pedestrian delay at existing crossings should not increase substantially. Average pedestrain delay at new crossings should be under 40s.

3. TRAFFIC ORIGIN-DESTINATION MATRIX ESTIMATION

Before designing and testing, the traffic profiles were needed. Existing turning count data at each intersection was collected from MassDOT. However, to figure out the link volume and turning volume for any traffic circulation alternative without the overpass, a matrix of Origin-Destinations (OD) volumes is needed. It should be consistent with 2010 volume counts and can be translated into link turning volumes. This section will introduce the method used to estimate the OD matrix.

3.1. The Origins, Destinations and Existing Turning Volumes

Firstly, origin and destination points are defined. Within study area, there are 11 origin or destination points, listed in Table 1. They are also shown in Figure 5.

Table 1 Origins and Destinations List

origins/destinations	Notes
A	Storrow Drive Westbound from Back Bay area
B	Storrow Drive Eastbound from Soldiers Field
C	Beacon Street from Back Bay area
D	Beacon Street toward Kenmore Square
E	Marlborough Street
F	Commonwealth Street from Back Bay area
G	Commonwealth Street toward Kenmore square
H	Newbury street from Back Bay area
J	Newbury street toward Kenmore Square
K	Boylston Street from Fenway
L	Boylston Street toward Fenway park

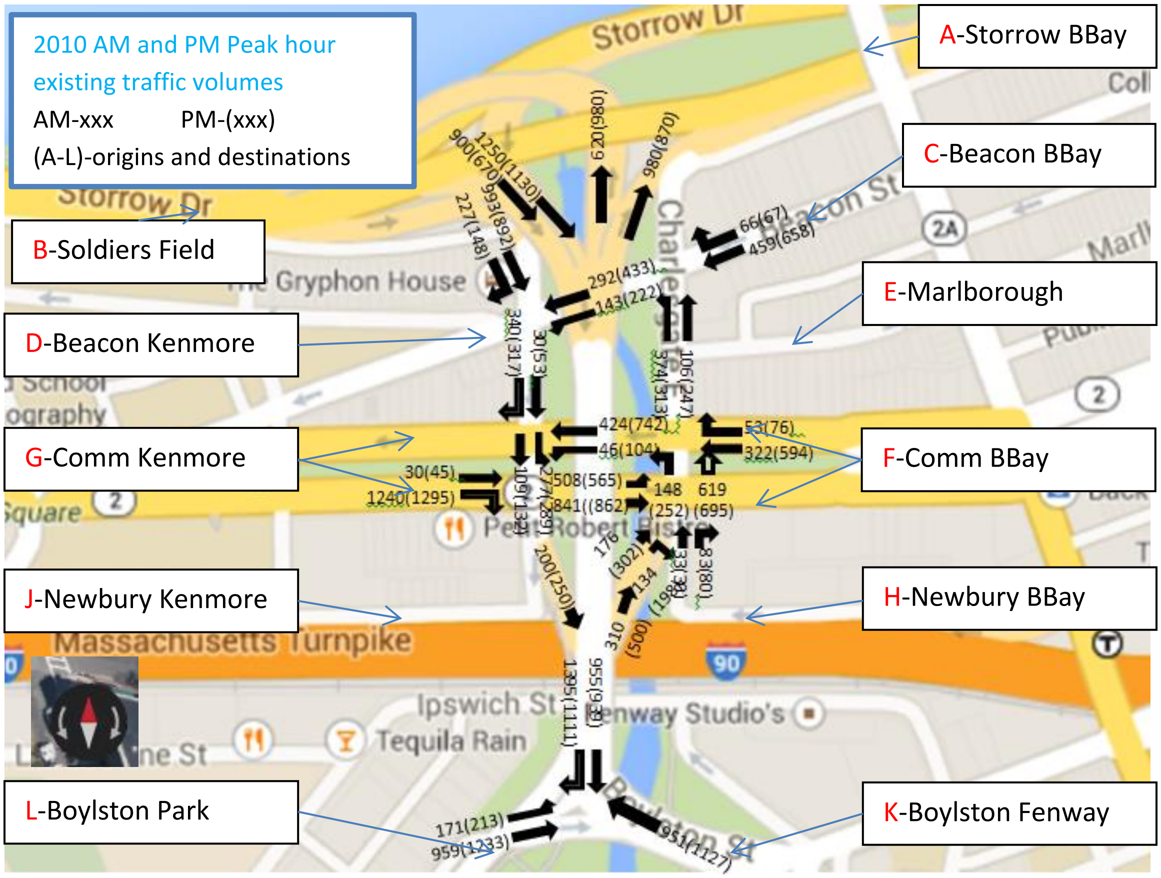


Figure 5 2010 AM and PM peak hour origins, destinations and traffic volumes

A few of the values of the OD matrix can be inferred directly from existing traffic counts. Whenever an observed count carries traffic from a single O-D pair, those volumes are the known values of OD matrix, which is shown in Table 2. For example, the volume from Beacon BBay to Storrow BBay equals to the right turn count from Beacon Street to the Charlesgate east ramp. The turning volume is 66 vehicles per hour so the value from C to A is 66 veh/hr. A few other volumes of the OD matrix can be directly inferred from turning counts. However, other volumes need to be modeled. For this, the multi-proportional method was used, as described in the next section.

Table 2 OD pairs with Volumes Determined Directly from Counts

from\to	A	B	C	D	E	F	G	H	J	K	L	total
A-Storrow BBay												2,110
B-Soldiers Field												1,260
C-Beacon BBay	66	37		279								525
D-Beacon Kenmore												
E-Marlborough												
F-Comm BBay												375
G-Comm Kenmore												1,270
H-Newbury BBay						33						116
J-Newbury Kenmore												
K-Boylston Fenway												951
L-Boylston Park										171		1,130
Total	1,420	750		1,285	192	1,008	454		107	1,126	1,395	7,737

3.2. Multi-Proportional Method

The Multi-proportional method is used to estimate an OD matrix based on a set of known sums of OD. The equation for estimate OD matrix is that

$$t_{ij} = s_{ij} \prod_{m} \prod_{k} f_{k,m}^{\ c_{ijk}} \qquad \text{Equaion 1}$$

where,

i = origin index

j = destination index

k = known sum index (each known sum represents a turning movement volumes)

m = iteration number

$[t_{ij}]$ = Estimate OD matrix

$[s_{ij}]$ = Seed matrix

$f_{k,m}$ = adjustment factor for iteration m, known sum k

$$f_{k,m} = \frac{b_k}{\sum_{1}^{i} \sum_{1}^{j} c_{ijk} t_{ij}}$$

b_k = constraints vector

[c_{ijk}] = Constraints matrix for known sum k (1 if constraint k includes OD pair i-jin its sum, 0 otherwise)

The requirement for known sums is that it should be consistent with each other, which says inflow = outflow. The peak hour volumes provided by massDOT is consistent with each other. For example, the total westbound inflow volumes at intersection Comm Ave (Kenmore) and Charlesgate east is the sum of 322 veh/hr from Comm Ave and 148 veh/hr from Charlesgate, which is 470. The total westbound outflow volumes also equals to 424 plus 46, which is 470. Therefore the outflow equals the inflow and the use of the multi-proportional method is acceptable.

3.3. Constraints of OD Matrix

Every existing traffic turning volume and link inflow/outflow represents a sum of OD volumes. For example, inflow on Boylston Fenway (point k) represents sum of all OD flow whose origin is k. Altogether the turning volumes supply 40 such sums. Five of them match a single OD volume; they were already given in Table 2. Every other 35 sum represents an constraint which is shown in Table 3. Each constraint refers to a sum of certain elements of the OD matrix, which are shown in Figure 3. For example, constraint 1 deals with the sum of two cells, the volumes from A to D and from B to D; that sum, which is the turning volumes from Charlesgate west to Beacon Steet, should equal 993 for the AM peak and 892 for the PM peak. Constraint 2 deals with the sum of 10 cells, and so forth.

These known sums include every column total, row total and existing turning volumes. This means that every OD matrix that satisfies these constraints will have the same set of row and column totals, as well as having totals that agree with the given turning volumes.

Table 3 constraints and explanation

Constraint	Known sums AM (PM)	notes
1	993 (892)	from A-Storrow BBay or B-Soldiers Field Rd to D-Beacon Kenmore
2	227(148)	from A-Storrow BBay or B-Soldiers Field Rd going thru at Beacon
3	1250(1130)	from Storrow BBay to Boylston Park and Boylston Fenway
4	900(670)	from Soldier Field Road to Boylston Park and Boylston Fenway
5	980(870)	from Boylston Fenway and Boylston Park to Storrow BBay
6	620(980)	from Boylston Fenway and Boylston Park to Soldier Field Road
7	134(198)	from Boylston Fenway and Boylston Park to Comm BBay
8	310(500)	from Boylston Fenway and Boylston Park to other destinations except Comm BBay and Storrow Drive
9	143(222)	from Beacon BBay to other destinations except Storrow BBay and Beacon Kenmore
10	322(594)	from Comm BBay to Comm Kenmore, Newbury Kenmore, Boylston Park and Boylston Fenway
11	53(76)	from Comm BBay to Marlborough, Storrow Drive and Beacon Kenmore
12	1240(1295)	from Comm Kenmore to other destinations except Newbury Kenmore, Boylston Park and Boylston Fenway
13	30(45)	from Comm Kenmore to Newbury Kenmore, Boylston Park and Boylston Fenway
14	83(80)	from Newbury BBay to all other destinations except Comm BBay
15	374(313)	from Comm BBay, Comm Kenmore and Newbury Kenmore to Storrow BBay
16	93(231)	from Comm BBay, Comm Kenmore and Newbury Kenmore to Soldier Field Road
17	200(250)	from other places to Boylston Park and Boylston Fenway except Storrow Drive
18	13(16)	from other places to Beacon Kenmore except Storrow Drive and Beacon BBay
19	192(211)	from other places to Marlborough
20	841(862)	from other places to Comm BBay except Boylston Park, Boylston BBay and Newbury Kenmore
21	424(742)	from other places to Comm Kenmore except Storrow Drive and Beacon BBay
22	30(53)	from Storrow Drive and Beacon BBay to Comm Kenmore
23	107(84)	from other places to Newbury Kenmore
24	955(939)	from other places to Boylston Fenway
25	1395(1111)	from other places to Boylston Park
26	46(104)	from Comm Eastbound to Charlesgate East and then go thru
27	231(185)	from Storrow drive to Newbury Kenmore and from Beacon BBay to Newbury Kenmore, Boylston Park and Boylston Fenway
28	109(132)	from Storrow drive and Beacon BBay to Newbury Kenmore, Boylston Park and Boylston Fenway
29	508(565)	from Comm Ave. west to Charlesgate West
30	148(252)	from Charlesgate West to Comm East
31	111(130)	from Newbury BBay, Boylston Fenway and Boylston Park to Storrow driveway, Beacon Kenmore and Marlborough
32	2110(1870)	from Storrow BBay to other destinations except Soldier Field Road
33	1260(970)	from Soldier Field Road to other destinations except Storrow BBay
34	951(1127)	from Boylston Fenway to other destinations except Boylston Park
35	959(1223)	from Boylston Park to other destinations except Boylston Fenway

Figure 6 constraints matrix

3.4. Seed Matrix

In the problem, the number of unknowns is bigger than the number of independent equations. As a result, there are many feasible solutions, that is, several different OD matrix estimates, which can satisfy any given constraint. The multiple-proportional method aims to find solution that satisfies all the constraints and are most consistent with our understanding of travel behavior, reflected in a so-called seed matrix. In the seed matrix [s_{ij}], the value of s_{ij} represents the propensity of travel from i to j. Cells of the OD matrix whose values are known (those shown in Table 1) are excluded from this estimation problem.

a. Null seed

One possible seed matrix is a so-called "null seed" which simply indicates which interchanges (OD pairs) must have zero volume – either because these interchanges violate one-way restrictions, represent U-turns, or are known quantities that have been removed from the problem – and which are allowed to have non-zero values. Entries in a null seed matrix, shown in Table 4, are 0 and 1, where 1 means that an interchange is allowed and 0 means it is not. In a null seed, no permitted interchange has any preference over another. Of course, interchanges coming from, or going to, popular origins and destinations are bound to have greater volume that interchanges involving little-used origins and destinations; however, that influence will be automatically taken care of by the constraints. The seed matrix only shows the propensity of travel from i to j without trying to account for the popularity of either i or j.

Table 4 null seed matrix

from\to	A	B	C	D	E	F	G	H	J	K	L	total
A	0	0	0	1	1	1	1	0	1	1	1	7
B	0	0	0	1	1	1	1	0	1	1	1	7
C	0	0	0	0	1	1	1	0	1	1	1	6
D	0	0	0	0	0	0	0	0	0	0	0	0
E	0	0	0	0	0	0	0	0	0	0	0	0
F	1	1	0	1	1	0	1	0	1	1	1	8
G	1	1	0	1	1	1	0	0	1	1	1	8
H	1	1	0	1	1	0	1	0	1	1	1	8
J	0	0	0	0	0	0	0	0	0	0	0	0
K	1	1	0	1	1	1	1	0	1	0	0	7
L	1	1	0	1	1	1	1	0	1	0	0	7
total	5	5	0	7	8	6	7	0	8	6	6	58

b. Graduated Seed

In a null seed, s_{ij} equals either 0 or 1 – travel from i to j is simply either permitted or not. A graduated seed, allowing values between 0 and 1, allows one to account for additional information about the propensity of travel between OD pairs. That additional information mainly has to do with competing paths in the street network. If the path in the subarea modeled is the only reasonable path from i to j, then its seed value s_{ij} will be 1, but if there is a competing path that takes, say, 60% of the traffic from i to j while the remaining 40% uses the roads in our subarea, then the seed value s_{ij} should be 0.4. For example, cars entering from C (Beacon BBay) are very unlikely to use Bowker Surface network to go to E (Marlborough) or F (Common BBay) since they can more easily to use Massachusetts Ave to reach these destinations. Therefore, the graduated seed value is set to 0.01. The value and explanation of the other OD pairs is showen in Table 5 and 6. Values were chosen based on Expert opinion. The superscripts in Table 5 correspond to an OD pair covered in Table 6.

Table 5 graduated seed matrix

From \ to	A	B	C	D	E	F	G	H	J	K	L	total
A-Storrow BBay	0	0	0	1	0.8[a]	0.5[b]	1	0	1	0.8[c]	1	6.1
B-Soldier Field Rd	0	0	0	0.7[d]	1	1	1	0	1	1	0.8[e]	6.5
C-Beacon BBay	0	0	0	0	0.01[f]	0.01[g]	1	0	1	0.6[h]	1	3.62
D-Beacon Kenmore	0	0	0	0	0	0	0	0	0	0	0	0
E-Marlborough	0	0	0	0	0	0	0	0	0	0	0	0
F-Comm BBay	0.1[i]	1	0	1	1	0	1	0	1	0.6[j]	1	6.7
G-Comm Kenmore	1	0.3[k]	0	0.1[l]	1	1	0	0	1	1	0.4[m]	5.8
H-Newbury BBay	1	1	0	1	1	0	1	0	1	1	1	8
J-Newbury Kenmore	0	0	0	0	0	0	0	0	0	0	0	0
K-Boylston Fenway	0.9[n]	1	0	1	1	0.3[o]	0.7[p]	0	1	0	0	5.9
L-Boylston Park	1	0.9[q]	0	1	1	1	0.5[r]	0	1	0	0	6.4
Total	4	4.2	0	5.8	6.81	3.81	6.2	0	8	5	5.2	49.02

Table 6 OD pairs with seed between 0 and 1

Pair No.	OD Pair	Competing Route	Fraction retained in Charlesgate subarea
a	Storrow BBay to Marlborough	Exit Storrow Drive earlier and use Comm Ave.	0.8
b	Storrow Back Bay to Common Back Bay	the same as above cars can down Storrow at BBay	0.5
c	Storrow Back Bay to Boylston Fenway	Exit Storrow at BBay will shorten the travel distance	0.8
d	from Soldier Field Road to Beacon Kenmore	Exit Storrow at BU will shorten travel distance	0.7
e	from Soldier Field Road to Boylston Park	also, exit storrow at BU will shorten travel distance	0.8
f	Beacon Back Bay to Marlborough	it is more reasonable to use Mass Ave. and Comm BBay to get Marlborough	0.01
g	Beacon Back Bay to Common Back Bay	the same as above, use Mass Ave. will shorten travel distance	0.01
h	Beacon Back Bay to Boylston Fenway	the same as above	0.6
i	Common Back Bay to Storrow Back Bay	they can enter Storrow at Back Bay	0.1
j	common back bay to Boylston Fenway	use Mass Ave. is an competitive Route	0.6
k	Common Kenmore to Soldier Field Rd	enter Storrow at BU is more reasonable	0.3
l	Common Kenmore to Beacon Kenmore	the demand is small	0.1
m	Common Kenmore to Boylston Park	cars can use Brookline Ave. to get there	0.4
n	Boylston Fenway to Storrow Back Bay	cars from Fenway Boylston can enter Storrow at BBay	0.9
o	Boylston Fenway to Common Kenmore	cars from Boylston Fenway area can use Hemenway to Comm Kenmore	0.3
p	Boylston Fenway to Common Back Bay	use Mass Ave is more reasonable	0.7
q	Boylston Park to Soldier Field RD	enter Storrow at BU is more reasonable	0.9
r	Boylston Park to Common Kenmore	Use Brookline Ave. is equally reasonable	0.5

3.5. Multi-Proportional Method of Estimating The OD Matrix

Multi-Proportional Method takes the seed matrix, constraints matrix and its corresponding known sum as inputs. The OD matrix is found by an iterative process in which, at each iteration, an adjustment factor is applied for every constraint that will force its sum to equal the known sum of the constraint. The adjustment factor for constraint k at iteration m is given by

$$f_{k,m} = \frac{target\,total}{current\,total} = \frac{b_k}{\sum_i \sum_j c_{ijk} t_{ij}}$$

Where t_{ij}= current OD matrix estimate for pair (i,j)

And a solution algorithm is given as follows:

1. Set $t_{ij} = s_{ij}$ for all i and j Make the seed matrix as the initial estimate OD matrix, that is, set m = 1
2. Set k=1

3. Accumulate the current sum for constraint k

$$sum_k = \sum_{\mathrm{i}} \sum_{j} c_{ijk} t_{ij}$$

4. Calculate adjustment factor for constraint k

$$f_{k,m} = \frac{b_k}{sum_k}$$

5. Adjust estimate

$$t_{ij} = t_{ij} \times f_{k,m}^{c_{ijk}} \text{ For all i and j}$$

Note that: the exponents, c_{jik}, are either zero or one, if a particular c_{ijk} =0, no change is made to t_{ij}, if a particular c_{ijk} =1, then the corresponding t_{ij} is simply multiplied by the adjustment factor $f_{k,m}$.

6. Set k=k+1, and repeat steps 2 to 5 until every constrain has been processed (k = 35).
7. Test for convergence: If $f_{k,m}$ is within a specified tolerance of 1, STOP. (For this example a tolerance of ε =0.005 was used.) Otherwise, set m=m+1 and return to Step 2 for all k.

Note that: the method is guaranteed to converge provided the constraints are consistent with each other

3.6. Form of Final Solution

From construction, the form of the final solution is

$$t_{ij} = s_{ij} \prod_{\mathrm{m}} \prod_{k} f_{k,m}^{\;c_{ijk}} \tag{1}$$

This can be simplified to

$$t_{ij} = s_{ij} \prod_{\mathrm{k}} F_k^{\;c_{ijk}} \tag{2}$$

Where $\mathrm{F}_k = \prod_m f_{km}$

Here F_k can be understood as the composite or overall adjustment factor for constraint k.

The form of equation 2 corresponds the logic of a gravity model, well known in transportation planning. In gravity model:

$$\mathrm{t}_{ij} = \frac{(\mathit{strength\ of\ origin})_i\,(\mathit{strength\ of\ destination})_j}{\mathit{impedance}_{ij}}$$

In multi-proportional method:

- seed (i,j) =1/(impedance)$_{ij}$
- For every ij pair, there is one origin-specific constraint (entry total); its F_k corresponds to strength of origin.
- For every ij pair, there is one destination-specific constraint (column total); its F_k corresponds to strength of destination.

In addition, every observed turning volume exercises some “gravity” to pull the solution, as needed, to get a particular sum to be correct.

The final estimated OD matrix is the solution that satisfies all the constraints and is most consistent with the understanding of the travel behavior in this subarea as indicated in the seed matrix, and has a final OD pair volume, adjustment factor and initial OD pair volume, which is seed matrix, which satisfies Equation 1 above.

3.7. Results and Analysis

The final estimated OD matrices for AM peak volumes are shown in Table 6 (based on the null seed) and Table 7 (based on the graduated seed). The method converged after 45 iterations. The iteration process has adjusted the seed matrix to satisfy all of the constraints. For example, the observed turning volume 1250 (constraint 3 in Table 3) should equal the sum of the volume from A to K and from A to L, which is 742 + 508 = 1250. Readers can verify that every other constraint, including row totals and column totals, have been satisfied.

The difference between the two OD matrix estimates is calculated in Table 8. Note that the column total and row total differences are 0, which means that the row total and the column total of the two OD matrixes is the same. Compared to the null seed, the graduated seed matrix simply shifts some volume from one cell to another cell. For example, for known sum 993, which is the sum of volume from A to D and from B to D, the graduated seed matrix shifts cars from B-D to A-D because the Exit of Storrow Drive near BU diverts some B-D traffic. As a result, the volume from B to D reduces by 27 and the volume from A to D increases by 27, maintaining the total sum. These changes are more consistent with our understanding of the characteristics of the OD matrix in this subarea.

Table 7 estimate OD matrix of null seed matrix

from\to	A	B	C	D	E	F	G	H	J	K	L	total
A	0	0	0	700	9	63	20	0	68	508	742	2,110
B	0	0	0	293	4	27	8	0	28	366	534	1,260
C	0	0	0	0	1	6	2	0	6	52	76	143
D	0	0	0	0	0	0	0	0	0	0	0	0
E	0	0	0	0	0	0	0	0	0	0	0	0
F	33	8	0	1	11	0	281	0	2	16	23	375
G	307	76	0	8	103	745	0	0	1	12	17	1,270
H	34	8	0	1	11	0	25	0	0	1	2	83
J	0	0	0	0	0	0	0	0	0	0	0	0
K	488	309	0	2	26	67	59	0	0	0	0	951
L	492	311	0	2	27	67	59	0	0	0	0	959
total	1,354	713	0	1,006	192	975	454	0	107	955	1,395	

Table 8 estimate OD matrix of graduated seed matrix

from\to	A	B	C	D	E	F	G	H	J	K	L	total
A	0	0	0	727	10	45	18	0	60	458	792	2110
B	0	0	0	266	6	47	9	0	31	427	473	1260
C	0	0	0	0	0	0	3	0	9	40	91	143
D	0	0	0	0	0	0	0	0	0	0	0	0
E	0	0	0	0	0	0	0	0	0	0	0	0
F	6	28	0	2	16	0	282	0	3	11	26	375
G	341	51	0	1	99	748	0	0	2	18	10	1270
H	27	14	0	1	8	0	28	0	0	2	3	83
J	0	0	0	0	0	0	0	0	0	0	0	0
K	481	337	0	4	27	33	68	0	1	0	0	951
L	499	283	0	4	26	101	45	0	1	0	0	959
total	1354	713	0	1006	192	975	454	0	107	955	1395	

Table 9 difference between estimate OD matrixes

from\to	A	B	C	D	E	F	G	H	J	K	L	total
A	0	0	0	27	1	-18	-2	0	-8	-50	50	0
B	0	0	0	-27	3	21	1	0	3	61	-61	0
C	0	0	0	0	-1	-6	1	0	3	-13	15	0
D	0	0	0	0	0	0	0	0	0	0	0	0
E	0	0	0	0	0	0	0	0	0	0	0	0
F	-27	20	0	2	5	0	2	0	1	-5	2	0
G	33	-25	0	-6	-5	3	0	0	1	6	-7	0
H	-6	5	0	0	-3	0	3	0	0	0	0	0
J	0	0	0	0	0	0	0	0	0	0	0	0
K	-7	28	0	2	1	-34	9	0	0	0	0	0
L	7	-28	0	2	-1	34	-14	0	0	0	0	0
total	0	0	0	0	0	0	0	0	0	0	0	

The largest differences between the two estimates are 61 vehicles per hour, which is about 7% of the combined OD volumes, which is 900. Remaining differences are small, which shows that estimates are only mildly sensitive to the seed matrix. While it may be argued that certain seed values may not be correct, it is unlikely that it would change OD flows much. Also, as stated, changing seeds only shifts values form one part of the matrix to another, total value are preserved.

After comparing the two OD matrices, the graduated seed matrix is more consistent with our understanding of the network behavior. The final OD matrix includes known OD values shown in Table 3 and the estimated OD matrix. The resulting OD matrices for the AM and PM are shown in tables 9 and 10, respectively.

Table 10 Final OD matrix of AM peak hour

AM peak hour OD matrix												
from\to	A	B	C	D	E	F	G	H	J	K	L	total
A	0	0	0	727	10	45	18	0	60	458	792	2110
B	0	0	0	266	6	47	9	0	31	427	473	1260
C	66	37	0	279	0	0	3	0	9	40	91	525
D	0	0	0	0	0	0	0	0	0	0	0	0
E	0	0	0	0	0	0	0	0	0	0	0	0
F	6	28	0	2	16	0	282	0	3	11	26	375
G	341	51	0	1	99	748	0	0	2	18	10	1270
H	27	14	0	1	8	33	28	0	0	2	3	116
J	0	0	0	0	0	0	0	0	0	0	0	0
K	481	337	0	4	27	33	68	0	1	0	0	951
L	499	283	0	4	26	101	45	0	1	171	0	1130
total	1420	750	0	1285	192	1008	454	0	107	1126	1395	7737

Table 11 Final OD matrix of PM peak hour

PM peak hour OD matrix												
from\to	A	B	C	D	E	F	G	H	J	K	L	total
A	0	0	0	660	12	53	8	0	7	479	651	1870
B	0	0	0	232	8	53	4	0	3	358	312	970
C	67	19	0	417	1	5	41	0	34	50	91	725
D	0	0	0	0	0	0	0	0	0	0	0	0
E	0	0	0	0	0	0	0	0	0	0	0	0
F	4	59	0	2	13	0	502	0	17	25	45	665
G	289	146	0	2	108	751	0	0	10	24	11	1340
H	13	23	0	1	5	30	29	0	1	2	3	107
J	0	0	0	0	0	0	0	0	0	0	0	0
K	409	512	0	5	29	46	119	0	6	0	0	1127
L	465	472	0	5	30	159	87	0	6	213	0	1436
total	1247	1230	0	1324	205	1097	790	0	84	1152	1111	8240

4. ROAD WIDTH AND INTERSECTION DESIGN AND ANALYSIS

Road widths (number of lanes) and signal plans were designed to account for the traffic volume expected after removing the overpass. This chapter will focus on the Surface Ramps Only with Pre-signal at Comm Ave & Charlesgate East Alternative.

The basic signal strategy is fixed time control, with a 90 s cycle length, using offsets that create green waves for traffic in all four directions. In addition, special treatments apply at particular intersections to reduce queue lengths and reduce pedestrian delay.

4.1. Number of Lanes and Cross Section

The number of lanes of the network is as shown in Figure 7. Charlesgate E and W are widened to three through lanes with an occasional exclusive left turn lane or right turn lane. The ramp onto Storrow Drive will still be two lanes while the ramp exiting from Storrow Drive will be widened to three lanes. Storrow Drive will become a two-way elevated highway with a median. Commonwealth Avenue and Beacon Street will remian as existing. There are other particular changes about left turn or right turn bays, which will be discussed in intersection layout section. Cross section details are shown in Table 12, whose location corresponding to cross section number is as shown in Figure 7. The width of travel lane, median and buffer, and sidewalk satisfies the engineering requirements.

A 14 ft wide pedestrian path will be proposed to connect the parks. The 14 ft wide pedestrian path will be on the west side of Charlesgate Bridge so the bridge needs to be expanded to 94 ft wide (existing width is 90 ft). It crosses into Charlesgate Park at a new signalized crossing across the Charlesgate West ramp between Comm Ave and the Mass Pike. The full pedestrian network is described in Section 4.5.

Table 12 Cross Section of the network

No.	name of the road	lane configuration	total width
1	two way Storrow Dr.		54ft
2	Charlesgate Bridge		94ft
3	Charlesgate E/W without exclusive left turn lane		52ft
4	Charlesgate E/W with exclusive left turn lane		58ft
5	Ramp of Charlesgate W		51ft
6	Ramp of Charlesgate E		42ft
7	Exit Ramp of Storrow E/W		37ft
8	Entering Ramp of Storrow E/W		26ft

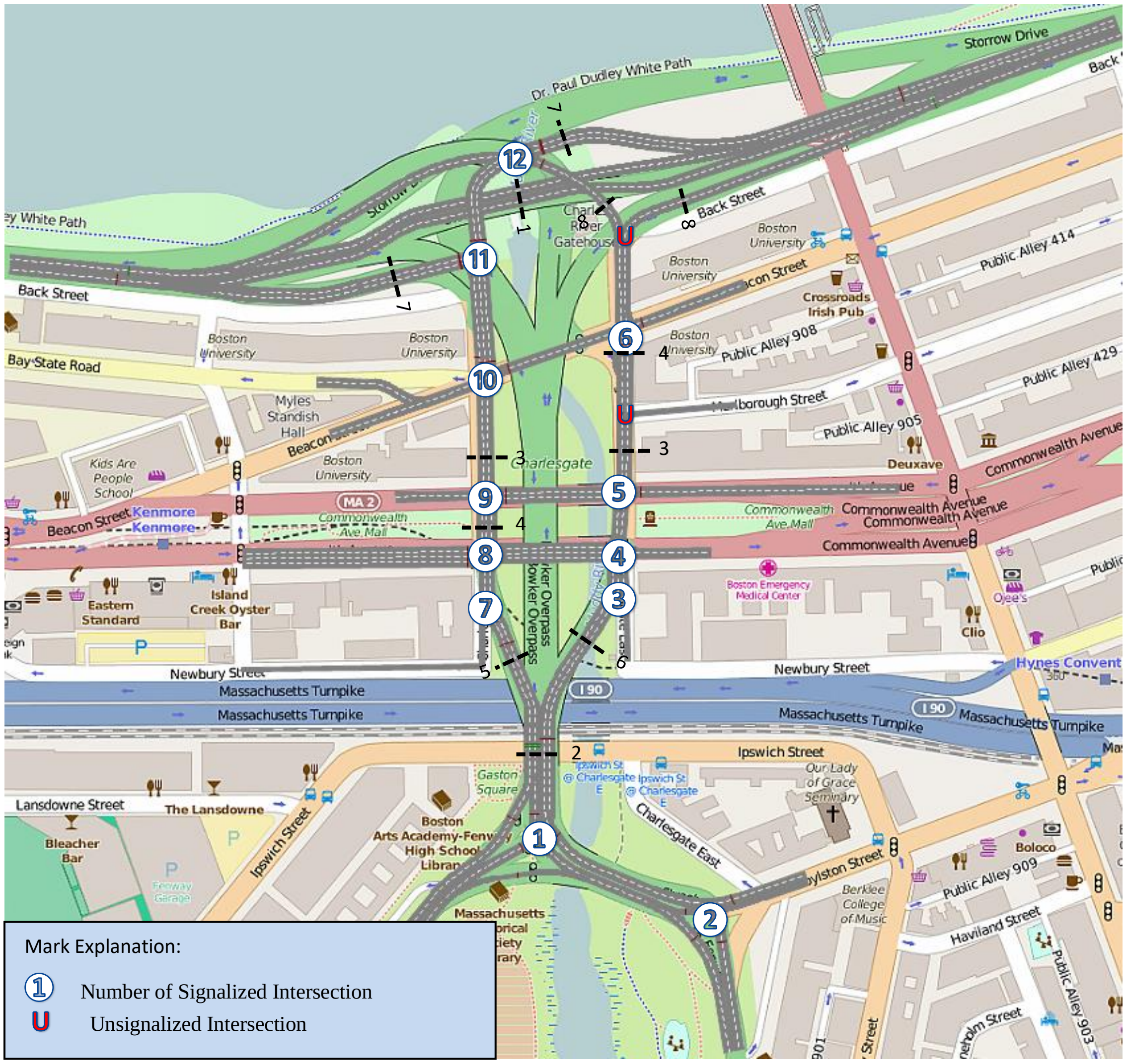


Figure 7 Roadway Layout of the proposed network superimposed on a map of existing roads

4.2. Intersection Layout and Signal Treatments

There are 12 signalized intersections in the network, as shown in Figure 7. Of those twelve:

- Intersections 3, 7, 11 and 12, are newly added to the network
- Intersections 1, 4 and 10, have substantialgeometric changes.
- The remaining five signalized intersections have minor modifications.

This section will describe the 4 newly added intersections and 3 intersections for which substantial changes are proposed.

Charlesgate @ Boylston Street (Intersection 1): Improved Pedestrian Crossing

Most of this intersection remains unchanged. The proposed change is for the southbound right turn lanes and the pedestrian crossing across those lanes. At intersection 1, SBR turn lanes are marked as two lanes and the pedestrian crossing and stop line are redesigned to provide space for SBR turn bay, which is as shown in Figure 8. The Stop lie and pedestrian crossing will be moved south and perpendicular to the edge of the islands, which will provide space for 50 feet long two-lane right turn bay. This right turn bay can only allow 6 vehicles waiting while, for a 90s cycle, the queue length of SBR turn movement will exceeds 6 vehicles for sure. In order to avoid queue spill back, the cycle length for SBR movement will be 45s, which can be done because the only conflicting movement for SBR movement is the pedestrian crossing. Shorter cycle length also means shorter delay for both traffic and pedestrians.

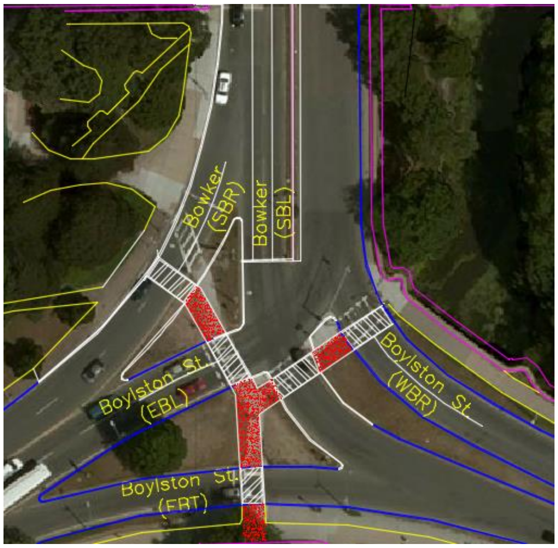


Figure 8 Intersection Charlesgate @ Boylston Street Layout

Charlesgate E ramp @ Newbury Street (Intersection 3) and Charlesgate E @ Commonwealth Avenue (Intersection 4) : Pre-signal

The Charelsgate E ramp will come down before meet Commonwealth Ave. and meet Newbury Street advance at intersection 3, which is as shown in Figure 9. The meet point is moved south about 55 feet to provide queue space for Charlesgate E ramp or Newbury Street, which can provide about 15 vehicles queuing.

The signal plan for these two intersections is coordinated to favor the traffic from Charlesgate E ramp to pass Commonwealth Ave. quickly and leave space for Newbury Street Queuing. The coordination of these two intersections has 4 stages, of which the detail information and explanation is as shown in Table 12. The two main stages, stage 1 and 3, are designed to provide progression for traffic from Charlesgate E ramp and allow traffic from Newbury Street to queue at intersection 4. The specific signal strategy is designed to relieve capacity at intersection 4 by removing the signal phase for Newbury Street and provide another signal phase for Newbury Street at intersection 3. With this change about 10 to 15s green time can be relieved at intersection 3.

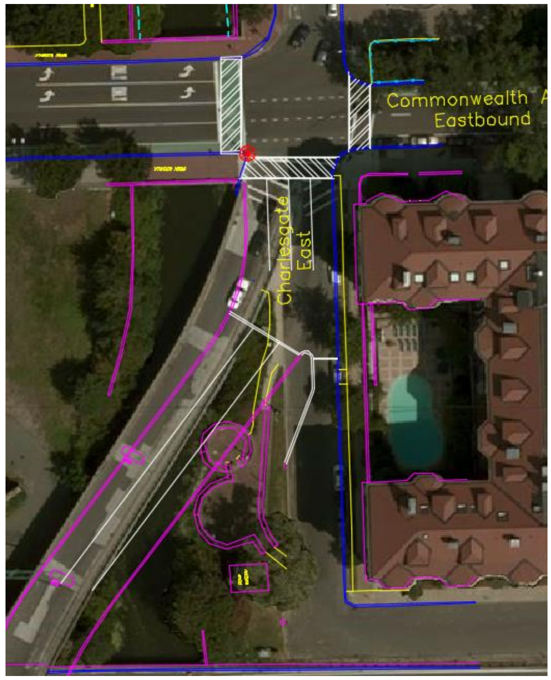


Figure 9 Intersection Charlesgate E ramp @ Newbury Street and Commonwealth Ave. Eastbound Layout

Table 13 Signal Stages for Intersection 3 and 4

Stage No.	Intersection 3		Intersection 4	Time Duration(s)	describtion
	Signal for Charlesgate E Ramp	Signal for Newbury	Signal for Charlesgate E		
1	green	red	green	40	Provide Progression for traffic from Charlesgate E ramp
2	red	green	green	9	Clear the queuing space and service Newbury Street, if have engough green time.
3	red	green	red	34	Allow traffic from Newbury Street to enter queuing space and choose the lane they want
4	green	red	red	7	Allow traffic from Charlesgate E ramp fill in the queuing space and intersection 3 to prevent starvation

Signal on Charlesgate W ramp (Intersection 7): Pedestrian Crossing

This signal is placed here to provide pedestrian crossing on Charlesgate W ramp. The proposed pedestrian path will be on west side of Charlesgate W ramp. In order to provide pedestrian access to the Charlesgate Park, the pedestrian crossing is provided at intersection 7. Signal plan here will be coordinated with intersection 8 to provide progression for traffic from Charlesgate W.

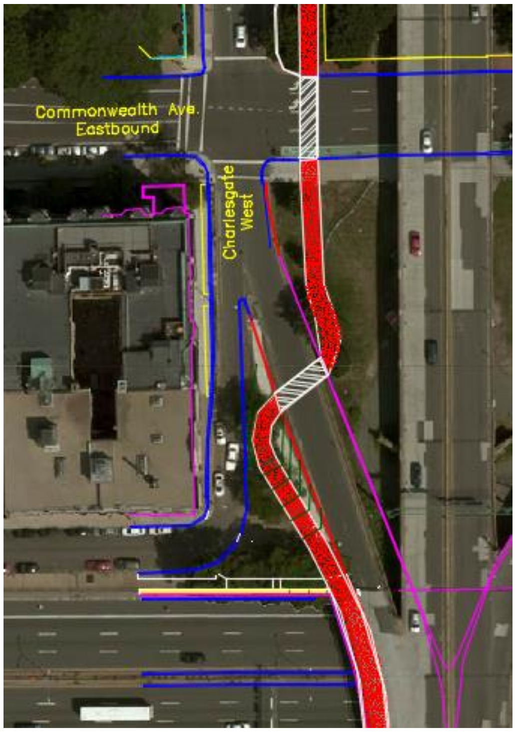


Figure 10 Intersection on Charlesgate W Ramp Layout

Charlesgate W, Beacon Street @ Bay State Road: Separate the intersection with Bay State Road

To ensure the safety of pedestrians and bicyclists crossing Beacon Street and Bay State Road, a bulbout will be constructed at the intersection to separate Bay State Road from the intersection, which is as shown in Figure 11. After the bulbout, the traffic want to enter Bay State Road can use the space between the bulbout and newly widened curb on Beacon Street.

These changes are designed to improve the capacity and improve the pedestrian safety. On one hand, the bolbout will reduce the pedestrian crossing distance from 75ft to 50ft, which can save 7s for SB traffic. The reduced crossing distance can also reduce the exposure time of pedestrian, which can improve the safety. On the other hand, the traffic from Charlesgate W entering Bay State Road will need to turn a bigger angle, which can make them face the pedestrian crossing Beacon Street and Bay State Road. This can help them notice pedestrians and improve the safety.

The signal here will be coordinated to upper stream 45s intersections 11 and 12 to provide progression for traffic from Storrow Drive and reduce the queue length. The detail coordination information will be discussed later.

Figure 11 Intersection Charlesgate W, Beacon St. @ Bay State Road Layout

Charlesgate W @ Exit Ramp from Storrow Drive

The three lane exit ramp will meet at this intersection and feed into four lane Charlesgate W, which is as shown in Figure 12. The volume on each ramp will exceeds one thousand vehicles during PM peak hour. To ensure the safety, signal control is needed at this intersection. The signal here will be coordinated to Intersection 12 to provide a progression for traffic from Storrow Drive Westbound.

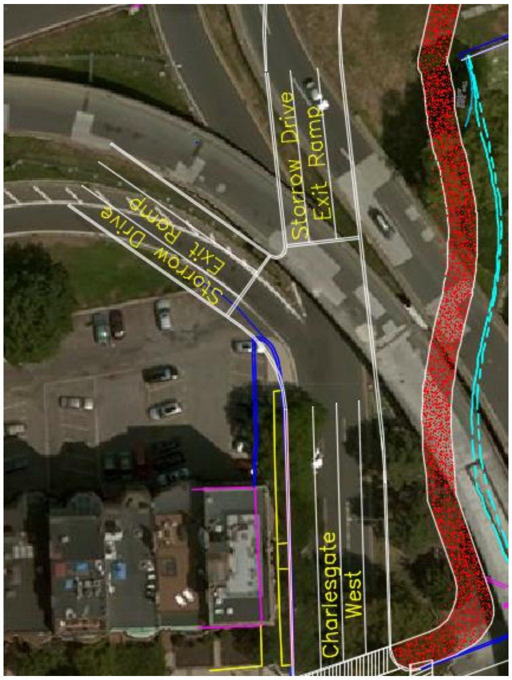


Figure 12 Intersection Charlesgate W @ Storrow Drive Exit Ramp Layout

Surface ramp "X"-intersection

This intersection is junction point of the three-lane exit ramp and two-lane entrance ramp of Storrow Drive. This surface intersection is designed to connect the Charlesgate Pakr to Esplanade. A pedestrian crossing here will provide access to the Esplanade.

This intersection has 45s cycle length and the signal will be coordinated with intersection 10 to provide progression for traffic exiting from Storrow Drive Westbound.

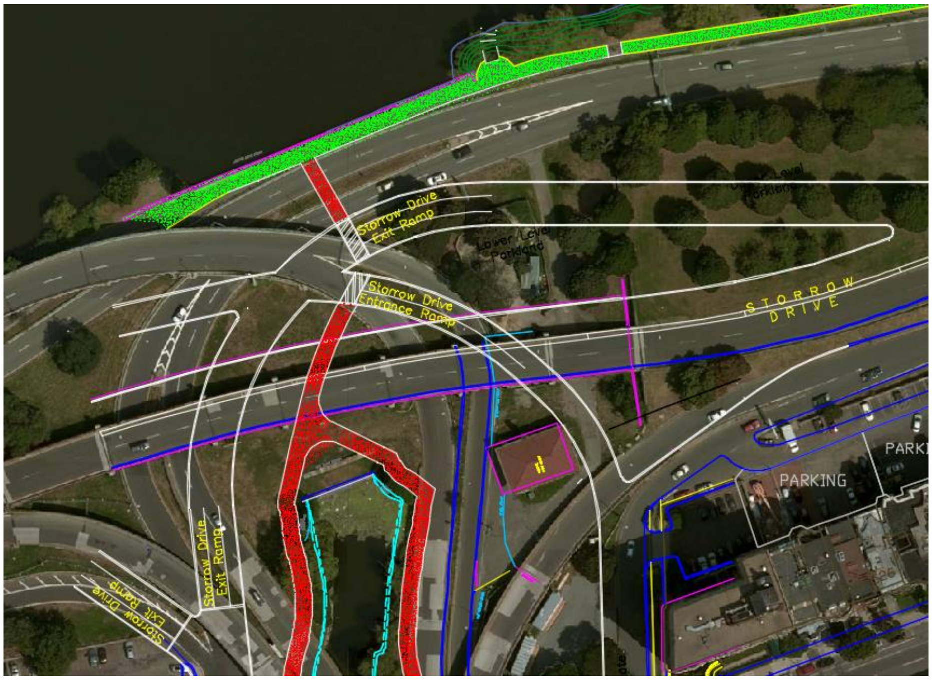


Figure 13 Surface "X" Intersection Layout

4.3. Signal Strategies

In addition to the special signal treatments to improve capacity or pedestrian crossing at particular intersections, which have been stated in the previous section, the 90s cycle fixed time control with offsets to provide green waves for all four directions is applied to the network.

In this network, there are 12 closely spaced signalized intersections and all of the roadways are one way road, which means green wave for all four directions are possible. Meanwhile, the volume of most directions will reach its capacity during the peak hours, which leaves little flexibility for actuated signal control. Compare to actuated-signal control, fixed time control performs better where the signal plan is designed to provide green wave in two dimensions (east-west as well as north-south and the volume reaches its capacity. As a result, this project chooses to apply fix time control in the network.

To provide a good coordination, all of the intersections have the same cycle length of 90 s, or a half-cycle (45 s). The cycle length is determined by the so-called natural cycle length (what's needed for traffic capacity and pedestrian crossings). The cycle length of each intersection is as shown in Table 13. The detail information about the signal plan for each intersection can be seen in Appendix.

Table 14 Cycle length of each intersection

type of intersection	No.	Name of Intersection	Cycle Length
signalized intersection	1	Bowker Overpass @ Boylston Street	90 and 45(SBR)
	2	Charlesgate @ Boylston Street and Fenway	90
	3	Charlesgate E ramp @ Newbury Street	90
	4	Charlesgate E @ Commonwealth Eastbound	90
	5	Charlesgate E @ Commonwealth Westbound	90
	6	Charlesgate E @ Beacon Street	90
	7	Charlesgate W ramp	90
	8	Charlesgate W @ Commonwealth Eastbound	90
	9	Charlesgate W @ Commonwealth Westbound	90
	10	Charlesgate W @ Beacon Street	90
	11	Charlesgate W @ Ramp of Storrow Eastbound	45
	12	X intersection	45

4.4. Analysis of Pinch Points

Existing buildings, streets, and river edges constrain the geometry of the road. This section analyzes pinch points to ensure that the widened road can fit within those constraints. There are two geometric issues for which analysis is needed: whether there is sufficient space for a widened Charlegate East without encroaching on the Muddy River, and whether the change proposed for how Charlesgate East merges with the downramp from Charlesgate Bridge results in too steep a downramp.

Charlesgate East

Between Comm. Ave. and Beacon Street, there appears to be space to widen Charlegate East. to 3 travel lanes. The wide, existing sidewalk on the city side is left unchanged. The road will still be 12 ft from the edge of the river.

Between the two Comm Ave roadways, curb lines can remain where they are today.

Charlesgate East Downramp

As described earlier, the Charlesgate Bridge downramp will be widened to three lanes and shifted slightly so that it meets Charlesgate East 55 feet further south than where they meet today, in order to allow the downramp traffic to merge with Charlesgate East traffic in advance of the intersection with Commonwealth Avenue. Figure xxx shows the geometry of the downramp. The net change in the ramp's direct shadow over the Muddy River is xxx.

The slope of the downramp will increase because it will touch down further from Commonwealth Ave. The average slope will increase from xxx to be 5.3 percent, which comes from 15ft elevation change divided by 280ft length. For motor traffic, that slope is well within normal street operations. For pedestrians, accessibility standards permit sidewalks to have the slope of the road they run along. For persons with walking disabilities who may have difficulty negotiating that steep a sidewalk, the project provides an alternative, accessible pedestrian path using the other Charlesgate ramp.

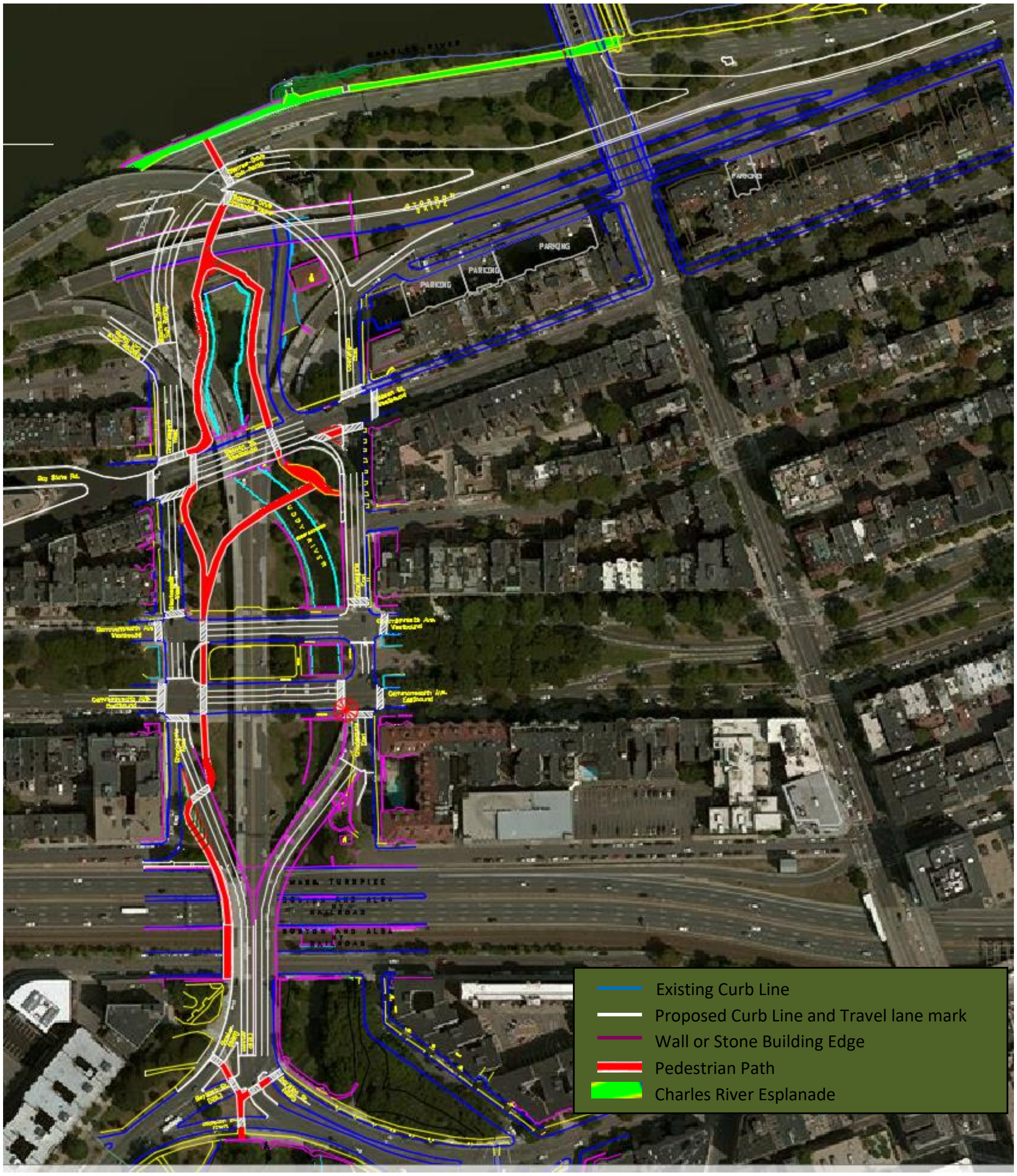


Figure 14 Network Geometric Plan

4.5. Analysis of Pedestrian Network

One of the objectives of this project is to restore the park and park connections, providing a nice experience for pedestrians walking in this network, which includes a pleasant path and short delays at intersections.

The 14ft wide pedestrian path, which is as shown in Figure 14, can provide enough space for two people walk side by side and one bicyclist to pass them. It can provide both pedestrians and bicyclists access to Charlesgate Park and Esplnande, which can connect the parks and also the bicyclist networks. Most of the path is separate from traffic and along Muddy River, which enables pedestrians to enjoy the Charlesgate Park and Muddy River.

To provide good walking experience, average delay for each pedestrian crossing should not exceed 40s. Pedestrian crossing delays during AM peak hours are as shown in Figure 15. Most of the pedestrian crossings along the path have delay under or equal to 20s, and the maximum pedestrian delay, for the three stage crossing at intersection 1, is 36.7s (far shorter than it is now).

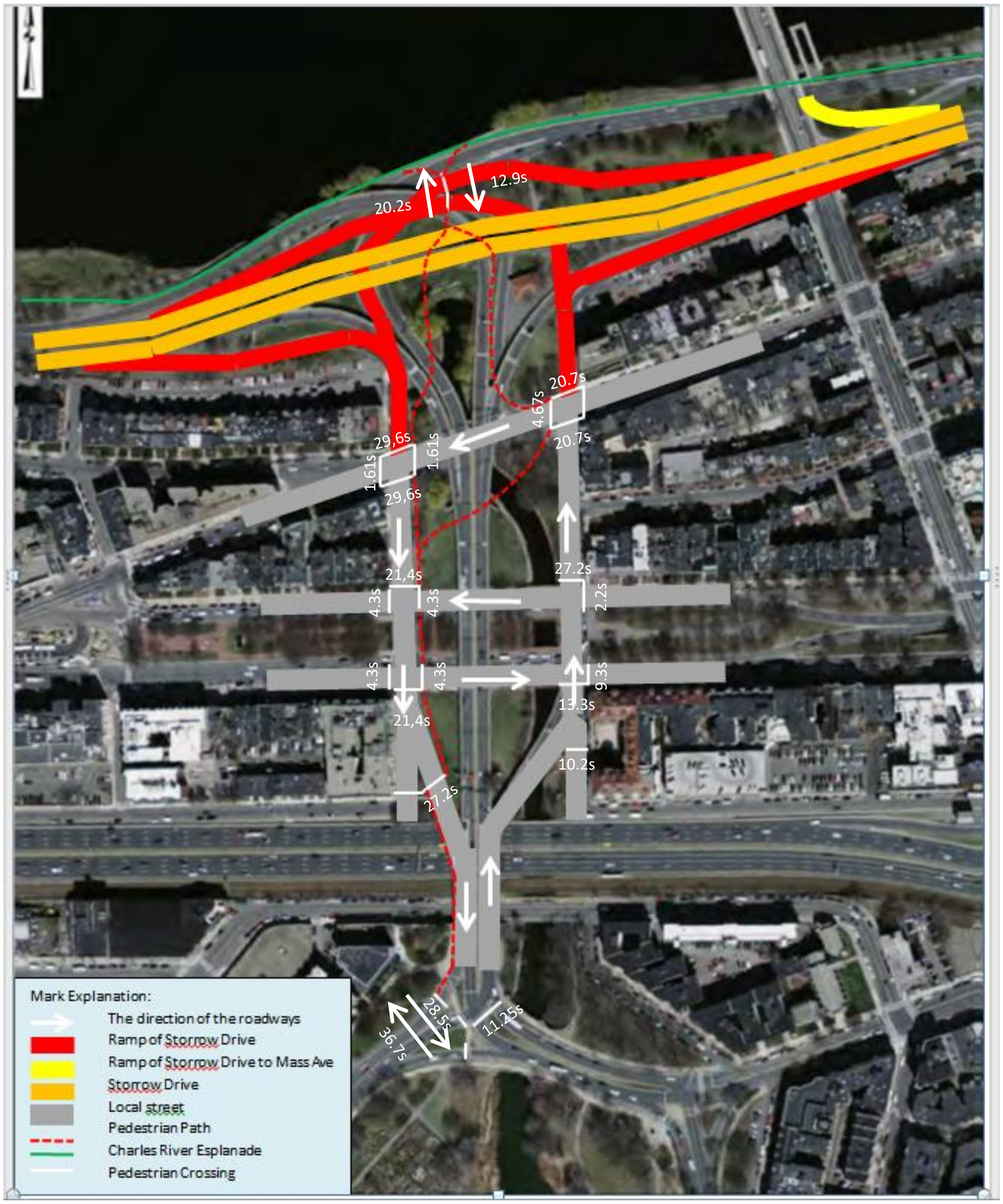


Figure 15 Pedestrian Paths and Delay

5. CAPACITY AND SIMULATION ANALYSIS

In previous section, the road width and signal plan are redesigned to account for the changes of traffic volume. The feasibility of SRO alternative will be tested and further the performance of all alternatives will be compared in this section. The test will be conducted in macroscopic simulation tool Synchro and microscopic simulation tool VISSIM. The objective of the test is

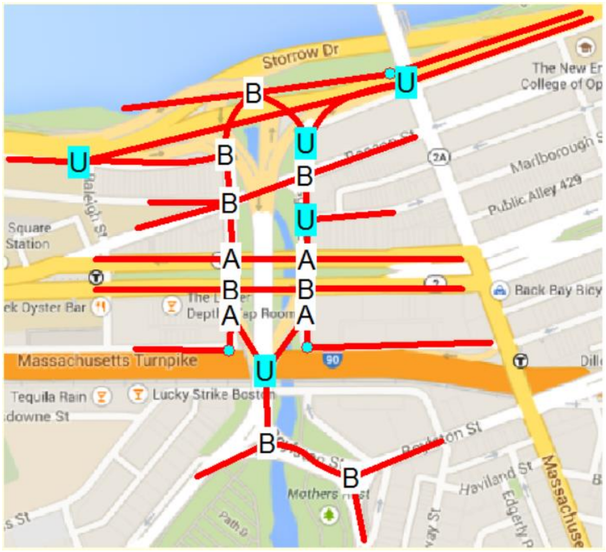
- Volume / capacity (v/c) ratio of each intersection should not be greater than 0.9. That will allow for potential growth and for events that lead to traffic surges.
- Delay to traffic movements that are now signalized should not increase substantially to avoid diversions.
- Delay added to traffic currently using overpass should be less than 90s.
- Queues should not spill back, especially the queue on the ramp from Storrow Drive.

Synchro is used to test the volume capacity ratio and delay at each intersection because it is good at test aggregate data. VISSIM was used to test the delay for traffic movement on overpass and the queue interactions such as spill back. Comparison of delays and travel time for traffic on overpass was also conducted in VISSIM.

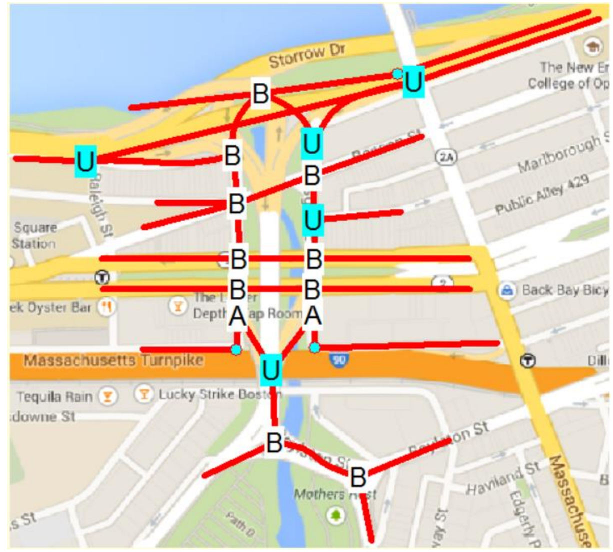
5.1. Capacity Analysis

The goal of the capacity analysis is to test the intersection delay and v/c ratio of the network. This analysis is conducted in Synchro because it is good at analysis the intersection delay and v/c ratio.

The results of the LOS for each intersection in Synchro are as shown in Figure 14. Note that U stands for unsignalized intersections. As indicated in the figure, every intersection has LOS better than C, which means delay at each intersection is not big. LOS doesn't change much compare to the condition before removing overpass, which means that the delay for traffic movements that are now signalized doesn't increase substantially.



AM Peak Hour LOS



PM Peak Hour LOS

Figure 15 Results of AM and PM peak hour

The maximum volume capacity ratio for each intersection during AM and PM peak hours is as shown in Table 14. 0.87 and 0.9 at surface "X" intersection is the maximum v/c ratio in the network for AM and PM peak hours respectively, both of which is smaller than or equal to 0.9. Therefore, this alternative satisfies the capacity requirement.

Table 15 Maximum V/C Ratio for each intersection

No.	Name of Intersection	Maximum V/C Ratio	
		AM	PM
1	Bowker Overpass @ Boylston Street	0.65	0.83
2	Charlesgate @ Boylston Street and Fenway	0.61	0.68
3	Charlesgate E ramp @ Newbury Street	0.57	0.67
4	Charlesgate E @ Commonwealth Eastbound	0.75	0.88
5	Charlesgate E @ Commonwealth Westbound	0.65	0.84
6	Charlesgate E @ Beacon Street	0.65	0.77
7	Charlesgate W ramp	0.62	0.57
8	Charlesgate W @ Commonwealth Eastbound	0.76	0.76
9	Charlesgate W @ Commonwealth Westbound	0.79	0.76
10	Charlesgate W @ Beacon Street	0.85	0.82
11	Charlesgate W @ Ramp of Storrow Eastbound	0.84	0.89
12	X intersection	0.87	0.9

In a word, the SRO alternative has enough capacity to handle the existing demand after removing the overpass. It provides good LOS for each intersection and adds little delay to traffic.

5.2. Simulation and Comparison

This project use microscopic simulation tool VISSIM to simulate and test the SRO-Pre alternative and then compare it to other alternatives. The test includes the following aspects:

- Queue should not spill back, especially the queue of the ramp from Storrow Drive
- Delay added to traffic currently using overpass should be less than 90s.

This section will introduce the Measure of Performance, simulation and results analysis.

5.2.1. Definition of Measure of Performance (MOP)

In this test, three types of Measure of Performance (MOP) are defined. The definition and purpose of each MOP is as shown below:

Number of Unserved Vehicles: In a simulation, unserved vehicles are those that are created but cannot enter the network before the simulation period ends due to congestion. It is designed to test the capacity and queue spill-back of the alternative. If the number of unserved vehicles exceeds 30, meaning the queue spill back to the entrance of the network, this alternative fails.

Maximum Queue Length: the maximum queue length of the exits ramp of Storrow Drive. The maximum queue length is designed to determine whether there will be blockage of Storrow Drive main road. It should not exceed the storage space, which is 370ft and 500ft for Storrow Drive westbound and eastbound exit ramp respectively. The location of queue counter is as shown in Figure 10. Queue counter 1 counts the queue length on the exit ramp from Storrow Drive outbound. Queue counter 2 counts the other exit ramp from Storrow Drive inbound. If the queue length exceeds the storage space, this alternative fails.

Delay: the delay of traffic from Storrow Drive to Charlesgate Bridge and from Charlesgate Bridge to Storrow Drive. It is comes from the difference between the real travel time and ideal travel time of the traffic.

These MOPs are divided into 2 levels-success criteria and performance criteria. The success criteria, including number of unserved vehicles and maximum queue length, are the criteria to determine whether the scenario is fail or success. The performance criteria, including delay, are the criteria to compare the performance among the success alternatives.

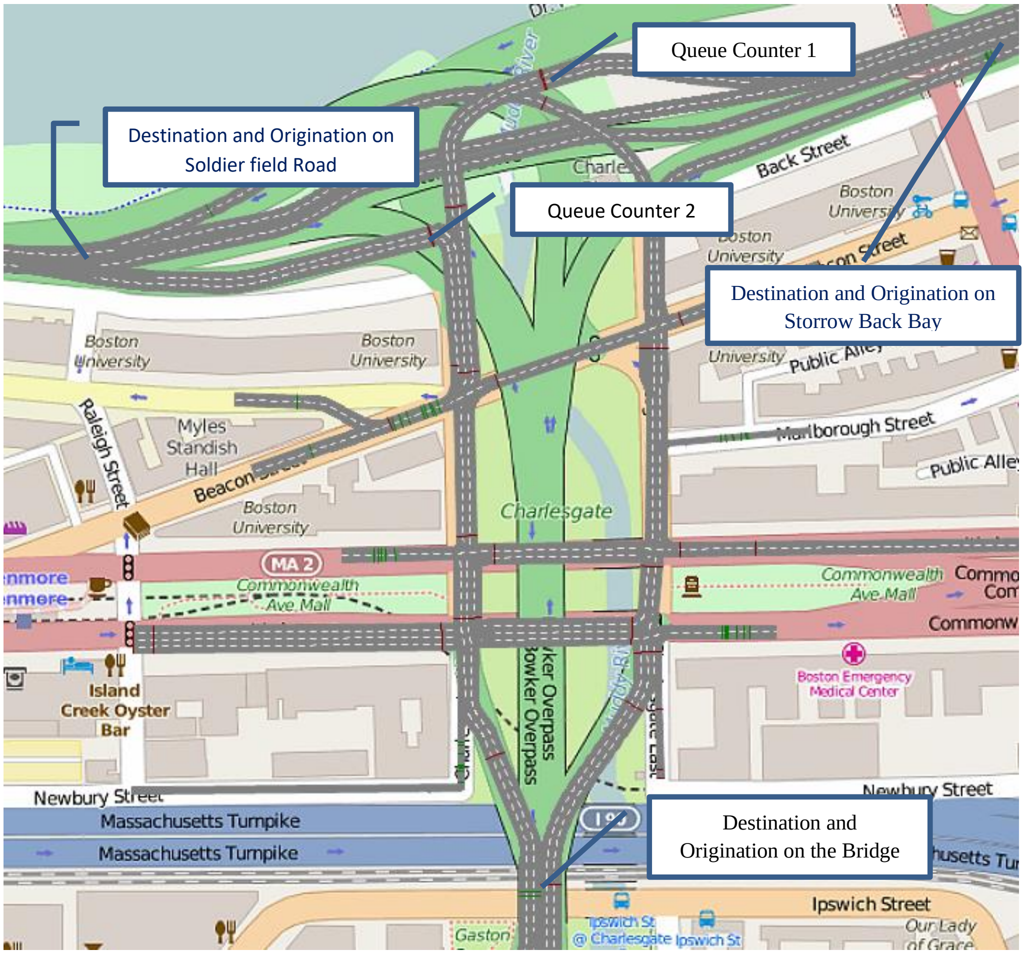


Figure 16 VISSIM model for the network

5.2.2. Simulation Results and Analysis

The simulation period is 50 min with 10 min warm-up period. OD matrix and signal plan is the same as Synchro except the offsets is adjusted according the distance between intersections in VISSIM. VISSIM use Wiedemann 74 car following model. In order to calibrate the capacity to the HCM ideal saturation flow rate 1900 veh/hr, the W74bxMulti factor is changed from its default value (3.0) to 3.4. In this test, three different demand levels, base level, 1.1 level (10% more than existing) and 1.15 level (15% more than existing), are simulated to test the ability to handle the potential traffic volume growth.

The simulation result of number of unserved vehicles, maximum queue length of Storrow Drive exit ramp and delays for traffic on overpass today is as shown in Table 16. The cells in red color mean the result in this cell doesn't satisfy the success criteria. According to the simulation results, the alternative can serve the existing traffic demand and an additional 10 percent traffic with queue length on Storrow Drive exit ramps less than 300ft and delay added to traffic on overpass today fewer than 45s. However, the alternative fails when accounting for an additional 15 percent traffic.

At the table shows, the only failures are with the 1.15 (15% growth) alternative.

In a word, the alternative can serve the existing traffic and an additional 10 percent potential growth.

Table 16 Simulation Result of SRO-Pre Alternative

scenario description			MOP		AM			PM		
					bx multi=3.4			bx multi=3.4		
No.	Esplanade Side	Carlesgate E ramp			base	1.1	1.15	base	1.1	1.15
1	SRO	Pre	unserviced vehicles		0	0	1	0	0	320
			Maximum queue count	Storrow Drive Westbound Exit Ramp	163.17	211.85	417.70	168.49	191.59	211.35
				Storrow Drive Eastbound Exit Ramp	207.81	276.11	585.46	222.86	296.71	1109.44
			Delay	Storrow BBay to Bridge	24.73	35.81	45.12	28.86	32.00	
				Soldier Field to Bridge	31.71	33.53	46.35	27.67	36.85	
				Bridge to Storrow Bbay	20.43	27.68	32.46	24.99	22.99	
				Bridge to Soldier Field	25.77	44.48	57.23	38.90	29.75	

5.2.3. Comparison of Alternatives

Six scenarios are defined according to the combination of alternatives on Esplanade side and Charlesgate E. The definition of 6 scenarios is as shown in Table 16. The 6 scenarios accounts for any possible combination of the conditions.

Detail information and purpose of each alternative is also as shown following:

SRO-Pre Alternative: the one favored by this study, with surface ramps to/from Storrow Drive and a pre-signal at the Comm Ave / Charlesgate East intersection.

RER-Pre: it retainsg existing elevated ramps and adds a pre-signal at the Comm Ave / Charlesgate East intersection, which solves the capacity problem of MassDOT alternative 1. It can be an intermediate alternative to remove the overpass without moving Storrow Drive.

Alternative 3: everything is the same as existing except the roadways are the same to the other alternatives. Compare it to alternative 2 can get the impact of the pre-signal.

Alternative 4: is the one with elevated ramps but close Newbury Street. 50% traffic from Newbury is added to Commonwealth westbound to make compensation for the disappeared traffic. Compare with alternative 2 and 3 can get the impact of close Newbury Street.

Alternative 5: is the one with surface ramps but Charlesgate E ramp as existing, which can restore the park but have limited capacity. Compare with alternative 1 will get the reason for pre-signal.

Alternative 6: is the one with elevated ramps but close Newbury Street. This alternative is defined to complete the comparison.

Firstly, we need to test the feasibility of each scenario. In order to handle the existing traffic volume and potential volume growth, the feasible solution should be able to handle the original demand and 1.1 times volume. Alternative which can handle 1.15 times volume is a plus.

The result of success criteria for each alternative at different demand level is as shown in Table 16. The cell in red color indicates fail. During AM peak hours, the traffic volume is not as high as during PM peak hour so most of the alternatives have enough capacity to handle the increased demand level. However, the critical movement during AM peak hours is from Storrow Drive to Boylston, which makes the X intersection and the intersection 11 become the critical intersection. The heavy demand results in blockage of the Storrow Drive sometimes. As a result, the main fail occurs during AM peak hour is because the maximum queue length exceeds the storage space. For example, although alternative 5 has enough capacity, it fails because the spill back of the queue.

During PM peak hour, volume is really high for both NB traffic and EB traffic. The high left turn demand and through demand of intersection 4 makes it to be the critical intersection during PM peak hours. Scenarios with Charlesgate E ramp as existing conditions fail in 1.1 level during the PM peak hours. This is because the existing condition at intersection 3 has limited capacity for SBT traffic, which separate times into 4 directions. The result shows that separate the time into 4 directions will not work when volume grows for 10 percent. Alternative 1, 2 and 4 success in both base level and 1.1 level during both AM and PM peak hours, which means they are the feasible solution. All of the alternatives fail in the case of 1.15 times volume during PM peak hour, which means none of the alternatives stands out for serving 15 percent volume increase.

Table 17 Scenario Description and Results of success criteria

scenario description			MOP	AM			PM		
				bx multi=3.4			bx multi=3.4		
No.	Ramp to Storrow	Carlesgate E ramp		base	1.1	1.15	base	1.1	1.15
1	SRO	Pre	unserviced vehicles	ok	ok	ok	ok	ok	fail
2	RER	Pre		ok	ok	ok	ok	ok	
3	RER	Null		ok	ok	ok	ok		
4	RER	DE		ok	ok	ok	ok	ok	fail
5	SRO	Null		ok	ok	ok	ok		
6	SRO	DE		ok	ok	fail	ok	fail	
1	SRO	Pre	Maximum queue count	ok	ok	ok	ok	ok	fail
2	RER	Pre		ok	ok	ok	ok	ok	
3	RER	Null		ok	ok	ok	ok		
4	RER	DE		ok	ok	ok	ok	ok	fail
5	SRO	Null		ok	fail	fail	ok		
6	SRO	DE		ok	ok	fail	ok	fail	
1	SRO	Pre	fail or not	ok	ok	ok	ok	ok	fail
2	RER	Pre		ok	ok	ok	ok	ok	fail
3	RER	Null		ok	ok	ok	ok	fail	fail
4	RER	DE		ok	ok	ok	ok	ok	fail
5	SRO	Null		ok	fail	fail	ok	fail	fail
6	SRO	DE		ok	ok	fail	ok	fail	fail

Although 1, 2 and 4 are all the success alternatives and none of them stand out for the ability to handle extra 5 percent volume growth, the performance for each scenario is different for sure. To compare the performance of the success alternatives, the travel time and delay for each alternative is measured. The comparison result in base demand level is as shown in Table 17. The travel time is almost the same for each scenario except for the travel time from Bridge to Soldier Field Road. The maximum difference is almost 30s difference and the difference comes from the treatment about the Strorrow Drive and its ramp. The X intersection adds about 30s delay for traffic from Bridge to Soldier. However, the good progression for Traffic from Storrow BBay westbound to the bridge makes the difference between the travel time of traffic on this direction in different scenario is nearly zero, which means the X intersection adds nearly zero delays for traffic from Storrow BBay to the bridge.

Table 18 Travel time comparison in base case

AM							
		1	2	3	4	5	6
travel time	Storrow BBay to Bridge	74.30508	75.39909	65.13266	54.30507	59.06857	59.01845
	Soldier to Bridge	72.80236	69.11209	68.90213	69.24357	69.02543	70.24526
	Bridge to Storrow Bbay	63.15777	63.74806	63.93128	56.35307	58.25489	57.79685
	Bridge to Storrow Soldier	79.58854	74.9264	71.64455	70.1354	79.86288	78.02978
PM							
		1	2	3	4	5	6
travel time	Storrow BBay to Bridge	79.73	70.44292	79.06651	72.00587	68.09479	66.47105
	Soldier to Bridge	71.3	69.25781	73.83028	71.51507	71.8245	72.08361
	Bridge to Storrow Bbay	69.64	61.85284	58.87537	62.07202	64.51162	58.21124
	Bridge to Soldier	91.66	75.62264	70.6406	72.77513	94.99289	89.30297

The delay results are as shown in table 18. The delay comes from the difference between the real travel time and the idea travel time. Firstly, the maximum delay is 38.9s, which is acceptable. All of the alternatives can provide a good service to traffic on Bowker Overpass today. The maximum difference between the delays for each scenario is 19.58s between scenario 1 and 4 for the travel time from the bridge to Storrow Drive westbound. The difference comes from X intersection and intersection 3. Alternative 4 has two intersections less. However, with two more intersections, this difference is acceptable.

In a word, all of these alternatives has almost the same level of service. Alternative 4 has the best performance because it has two intersections less. However, close Newbury Street will result in other issues. Traffic will enter the network somewhere else. Alternative 2 still has the ramp separate the Charlesgate Park and cut the Charles River Esplanade, which is not proposed by this project. However, it can be an intermediate solution. Step 1 of the reconstruction project is to widened the road and bring the ramp of Charlesgate E down before the intersection to provide traffic a good service. Step 2 is to move Storrow Drive and its ramps to restore and reconnect the parks.

Table 19 Delay Results for PM base case

Scenario NO.	DELAYMEASUREMENT	STOPDELA	STOPS(ALL	VEHDELAY	VEHS(ALL)	PERSDELA	PERS(ALL)
1	Storrow BBay to Bridge	9.75	0.76	28.86	935	28.86	935
	Soldier to Bridge	9.63	1.08	27.67	519	27.67	519
	Bridge to Storrow Bbay	11.65	0.74	24.99	666	24.99	666
	Bridge to Storrow Soldier	16.82	1.24	38.90	813	38.90	813
2	Storrow BBay to Bridge	8.25	0.65	23.80	878	23.80	878
	Soldier to Bridge	9.05	1.05	26.71	486	26.71	486
	Bridge to Storrow Bbay	11.01	0.68	22.06	695	22.06	695
	Bridge to Storrow Soldier	11.24	0.71	23.30	775	23.30	775
4	Storrow BBay to Bridge	8.87	0.68	25.85	859	25.85	859
	Soldier to Bridge	10.39	1.13	29.25	541	29.25	541
	Bridge to Storrow Bbay	9.91	0.71	21.60	680	21.60	680
	Bridge to Storrow Soldier	8.97	0.63	19.32	772	19.32	772

6. CONCLUSION

The objective of this project is to find a feasible surface alternative that has enough capacity to carry all of the existing traffic without relying on traffic diversions, reconnect Charlesgate Park with the Esplanade, and provide a pedestrian connection to the park.

The proposed SRO-Pre alternative can provides traffic good LOS while providing pedestrian access to the park and reconnect the Esplanade. Traffic capacity, delay and queue interactions are tested and proved in this project. This alternative is feasible from the viewpoint of traffic. Meanwhile, analysis of pedestrian network and delays conducted in this project also shows that this alternative can provide pedestrian good walking experience.

However, the construction expense of moving Storrow Drive and its ramps may be too much for now. It is a good intermediate option to just widen the existing road and reconstruct the ramp of Charlesgate to replace the overpass. This is enough to carry the existing demand level and can restore part of the park. After that, we can study more about how to move the Storrow Drive and restore the park.

This project also used and tested the method using multi-proportional method to get OD matrix from the turning counts in a network with 6 intersections and 11 Origin or Destination points. The result shows that this method can be used for complex network to get the OD matrix which is consistent with the turning counts and the traffic behavior in this network. It is a good tool to estimate the demand.

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