Technical Analysis for BRT in the Greater Boston Area

October 2014

In 2013, through a grant from the Barr Foundation, the Institute for Transportation and Development Policy (ITDP) began a technical analysis to determine which corridors could have the potential for gold-standard bus rapid transit (BRT). ITDP is a non-profit that focuses on the design and implementation of BRT systems around the world and has helped to design many of the gold-standard BRTs outside of the US. To date, there are no gold-standard BRTs in the US but there is good potential for Boston to build the first.

Initial Corridor Selection

Existing Ridership

When determining which corridors are ripe for BRT, ITDP applies a methodology that it has used in all of the systems it has helped to design – that is, to focus on the existing ridership as an indication of where BRT could be most successful. BRT infrastructure is generally designed to provide the greatest time savings for the greatest number of people so looking at where the greatest numbers of people currently travel is an important first step. Often, it is the instinct of governments to build BRT where there is no mass transit at all – not even a bus line. But where there are currently no buses, one must rely on a slow build-up of demand over time and it could be years before buses are full and high frequency can be justified. This could lead to empty bus lanes and negative public perception of the project. It also means new operating costs to be carried by the transit agency. By focusing on corridors with high existing demand, the system is guaranteed to have passengers from Day 1, with well-used bus lanes and a reduction in operating costs due to a bus system which operates more efficiently.

In many cities, travel models are used for selecting corridors. In our experience working across the US and internationally, such models are complicated, nontransparent, and often obscure the main variable which actually matters for determining the success of a future BRT corridor: existing ridership.

ITDP therefore began its analysis by working with MassDOT and MBTA to map the demand patterns of all bus passengers across the MBTA urban core. We do this by aggregating bus ridership on each street, by segment. It is important to look at the aggregate ridership rather than the route-by-route ridership since BRT investments are for infrastructure and not for routes. The BRT services which operate within BRT infrastructure can be numerous. The figure below shows the aggregated link-by-link bus ridership in the Boston area and the numbers are displayed in persons per hour per direction (PPHPD), the typical metric used internationally to calculate demand.

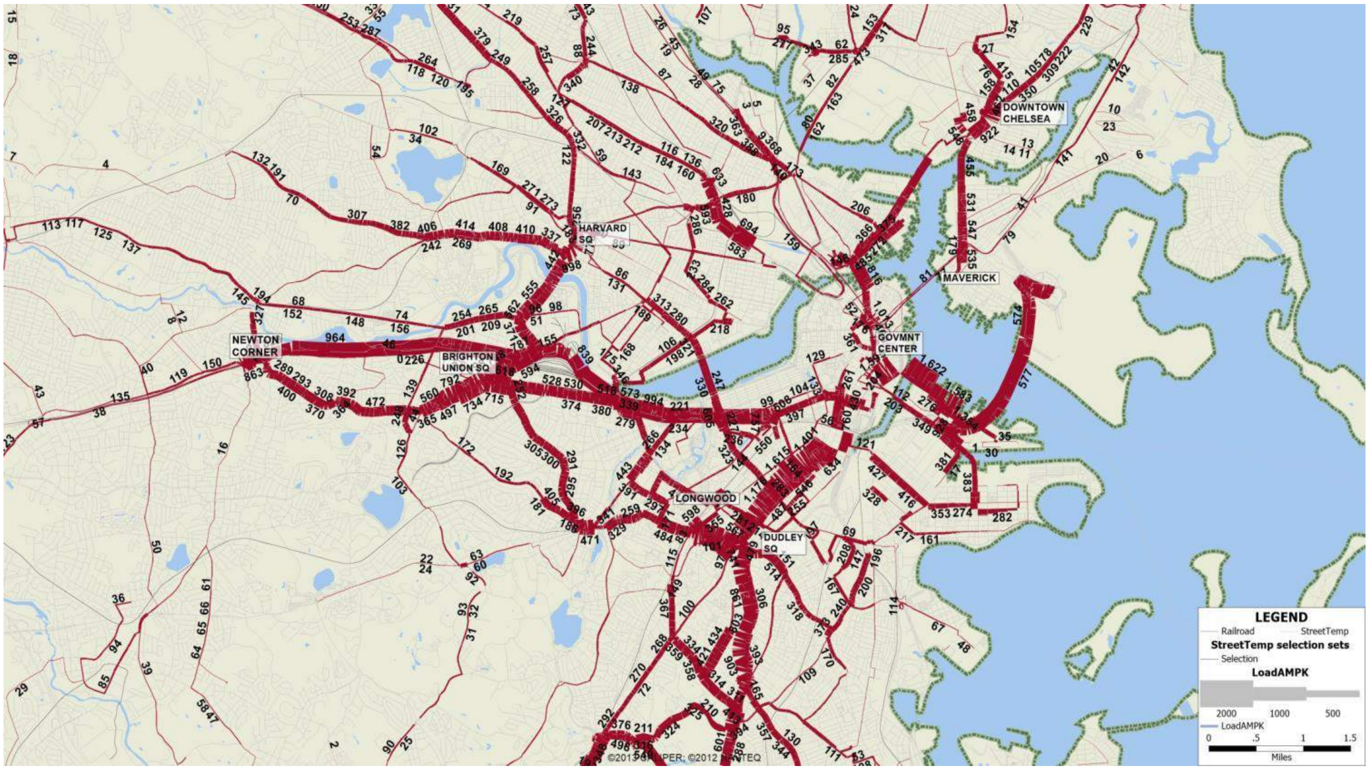

Figure 1: AM peak hour MBTA bus ridership PPHPD on streets in the MBTA urban core

It is generally advised that to dedicate a lane for buses, the lane must carry at least 1,200 PPHPD. Such volumes are rare in the Boston area aside from Washington Street where the Silver Line currently runs. However, it is fair to assume that if BRT is built on a corridor, the demand will increase due to the attractiveness of the system. If a sophisticated service plan is designed (i.e., pulling in bus routes from nearby streets), the PPHPD could also increase once the BRT is built. Therefore, as a baseline, we look for at a minimum 400 PPHPD in order to consider a corridor for BRT. Based on the map above, we then circled several potential corridors which meet a minimum 400 PPHPD.

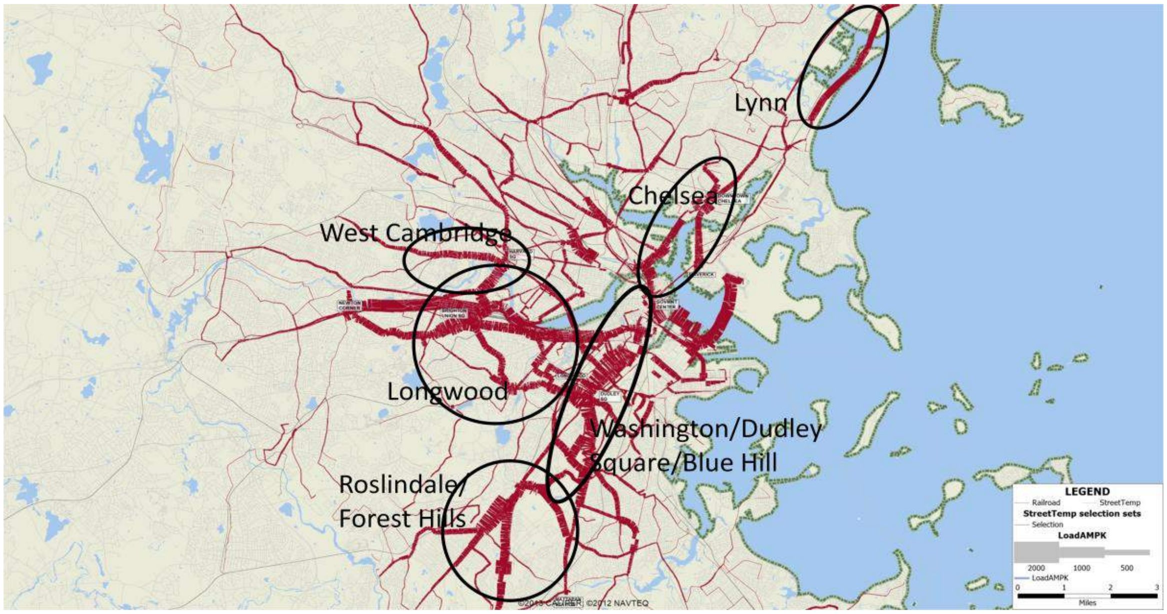

Figure 2: Potential corridors, based on high bus demand

Ranking them by demand, we get the following:

Rank	Corridor	pphpd
1a	Upgrade of existing Washington Silver Line	1615
1b	Extension Dudley Sq to Mattapan	976
1c	Extension to Government Center	???
2	Orange Line Extension Forest Hills South	1200
3	Harvard Square South to Newton Corner	998
4	Mass Turnpike	964
5	Downtown Chelsea to Government Center	922
6	Green Line Extension Lechmere	694
7	Allston Union Square to Dudley Square	598
8	Allston Union Square to Longwood Medical	530
9	Harvard Square West on Mt. Auburn	410
10	Blue Line Extension Wonderland to Lynn	400

Figure 3: Potential BRT corridors, ranked by demand only

Because Corridor 1 was long, we divided it into subsections: 1a was the upgrade of the existing Washington Street Silver Line, 1b was the Blue Hill Avenue corridor from Dudley to Mattapan, and 1c was an extension through downtown to Government Center. While there are currently no bus routes that travel from Dudley Square through to Government Center, it is worth exploring such an extension as Downtown Boston is still the biggest commercial hub in the region and many transit passengers are traveling there. Extending Corridor 1 through to

Government Center, or beyond, is likely to have benefits anyway. Downtowns are generally the only place where we make an exception despite not having existing ridership.

Note also that the streets which parallel the planned Green Line extension from Lechmere currently experience high bus demand. This indicates that extending the Green Line was a good choice. We labeled it as Corridor 6 on the table above but since a transit improvement is already being made to that corridor, we drop Corridor 6 from further consideration.

Existing speeds

We then turn to speeds. Existing speeds also matter, since BRT is designed to reduce the delay associated with slow travel speeds. Therefore, ITDP collected data from MBTA in order to map the existing bus speeds on each corridor. In the map below, we overlaid speeds (colors) on passenger demand (line thickness) to determine where high demand AND slow travel speeds are present.

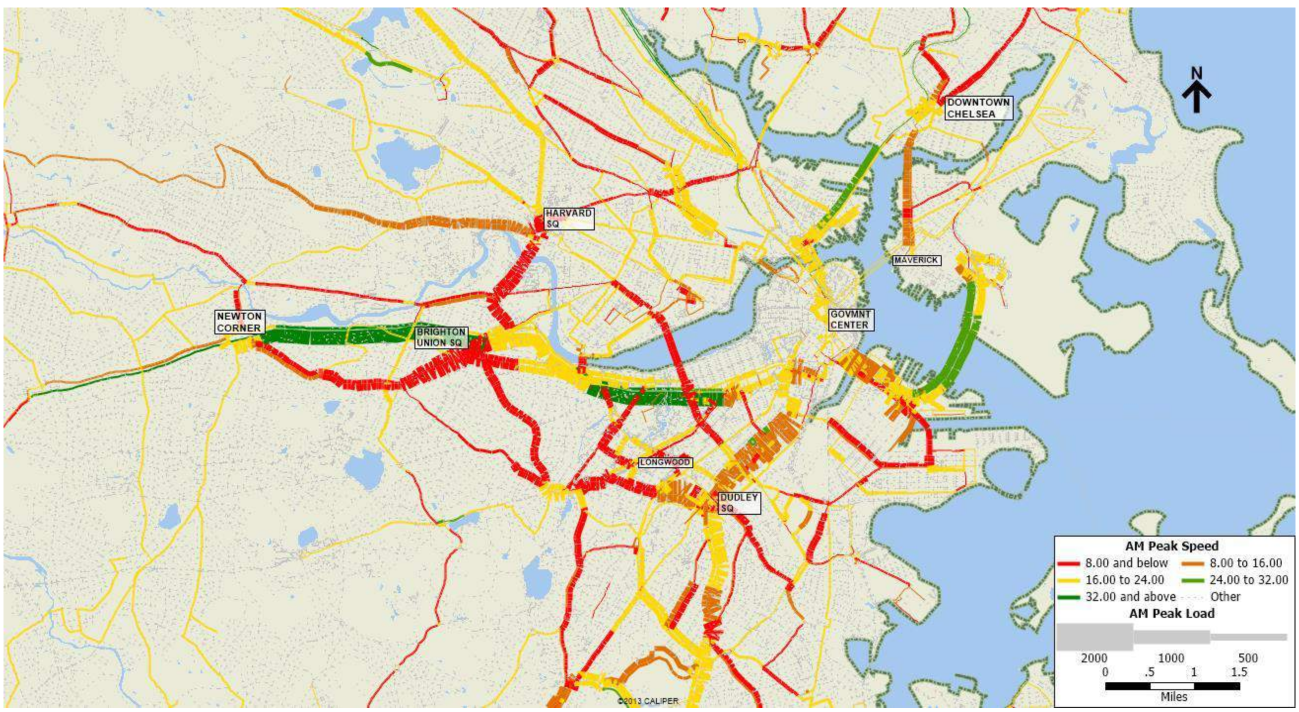

Figure 4: MBTA bus speeds and demand, shown together.

If we now look again at the corridor rankings, this time including speeds, we end up with the following:

Rank	Corridor	pphpd	Delay
1a	Upgrade of existing Washington Silver Line	1615	
1b	Extension Dudley Sq to Mattapan	976	
1c	Extension to Government Center	???	
2	Orange Line Extension Forest Hills South	1200	
3	Harvard Square South to Newton Corner	998	
4	Mass Turnpike	964	
5	Downtown Chelsea to Government Center	922	
6	Allston Union Square to Dudley Square	598	
7	Allston Union Square to Longwood Medical	530	
8	Harvard Square West on Mt. Auburn	410	
9	Blue Line Extension Wonderland to Lynn	400	

Figure 5: Potential BRT corridors, ranked by demand and showing speeds

The figure above tells us that most of the corridors where there is high bus demand also experience slow bus speeds and therefore, most are good candidates for BRT. Corridor 4, the Massachusetts Turnpike, stands out as having relatively good bus speeds of over 32 mph. BRT infrastructure would therefore have little benefit on the Mass Pike and so we removed this one from consideration. The Washington Street Silver Line also experiences relatively good travel speeds; however, given the high number of potential beneficiaries on that corridor and the room for improvement in speed, we recommended keeping this corridor in. Further, if Corridor 1a is extended through Downtown Boston to Government Center or beyond, passengers traveling from Dudley Square to Downtown Boston will experience significant improvements in travel speed due to the avoidance of a transfer to the Red or Orange Line and/or the long walk from Downtown Crossing to their final destinations.

Extending Corridor 1a through Downtown Boston could also help relieve congestion on the rail system, as much of the worst rail congestion is in Downtown Boston. We also collected data from MBTA to map the demand on the rail system, as below.

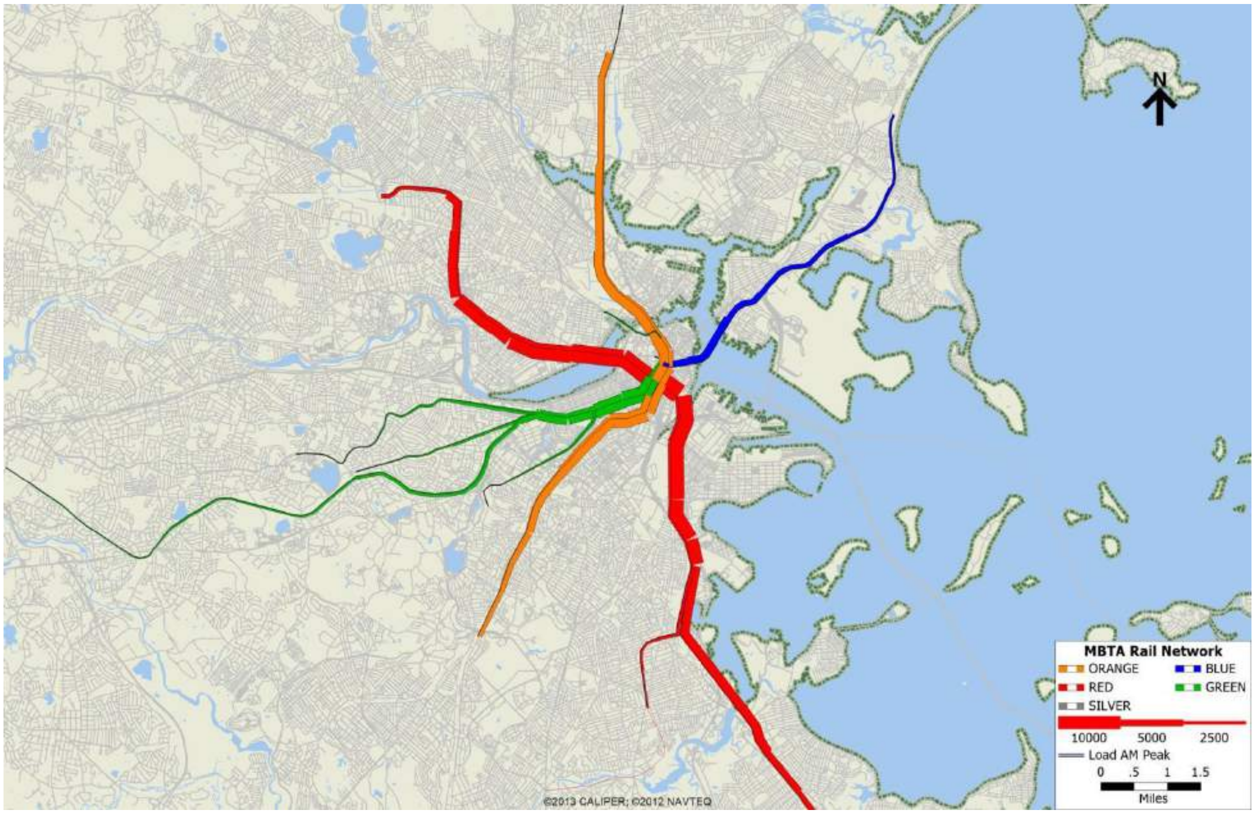

Figure 6: Passenger demand on the MBTA Rail Network is highest through Downtown Boston

So, the corridors under initial consideration were the following:

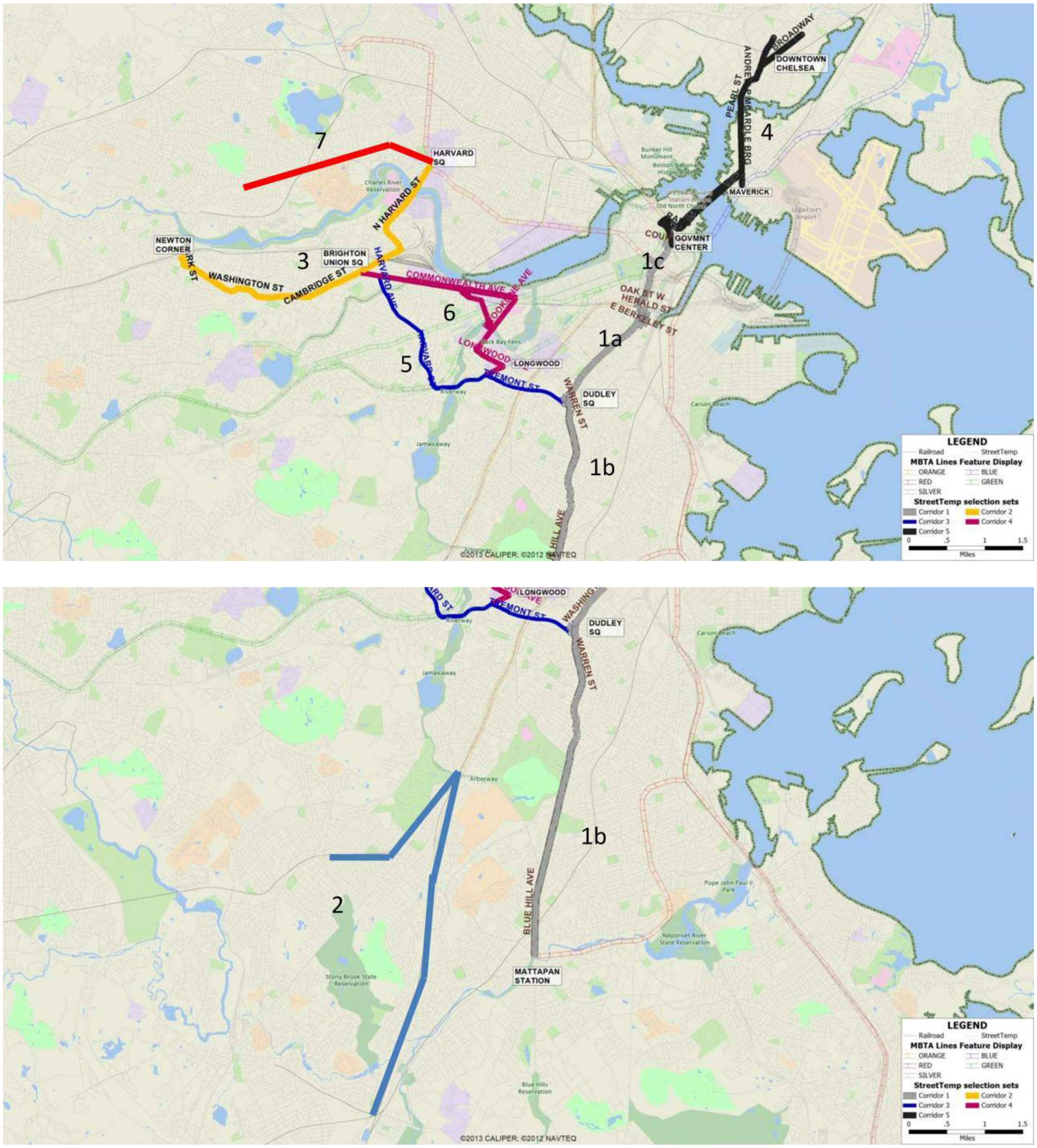

Figure 7: Northern (top) and southern (bottom) maps of potential BRT corridors

Land use and development

The final variable we looked at to determine which corridors might make sense is land use changes and development plans. BRT has been proven to help stimulate development. ITDP recently released a report entitled *More Development For Your Transit Dollar: An Analysis of 21 North American Transit Corridors* which concludes that per dollar invested into mass transit, BRT yields more dollars of private investment than LRT. We have found that if BRT is built in the right corridor, and the government focuses its development support around that corridor, there is a strong chance that the corridor will develop. Choosing the right corridor is generally a question of where development is already beginning to occur and where the government is planning for near-future development.

ITDP worked with MAPC and BRA to map development-related data and information. We divide this information into two categories:

1. Development projects which have been recently built (since 2010), are under construction, or have been permitted but not constructed.
2. Areas where the government is focusing its future development efforts.

These are the only two categories where it could potentially make sense to propose an additional BRT corridor, even if no existing bus routes or demand can be found. In the case of category 1, it is possible that transit has not yet caught up with development and that a new BRT corridor could serve the new development well, particularly if regulations are in place to restrict parking in these new developments (restricted parking reduces car use and leads to higher transit use). In the case of category 2, a new high-capacity transit line may well be a draw to potential developers that the city is looking to attract. Again, strong parking regulations would need to be in place in order to make such BRT corridors a success.

On the following map, category 1 is depicted with circles (blue for residences and red for employment) and category 2 with rectangles. We overlaid this data on the proposed BRT corridors and the existing and future T rapid transit lines.

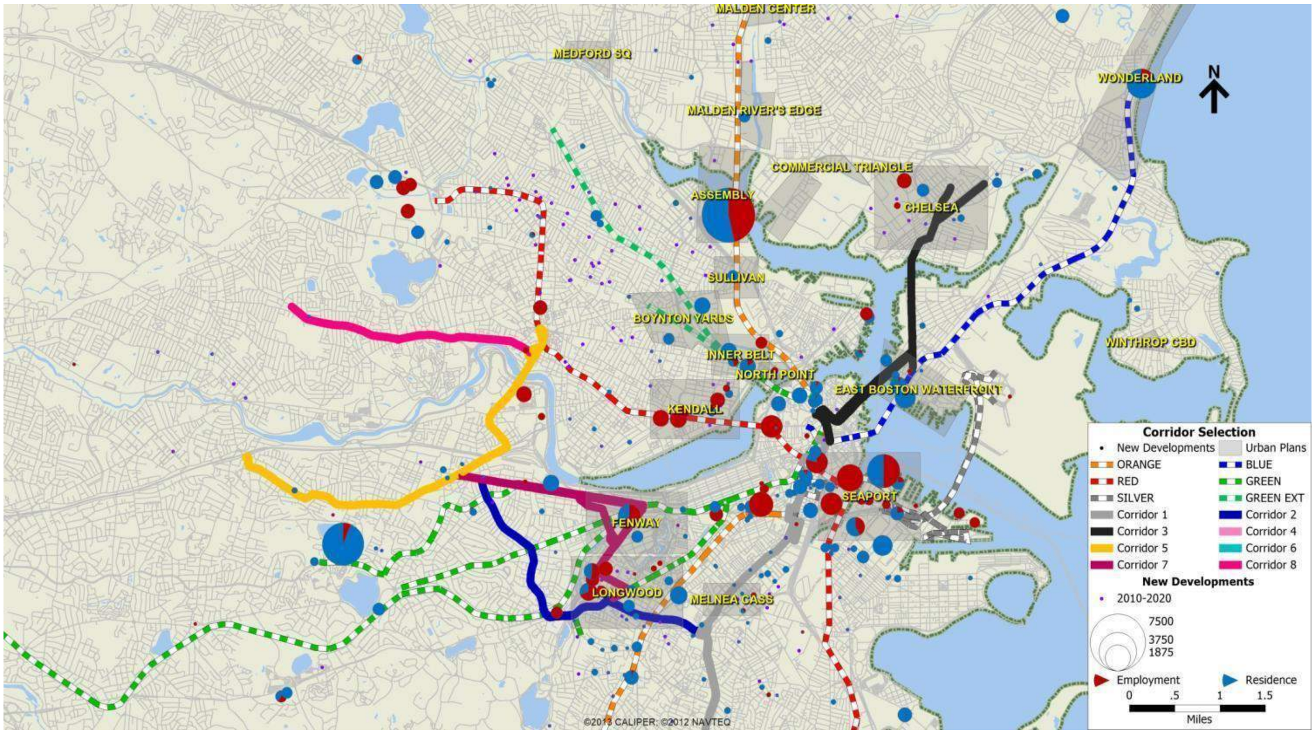

Figure 8: New and in-progress developments and areas of focus for future development

The map above shows that most of the new and planned development is occurring along or near the T lines, indicating that the Boston area is already employing international best practice in development – that is to develop around transit. Some of the other new and planned development is occurring along some of the BRT corridors already proposed in this study. Kendall Square becomes notable, however, in that plans for development span a large area not entirely covered by existing or planned transit. We, therefore, left open the possibility that BRT that provides access to Kendall Square might be worth looking at.

As with the methodology described above for selecting BRT corridors based on *existing* ridership, we put the most emphasis on category 1. Category 1 gives us a sense of where development is already occurring and where it is likely to continue. If there is no mass transit serving a major concentration of new development, it might be worth considering.

Outside of these two variables, which rely solely on a careful documentation of existing conditions, other variables are difficult to quantify as they are hard to prove and based largely on speculation. However, once an initial set of corridors has been identified, additional criteria may be then be considered in order to narrow down the corridors into a BRT network and phasing plan.

When we work with cities that are looking to build out BRT networks, we therefore like to begin by mapping existing bus ridership and existing bus speeds. We then rank the corridors based on these two criteria. We generally remain neutral with respect to corridor selection except in terms of what makes the most sense technically. The purpose is to create a transparent process by which all parties in the room can agree that there is sound, technical justification for selecting one specific corridor for BRT.

Latent demand

As discussed above, the best indicator for future BRT ridership is existing bus ridership. Most of the successful BRT systems in the world were built on corridors or parallel to corridors with high levels of existing bus ridership and with slow speeds.

There is one final case in which it is possible that a new high-capacity transit corridor could generate brand new ridership: that is, when the routing of the current bus lines or rail network is inconvenient for a number of transit passengers and that a more direct connection could reduce travel time for many passengers. Several members of the Study Group suggested that the Urban Ring was designed for this purpose.

ITDP's very preliminary look at the Urban Ring indicates that there is some evidence of high transfer volumes from one transit mode or transit line to another in some locations. These could indicate that the route structure is misaligned with the transit demand patterns. It is thus possible that some of these links could benefit from a direct high-capacity mass transit connection.

The maps that we produced provide a large amount of information regarding what transit ridership patterns look like today and what they will probably look like in the near future. However, the maps do not capture all existing transit ridership patterns since, as mentioned above, some riders may be taking more than one route, in an indirect path, in order to reach their destination. In this case, a transit model can provide a better understanding of a passenger's full start-to-finish trip, and what would happen with the introduction of a new route or high-capacity transit link.

In order to determine whether there are some corridors which could benefit from the introduction of new BRT infrastructure and services, a transit model becomes worthwhile here.

ITDP solicited the Study Group for input into whether there might be some corridors worth modeling to determine whether there might be enough latent demand to place it among the ranking of potential BRT corridors. The Study Group requested that ITDP look at Sullivan to Longwood for this purpose.

Because it is the mission of both ITDP and the Study Group to provide a fully transparent process for BRT corridor selection, we sought to avoid typical "black box" modeling in which assumptions are not made clear and the process is so obscured that the output of the model is taken as a given. Since we could not obtain full and open information about the assumptions in the CTPS model, we instead built our own model from the ground up and documented every step of the process, seeking Study Group input and verification. Full documentation of the modeling process for this corridor can be found in Appendix A – ITDP Results of Corridor 9 Modeling.

The results show that Corridor 9 would rank 9th or 10th (depending on which bridge the corridor traverses) using our corridor ranking process based purely on opening year projected passengers per peak hour per direction. We increased all corridor ridership by 30% since Corridor 9 was based on opening year projections and we wanted to create a fair apples-to-apples comparison (note that by the time we modeled Corridor 9, some minor changes had been made to the intial set of corridors based on Study Group input).

Boston Corridors Ranked by Projected Opening Year PPHPD		
Corridor	**PPHPD**	**Rank**
Washington Silver Line	2100	1
Silver Line extension Dudley to Mattapan	1269	2
Silver Line Extension to Government Center	???	3
Allston Union Square to Dudley Square	1465	4
Downtown Chelsea to Govt Center	1580	5
Forest Hills to West Roxbury	1400	6
Harvard Square S. to Newton Corner	1180	7
Forest Hills to Wolcott Sq	1039	8
Corridor 9, Mass Ave Br Scenario	994	9
Corridor 9, BU Bridge Scenario	908	10
Allston Union Square to Longwood Medical Center	689	11
Harvard Square to Watertown	533	12

Therefore, we added one corridor to the list based on latent demand: Sullivan to Longwood.

Narrowing Down the Corridors

Once the Study Group agreed on the technical basis for the selection of the above corridors, it was also agreed that this was the universe of corridors from which to make recommendations. The Study Group was ready to develop a strategy on community engagement but wanted first to narrow down this set of corridors to a set that was more realistic to work with. Based on a number of considerations, particularly on an understanding of the communities affected by each corridor, the Study Group narrowed down the initial corridors as follows:

- **Dudley to Downtown:** Corridor 1a ("Upgrade of existing Washington Silver Line") and 1c (Extension to Government Center) were combined into a single corridor and extended to Haymarket to provide even more coverage through Downtown
- **Dudley to Mattapan**: Corridor 1b ("Extension Dudley Sq to Mattapan") was kept fully intact and renamed "Dudley to Mattapan."
- **Harvard to Dudley:** Recognizing the attractiveness of a corridor which traverses Fenway and Longwood Medical Area ("Allston Union Square to Longwood Medical" based on the initial corridor selection), combined with the high demand on the link from Harvard Square going south (the northernmost link of "Harvard Square South to Newtown Corner"), and finally a connection of these links to Dudley Square (the easternmost piece of "Allston Union Square to Dudley Square"), a new corridor was formed, including many of the high demand links from other corridors, and named "Harvard to Dudley."
- **Readville to Forest Hills:** While there were originally two options for the "Orange Line Extension Forest Hills South" corridor, the final decision was to consider a corridor which travels from Forest Hills south on Hyde Park Avenue to Readville
- **Sullivan to Longwood:** This is the former "Corridor 9" which was modeled per the section above entitled, "Latent Demand."

The final map of corridors under consideration was thus:

Figure 9: Map of potential BRT corridors narrowed down by Study Group

Once the above corridors were solidified as the corridors on which to begin outreach, some additional technical work was requested by the Study Group in order to provide as full as possible an understanding of the details of each corridor. ITDP then looked at potential routings for the BRT infrastructure on each corridor, based on existing street widths, and the potential benefits to be gained by passengers on each corridor, in the form of travel time savings.

Corridor routings and cross sections

While many bus routes may use a BRT corridor for some portion of their route, turning onto the corridor to take advantage of the high-quality infrastructure and turning off where necessary, the infrastructure itself must be continuous. Initial engagements with communities quickly demonstrated that a conceptual idea of the corridor was not enough – communities wanted to know where exactly the BRT infrastructure might go. In response, ITDP looked in detail at each corridor and proposed routings, routing alternatives, and cross sections, based on the nature of each street.

It is important to note here that the width of a street matters but contrary to popular belief, BRT *does not* require a minimum street width. A wider street certainly makes it easier to dedicate a lane for BRT but even a narrow street can be repurposed for BRT-only. For example, in Mexico City, the government took a very narrow street, right through the historic downtown (Centro Historico) and removed all cars, dedicating it for BRT only.

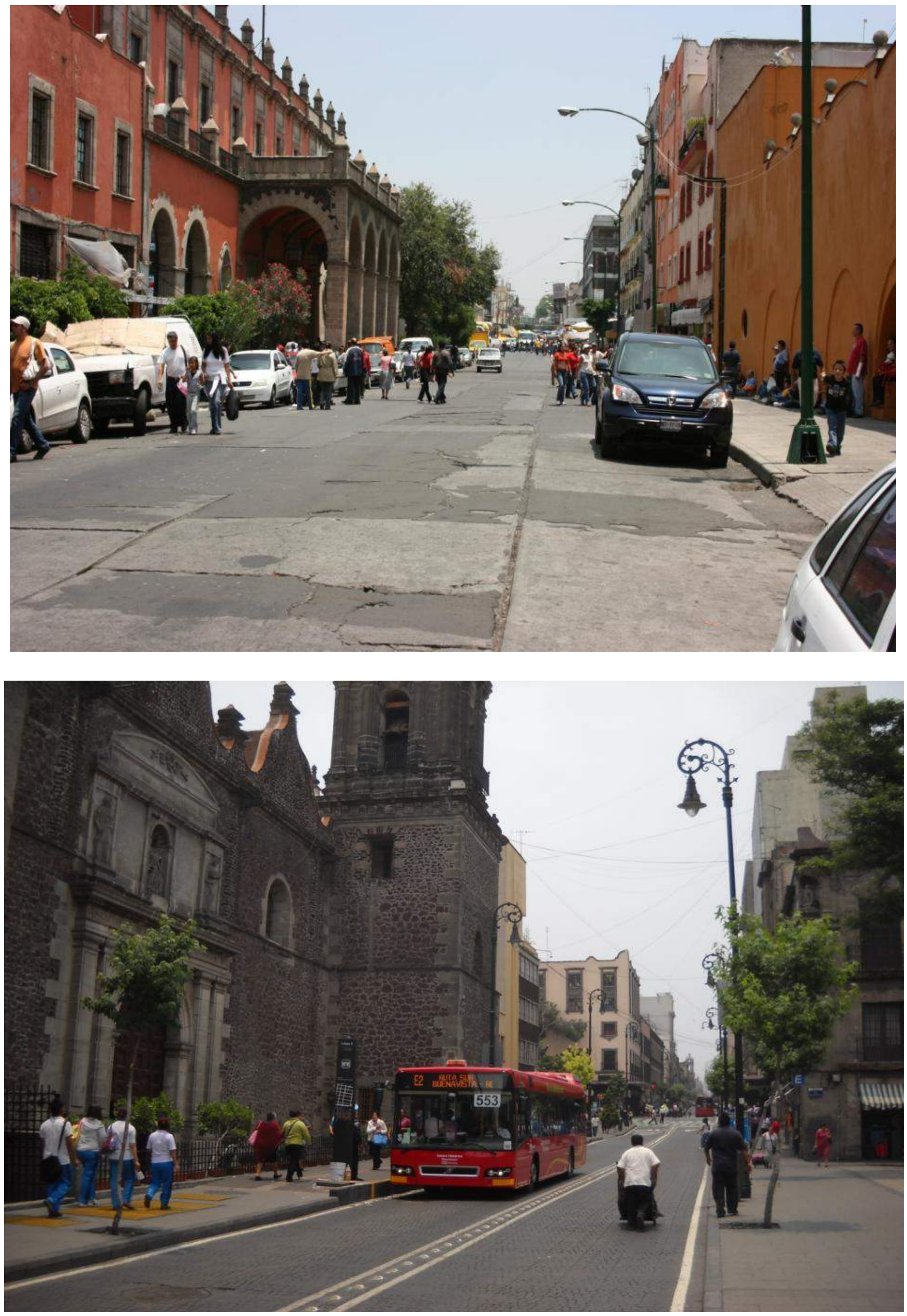

Figure 10: Narrow street in Centro Histórico, Mexico City, converted to BRT-only

Appendix B includes all proposed routings, routing alternatives, and cross sections for each corridor.

Travel Time Savings

The final piece of technical work requested by the Study Group was a calculation of the benefits to passengers if gold-standard BRT were built in each corridor. In order to do this, we carried out what is known as a "travel time savings analysis."

A travel time savings analysis begins with existing end-to-end travel times for bus passengers on each corridor and applies the elements of gold-standard BRT to determine the resulting travel times. Appendix C includes a full report on the time savings analysis done for each corridor. The main results are as follows:

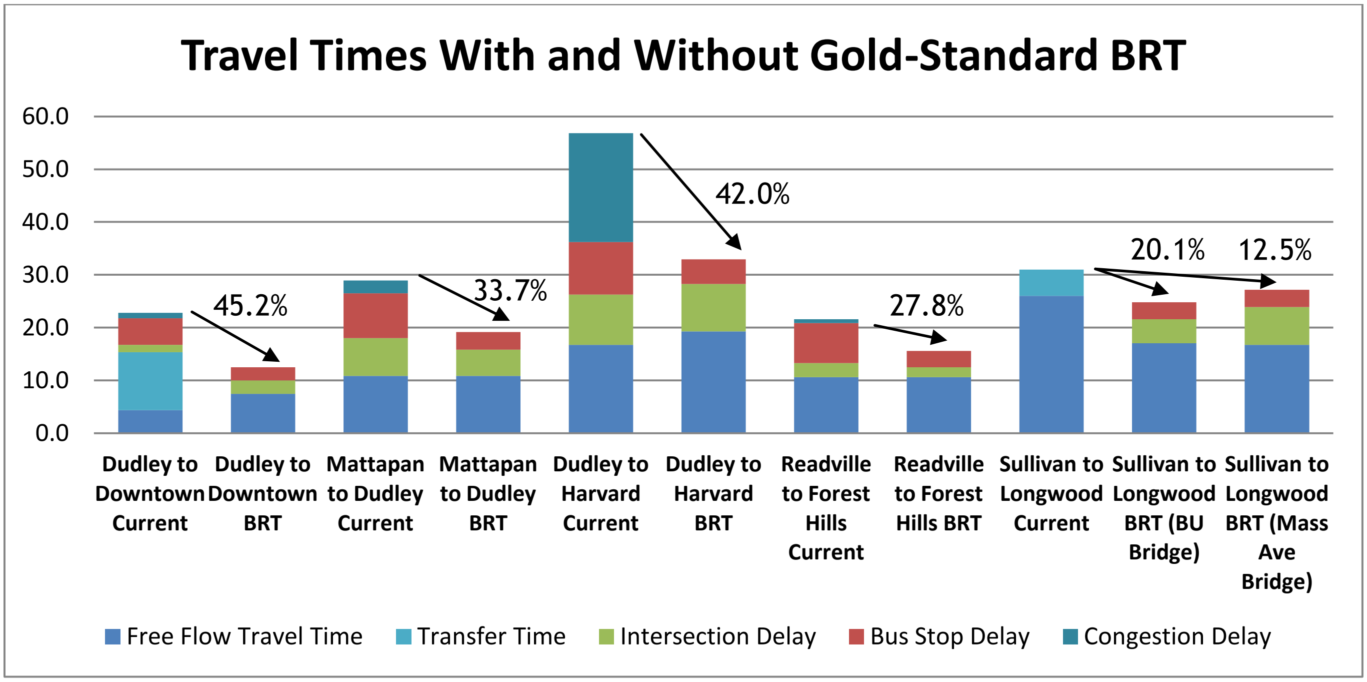

Figure 11: Travel time savings by corridor based on each element Gold Standard BRT

In absolutes, the most substantial travel time savings were on the Dudley to Harvard Corridor where the end-to-end travel time drops by 23.9 minutes with gold-standard BRT. However, this is due in part to the fact that Dudley to Harvard is longer than the other corridors. When looking at the percent reduction in travel time from current to BRT scenarios on each corridor, the greatest *percentage* reductions are found on Dudley to Downtown (45.2%). However, two other corridors – Dudley to Harvard and Mattapan to Dudley – both show considerable percentage reductions in travel times. The Readville to Forest Hills and Sullivan to Longwood corridors show smaller travel time savings than the other three.

Another way of representing this is as follows:

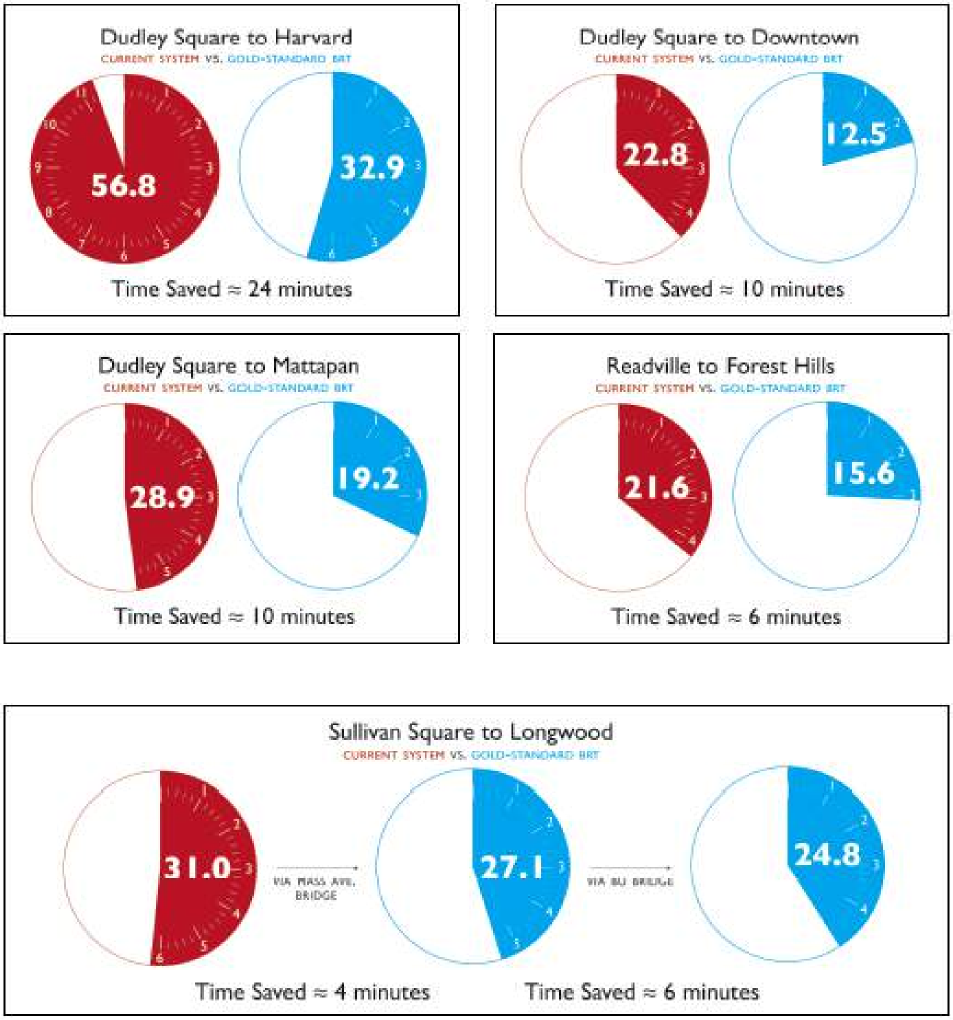

Figure 12: Travel time savings, by corridor, created by Gold Standard BRT

Gold-standard BRT has the potential to reduce current travel times by transit on each of the corridors by between 20% and 45%. Given that the demand on each of the corridors meets a minimum to justify a gold-standard BRT investment, these findings provide further evidence that gold-standard BRT can be both justified and beneficial in these corridors. While further, more detailed technical analysis is still necessary in order to determine the precise alignment, services, costs, etc., this analysis provides the basic results necessary to confirm the viability of BRT in these corridors.

Which corridor ultimately moves forward must be the result of a strong community-based process. While the technical case for gold-standard BRT is strong, the Greater Boston Bus Rapid Transit Study Group, the local communities, stakeholders, and politicians are now weighing all other factors important when a city makes a new investment and/or changes the streetscape dramatically.

Appendix A: ITDP Results of Corridor 9 Modeling

[see attached file of same name]

Appendix B: Corridor Routings and Cross Sections

[see attached file of same name]

Appendix C: BRT Travel Time Savings Analysis

[see attached file of same name]

MEMORANDUM

To: BRT Study Group

From: Annie Weinstock, Elkin Bello ITDP

Re: Results of Corridor 9 Modeling

Date: May 2, 2014

Results

The results show that once the projected shift of passengers from current rail passengers are included, the Western section of Corridor 9 north of the Charles River, whether it takes the Massachusetts Avenue Bridge or the Boston University Bridge, would rank 9th or 10th using our corridor ranking process based purely on opening year projected passengers per peak hour per direction (i.e., increasing all corridors by 30% to match opening year demand on Corridor 9).

Boston Corridors Ranked by Projected Opening Year PPHPD		
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Washington Silver Line	2100	1
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Harvard Square to Watertown	533	12

Figure 1: All corridors from previous analysis with a 30% increase, and both Corridor 9 scenarios included in the rank order

The demand on the Western section of the Urban Ring was modeled assuming full BRT infrastructure from Sullivan Square/Assembly Square down to Ruggles. To be comparable to other corridors, we looked at the maximum load on the critical link. In fact, the maximum load on the critical link for Corridor 9 on both scenarios (Mass Ave Bridge & BU Bridge) occurs south of the Charles River, at the approach to the Longwood Medical Area on Fenway where there is currently no transit link. As those sections of the Western part of the Urban Ring were already identified as part of other corridors already included, and as only the demand north of Commonwealth Avenue are new to this corridor, we took the maximum load on the critical link north of Commonwealth Avenue, which roughly occurs directly on the Mass Ave or BU Bridges.

Figure 2: Mass Ave Br Scenario, highest PPHPD on Mass Ave Br

Figure 3: BU Br Scenario, highest PPHPD on BU Bridge

The total demand on the Massachusetts Avenue Bridge (994) is actually split between services that in our modeling, we considered 'BRT' Services (515) as well as those that are local services (479). However, we would recommend that all services use the BRT infrastructure wherever possible, and particularly on a bridge where there are no stations with which to interface. On the BU Bridge Scenario, however, all of the demand using the BU Bridge would be on a BRT service (908). Since both would probably use the BRT infrastructure we simply used total demand on the Mass Ave Bridge (994) and total demand on the BU Bridge (908).

Figure 4: Mass Ave Bridge Scenario, demand coming south down Mass Ave

The majority of the demand north of the Charles River is coming from Central Square down Massachusetts Avenue (perhaps 2/3 of it), and a much smaller share (perhaps ¼) of the demand is coming from Sullivan Square/Assembly Square, so it might make more sense to simply connect Central Square to the Massachusetts Avenue or BU Bridges and then connect with the other BRT corridors.

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Institute for Transportation & Development Policy

Figure 5: PPHPD on Mass Ave Bridge scenario is in Longwood for reasons described in text

The maximum load on the critical link of the entire corridor constitutes a curious jump in demand along Fenway to Longwood. It is interesting for a couple of reasons. It is partially generated because the proposed BRT would create a new transit link that currently does not exist which would remove a considerable trip diversion caused by the one way approach to Longwood along Fenway, emphasizing the importance of the inclusion of this link in serving the Longwood medical area.

Corridor 9 does meet the minimum projected demand on both the BU Bridge and the Mass Ave Bridge alternatives. A more detailed service planning analysis could provide us with more information regarding which scenario will be more productive. However, political and community-related matters are more likely to outweigh the relatively minor differences in demand. Therefore, if the Study Group agrees, we recommend moving forward with Corridor 9 and conducting an analysis similar to that conducted for the other corridors over the coming month.

Why did we model Corridor 9?

At the September 25, 2013 BRT Study Group meeting, ITDP first presented its analysis indicating on which corridors BRT infrastructure investments could make the most sense from a technical perspective. BRT infrastructure is generally designed to provide the greatest time savings for the greatest number of people. We began this analysis by looking at where the greatest number of bus passengers currently travel today. It is on these corridors that we have the greatest chance for building a successful BRT which will benefit the most people and can be a project the rest of the city, and country, can point to as a successful BRT.

It is generally recommended that in order to dedicate a lane of traffic for public transportation, the opening year demand on the public transportation (measured in persons per hour, per direction – pphpd) must be at minimum 1,200. Demand on bus corridors in Boston is generally much lower than this. However, it is likely that a high-quality BRT can attract demand from nearby bus routes, automobiles, etc. It is important that BRT be able to demonstrate some degree of success from the opening year and that buses do not run empty for years until demand begins to materialize. Empty buses and low frequencies mean operational losses, an empty-looking bus lane, and a public relations problem – particularly as valuable road space has been given up for the BRT.

Therefore, as we looked at the existing bus network in order to determine where BRT might make sense technically, we allowed for a minimum threshold of aggregated existing bus ridership of 400 pphpd. Internationally, 400 is quite low but it was an absolute minimum threshold. A corridor with 400 pphpd would need to be very attractive to the local stakeholders in order to be justifiable, as the demand can be serviced by about 7 buses an hour, or every 8.5 minutes, leaving the bus lane empty most of the time. Most of the corridors we selected were higher. We also looked at speeds since high-quality BRT is designed to reduce the delay associated with slow travel speeds. This analysis resulted in an initial list of eight corridors where BRT could make sense.

These two variables – existing demand and existing speed – rely solely on a careful documentation of existing conditions. Corridors with high demand and low speeds do not generally require modeling in order to verify that they will work as BRT corridors.

In too many cities, complex multi-criteria analysis is used for selecting transit corridors (BRT, LRT, or otherwise) based on a wide range of non-transparent variables that are impossible to corroborate and mainly reflect the biases of the project promoter. Such analysis may then be backed up with a 'demand' estimate based on a travel demand model which may be largely a "black box" of assumptions, and the ridership projection is made for a year so far in the future that the results can never be compared against the actual result. As such, complex multi-criteria analysis and modeled future year ridership estimates tend to produce the results desired by the project promoter rather than providing an objective basis for selection of alternatives among multiple options.

In our experience working across the US and internationally, such a corridor selection methodology can be complicated, nontransparent, and often obscure the main variables which stakeholders actually need for determining the success of a future BRT corridor: existing transit ridership and existing speed. Thus, ITDP based its primary corridor selection screening process on these two simpler criteria which are easy to understand and corroborate and harder to dispute.

Through discussions with the BRT Study Group, we learned of a possible ninth corridor which, for the reasons described below, seemed to have some potential for being a success in opening year. The BRT Study Group recommended that we look into the corridor from

Longwood to Kendall (or Lechmere or Sullivan) as a possible Corridor 9. This corridor has a few existing MBTA bus routes using different segments. On the highest demand segment, Routes #1, CT1 add up to 350 pphpd along Massachusetts Avenue. Other routes present partially along Corridor 9's alignment are the CT2 and 55. This bus demand was not, on its own, high nor prolonged enough for this corridor to pass our initial screening. However, the general concept behind building this corridor as BRT is to shorten the long trip with the cumbersome transfer that people traveling from Kendall to Longwood must today make using the T. This concept, therefore, still relies on existing transit riders and is still somewhat more reliable than long-range employment, modal shift, and land use predictions.

That said, it still requires a model to predict how many of T riders would switch to BRT were there a BRT on the corridor in question.

Finally, in our initial analysis, we also looked at where land is developing in the region since this represents a potential new transit market currently unserved by existing bus routes. Development was somewhat scattered and not necessarily concentrated enough to warrant an entirely new BRT corridor. There were a few exceptions, two of which are already covered by the Harvard to Dudley corridor: the Harvard Allston development area and the development along Boylston Street in the Fenway. There is also some concentrated new development along the Green Line extension, where it would not make sense to also propose a BRT, and in the Seaport District, already served by the Silver Line Waterfront. The final exception was in the Kendall area where there has been a concentrated effort on the part of the City of Cambridge to develop. This area coincides with the potential Corridor 9 and so we made the final decision to study the corridor and determine whether it meets the threshold for demand.

Under these circumstances we extended our initial analysis from simply analyzing existing passenger ridership on MBTA and TMA bus lines to a more comprehensive simulation process including interactions with T lines and potential shifting ridership.

Modeling Methodology

The most common way of predicting future ridership of a BRT on a corridor is to build a transit model. A model of this kind does currently exist for the Boston region and is managed by the Central Transportation Planning Staff (CTPS). After several months of unsuccessfully attempting to obtain the model directly from CTPS, we were given access to a set of the baseline conditions, in the form of direct assignment results of two scenarios[1] of a transit model put together by MIT for the West Ring analysis of their Inner Core Ring Study using CTPS model's street network and transit routes. The baseline demand matrix used in MIT's model is based on the results of the 2012 Massachusetts Travel Survey carried out by MassDOT, which is a household survey that asks people about their day-to-day travel patterns and contains information for captive transit trip desires in the Boston region. Such origin-

[1] Scenarios provided by MIT included stop-to-stop passenger ridership for: (1) Baseline scenario with existing MBTA routes – commuter rail, T and bus and (2) Implementation scenario for West Ring BRT corridor connecting Assembly Sq. to Dudley Sq. Map included further in document.

destination (OD) data can be quite useful for medium and long range transportation planning analysis supported on comprehensive and multimodal networks. However, since MIT's model does not measure actual trips taken on the bus network, it does not fully reflect existing conditions, particularly on the bus network which we still use as our base. The challenge was then to design a methodology that allowed us to merge and profit from both datasets: MBTA bus ridership and OD desire trips from MTS household survey processed by MIT.

The map we created of existing bus ridership is based on MBTA Automated Passenger Count (APC) data onboard the buses. This is the most accurate method of determining bus ridership. After discussing with MIT and comparing their output data with MBTA riderships, a discrepancy in ridership values between the two methods was noted. MIT explained that they did not calibrate their model in order to balance and adjust differences between forecasted and observed demand. This calibration procedure was beyond the initial and desired scope of the study MIT embarked into and thus was not included into their work plan. As a result, the future conditions in their model alone would not be sufficient for us to determine ridership on Corridor 9.

In spite of these discrepancies, MIT's effort to forecast passenger ridership scenarios on a regional multimodal network inferred from household trip desire information was the only data source at hand which would allow us to determine transfers from the T to Corridor 9. Because we had the more reliable data on existing bus ridership, we used MIT's data to complement the model we had built in order to determine both future ridership coming from existing bus routes and future ridership transferring from the T to a new BRT along Corridor 9.

To illustrate these discrepancies, we present actual ridership for the weekday AM peak hour for the route CT2 and compare it to the baseline conditions CT2 ridership as modeled in MIT's study.

Table 1 CT2 Ridership comparison Actual CT2 ridership vs. MIT's baseline on the CT2, by direction

AM peak Ridership	Actual	MIT	Correction factor
CT2-1	539	914	0.589
CT2-2	432	657	0.658

The use of the correction factor and adjustment procedure used on MIT's model results is explained further on the document.

The correction factors obtained from the direct comparison of ridership on route CT2 for MBTA baseline and MIT West Ring scenarios (shown in Table 1) were used to calibrate and adjust the output ridership for the West Ring service, included in MIT's BRT implementation scenario. Ridership volumes for this particular route account primarily from transfers between rail and BRT that were previously impossible to identify with the MBTA OD matrix. As a clarification, these ridership volumes were adjusted following the above methodology because the source baseline scenario from MIT's model was not calibrated to existing conditions and thus this inaccuracy is consequently carried over to the forecasted future scenario.

The diagram below shows the steps and process followed to obtain the OD matrix feeding the transit model used to forecast demand for Corridor 9.

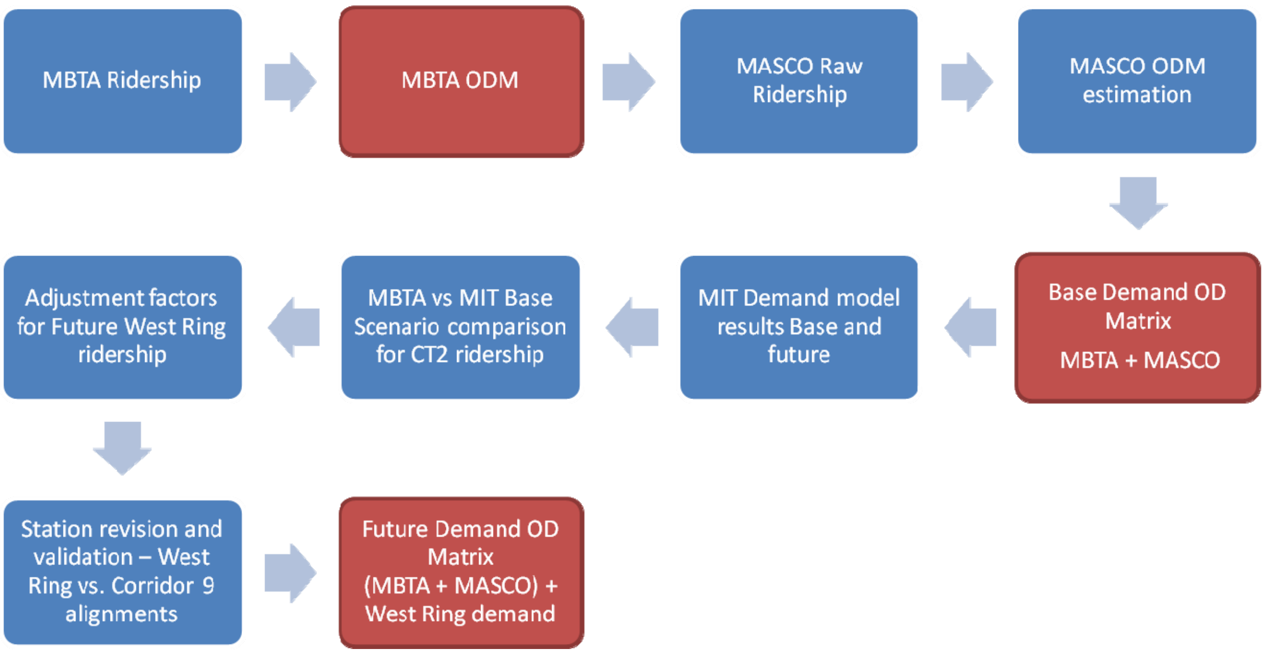


Figure 6 Process followed to obtain trip matrices used on Corridor 9 demand analysis - Red boxes denote OD matrices

Modeling Corridor 9, Existing Conditions

Using TransCAD, one of the best transport modeling software packages for this purpose, we built the Boston transit network using:

- NAVTEQ's regional street database
- Boston's route itineraries processed from MBTA's boarding/alighting tables
- Transit speeds from MBTA's APC database
- Stop-to-stop trip matrix ODM inferred from MBTA's boarding/alighting tables.
- Reference ridership data calculated from MBTA's boarding/alighting tables and loaded into the network

With these components we modeled a baseline scenario that was adjusted to match the existing conditions by internal trip matrix adjustments procedures using 75 control points strategically located throughout the city. The calibration achieved a satisfactory correlation index R^2 of 0.78 and angle coefficient 0.9005 as seen in Figure 2.

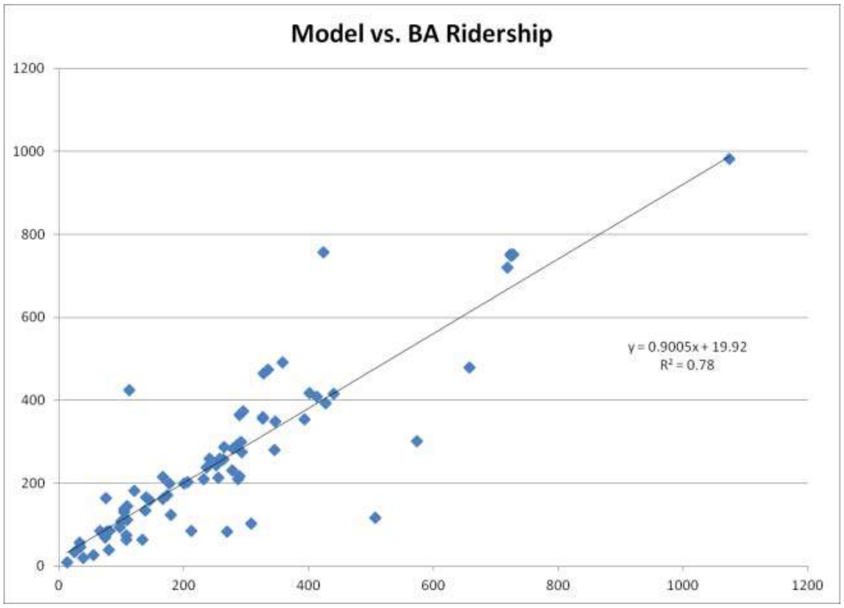


Figure 7 Linear Regression of Model Results at AM Peak Hour

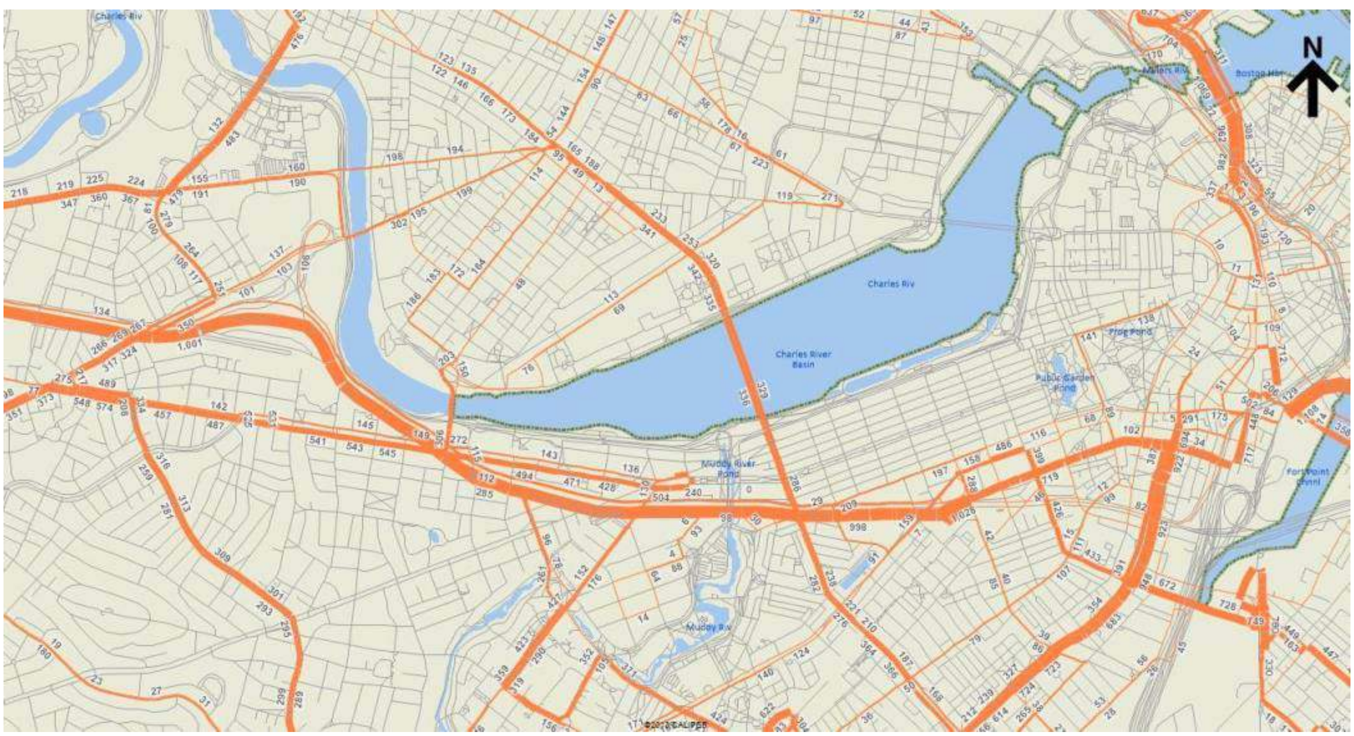


Figure 8 Passenger loads from MBTA boarding alighting tables

The differences seen between our model's output demand and the map presented initially to the study group could be explained based on the following factors:

- Different source datasets. Initial loads and speeds were obtained from a database using "timepoints" which are reference points along a route's itinerary used to mark passing times which later would be joined with load information to obtain the database used including speed and load per link. The information was processed on a link level because some of these timepoints are shared by multiple routes coming from different directions. In this case, trip desires in the form of an OD matrix were obtained from detailed boarding/alighting data including passenger movements stop to stop. This change revealed some difference in existing conditions data we originally processed and the data we used to build the model. Likely, the way in which the MBTA processed its raw boarding and alighting data resulted in some errors. However, this difference was on the margins and does not change the results of our original analysis.

- Fratar distribution used to generate an OD matrix from boarding/alighting tables. This methodology uses probability to distribute given passenger movements at a stop to the following stops along the itinerary in order to give us a probabilistic sense of trip origin and destination pairs. Some error is intrinsic in this method but our R^2 of 0.78 is within reason.

Finally, in order to ensure that we had included all of the demand currently traveling in the area of influence of Corridor 9, we analyzed and incorporated demand from private routes and shuttles operating within the Longwood Medical Area. These services, being privately operated, are not covered by MBTA's route inventory and we had to obtain them separately and include them into the OD matrix separately. Demand figures were received in an aggregated form and formatted to match the timeframe of AM peak period. Ridership data converted in OD pairs from the following services was included in the analysis:

- Ruggles express (MASCO)
- JFK/UMass (MASCO)
- M2 Cambridge – Harvard (MASCO)
- EZRide (Charles River TMA)

With a baseline scenario calibrated to existing demand conditions, the remaining piece of the analysis was to model the expected shifting demand from T lines. To forecast this demand on a future Corridor 9 BRT we used MIT's model results for the West Ring corridor scenario. The West Ring corridor used is shown in the following picture.

Figure 9: MIT's West Ring Corridor and Stops

The West Ring corridor displayed above follows an alignment that has long been the center of discussion and has been analyzed in several transit planning studies in Boston.

ITDP has taken a close look at the various studies available on the subject as well site inspections and discussions with local officials and experts and selected two variations of a corridor routing which would connect opposite banks of the Charles River. Option A connects Fenway with Kendall via the Massachusetts Avenue Bridge and is a more direct connection between these two points. Option B connects Fenway with Kendall across the BU Bridge and is less direct between these two points but serves more origins and destinations in between. These alternatives are shown in Figures 5 and 6.

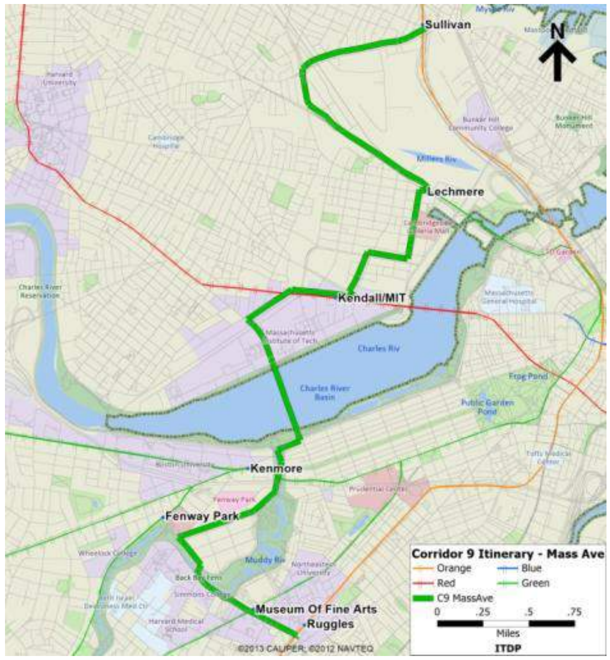


Figure 10: Corridor 9 Option A: Massachusetts Avenue Bridge Alternative

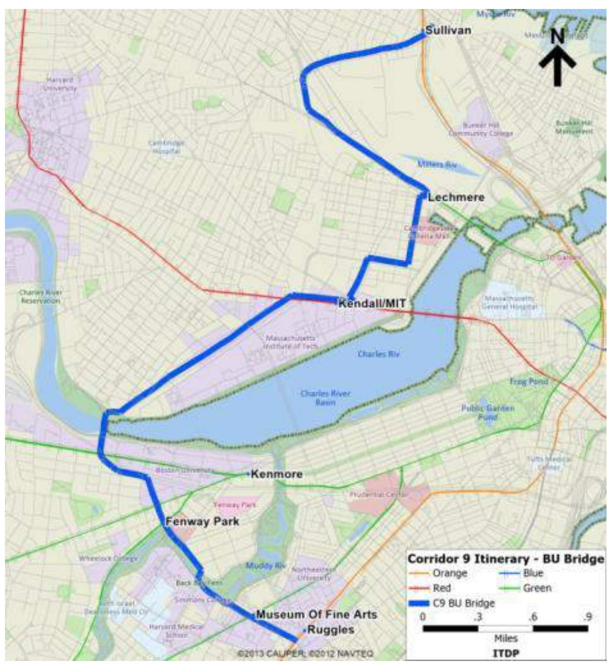


Figure 11: Corridor 9 Option B: BU Bridge Alternative

We then modeled opening year Corridor 9 ridership based, again, on existing bus ridership in the area and potential ridership shifts from the T.

Modeling Corridor 9, Opening Year

In modeling future conditions for Corridor 9, it was important that we develop criteria for judging it that matched as closely as possible to the criteria we used to select the other corridors. For the other corridors, we selected a minimum threshold of 400 pphpd existing bus passengers (for reasons described in detail at other points in this process). In modeling Corridor 9, we could not use the same 400 pphpd threshold since through modeling we are already looking at future conditions, even if those future conditions are the first year of services. By building a BRT, we are already building a faster, more attractive transit link. If we want to compare apples to apples, since we cannot consider the existing conditions for a corridor which does not exist (Corridor 9), we have to consider opening year conditions for the other corridors, assuming they have been built as BRT. Without the resources to model opening year conditions on all of the corridors, we used professional judgment to set a threshold. From our experience, in opening year, a BRT system might get on average, a 30% increase over and above existing conditions. We therefore increased 400 by 30% to get 520 as our minimum threshold for Corridor 9.

With that in mind, we then considered two components for predicting future ridership on Corridor 9:

1. Shifting ridership from nearby bus routes: This was obtained from modeling the existing bus network using actual MBTA data, but through adding a new corridor and bus route with higher speeds and better performance.
2. Shifting ridership from the T: This was obtained taking the portion of the trips that shifted from the T in the MIT model and adding it to the shift from nearby existing bus routes (#1 above). Shifts from the T are due to the more direct and convenient routing.

We did not consider shifting ridership from automobiles since this is more difficult to predict and less reliable. Additionally, since we looked only at existing ridership on the other corridors, it was important to have as equal a comparison as possible from one corridor to another.

We then selected two main scenarios:

1. **Mass Ave Bridge:** Future demand (Base + West Ring) with BRT along Mass. Ave Bridge
2. **BU Bridge:** Future demand (Base + West Ring) with BRT along BU Bridge

We developed a simple BRT service plan for each scenario as shown in Figures 7 and 8. Area coverage and service frequency was ensured equally for both scenarios to avoid biased results. The service plans were as follows:

- **Mass Ave Bridge Scenario:** Route 1 and Route CT1 are kept as is running on lower frequencies (4 buses/hour). A Route 1-BRT (BRT A) was created using the original Route 1 itinerary and rerouting it though Longwood Medical Area to use the BRT infrastructure. BRT B was created by making a new BRT service from Sullivan running south over the Mass Ave Bridge, and continuing west on Route 57 to Union Square. BRT C was created by making a new BRT service from Sullivan running south over the Mass Ave Bridge, and continuing south to Longwood and finishes the CT2 alignment from Longwood to Dudley. All BRT services have a frequency of 20 buses/hour.

- **BU Bridge Scenario:** Route CT2 is kept as is running on shorter frequencies (4 buses/hour) and a route CT2-BRT (BRT A) was created using the original route CT2 itinerary and rerouting it through LMA to use the BRT infrastructure. BRT B follows the BRT infrastructure from end to end. BRT C follows the BRT infrastructure from Sullivan to the BU Bridge and turns west on Commonwealth Avenue to follow the Route 57 to Union Square. All BRT services have a frequency of 20 buses/hour.

These service plans are only initial ideas of possible services and were created for the purposes of modeling Corridor 9. A more detailed service plan should be created if Corridor 9 moves forward and could have different impacts on demand results.

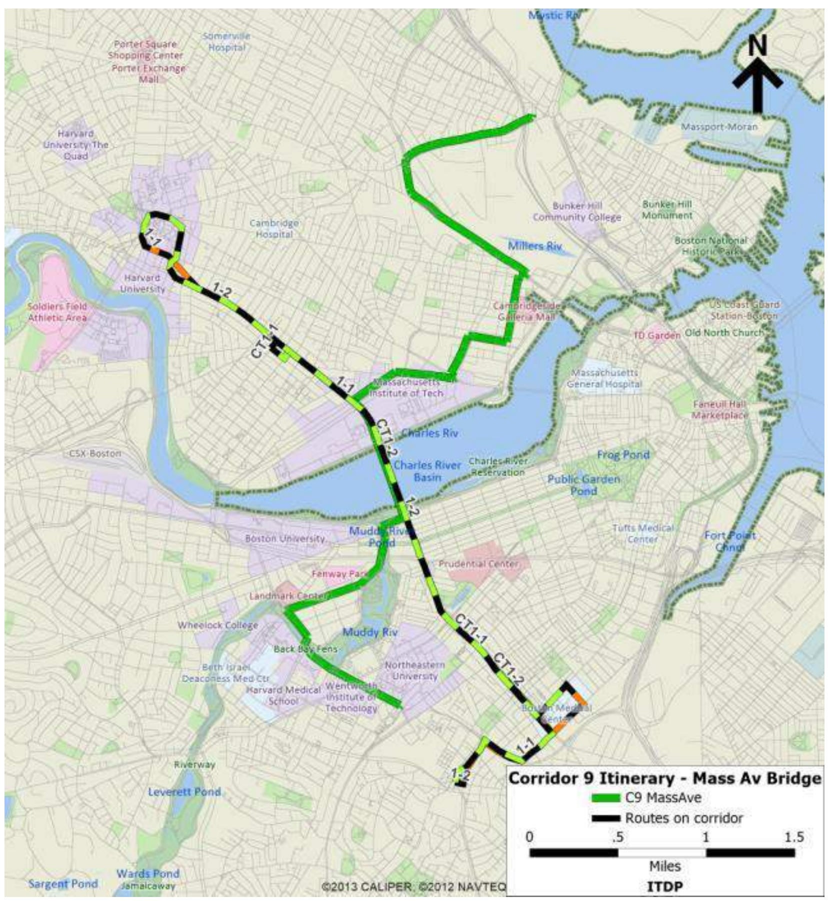


Figure 12: Current services overlapping with Mass Ave Bridge Scenario (incl infrastructure)

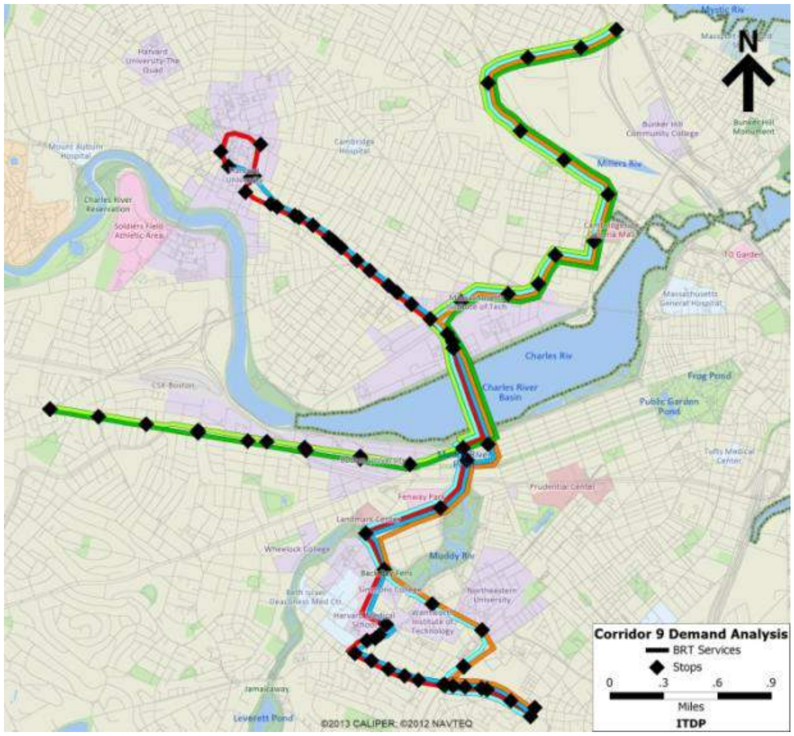


Figure 13: Mass Ave Bridge BRT Service Plan Scenario

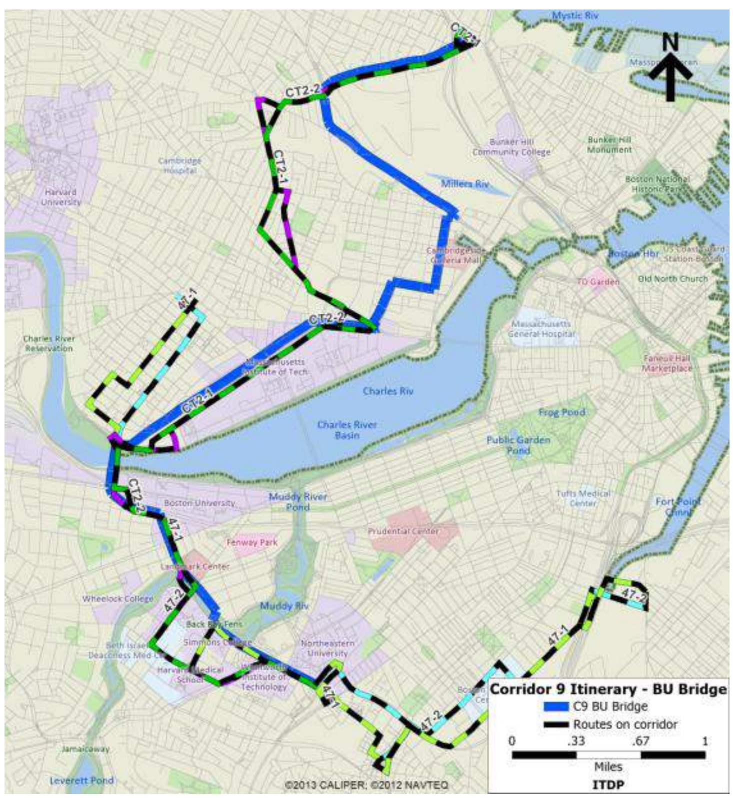


Figure 14: Current services overlapping with BU Bridge Scenario (incl infrastructure)

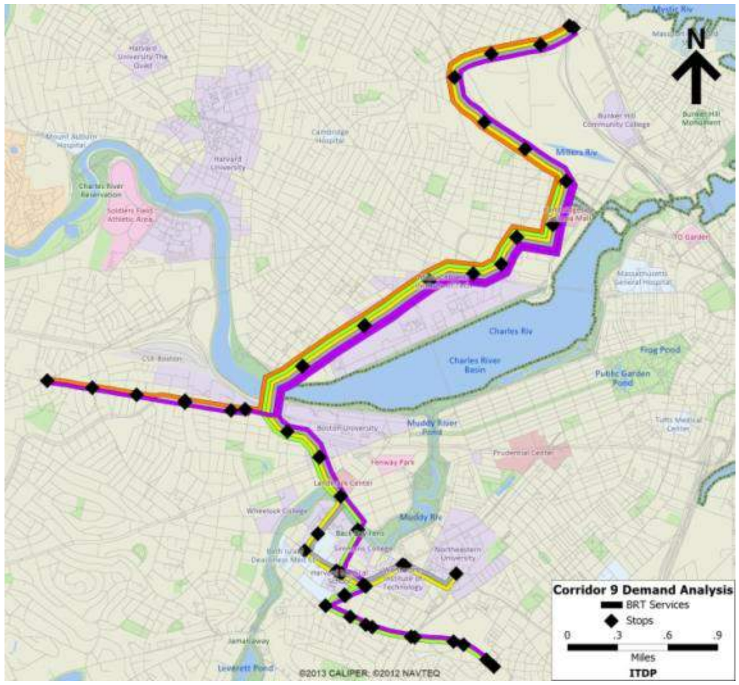
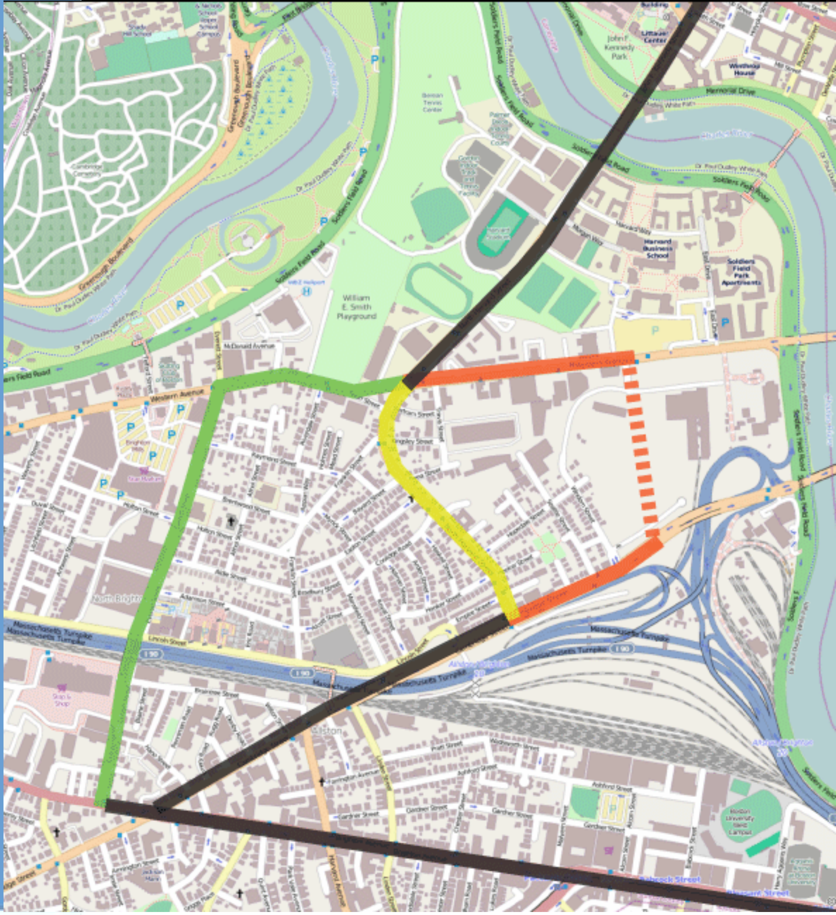


Figure 15: BU Bridge BRT Service Plan Scenario

Appendix B: Corridor Routings and Cross Sections

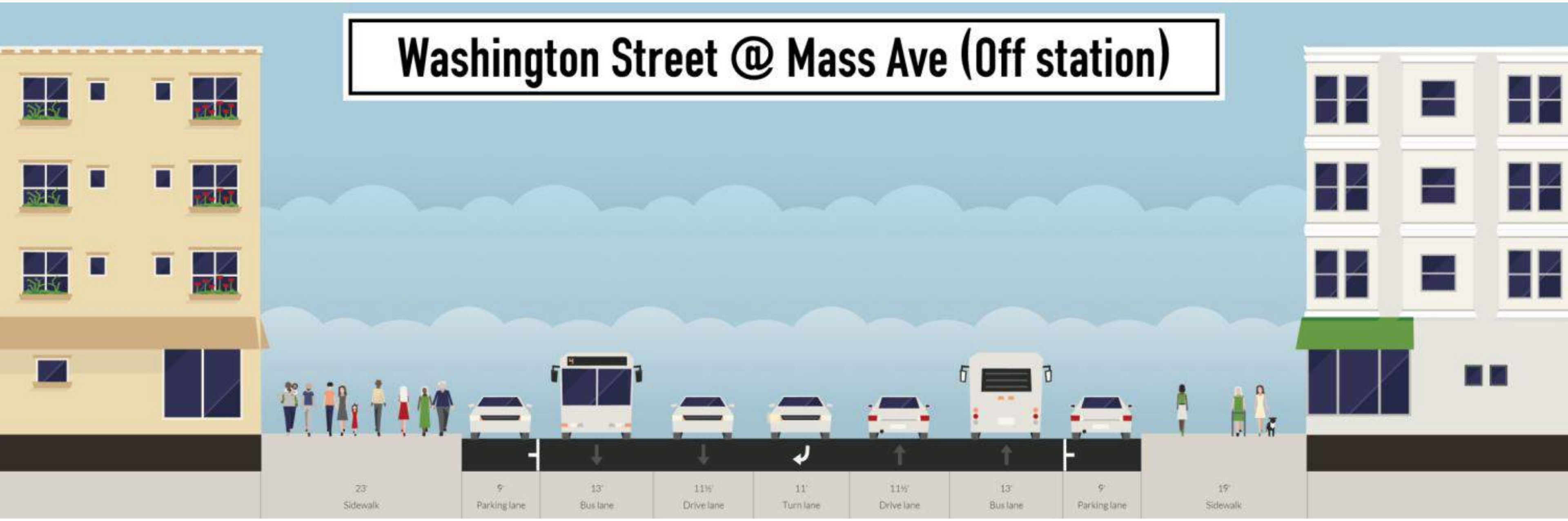


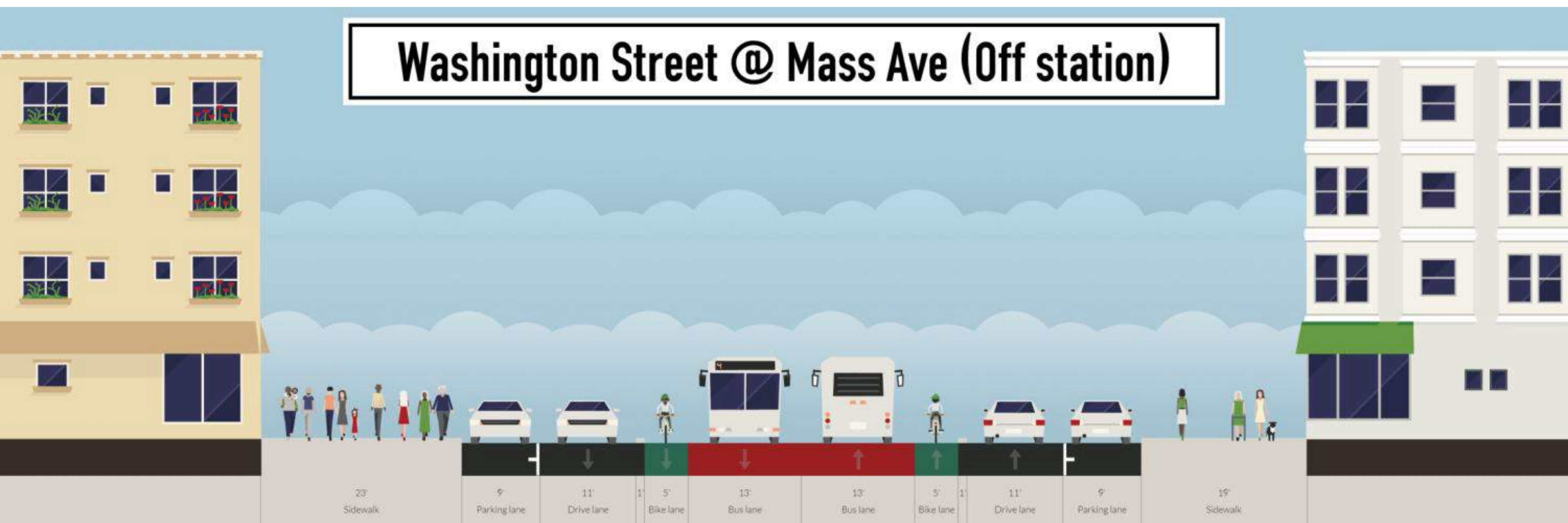
Institute for Transportation & Development Policy

Dudley to Downtown

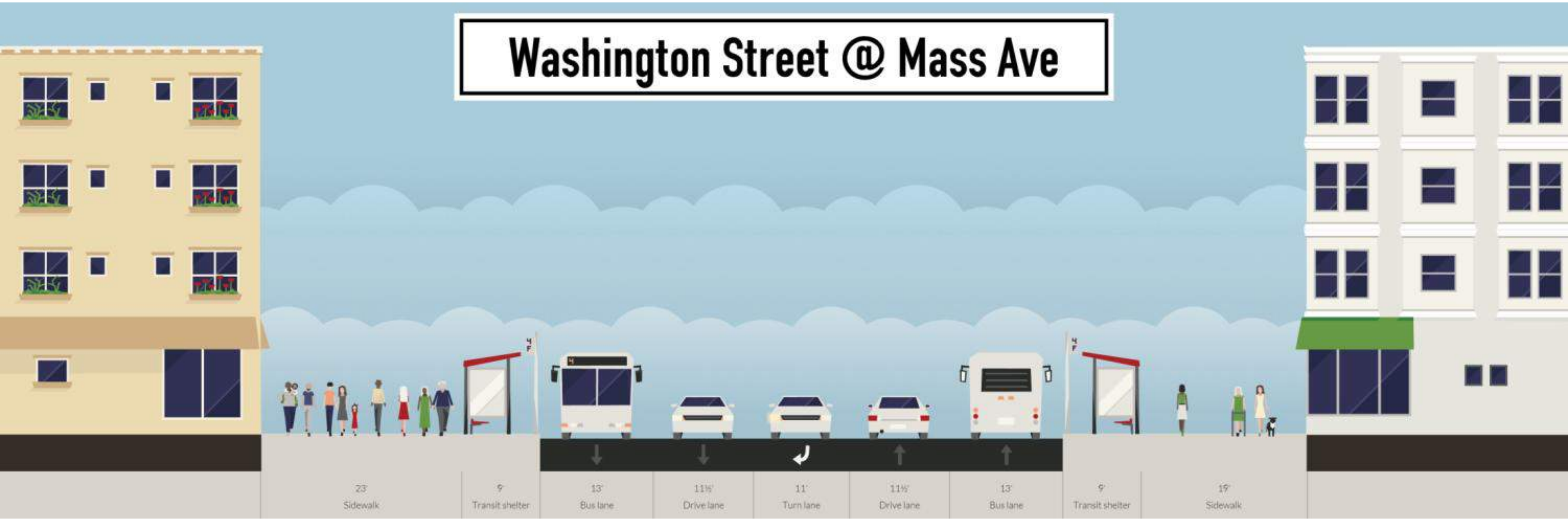
Dudley to Downtown: Routing

Silver Line to Gold Standard BRT





Silver Line to Gold Standard BRT



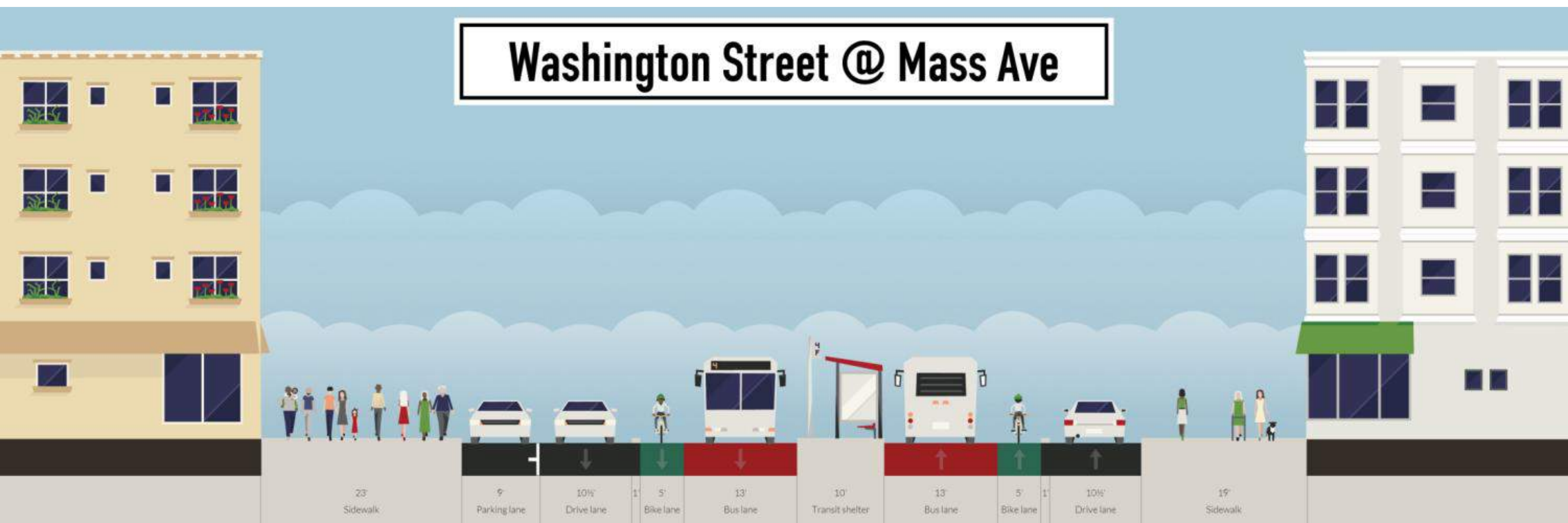


Illustration of a complete street built around BRT

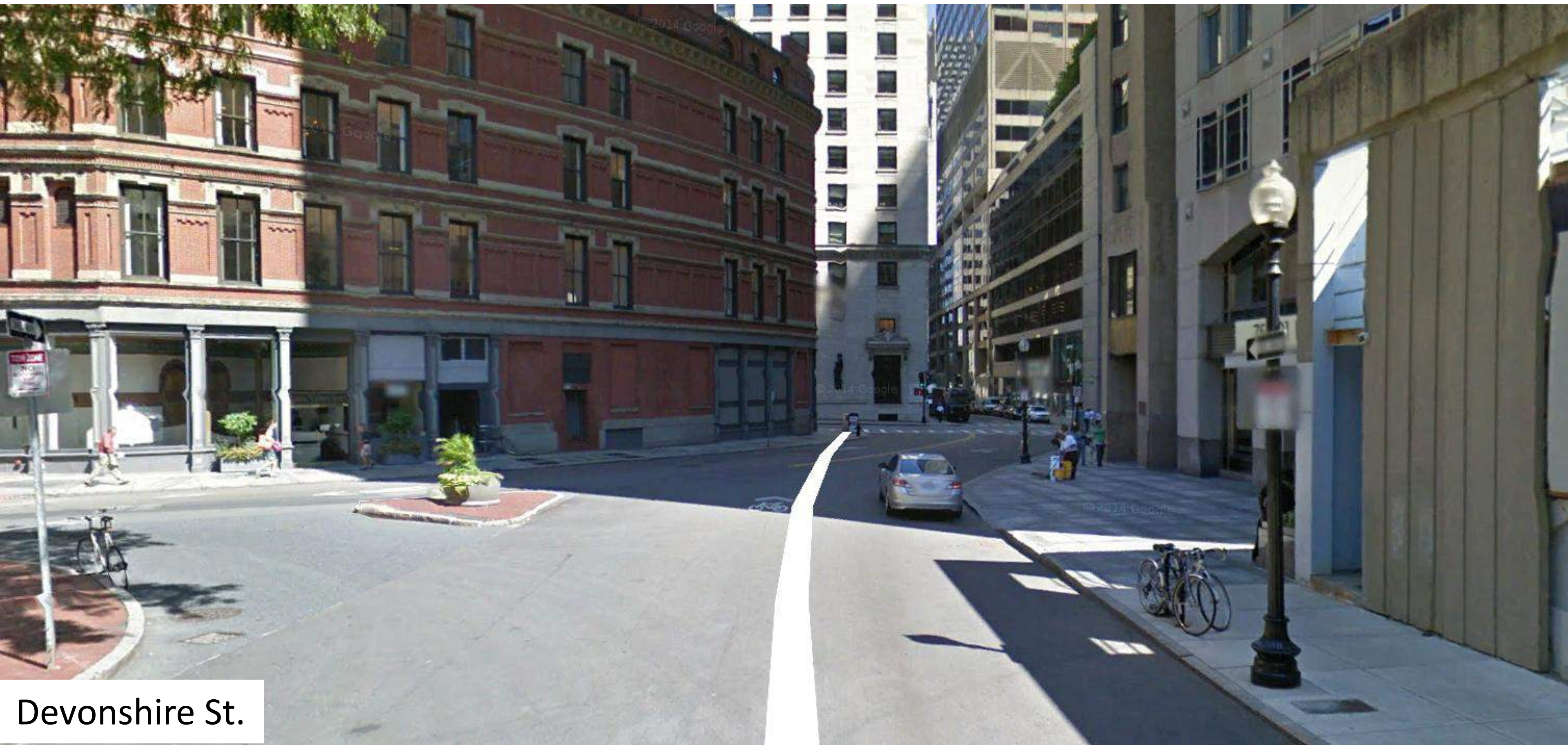
Downtown Routing Options

Downtown Routing Options

- Option A
  - BRT Only on Devonshire
  - Possibility for short bus/ped section on Washington Street
- Option B
  - Two one way pairs
- Both Option A and B allow for direct connection to the Orange Line and Red Line and Green Line connections within walking distance.

Option A

- Potential for BRT only street on narrow streets
- Provides Connection to Orange Line and Red Line with Green Line within walking distance.



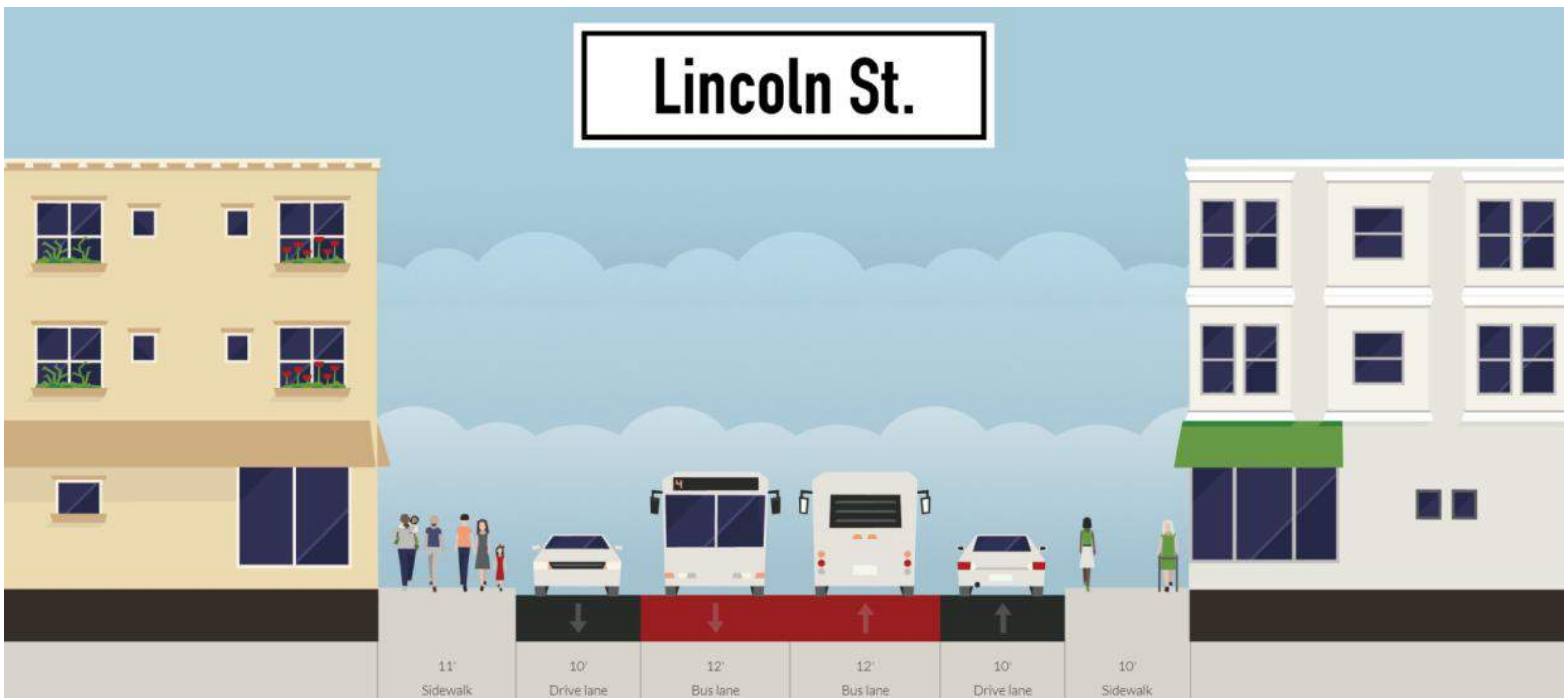
Devonshire St.

Option A

Kneeland St.
11' Sidewalk
9' Parking lane
10' Drive lane
11' Drive lane
11' Drive lane
10' Drive lane
9' Parking lane
9' Sidewalk

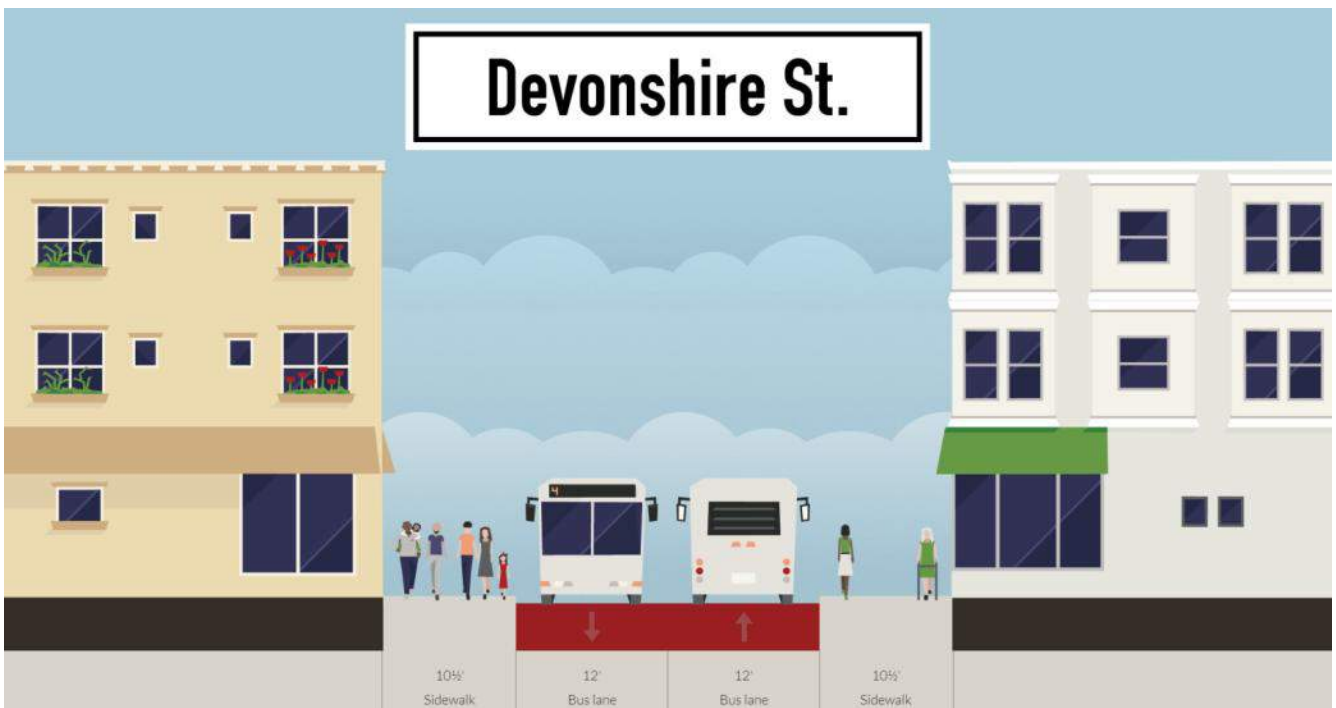
Kneeland St.
11' Sidewalk
9' Parking lane
10' Drive lane
11' Bus lane
11' Bus lane
10' Drive lane
9' Parking lane
9' Sidewalk

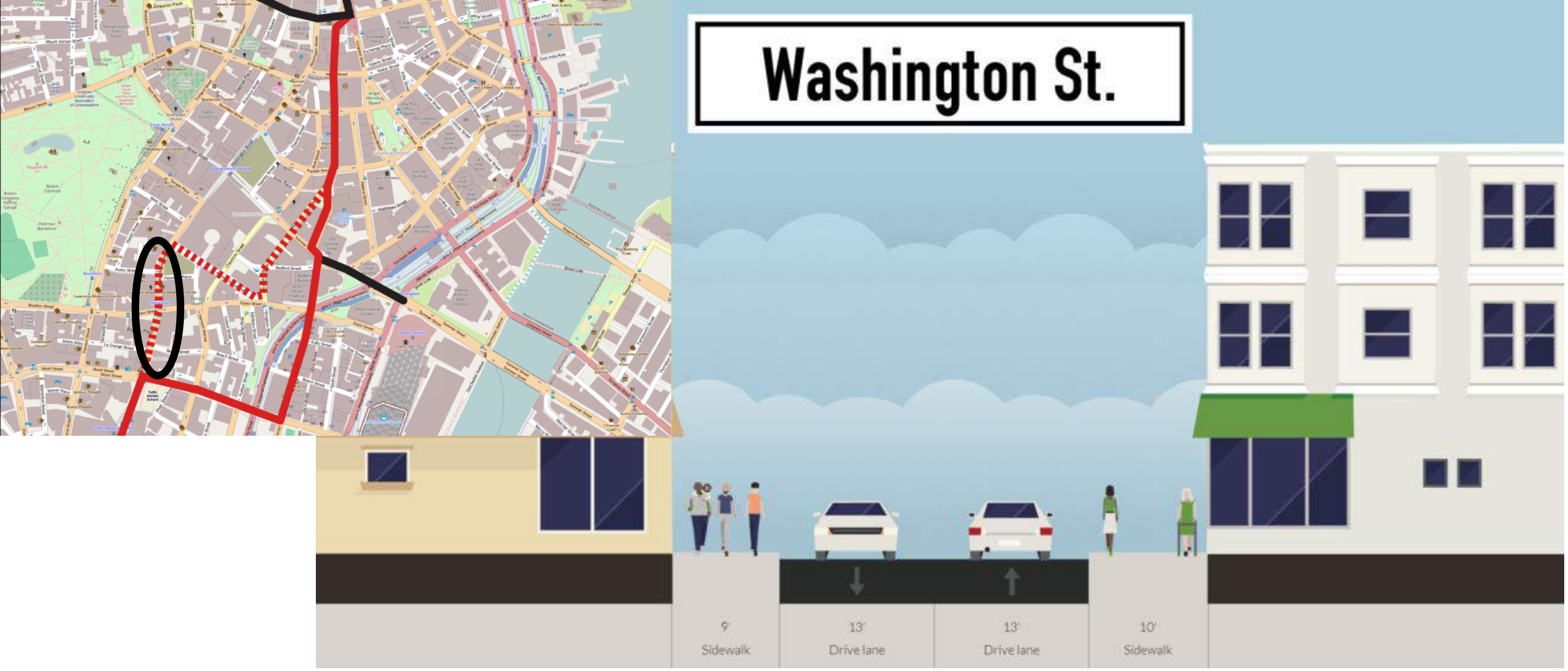
Lincoln St.
11' Sidewalk
9' Parking lane
13' Drive lane
13' Drive lane
9' Parking lane
10' Sidewalk



Lincoln St.
11' Sidewalk
10' Drive lane
12' Bus lane
12' Bus lane
10' Drive lane
10' Sidewalk


Devonshire St.
6'
Sidewalk
8'
Parking lane
13'
Sharrow
8'
Parking lane
10'
Sidewalk


Devonshire St.
10½'
Sidewalk
12'
Bus lane
12'
Bus lane
10½'
Sidewalk



Washington St.
9' Sidewalk
13' Drive lane
13' Drive lane
10' Sidewalk

Washington St.
11' Sidewalk
12' Bus lane
12' Bus lane
10' Sidewalk

Ave De Lafayette
7' Sidewalk
9' Parking lane
15' Drive lane
9' Parking lane
12' Sidewalk

Ave De Lafayette
14' Sidewalk
12' Bus lane
12' Bus lane
14' Sidewalk


Otis St.
6' Sidewalk
8' Parking lane
11' Sharrow
10' Drive lane
5' Sidewalk


Otis St.
8' Sidewalk
12' Bus lane
12' Bus lane
8' Sidewalk

Option B

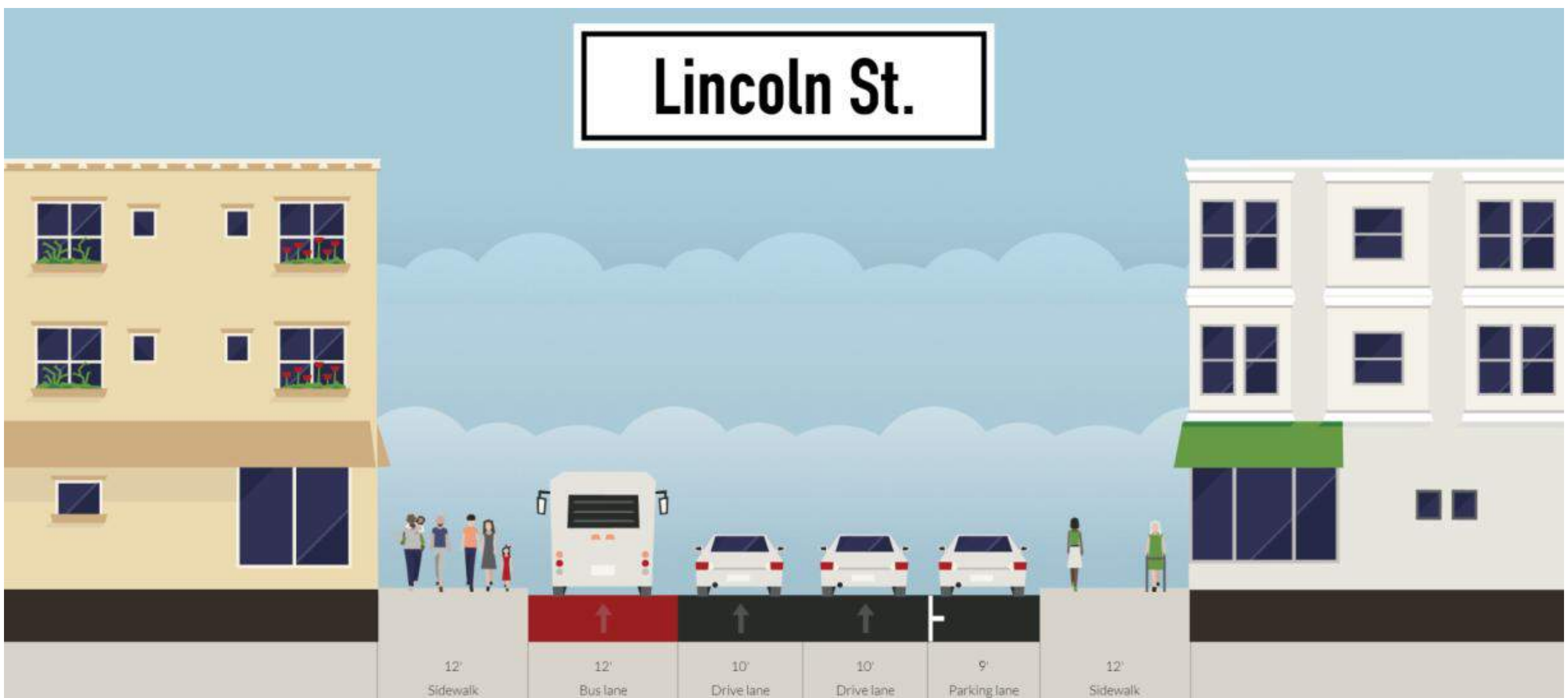
- Two one-ways pair possible on Devonshire and Arch.
- Provides connection to Orange Line with Red and Green Lines within walking distance.

Option B


Kneeland St.
11' Sidewalk
9' Parking lane
10' Drive lane
11' Drive lane
11' Drive lane
10' Drive lane
9' Parking lane
9' Sidewalk


Kneeland St.
11' Sidewalk
9' Parking lane
10' Drive lane
11' Bus lane
11' Bus lane
10' Drive lane
9' Parking lane
9' Sidewalk


Lincoln St.
11' Sidewalk
9' Parking lane
13' Drive lane
13' Drive lane
9' Parking lane
10' Sidewalk


Lincoln St.
12' Sidewalk
12' Bus lane
10' Drive lane
10' Drive lane
9' Parking lane
12' Sidewalk

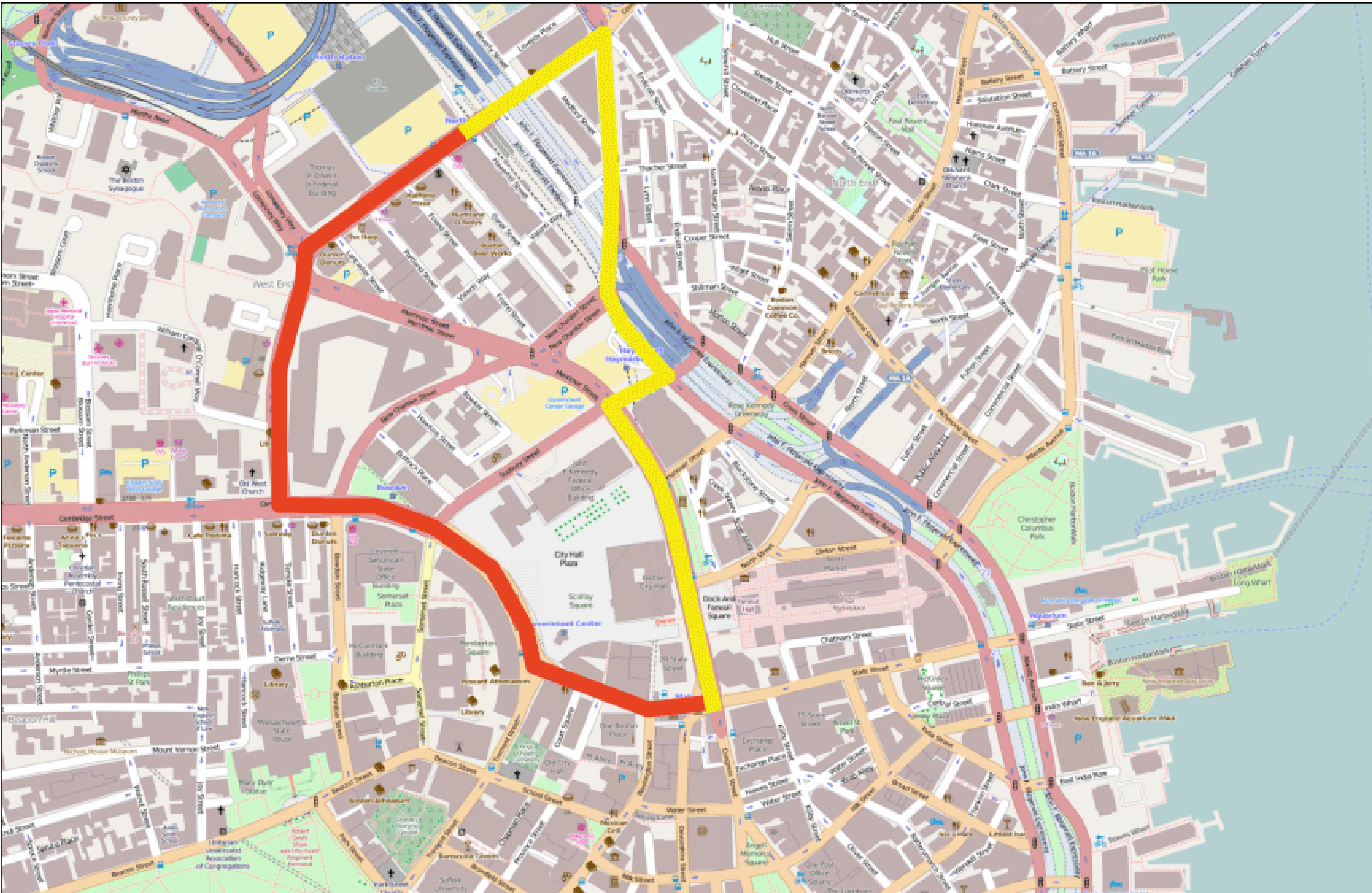
Devonshire St.
6'
Sidewalk
8'
Parking lane
13'
Sharrow
8'
Parking lane
10'
Sidewalk

Devonshire St.
6'
Sidewalk
12'
Bus lane
10'
Drive lane
1'
6'
Bike lane
10'
Sidewalk


Arch St.
9' Sidewalk
9' Parking lane
14' Drive lane
9' Parking lane
9' Sidewalk


Arch St.
10' Sidewalk
9' Parking lane
10' Drive lane
12' Bus lane
9' Sidewalk

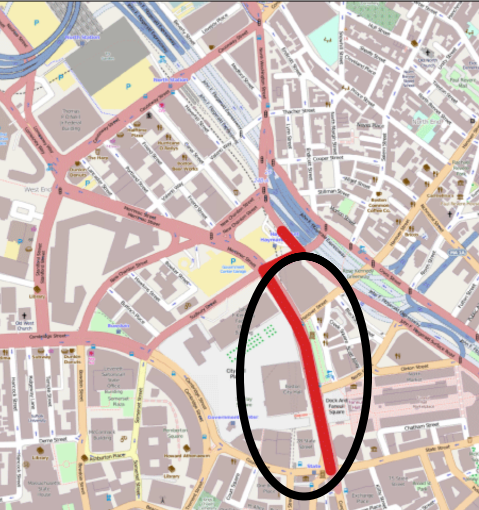
Connection to North Station: Options

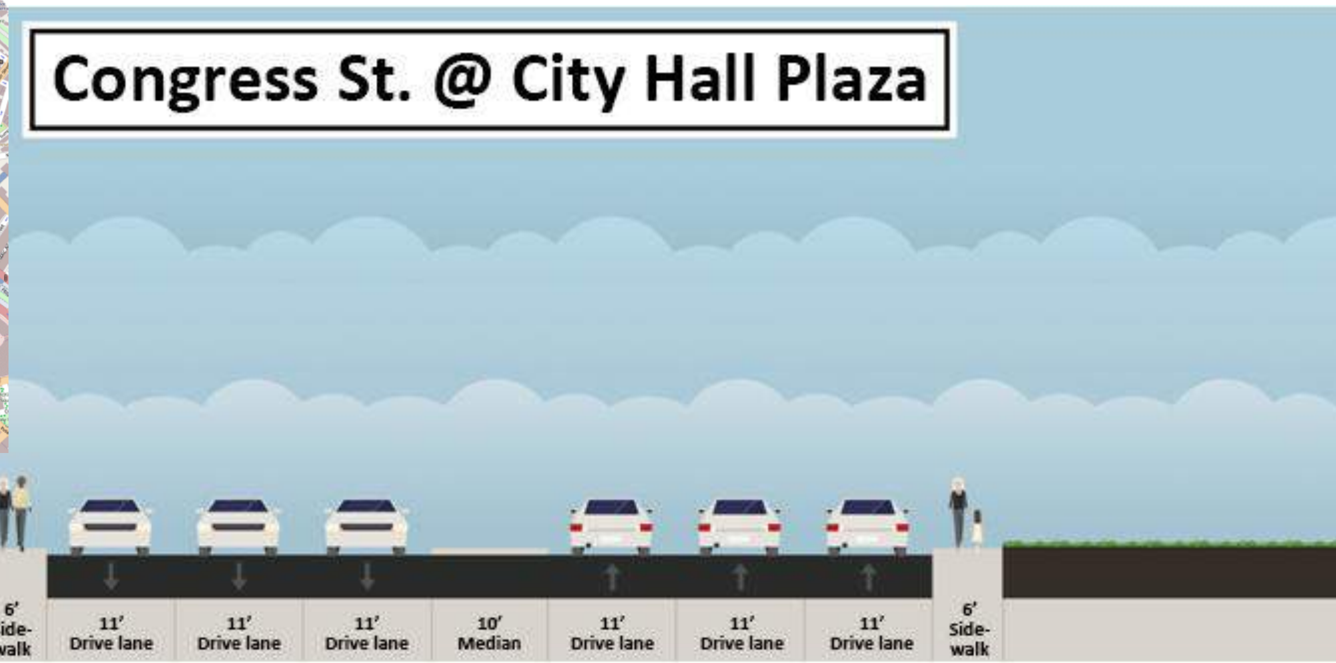


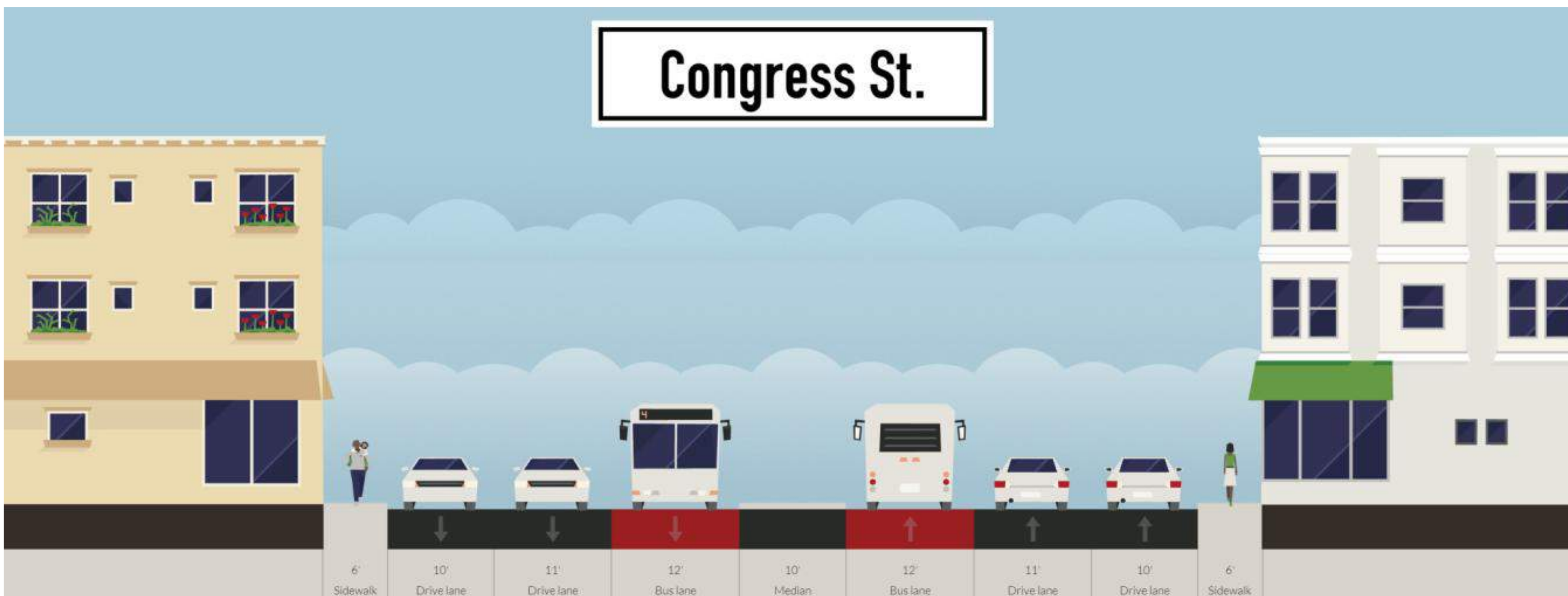
Connection to North Station: Options

- Option A is a connection to Haymarket only.
- Option B is a one-way loop via Cambridge Street.
- Option C is a one-way loop via Merrimac and Congress Streets.

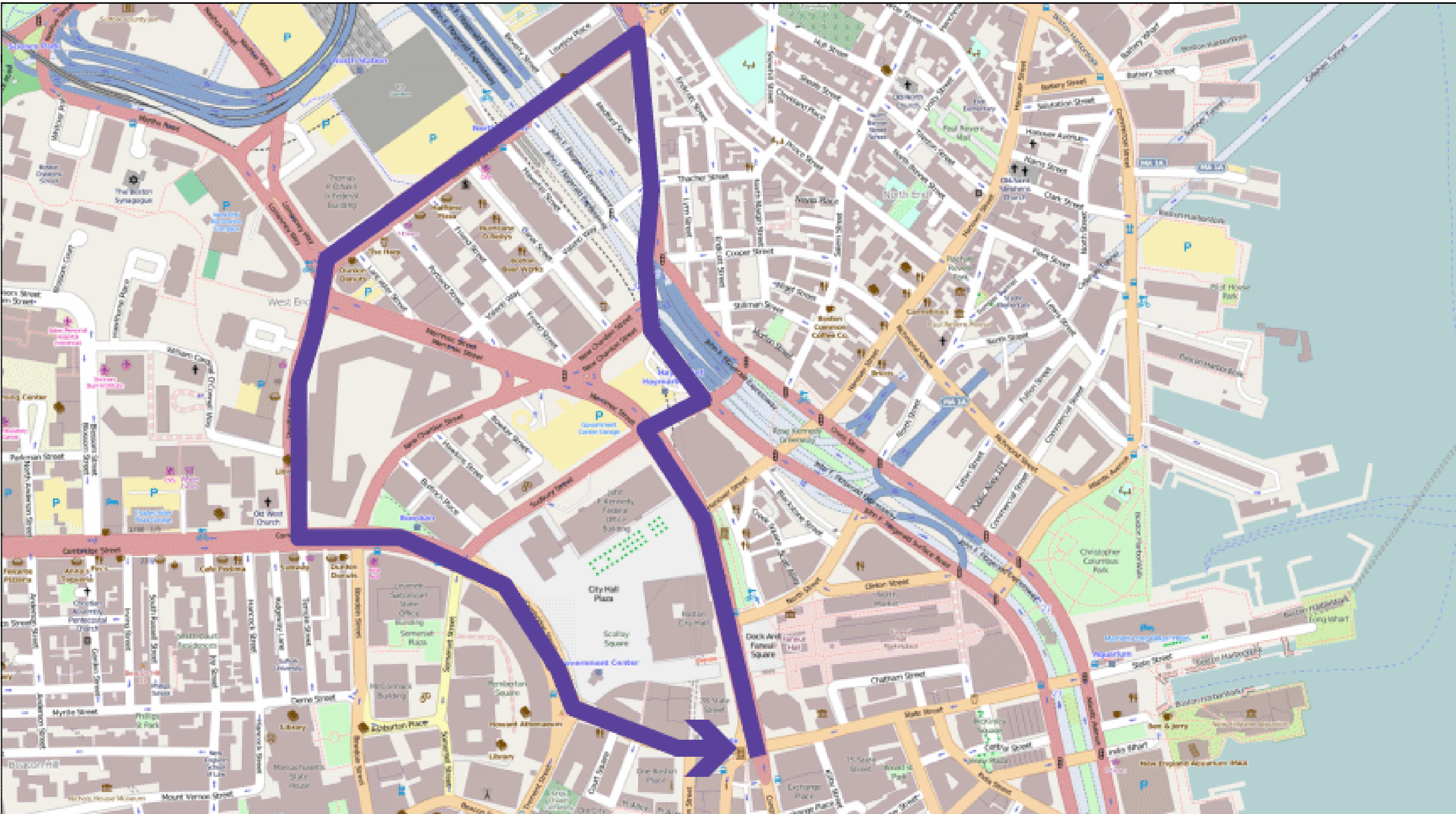
Option A: Haymarket Terminus

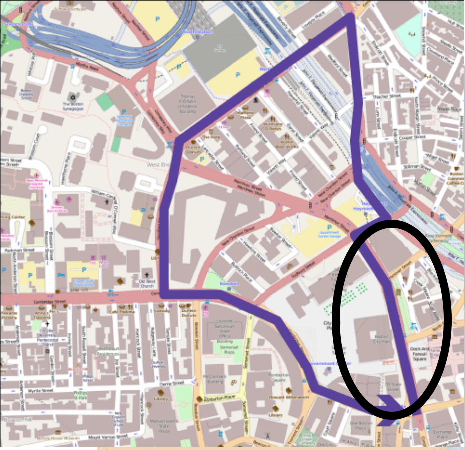


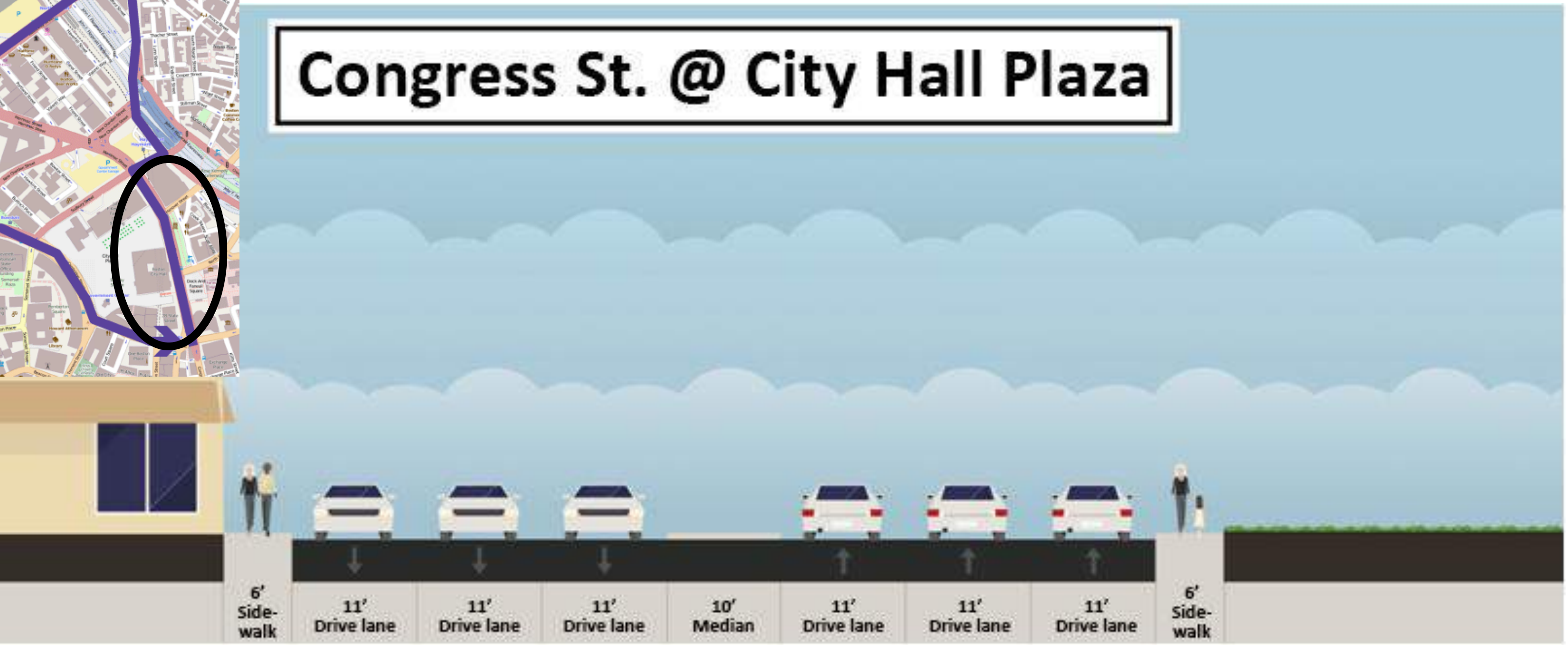

Congress St. @ City Hall Plaza
6' Side-walk
11' Drive lane
11' Drive lane
11' Drive lane
10' Median
11' Drive lane
11' Drive lane
11' Drive lane
6' Side-walk

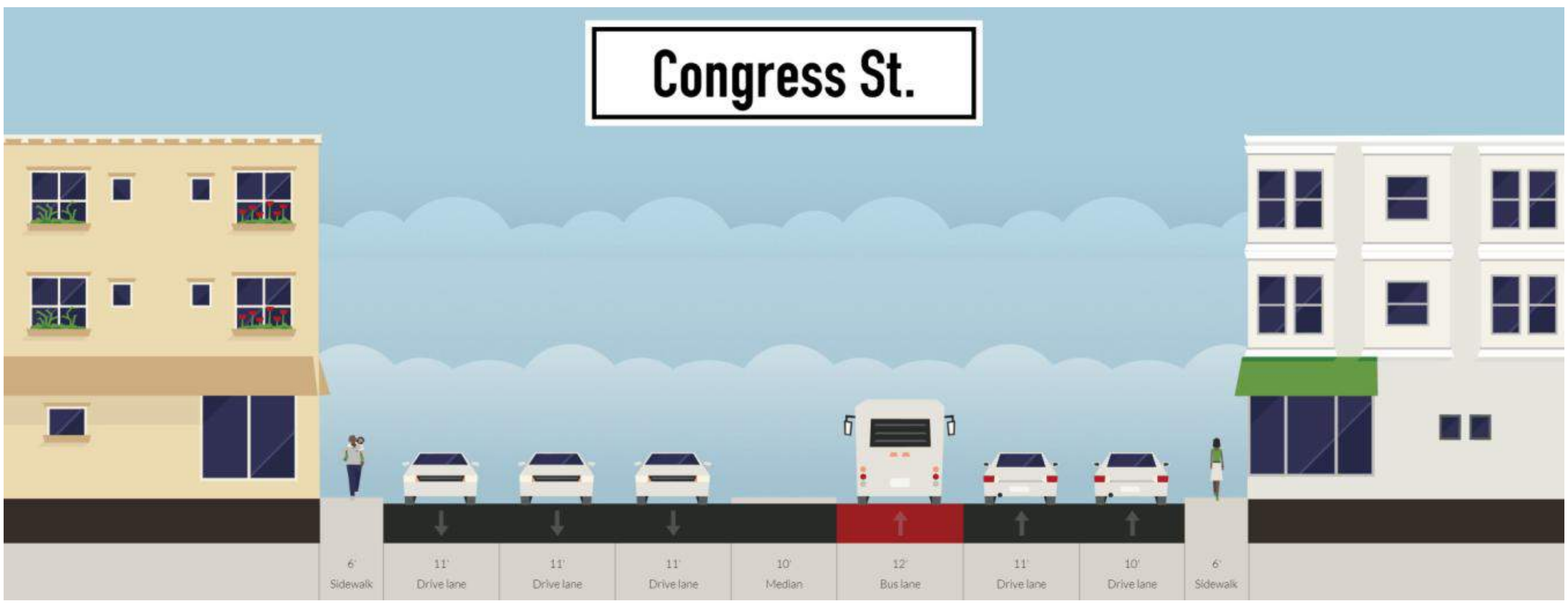

Congress St.
6' Sidewalk
10' Drive lane
11' Drive lane
12' Bus lane
10' Median
12' Bus lane
11' Drive lane
10' Drive lane
6' Sidewalk

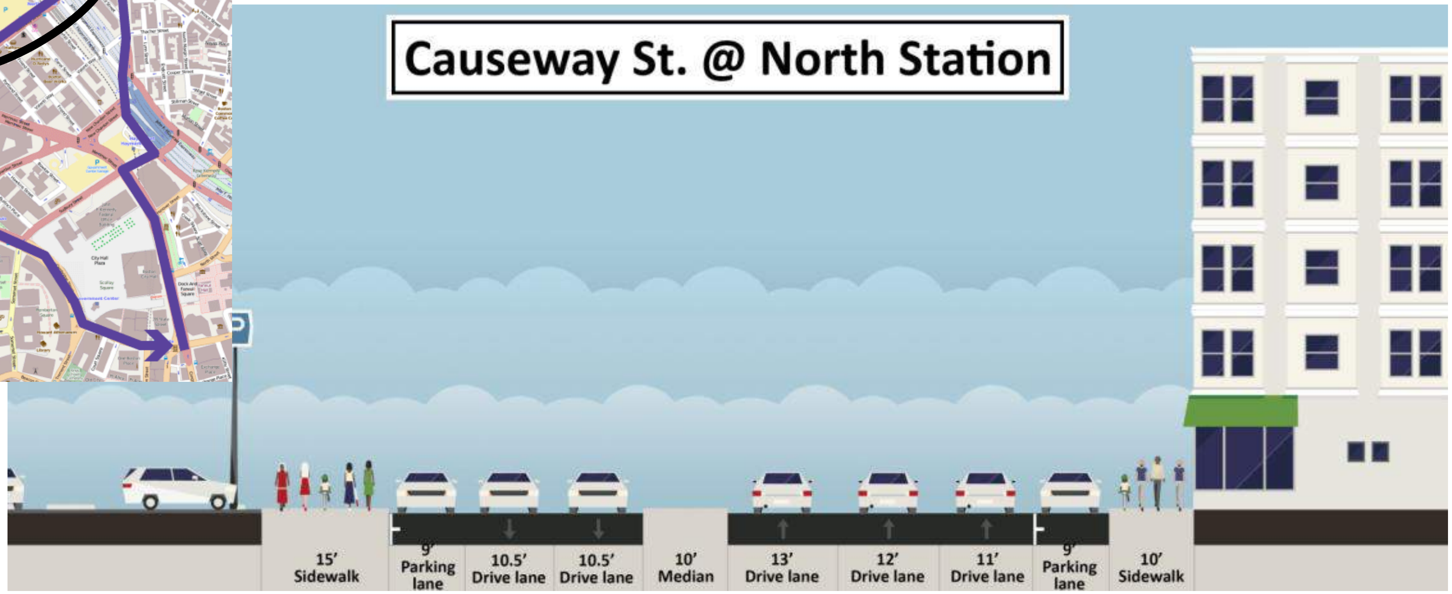
Option B: One way loop via Cambridge Street

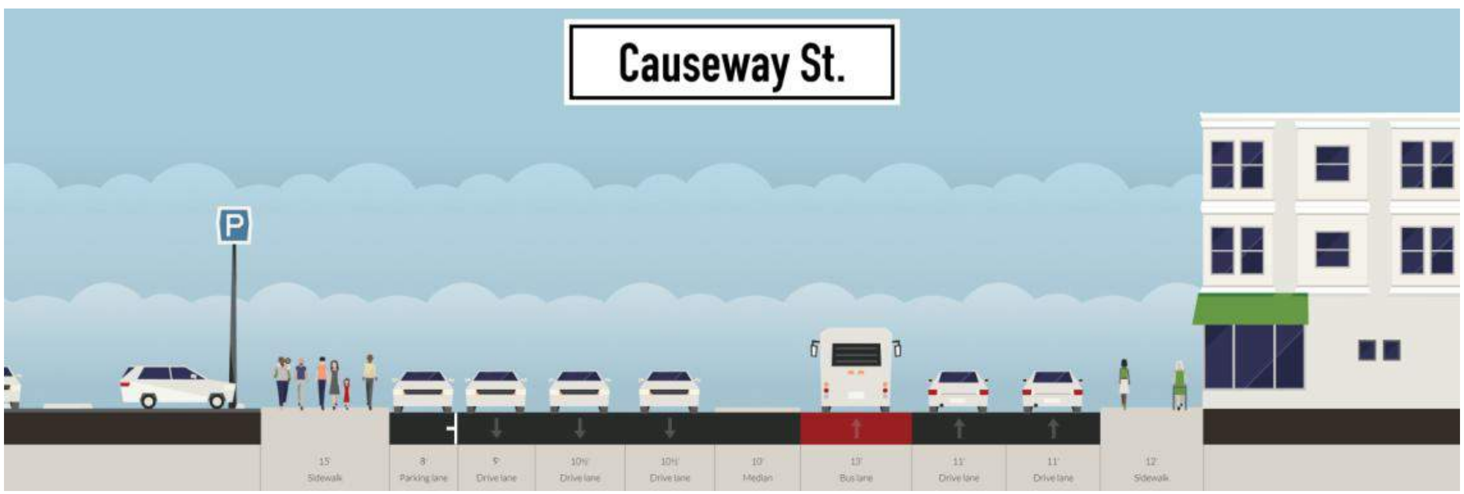


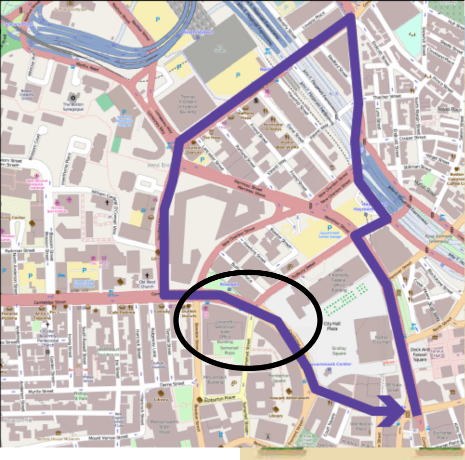


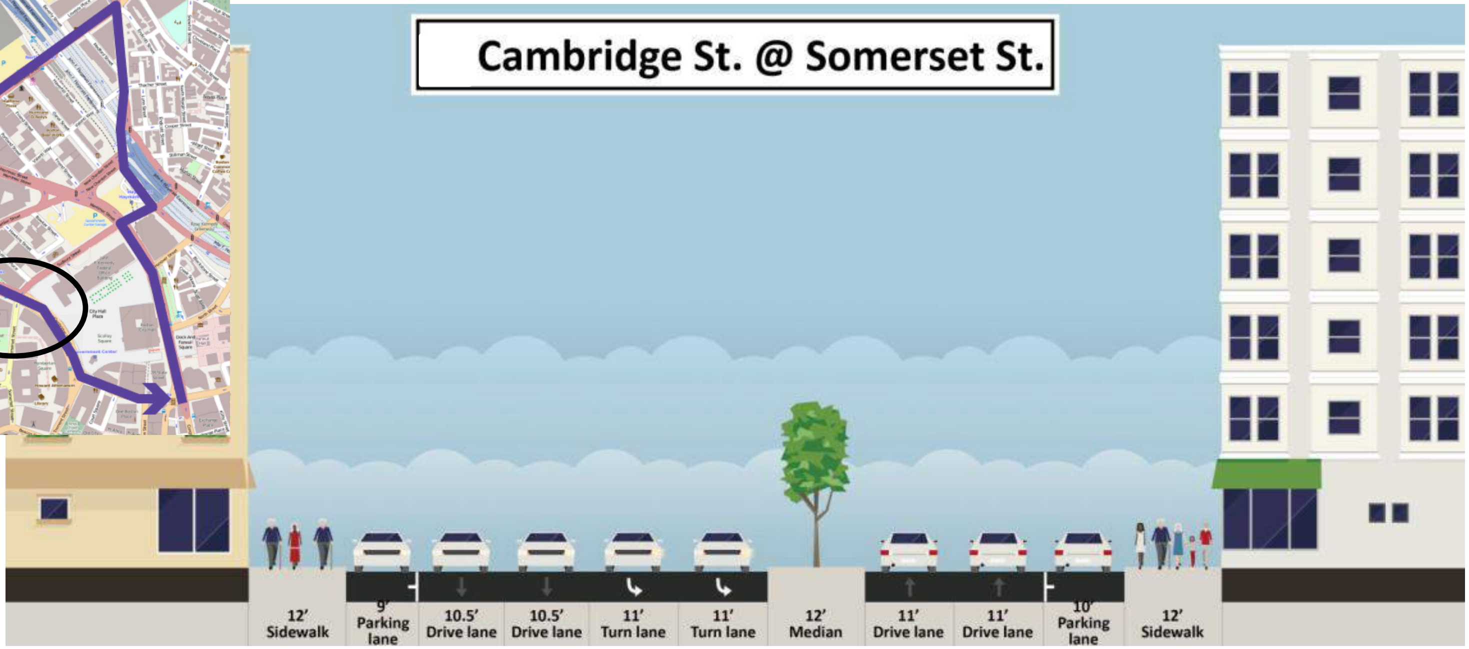

Congress St. @ City Hall Plaza
6' Side-walk
11' Drive lane
11' Drive lane
11' Drive lane
10' Median
11' Drive lane
11' Drive lane
11' Drive lane
6' Side-walk

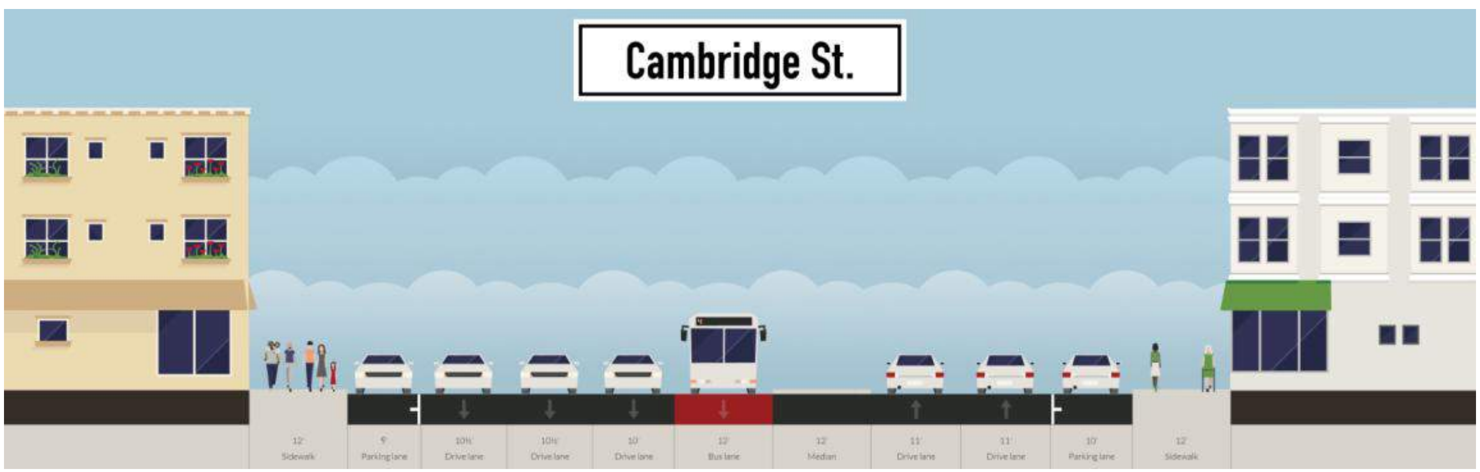

Congress St.
6' Sidewalk
11' Drive lane
11' Drive lane
11' Drive lane
10' Median
12' Bus lane
11' Drive lane
10' Drive lane
6' Sidewalk


Causeway St. @ North Station
P
15’ Sidewalk
9’ Parking lane
10.5’ Drive lane
10.5’ Drive lane
10’ Median
13’ Drive lane
12’ Drive lane
11’ Drive lane
9’ Parking lane
10’ Sidewalk

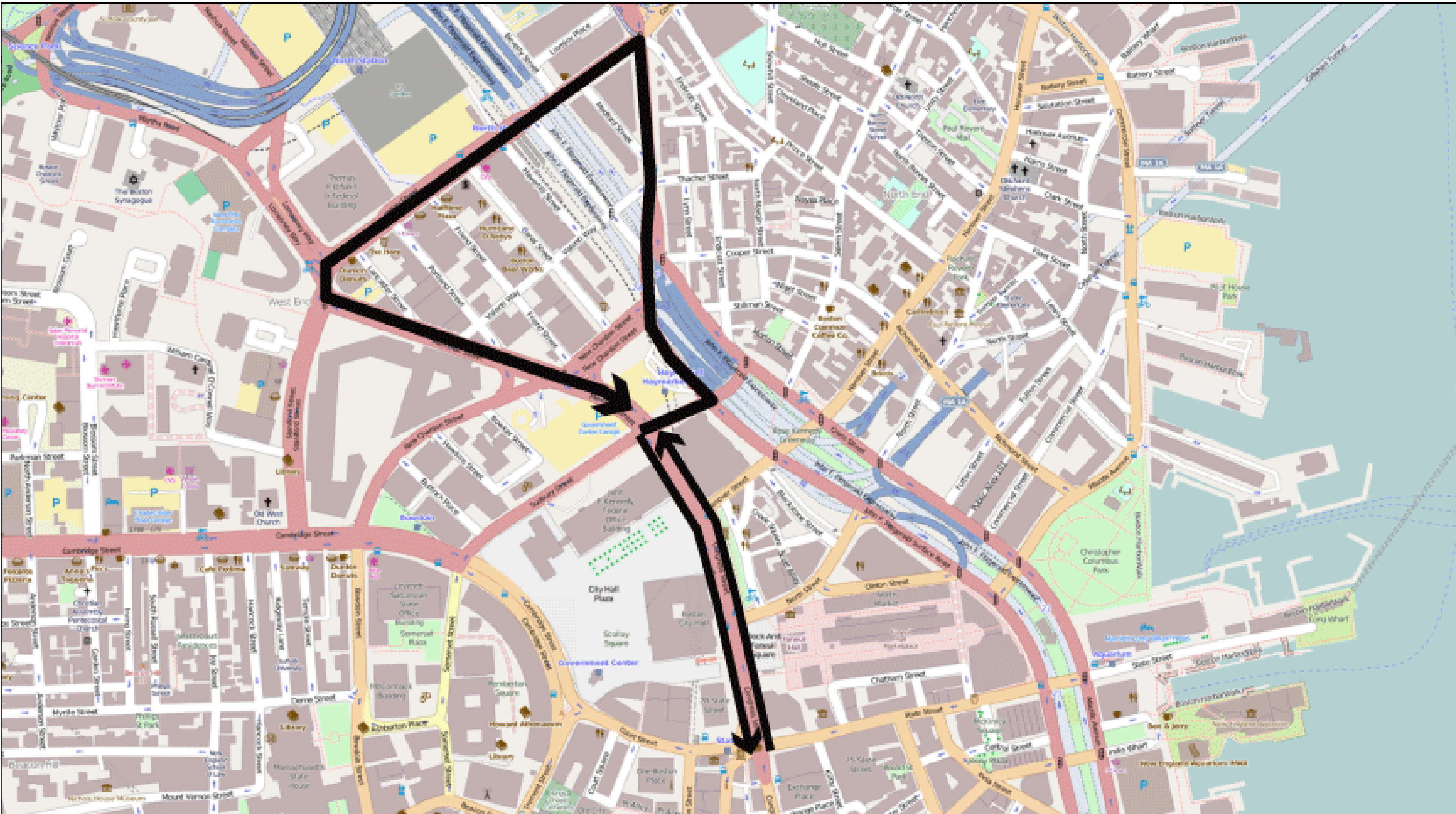

Causeway St.
P
15' Sidewalk
8' Parking lane
9' Drive lane
10½' Drive lane
10½' Drive lane
10' Median
13' Bus lane
11' Drive lane
11' Drive lane
12' Sidewalk

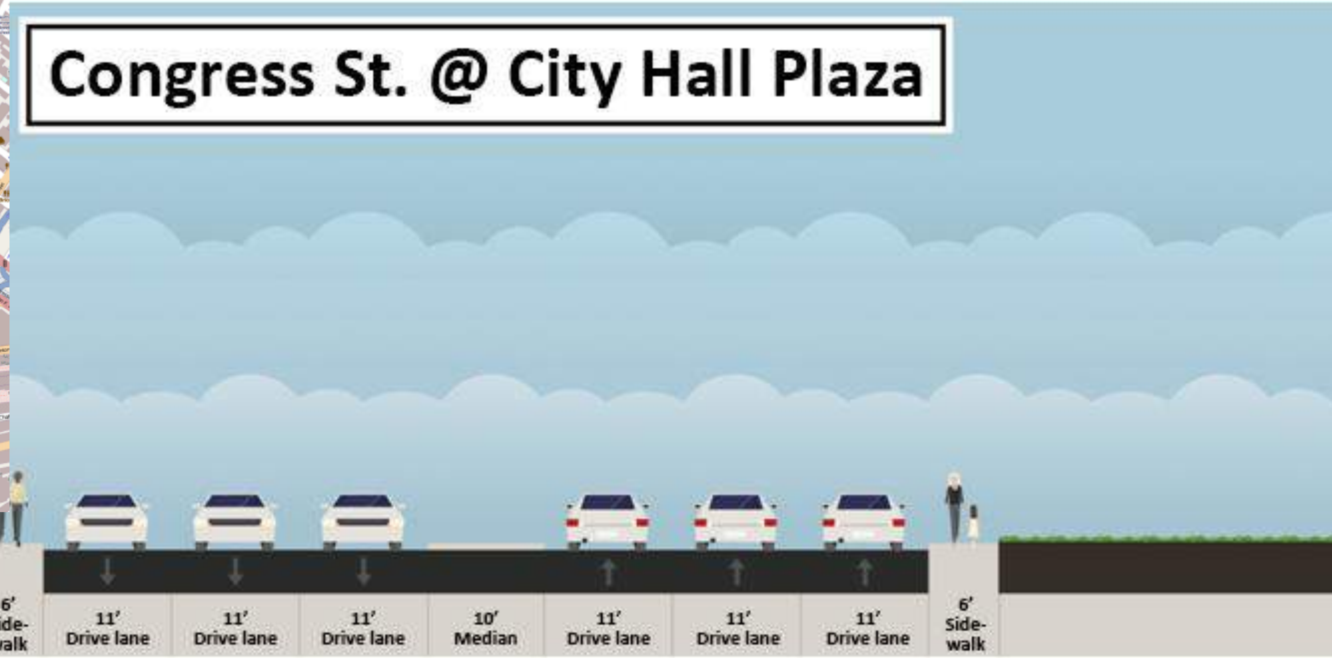


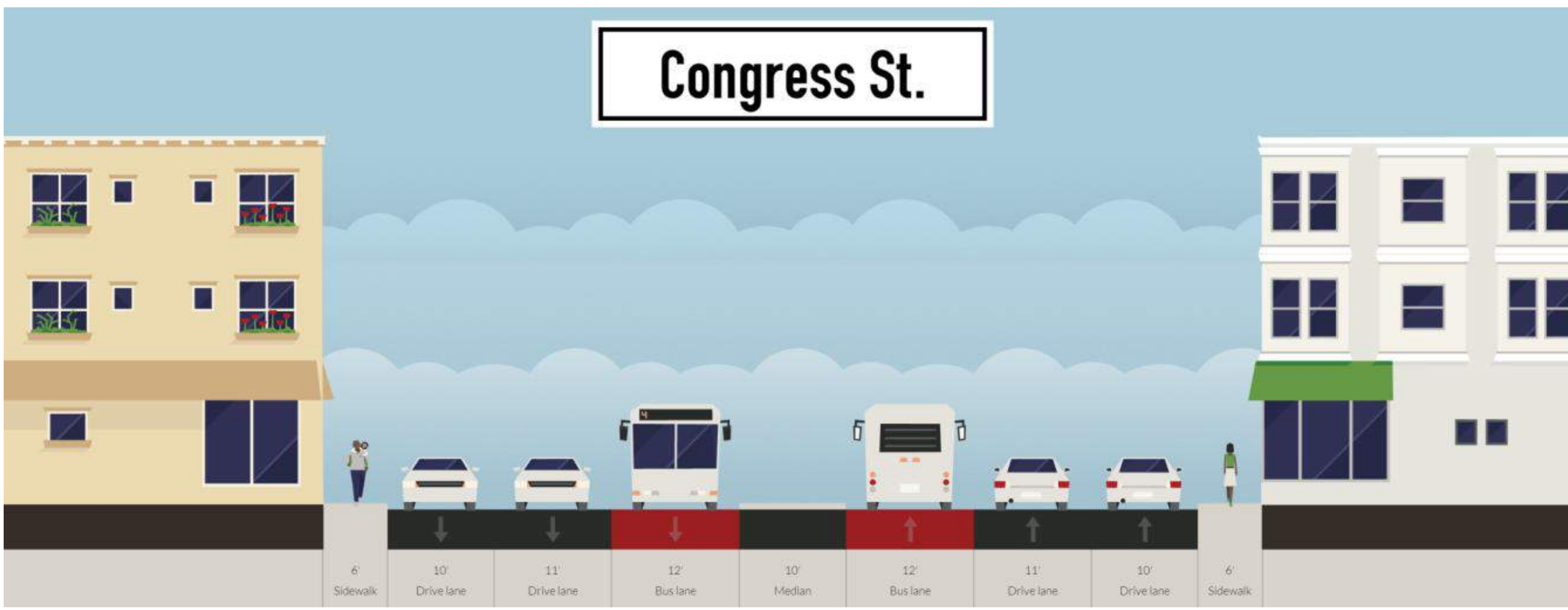

Cambridge St. @ Somerset St.
12' Sidewalk
9' Parking lane
10.5' Drive lane
10.5' Drive lane
11' Turn lane
11' Turn lane
12' Median
11' Drive lane
11' Drive lane
10' Parking lane
12' Sidewalk


Cambridge St.
12' Sidewalk
9' Parking lane
10½' Drive lane
10½' Drive lane
10' Drive lane
12' Bus lane
12' Median
11' Drive lane
11' Drive lane
10' Parking lane
12' Sidewalk

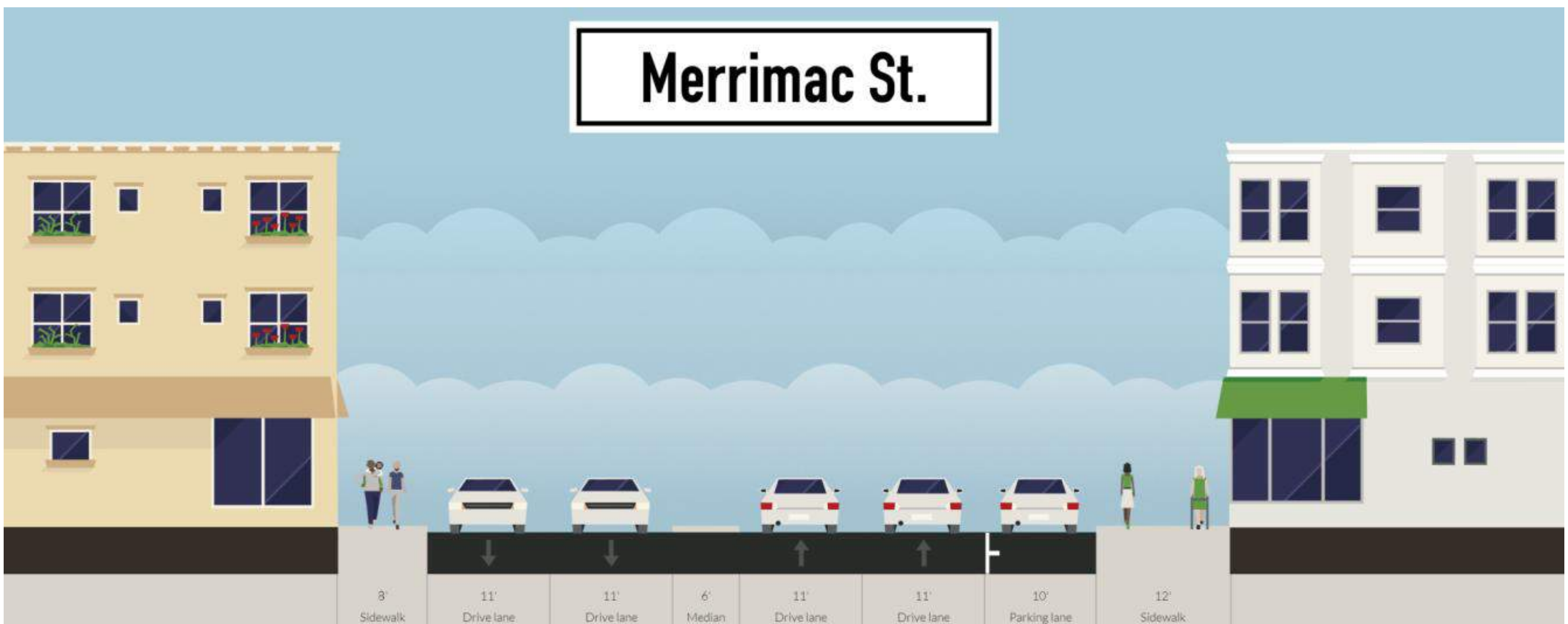
Option C: One way loop via Merrimac and Congress Streets



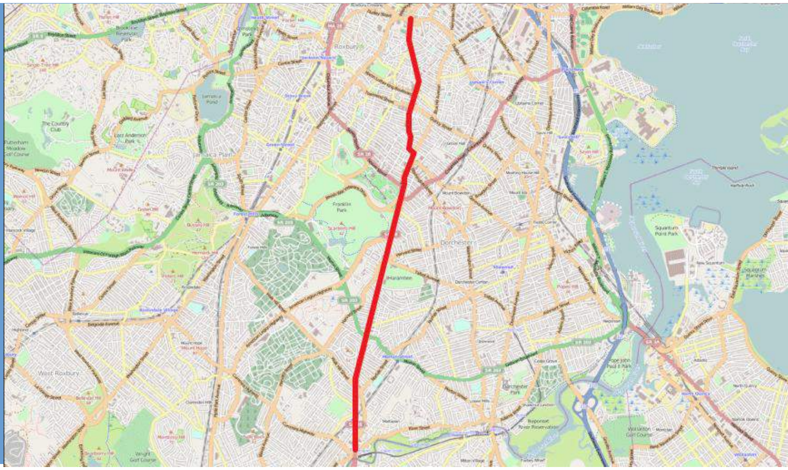

Congress St. @ City Hall Plaza
6' Side-walk
11' Drive lane
11' Drive lane
11' Drive lane
10' Median
11' Drive lane
11' Drive lane
11' Drive lane
6' Side-walk


Congress St.
6' Sidewalk
10' Drive lane
11' Drive lane
12' Bus lane
10' Median
12' Bus lane
11' Drive lane
10' Drive lane
6' Sidewalk


Merrimac St.
8' Sidewalk
11' Drive lane
11' Drive lane
6' Median
11' Drive lane
11' Drive lane
10' Parking lane
12' Sidewalk

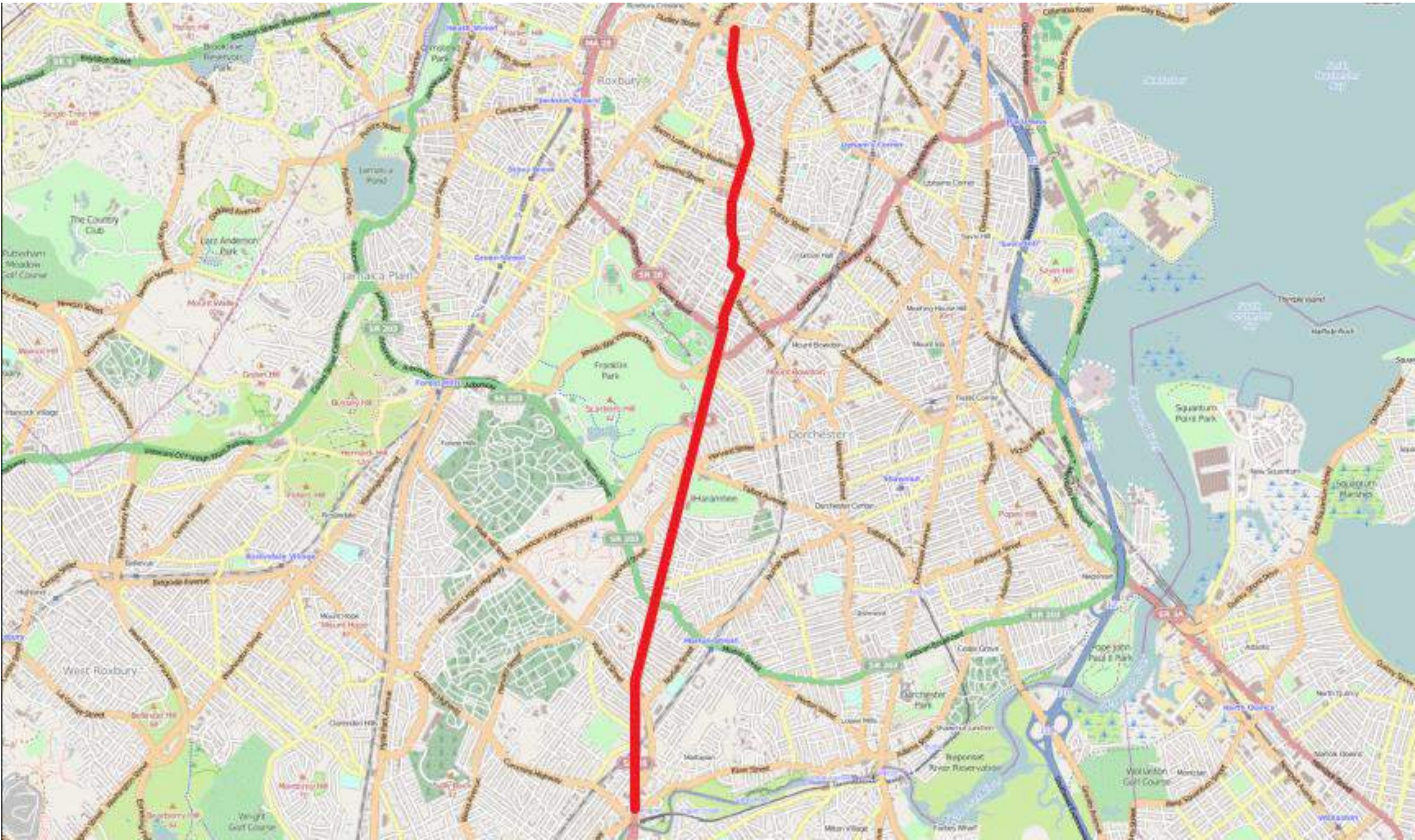

Merrimac St.
8' Sidewalk
11' Drive lane
11' Drive lane
6' Median
11' Drive lane
11' Drive lane
10' Parking lane
12' Sidewalk

Dudley to Mattapan

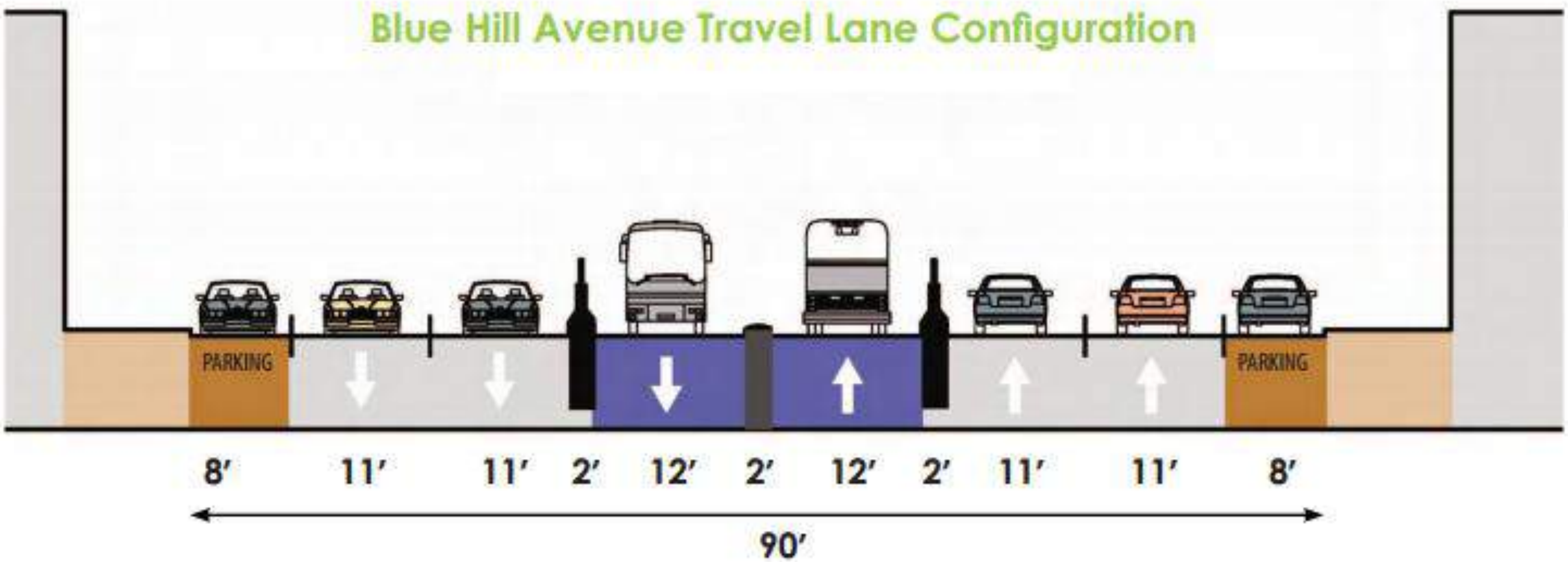


ITDP

Dudley to Mattapan:
General Routing



This is similar to the previous Blue Hill Ave BRT Configuration




Warren St
12'
Sidewalk
9'
Parking lane
11'
Sharrow
11'
Sharrow
9'
Parking lane
8'
Sidewalk


Blue Hill Avenue
12'
Sidewalk
9'
Parking lane
11½'
Drive lane
11½'
Drive lane
9'
Parking lane
12'
Sidewalk

Alternatives to the narrow section of Warren St. are hard to find.

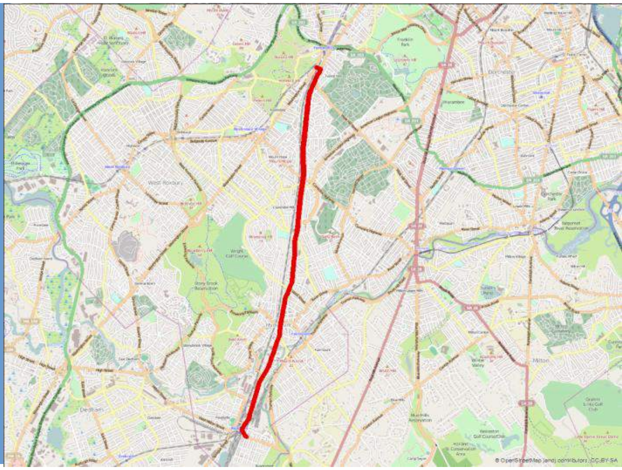
Turning to Blue Hill before they merge is an option.

But, the roadway is still narrow and existing demand is currently on Warren St.

Blue Hill Avenue to Mattapan

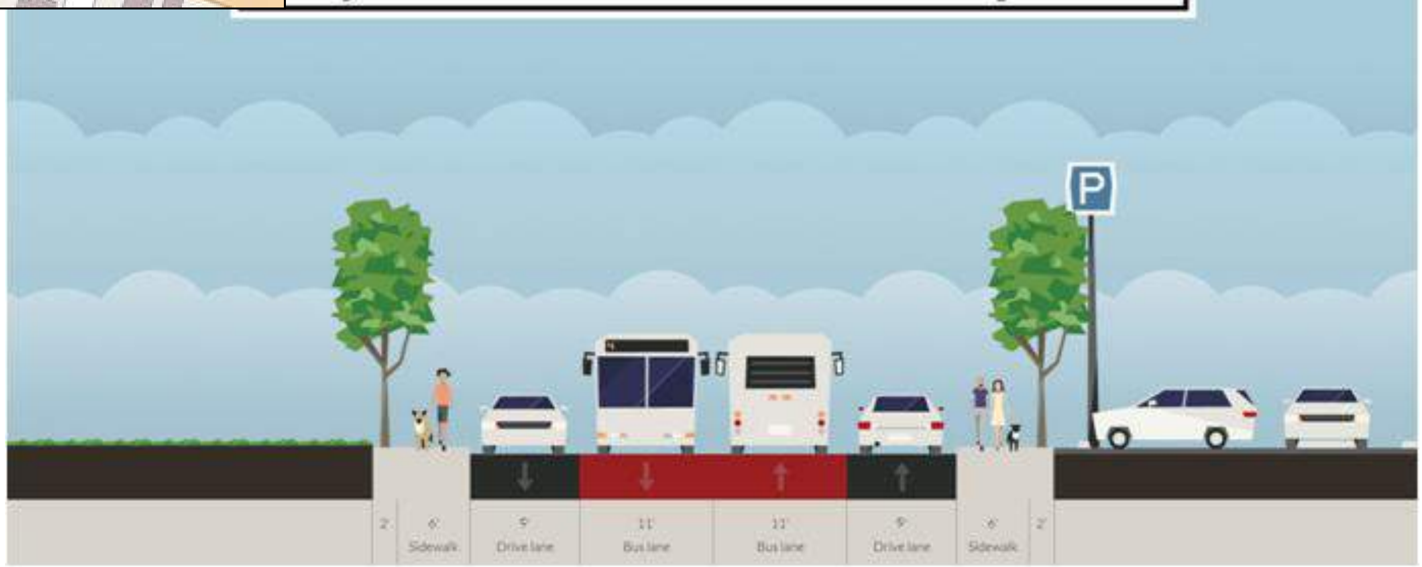
- After it merges with Warren St., it has ample space for Gold Standard BRT
- Existing demand is already high on Blue Hill Avenue
- It has overwhelming advantage over any possible alternatives.

Readville to Forest Hills



Hyde Park Ave@Wolcott Square

Hyde Park Ave @ Wolcott Square



Two Options for when road narrows

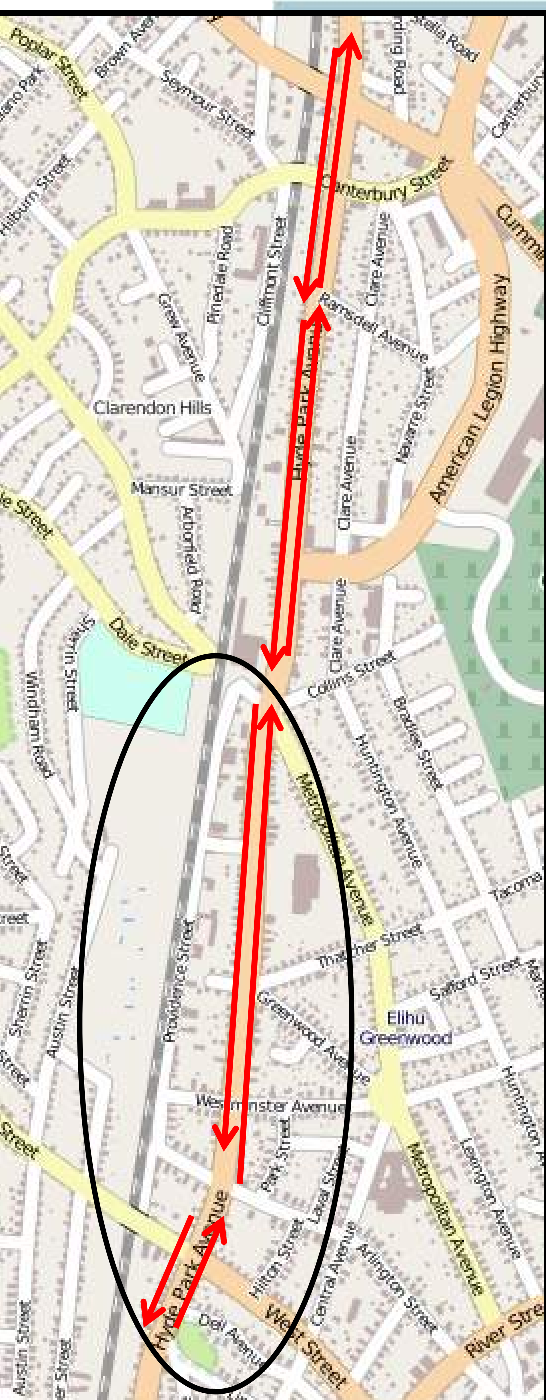
Option A: Two way BRT, one way private vehicles

Option B: One way pairs

Hyde Park
Boston Preparatory Charter School
Perkins Avenue
Avila Road
River Street
Barry Street
Oak Place
Business Street
Adams Street
Reservation Road
Factory Street
Hyde Park Avenue
Dana Avenue
Margin Street
Fulton Street
A Street
B Street
Neponset River
Mother Brook
Wilton Street
Neponset River Reservation
Winter Street
Mason Street
Glenwood Avenue
Tyler Street

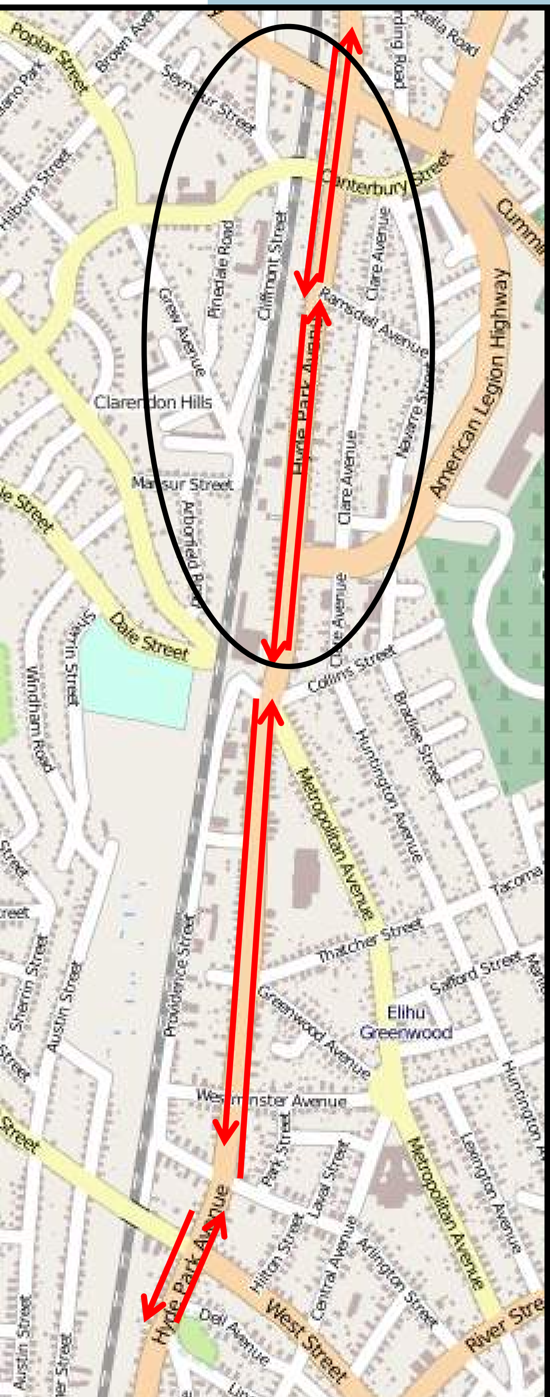
Hyde Park Ave @Pingree St

Hyde Park Ave @ Pingree St
6' Sidewalk
2'
2'
8' Parking lane
9' Drive lane
11' Bus lane
11' Bus lane
9' Drive lane
8' Parking lane
2'
2'
6' Sidewalk


Poplar Street
Seymour Street
Canterbury Street
Clarendon Hills
Mansur Street
Hyde Park Avenue
Ramsdell Avenue
American Legion Highway
Clare Avenue
Collins Street
Dale Street
Metropolitan Avenue
Huntington Avenue
Thatcher Street
Providence Street
Greenwood Avenue
Elihu Greenwood
Westminster Avenue
Park Street
Hilton Street
Central Avenue
Arlington Street
Dell Avenue
West Street
River Street


Hyde Park Ave @ West St
6' Sidewalk
2'
2'
11' Parking lane
14' Drive lane
14' Drive lane
11' Parking lane
2'
2'
6' Sidewalk


Hyde Park Ave @ West St
6' Sidewalk
2'
2'
8' Parking lane
9' Drive lane
12' Bus lane
12' Bus lane
9' Drive lane
2'
2'
6' Sidewalk



Hyde Park Ave @ Canterbury St

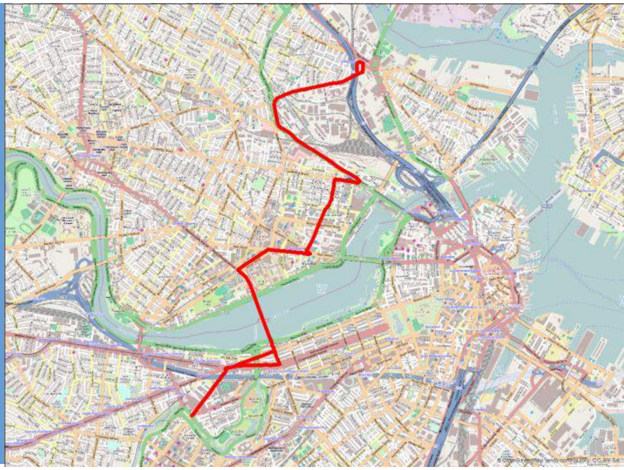
Hyde Park Ave @ Canterbury St


Hyde Park Avenue
Wenham Street
Varney Street

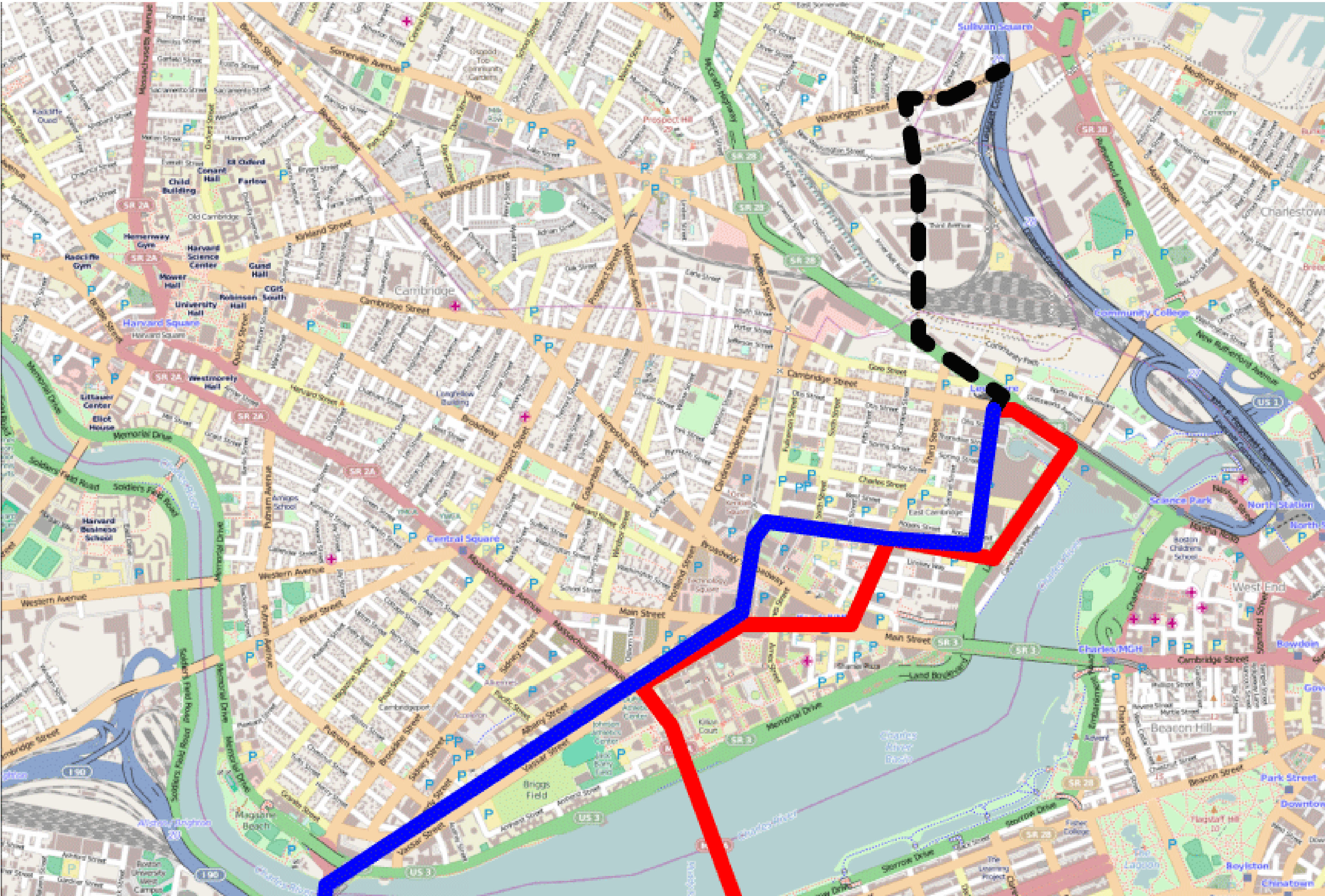

Hyde Park Ave @ Ukraine Way
2'
6' Sidewalk
2'
8' Parking lane
9½' Drive lane
10' Drive lane
10' Drive lane
9½' Drive lane
8' Parking lane
2'
6' Sidewalk
2'


Hyde Park Ave @ Ukraine Way
6' Sidewalk
2'
8' Parking lane
9' Drive lane
11' Bus lane
11' Bus lane
9' Drive lane
8' Parking lane
2'
6' Sidewalk

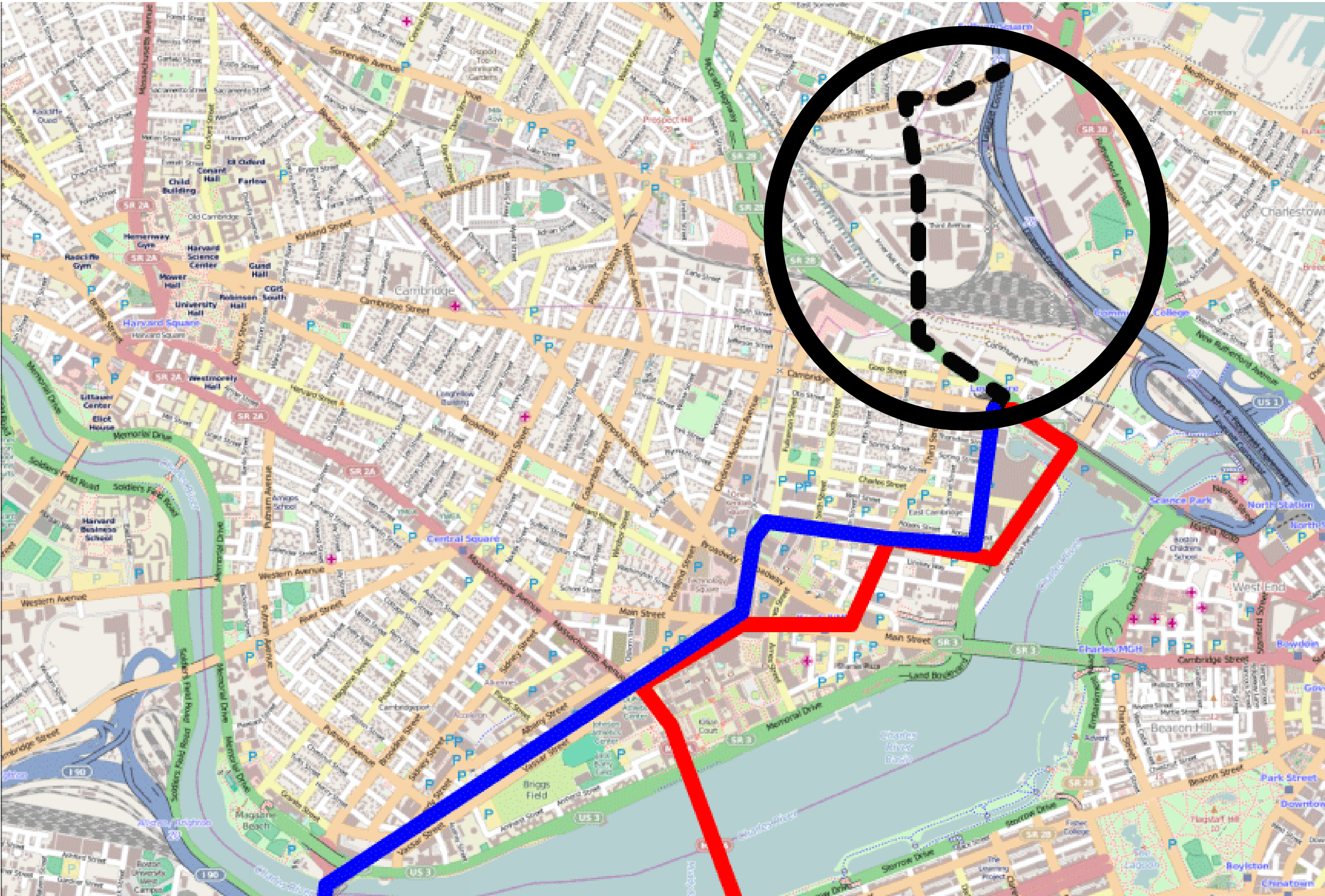
Sullivan to Ruggles



Options for Sullivan to Ruggles



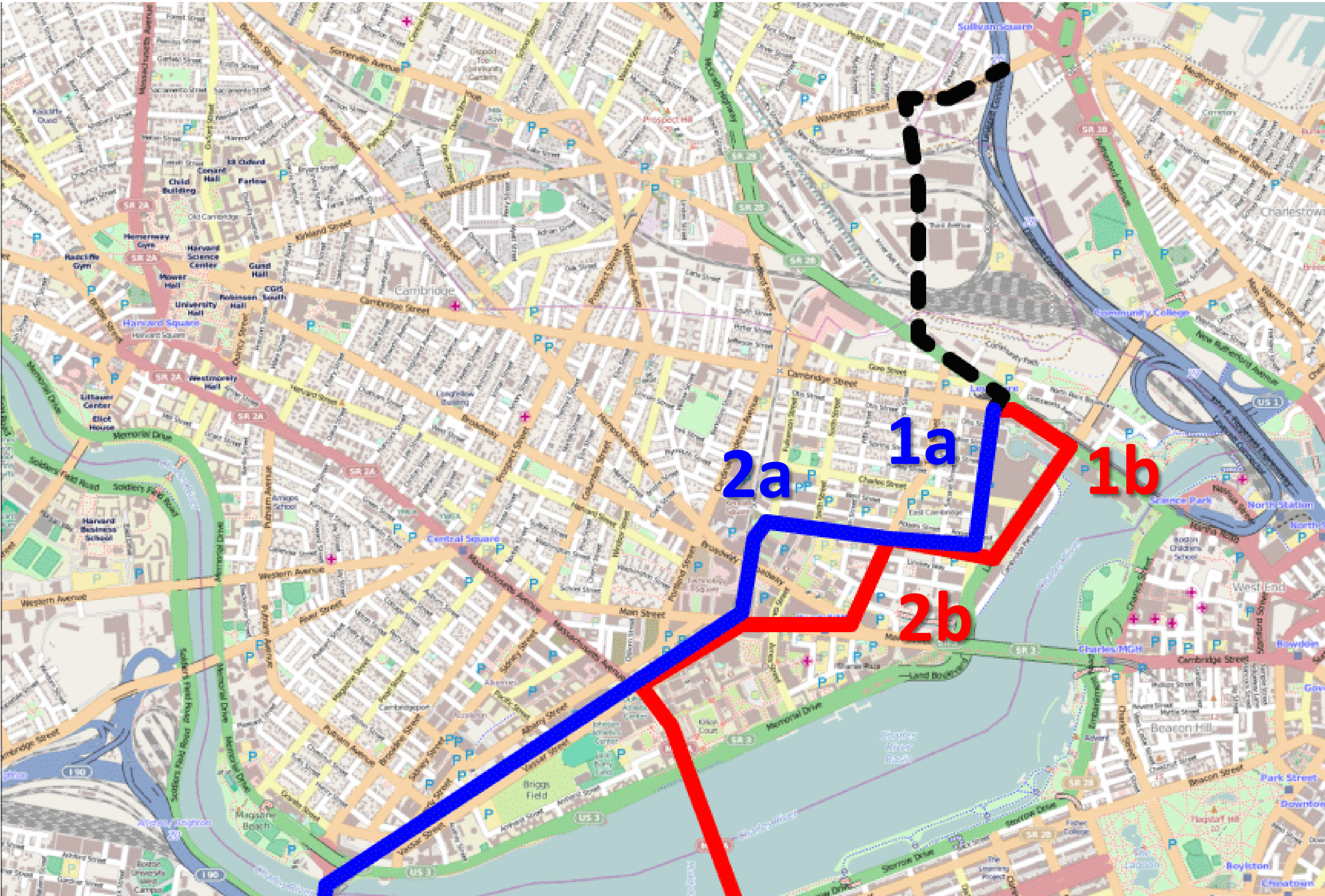
Inner Belt: Costly infrastructure needed

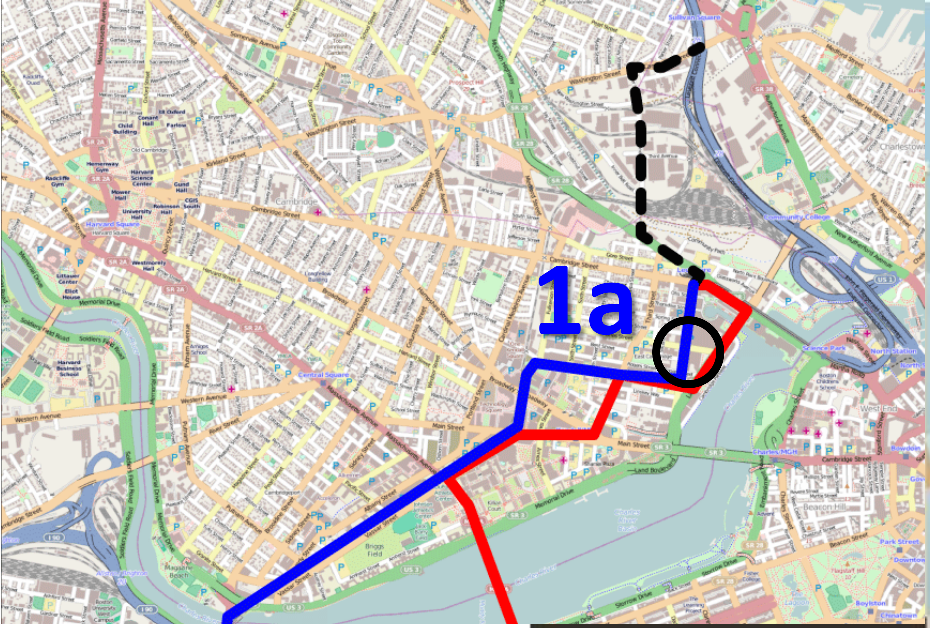


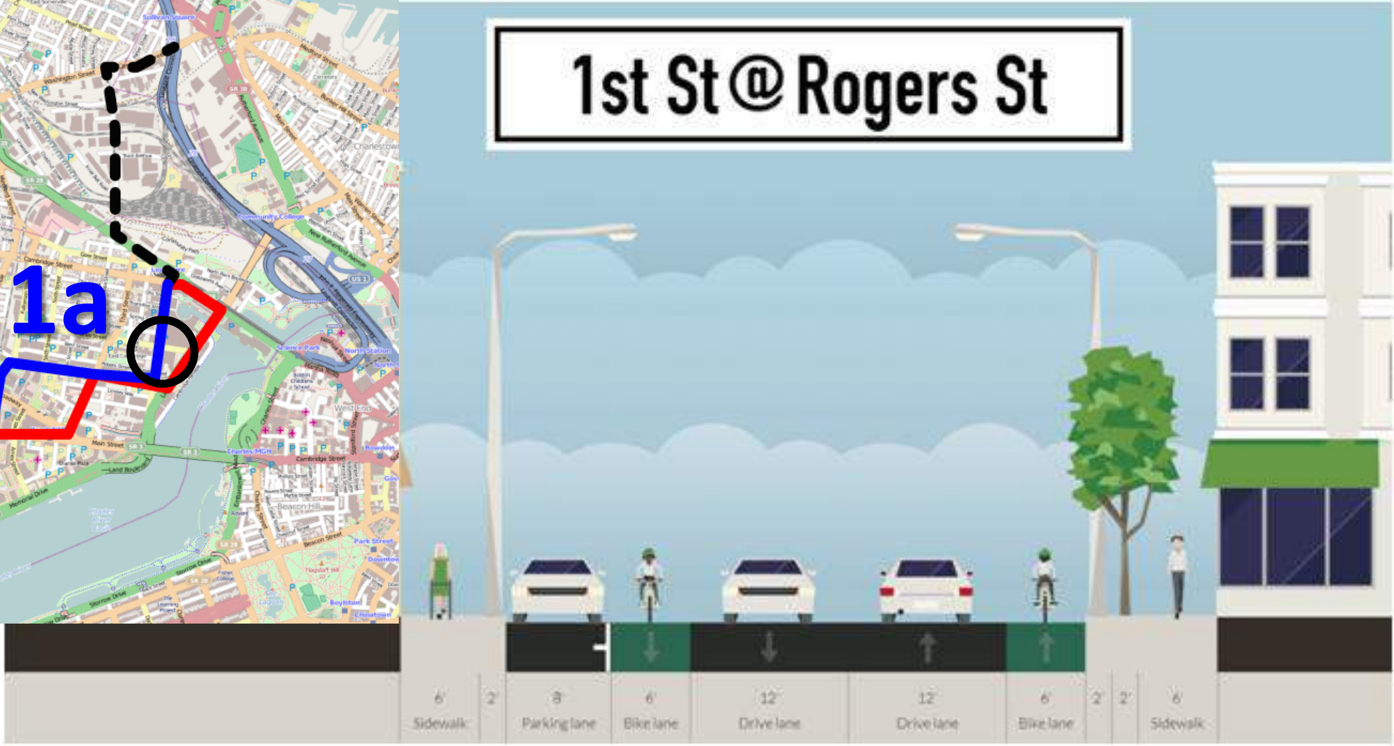
Options for Sullivan to Ruggles

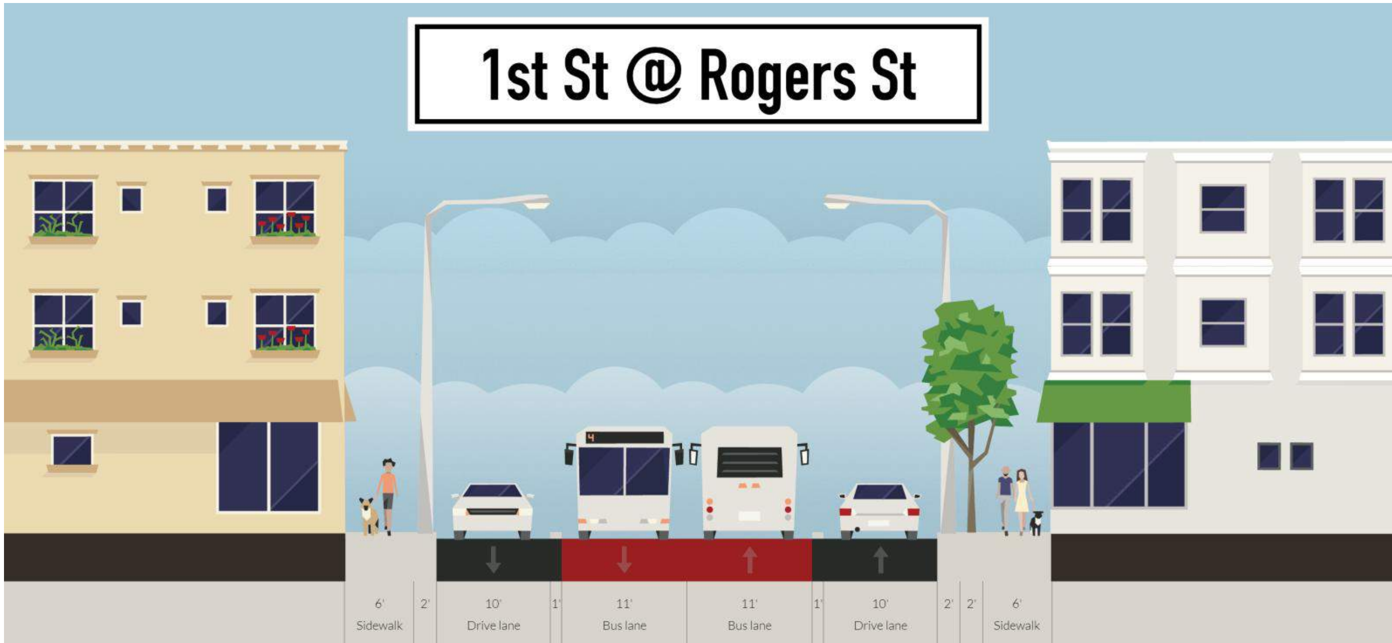
- Option A: Over the BU Bridge
  - Model showed PPHPD of 908
  - BU Bridge has space constraints
  - **Time savings: 31.0 minutes to 21.8 minutes (-20.1%)**
- Option B: Over the Mass Ave Bridge
  - Higher demand: model showed PPHPD of 994
  - Infrastructure on Mass Ave Bridge would also benefit 1 and CT1 routes
  - **Time savings: 31.0 minutes to 27.1 minutes (-12.5%)**

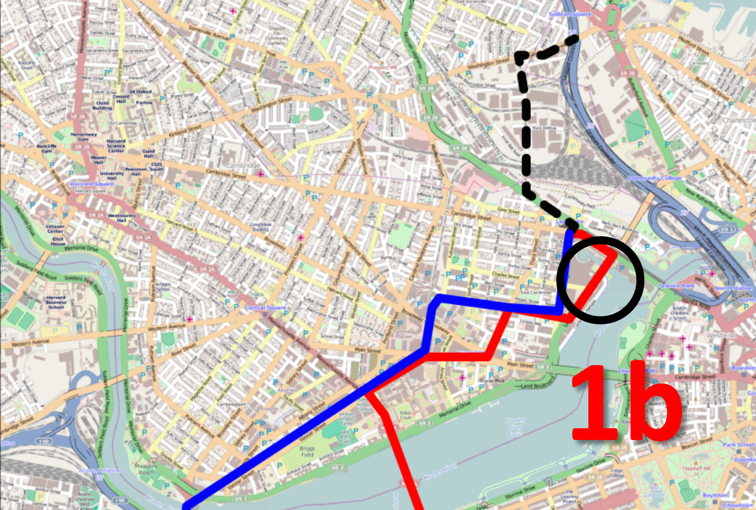
Options through East Cambridge

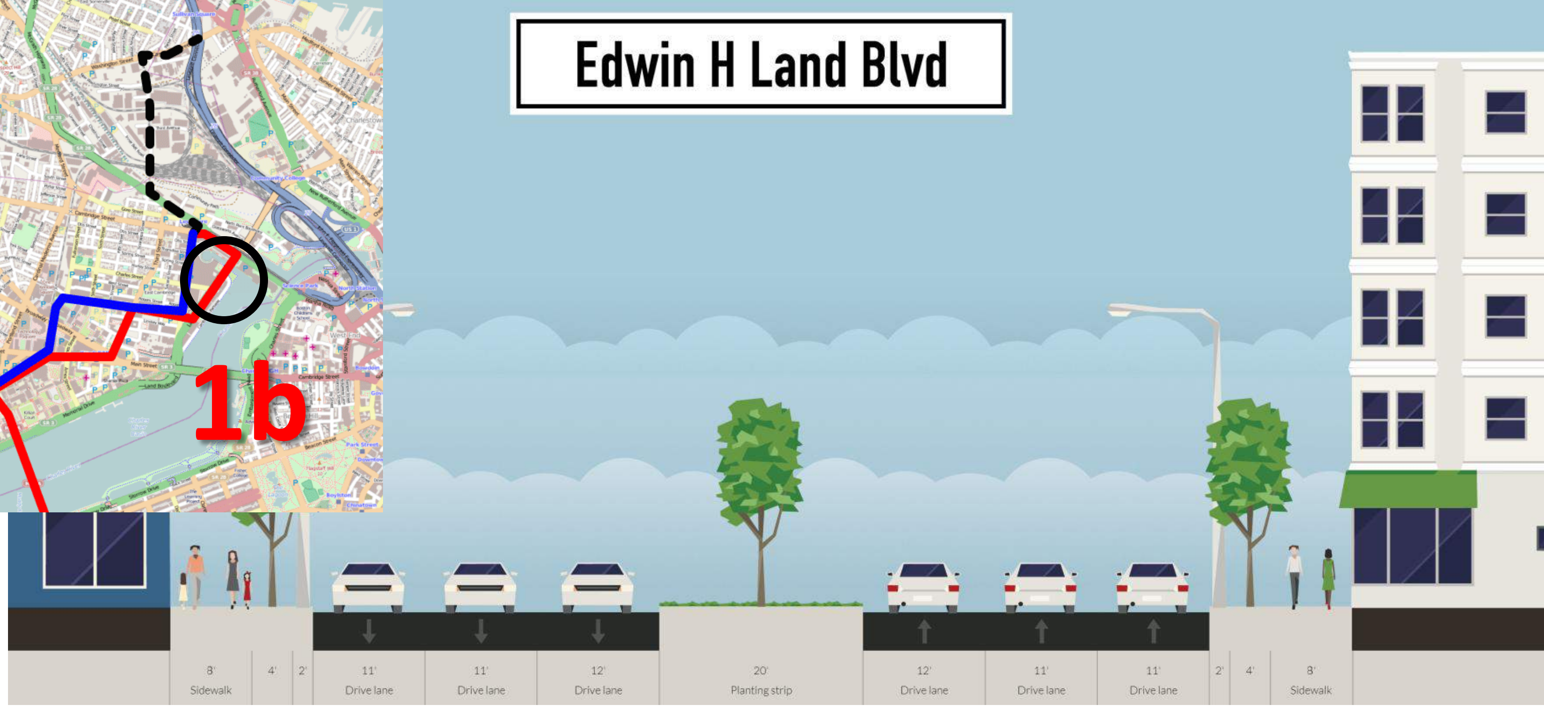


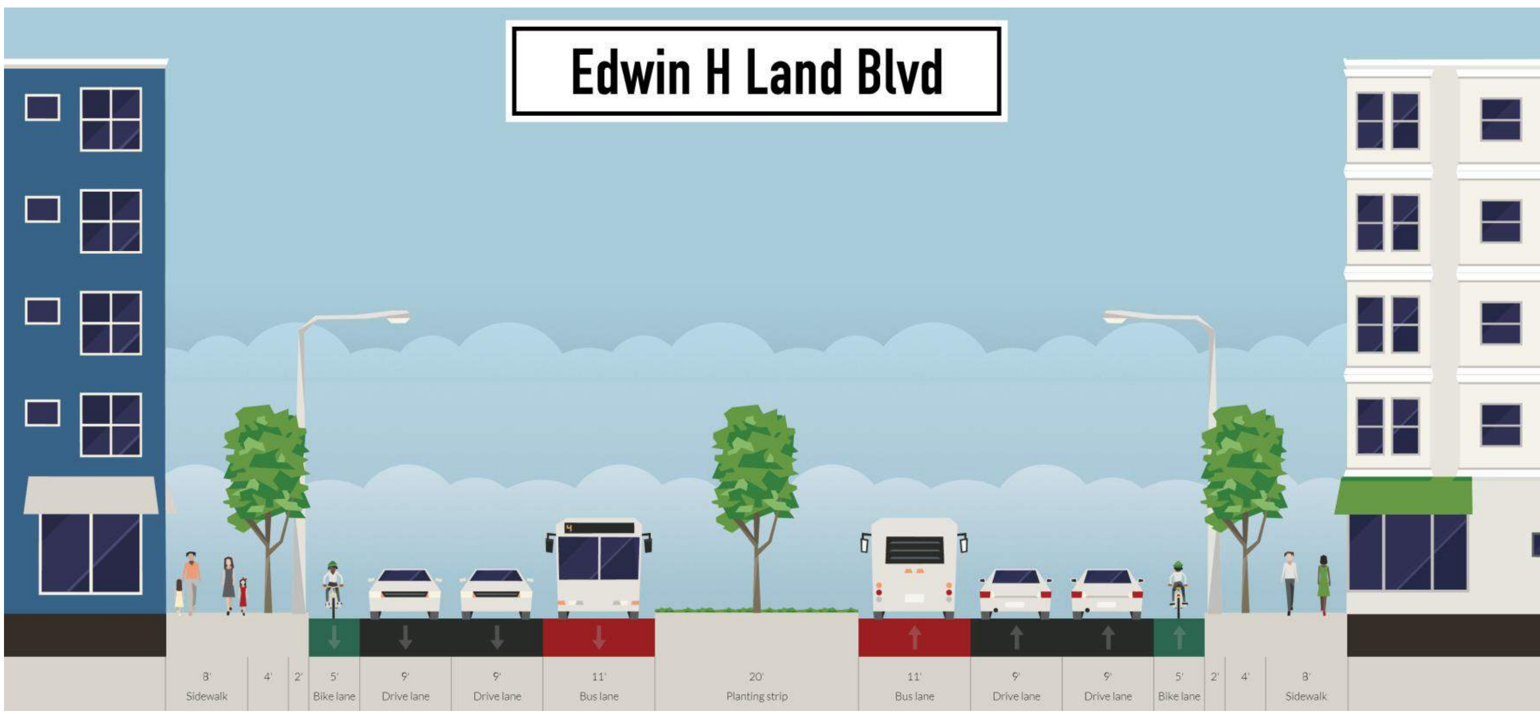

1a


1st St @ Rogers St
6'
Sidewalk
2'
8'
Parking lane
6'
Bike lane
12'
Drive lane
12'
Drive lane
6'
Bike lane
2'
2'
6'
Sidewalk


1st St @ Rogers St
6'
Sidewalk
2'
10'
Drive lane
1'
11'
Bus lane
11'
Bus lane
1'
10'
Drive lane
2'
2'
6'
Sidewalk


1b


Edwin H Land Blvd
8'
Sidewalk
4'
2'
11'
Drive lane
11'
Drive lane
12'
Drive lane
20'
Planting strip
12'
Drive lane
11'
Drive lane
11'
Drive lane
2'
4'
8'
Sidewalk

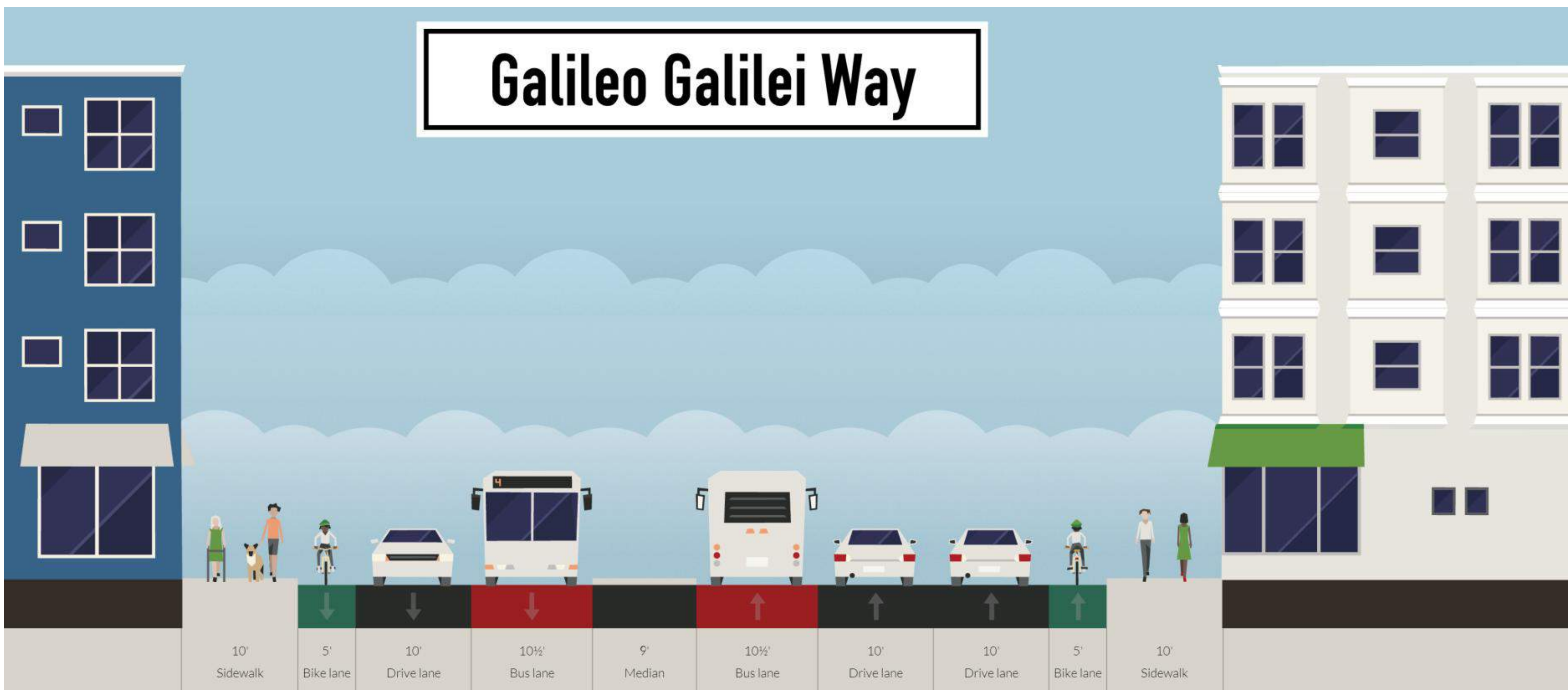

Edwin H Land Blvd
8'
Sidewalk
4'
2'
5'
Bike lane
9'
Drive lane
9'
Drive lane
11'
Bus lane
20'
Planting strip
11'
Bus lane
9'
Drive lane
9'
Drive lane
5'
Bike lane
2'
4'
8'
Sidewalk

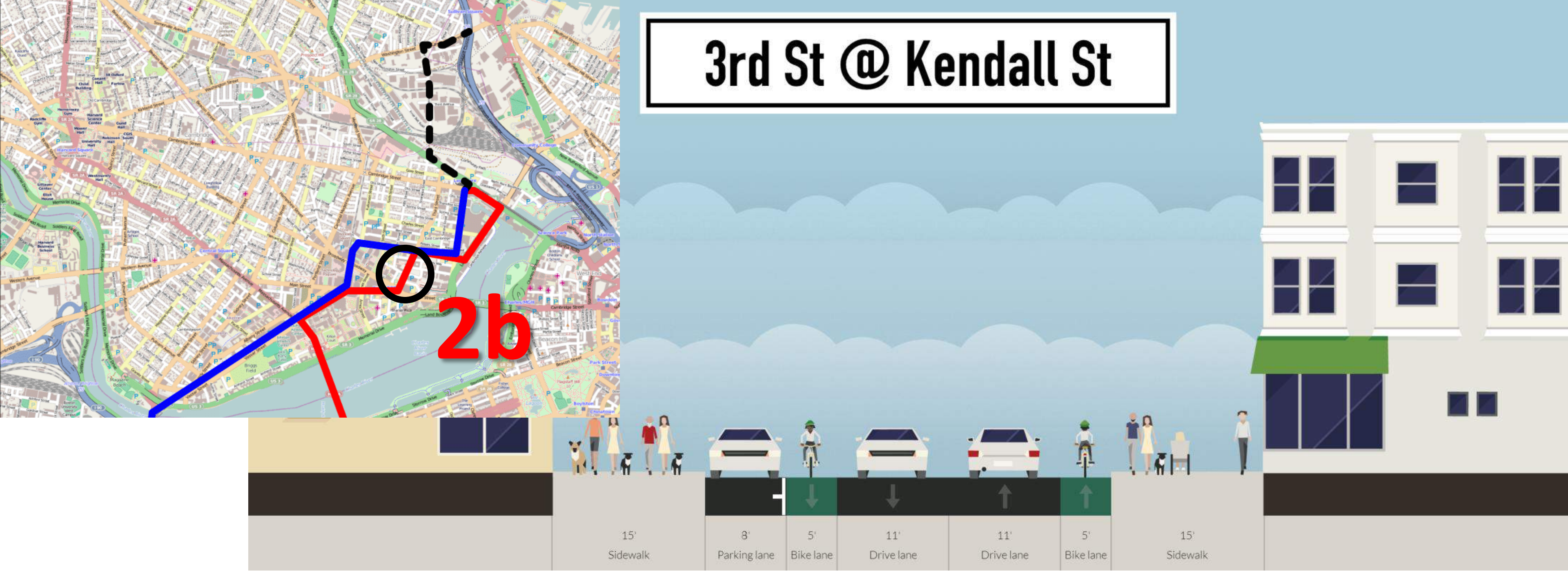
Binney St@3rd St
10' Sidewalk
2'
2'
6' Bike lane
9½' Drive lane
9½' Drive lane
6'
10' Turn lane
10' Drive lane
9' Drive lane
6' Bike lane
2'
2'
10' Sidewalk

Binney St@3rd St
10' Sidewalk
2'
2'
5½' Bike lane
9' Drive lane
11' Bus lane
6'
11' Bus lane
9' Drive lane
9' Drive lane
5½' Bike lane
2'
2'
10' Sidewalk

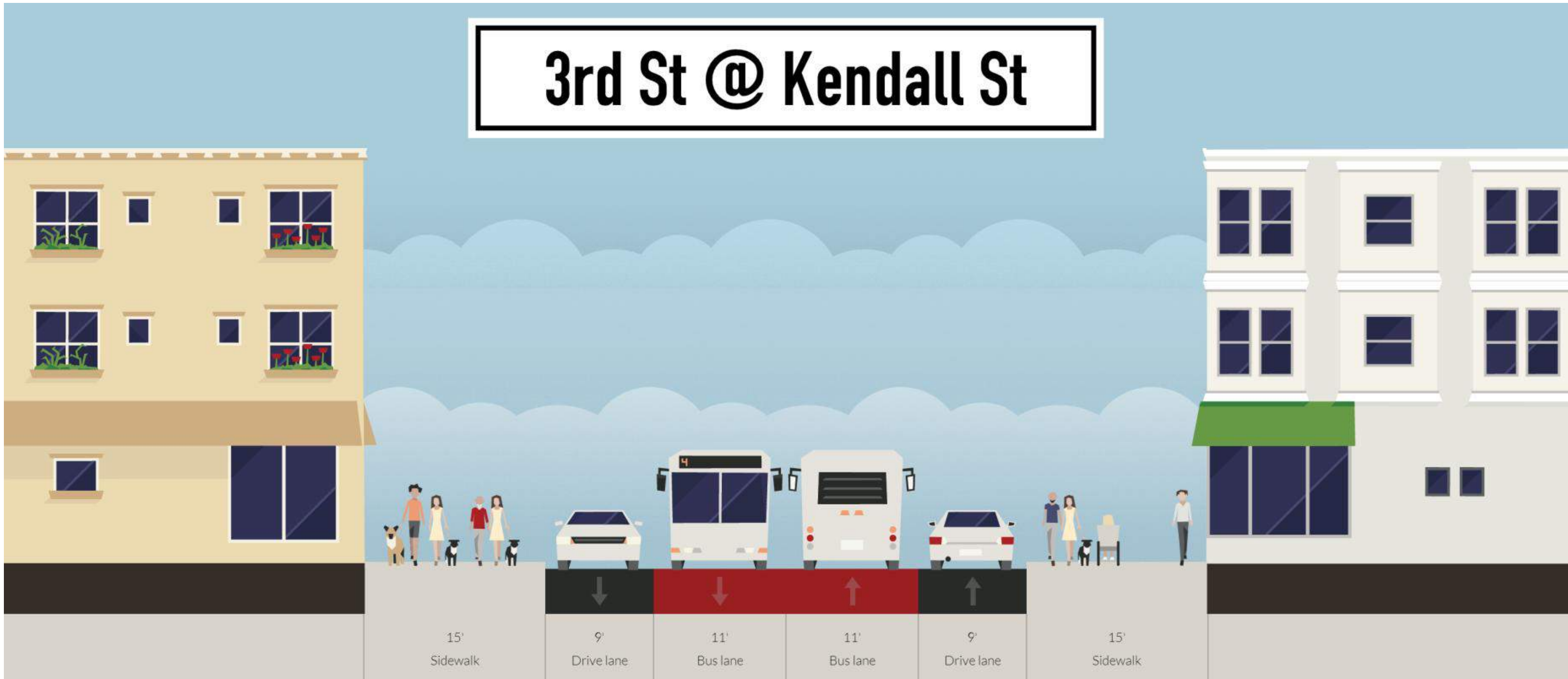

2a


Galileo Galilei Way
10'
Sidewalk
9'
Turn lane
5'
Bike lane
10'
Drive lane
10'
Turn lane
9'
Median
11'
Drive lane
11'
Drive lane
5'
Bike lane
10'
Sidewalk

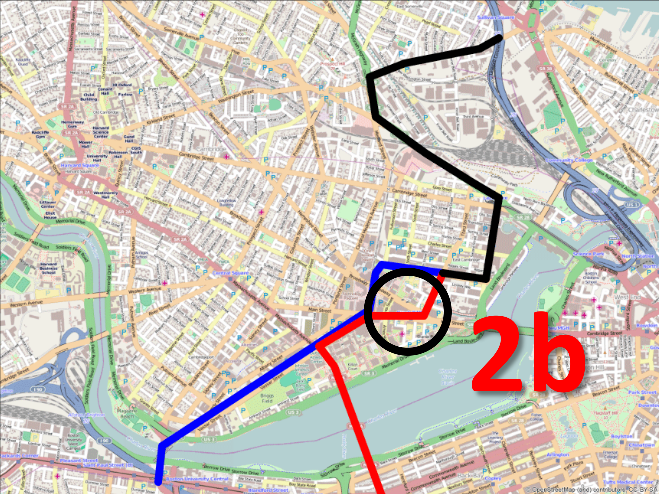

Galileo Galilei Way
10'
Sidewalk
5'
Bike lane
10'
Drive lane
10½'
Bus lane
9'
Median
10½'
Bus lane
10'
Drive lane
10'
Drive lane
5'
Bike lane
10'
Sidewalk



2b
3rd St @ Kendall St
15' Sidewalk
8' Parking lane
5' Bike lane
11' Drive lane
11' Drive lane
5' Bike lane
15' Sidewalk



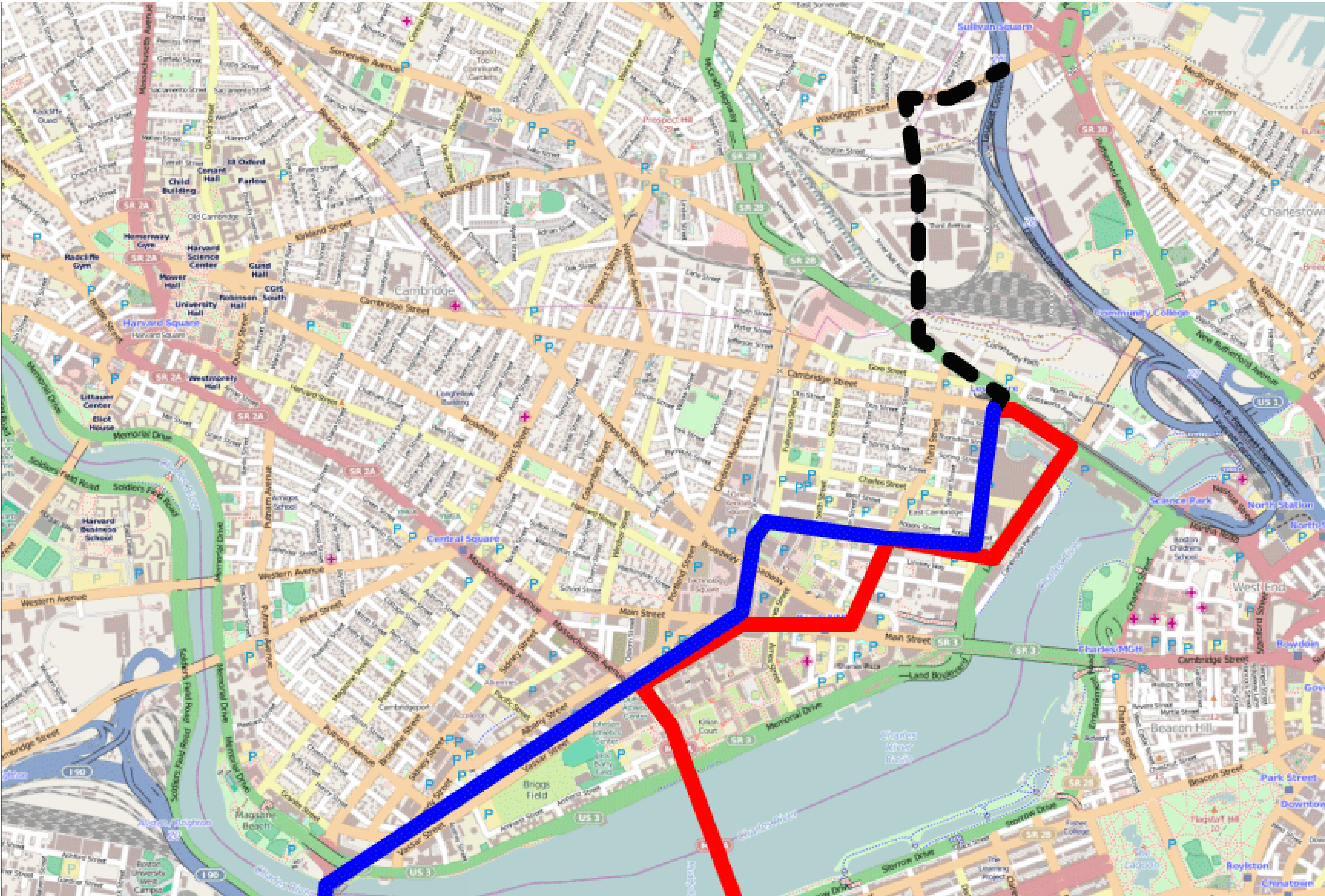
3rd St @ Kendall St
15' Sidewalk
9' Drive lane
11' Bus lane
11' Bus lane
9' Drive lane
15' Sidewalk


2b

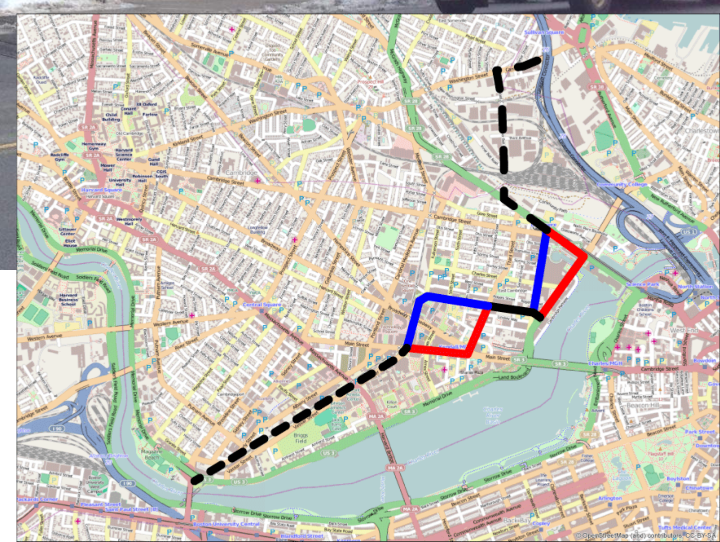

Main St@Ames St
10' Sidewalk
4'
2'
9' Parking lane
6' Bike lane
10' Drive lane
6'
12' Drive lane
8' Parking lane
2'
4'
10' Sidewalk


Main St@Ames St
12½' Sidewalk
4'
2'
6' Bike lane
1'
11' Bus lane
10' Transit shelter
11' Bus lane
1'
6' Bike lane
2'
4'
12½' Sidewalk

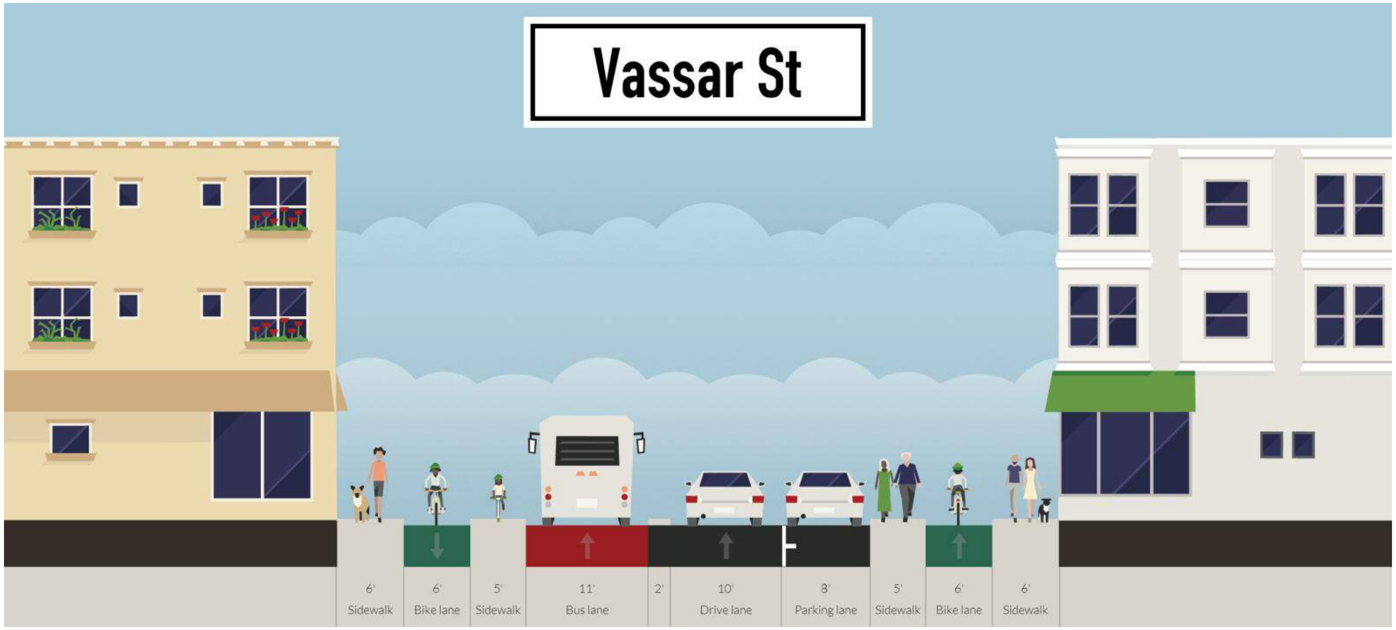
Two Options to Bridges

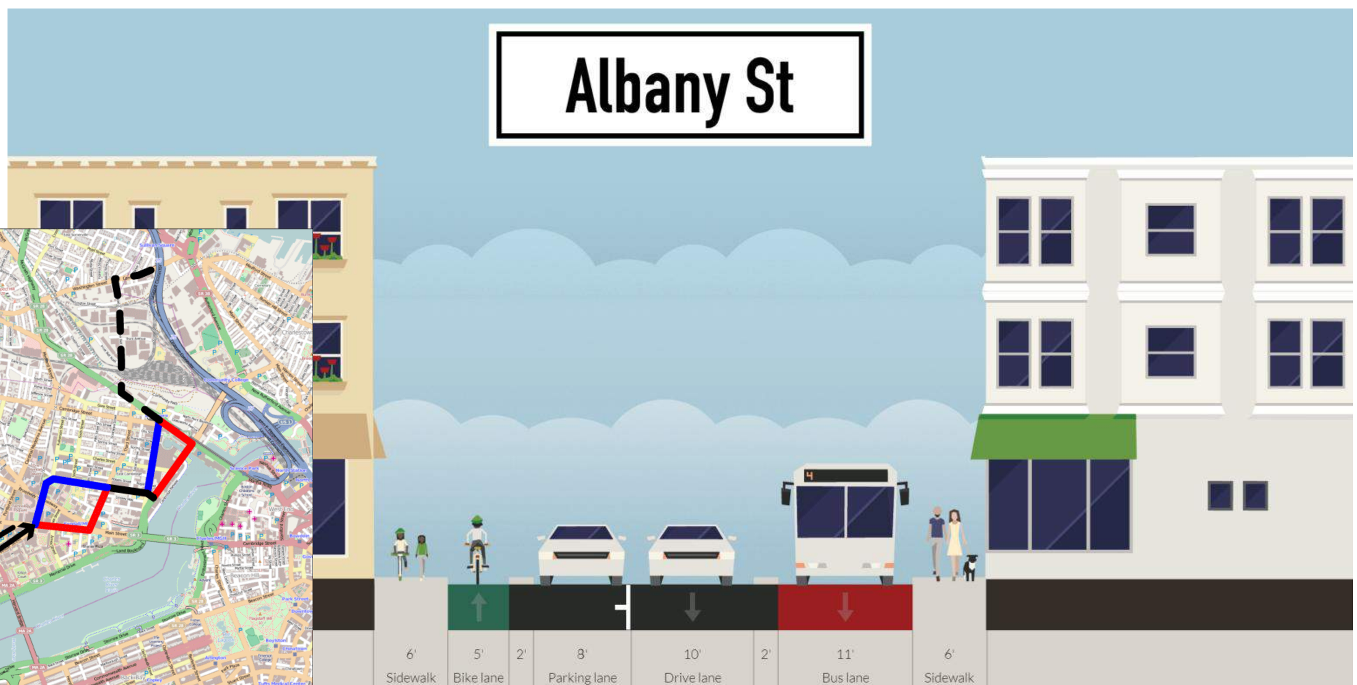


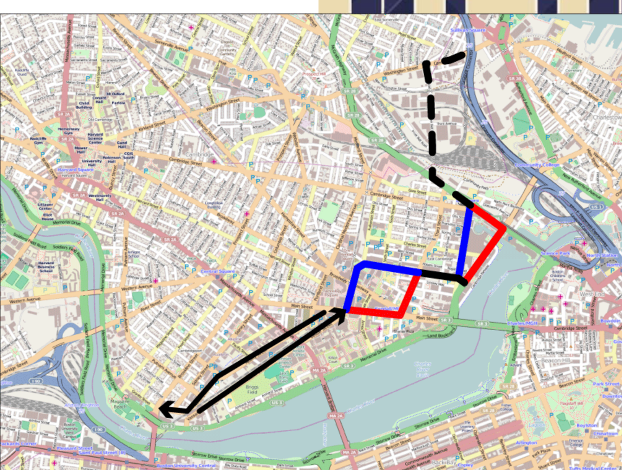
Option A: Grand Junction ROW

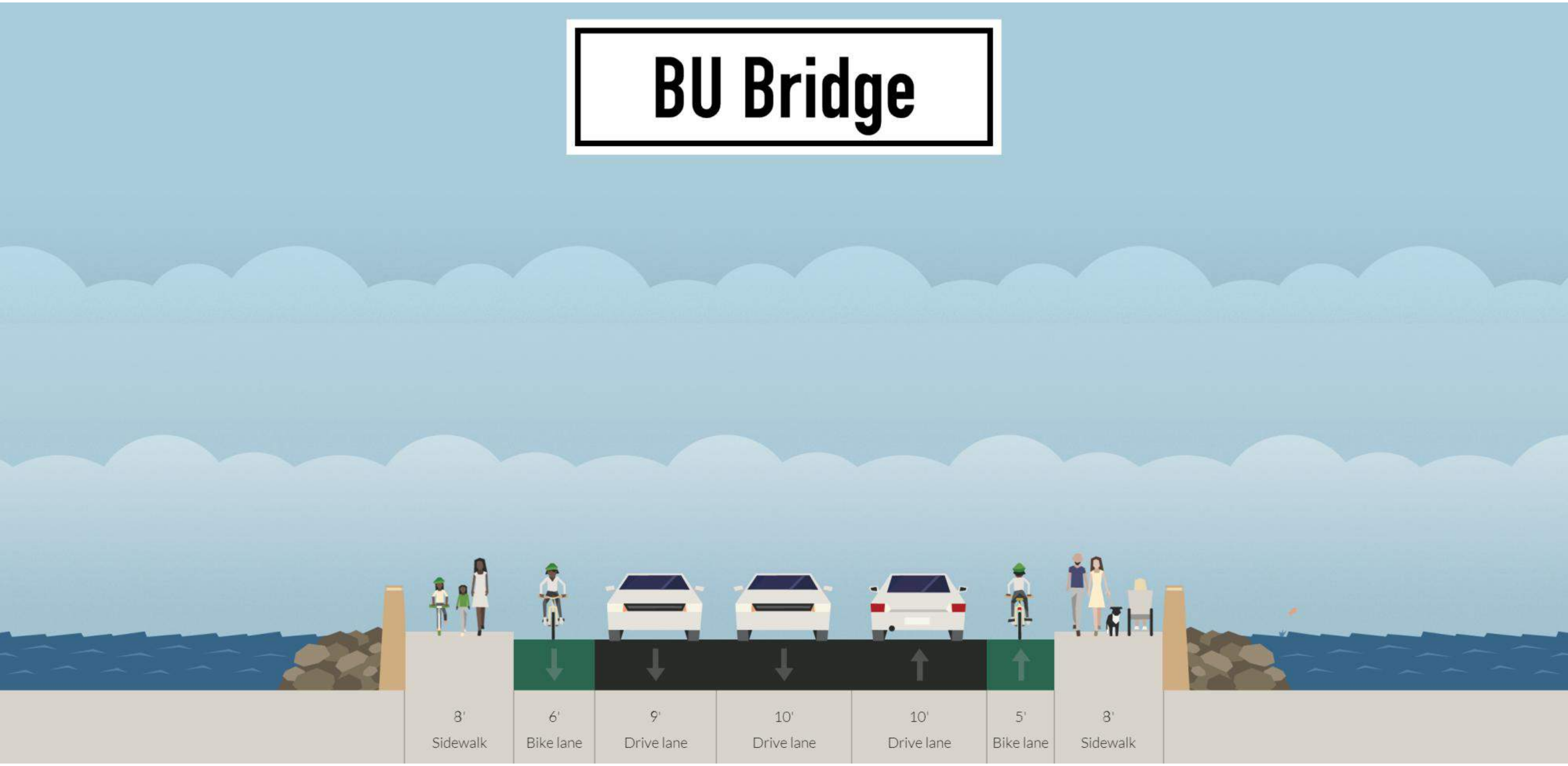


Option B: One-Way Pairs on Vassar St and Albany St

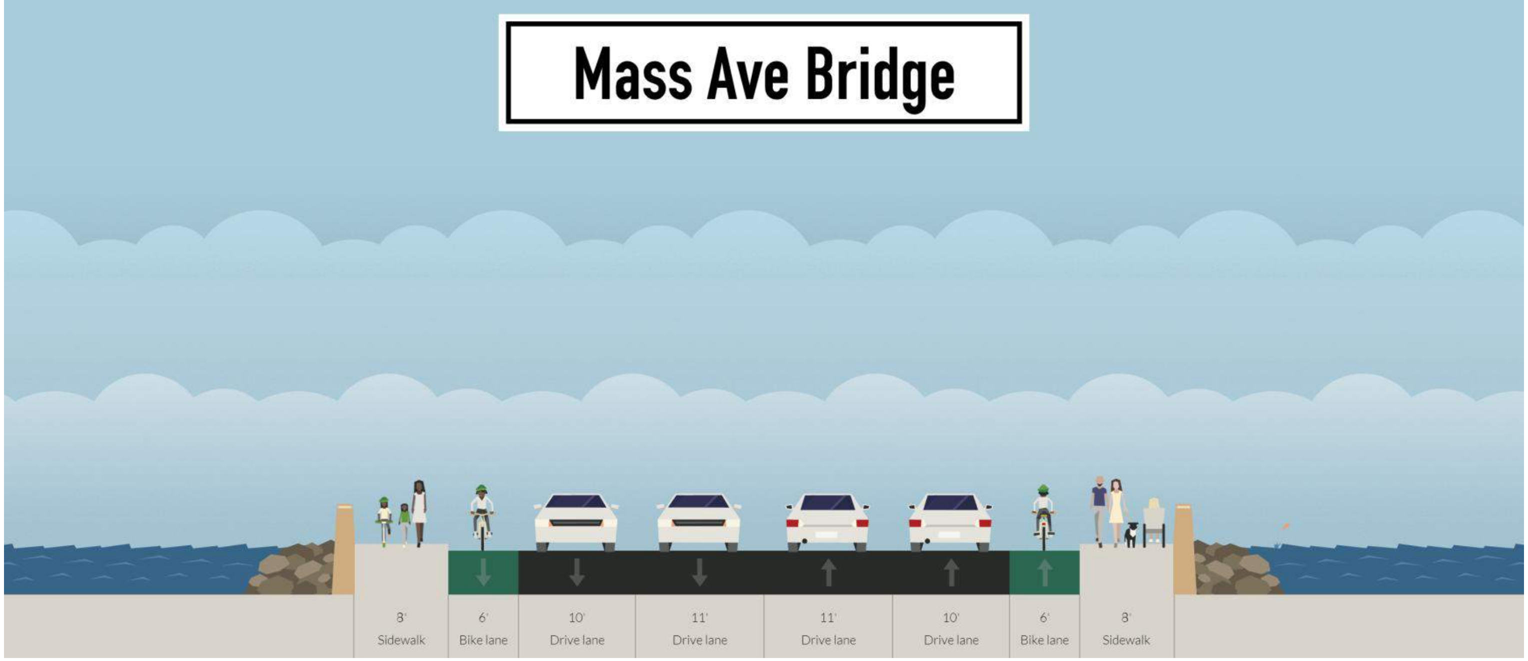


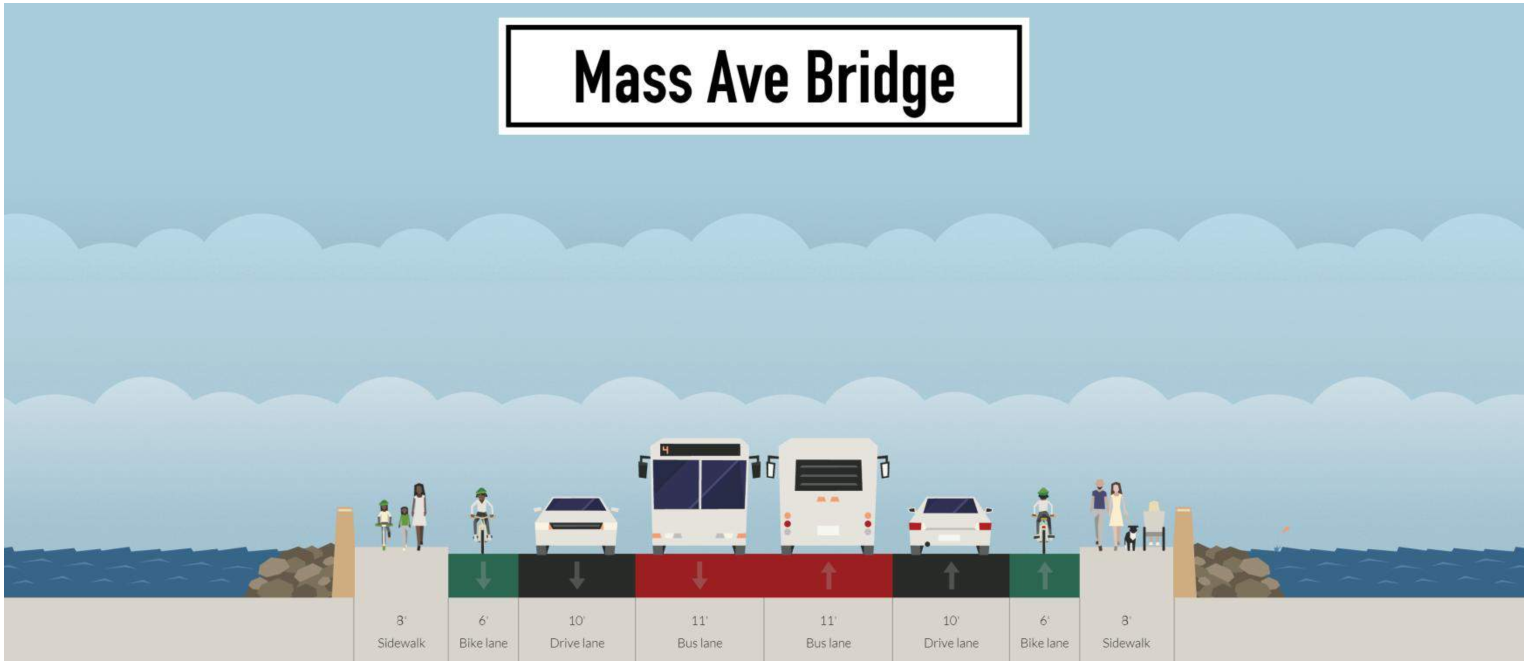






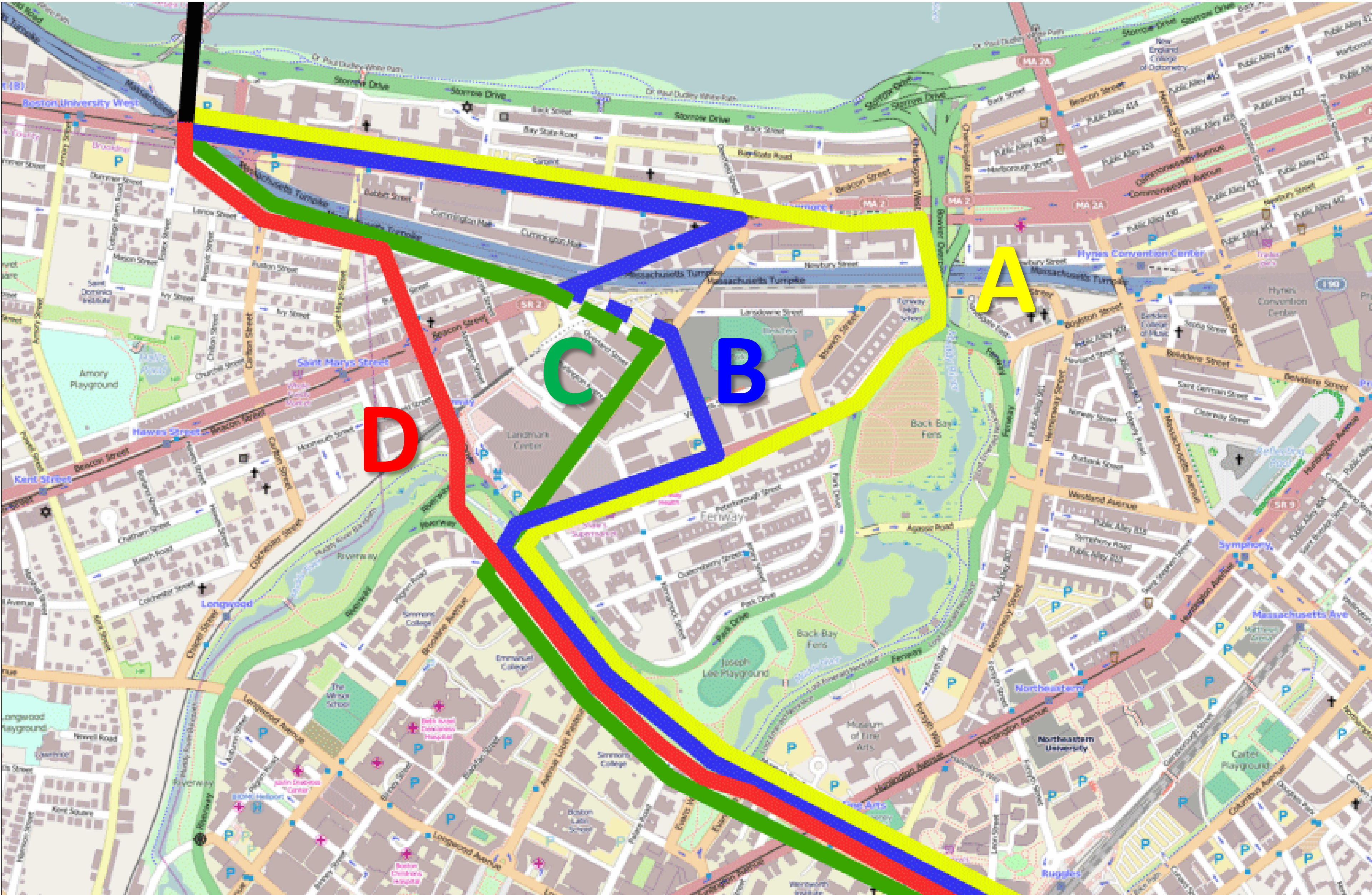
BU Bridge does not have much room for separated lanes.





Mass Ave Bridge has more space.

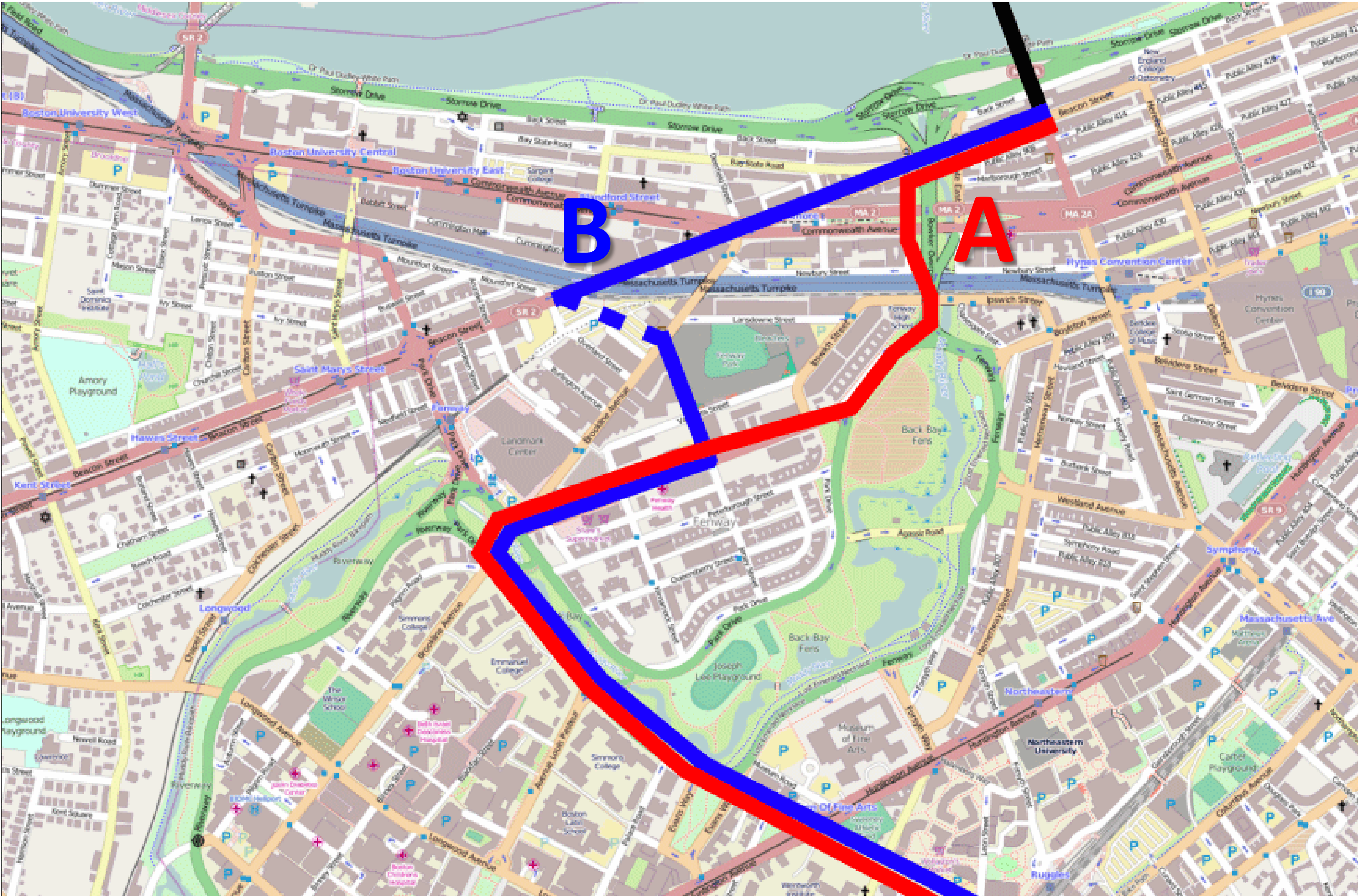
Options for BU Bridge to Ruggles



Options for BU Bridge to Ruggles

- Option A: Charlesgate-Boylston-Fenway
  - Brings great benefit to 57
  - Provides access to Fenway
  - Serves development along Boylston
- Option B: Beacon-Yawkey-Boylston
  - Brings benefit to 47
  - More direct routing
  - Provides connection to Yawkey Station
- Option C: Mountfort-Brookline
  - Serves 47 but misses 57
  - No service to Fenway and Boylston
- Option D: As modelled
  - Similar to Option C
  - Would require modifications to reconstructed rotary at Beacon Street

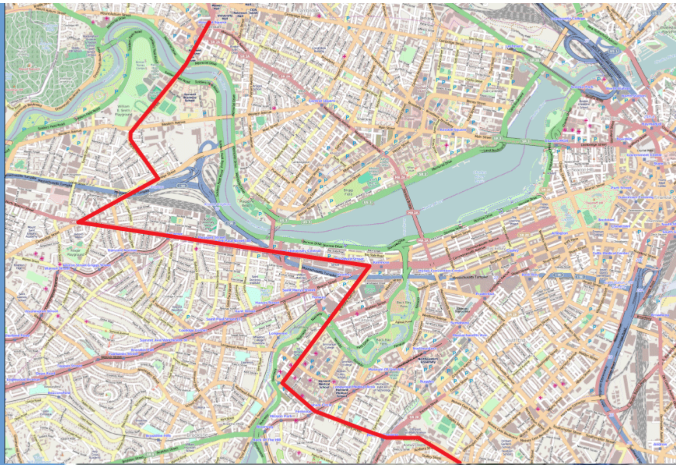
Options for Mass Ave Bridge to Ruggles



Options for Mass Ave Bridge to Ruggles

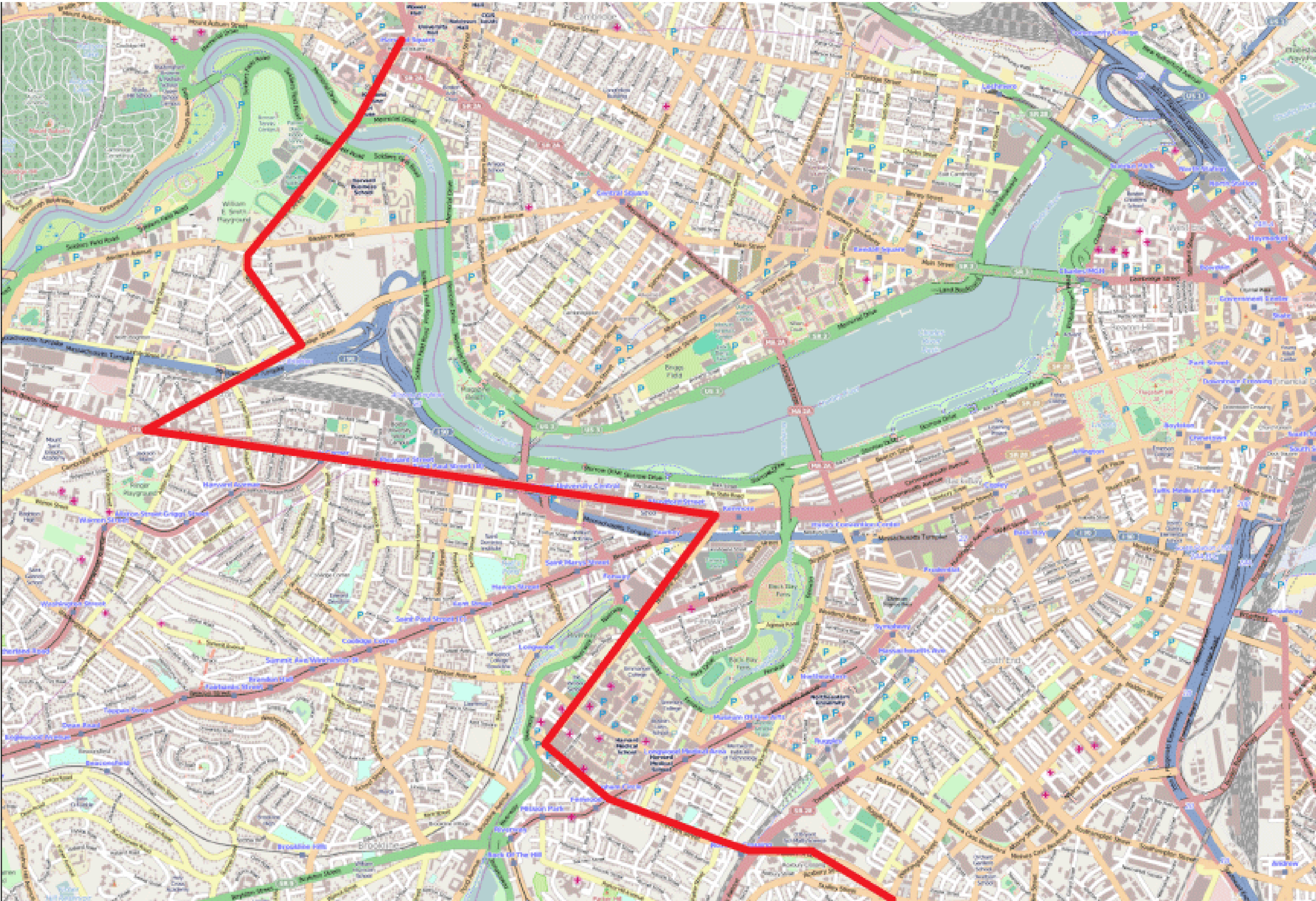
- Option A: Charlesgate-Boylston-Fenway
  - Brings great benefit to 57
  - Provides access to Fenway
  - Serves development along Boylston
- Option B: Beacon-Yawkey-Boylston
  - Brings benefit to 47
  - More direct routing
  - Provides connection to Yawkey Station

Harvard to Dudley



ITDP

Harvard to Dudley: General Routing



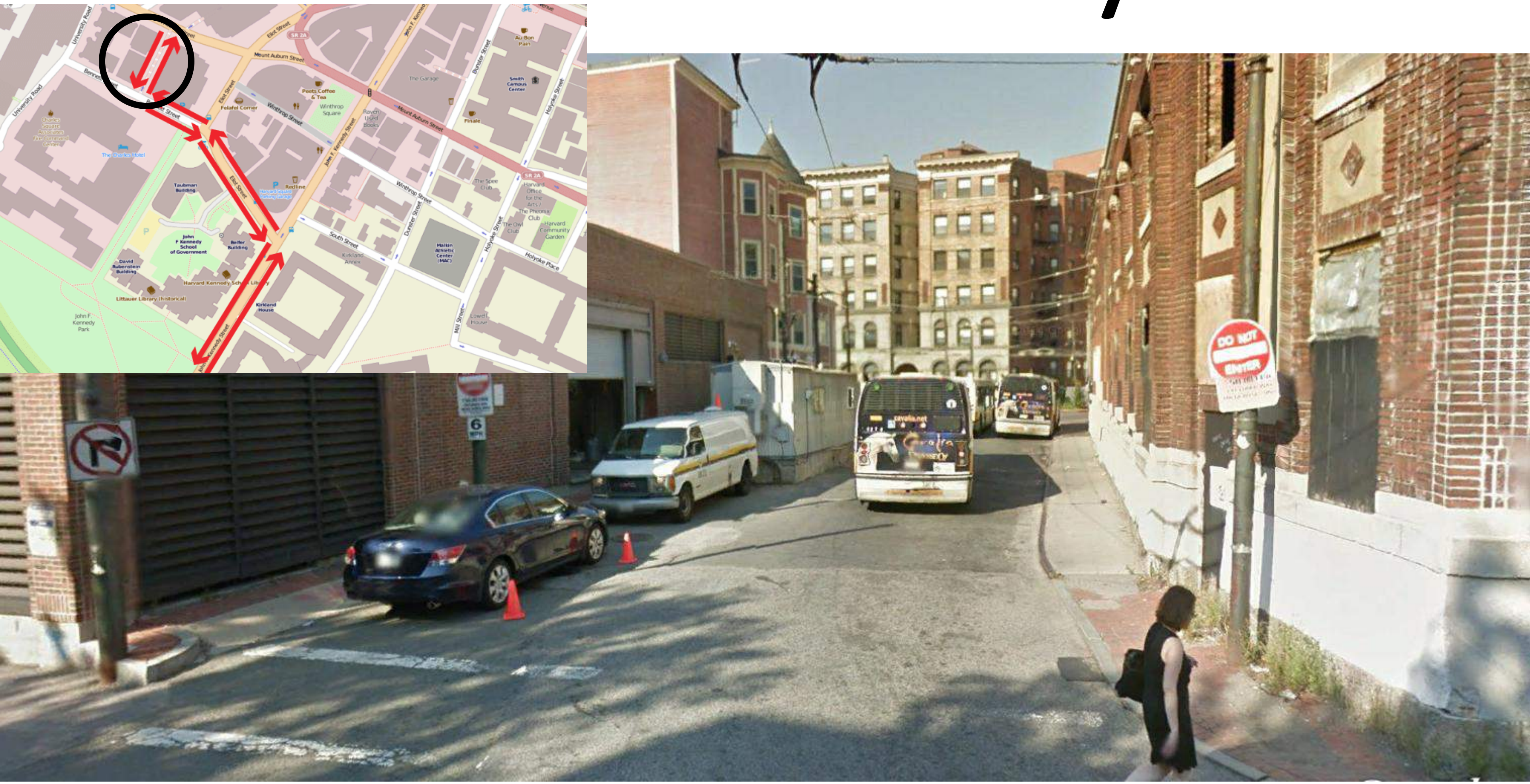
BRT Infrastructure Options through Harvard Square

The Harvard Bus Tunnel stations could be used: great connections to the Red Line.
Area could be made a pre-paid zone

Approach to the Harvard Bus Tunnel

Harvard Square Option A:
Eliot St- Bennett Street-Bennett Alley

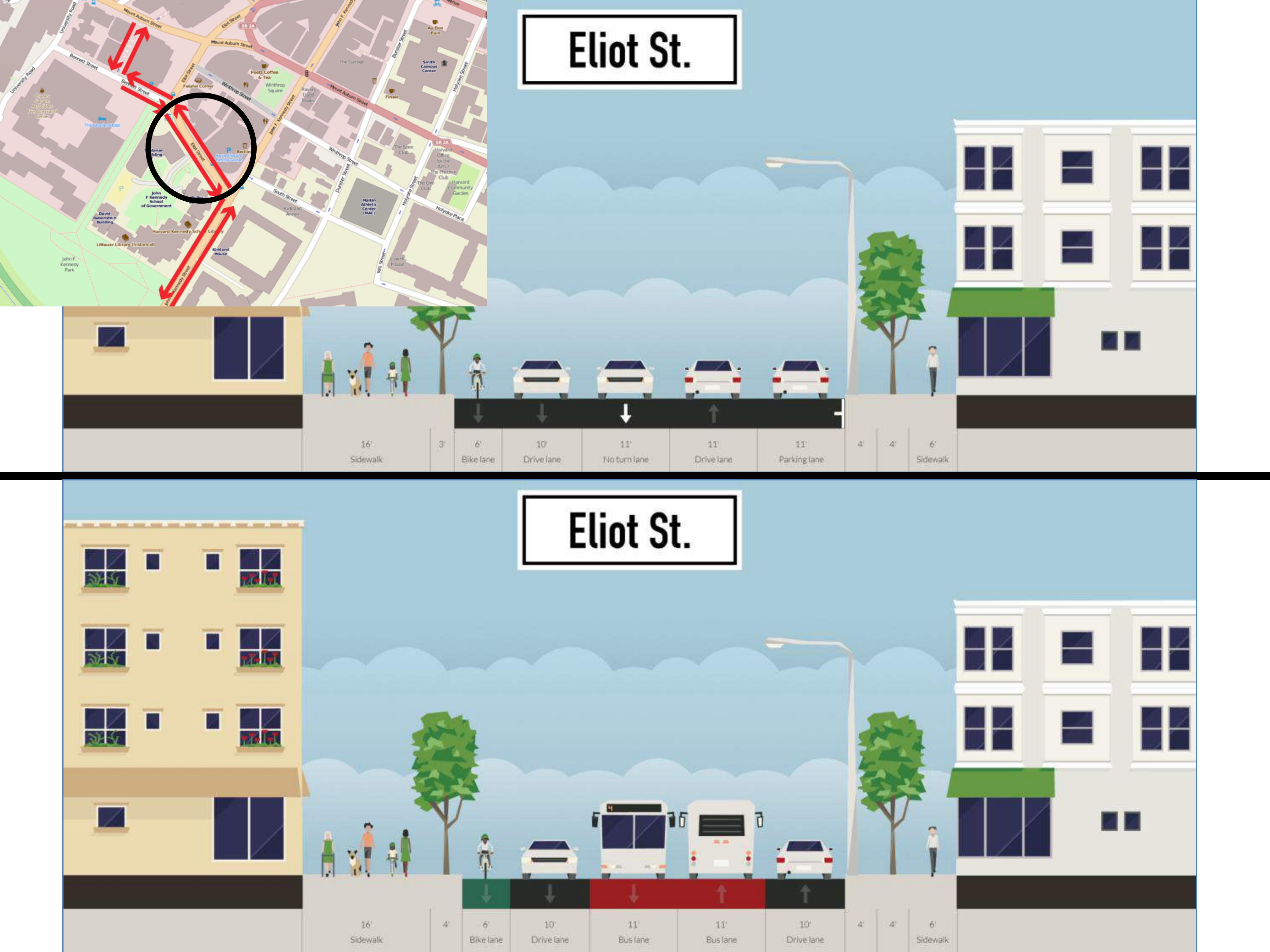
Bennett Alley



Bennett Alley is the most logical approach to the bus tunnel, as it the approach currently used by most routes.


Bennett Alley
5' Sidewalk
9' Parking lane
10' Drive lane
10' Drive lane
6' Sidewalk


Bennett Alley
5' Sidewalk
9' Drive lane
10' Bus lane
10' Bus lane
6' Sidewalk

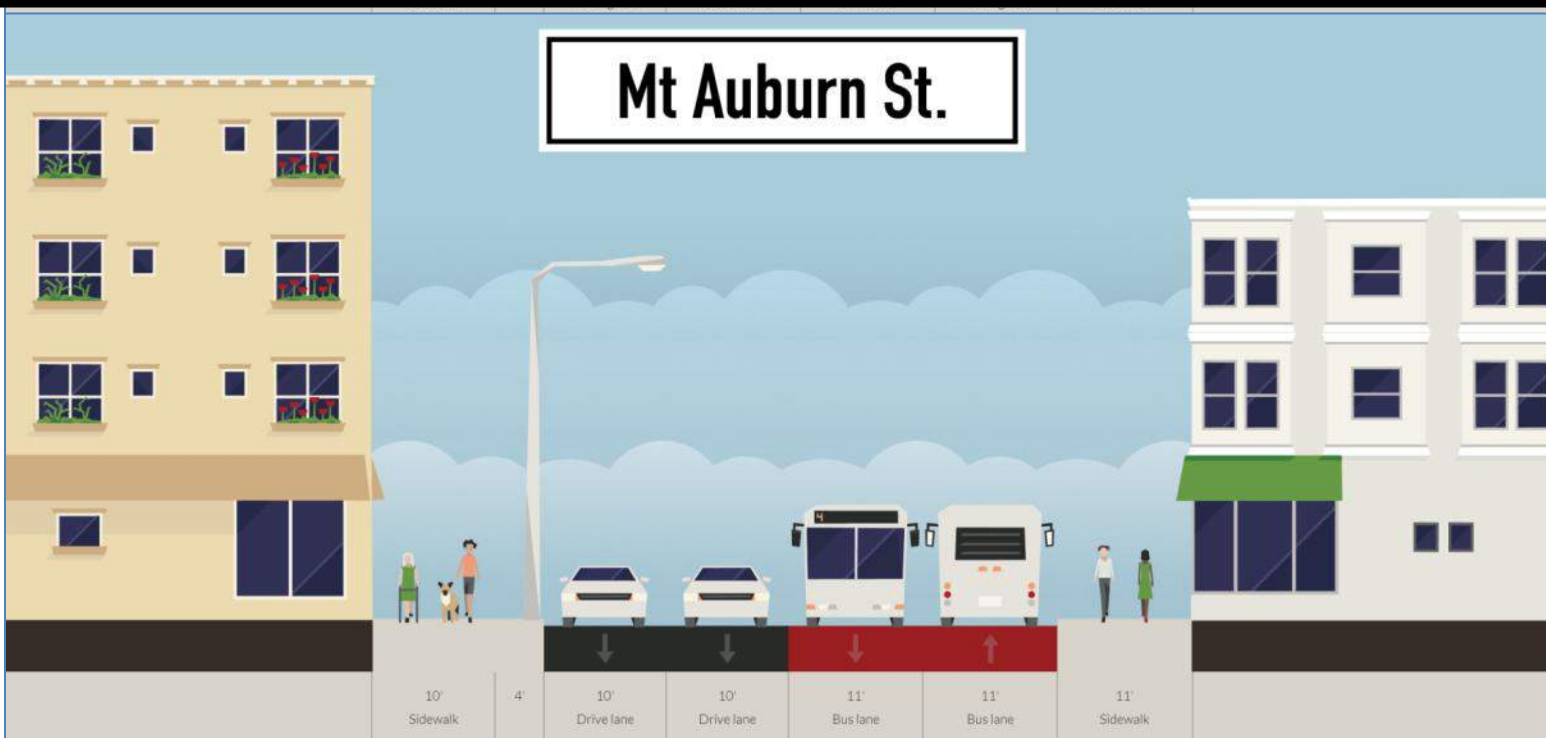


Eliot St.
16' Sidewalk
3'
6' Bike lane
10' Drive lane
11' No turn lane
11' Drive lane
11' Parking lane
4'
4'
6' Sidewalk
Eliot St.
16' Sidewalk
4'
6' Bike lane
10' Drive lane
11' Bus lane
11' Bus lane
10' Drive lane
4'
4'
6' Sidewalk

Harvard Square Option B: Eliot Street-Mt. Auburn Street


Mount Auburn Street
Eliot Street
Bennett Street
University Road
Winthrop Street
John F. Kennedy Street
Dunster Street
Holyoke Street
South Street
Winthrop Square
John F. Kennedy School of Government
Harvard Kennedy School Library
Kirkland House
John F. Kennedy Park

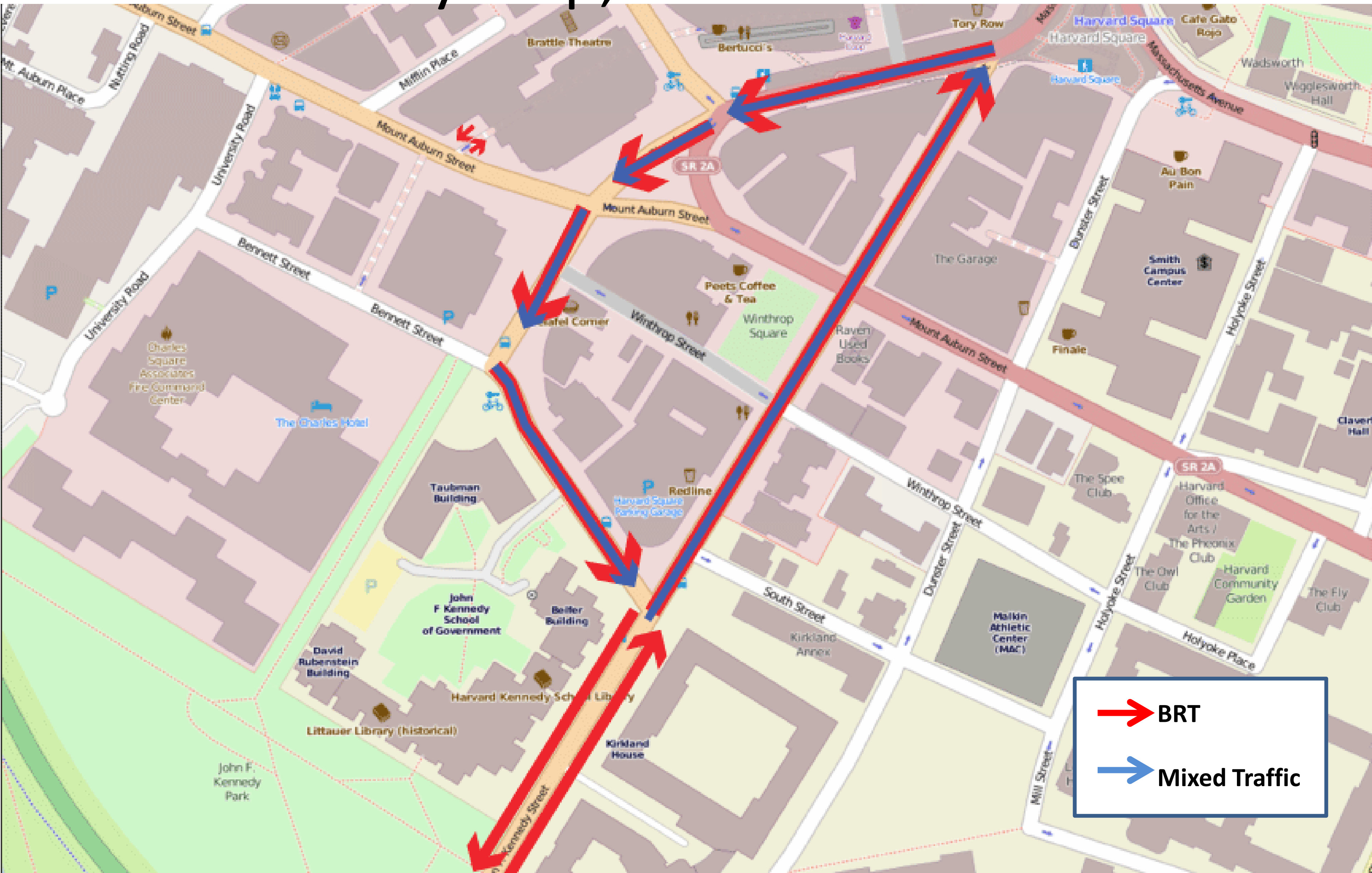

Mt Auburn St.
10'
4'
10'
11'
11'
10'
11'


Mt Auburn St.
10' Sidewalk
4'
10' Drive lane
10' Drive lane
11' Bus lane
11' Bus lane
11' Sidewalk

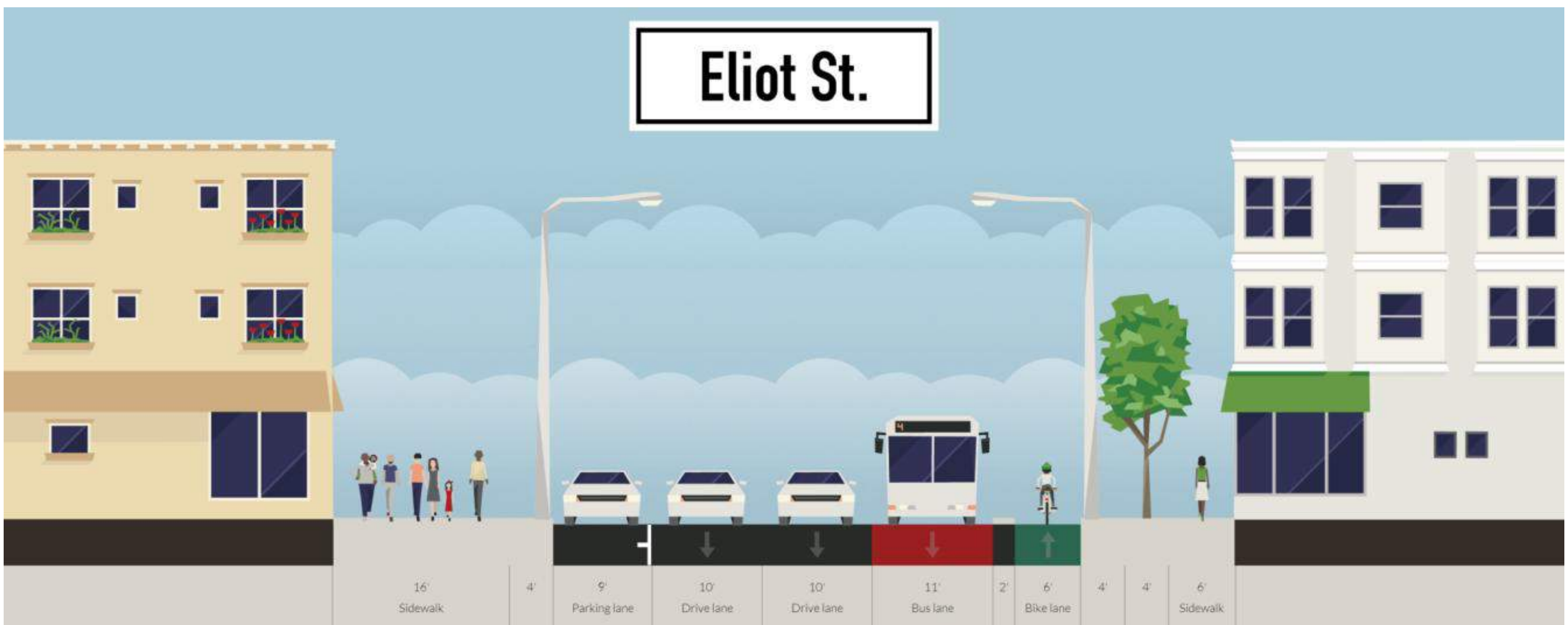
Eliot St.
16' Sidewalk
3'
6' Bike lane
10' Drive lane
11' No turn lane
11' Drive lane
11' Parking lane
4'
4'
6' Sidewalk

Eliot St.
16' Sidewalk
4'
6' Bike lane
10' Drive lane
11' Bus lane
11' Bus lane
10' Drive lane
4'
4'
6' Sidewalk

Harvard Square Option C: One way loop, BRT + mixed traffic

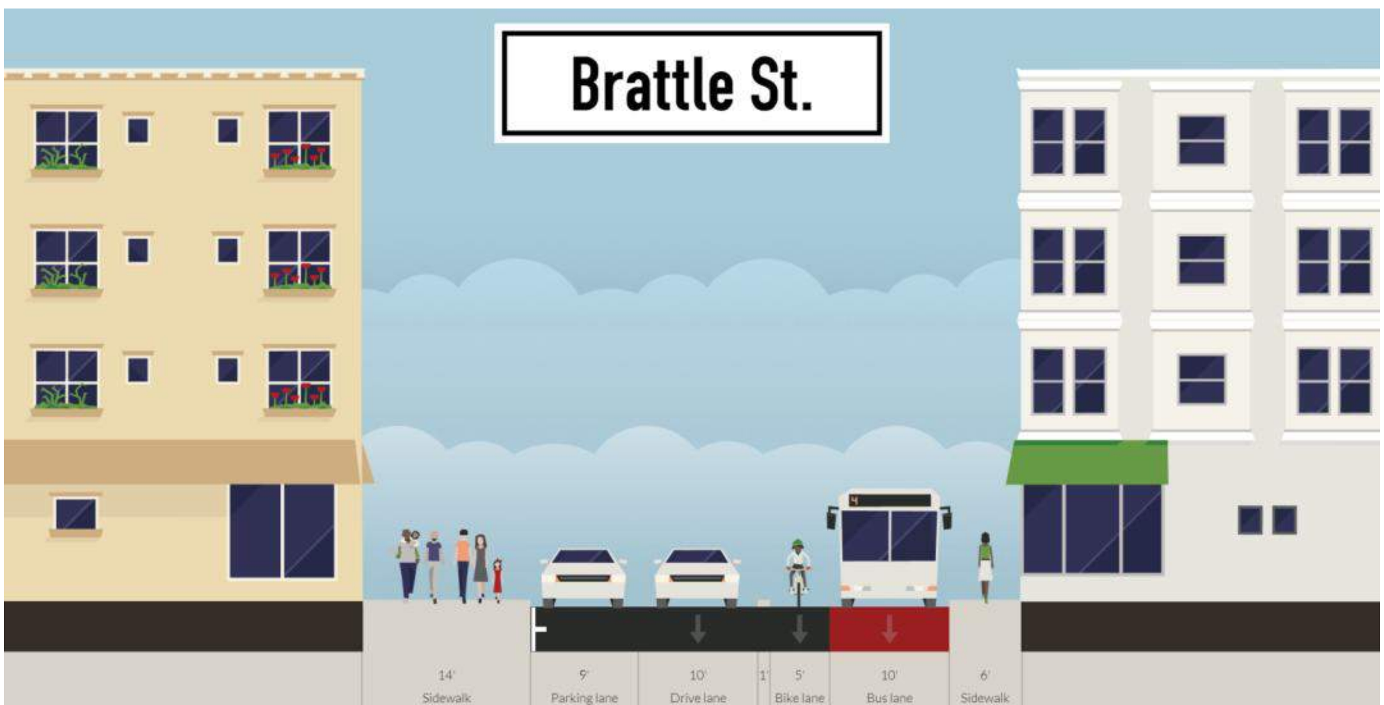



Eliot St.
16' Sidewalk
3'
6' Bike lane
10' Drive lane
11' No turn lane
11' Drive lane
11' Parking lane
4'
4'
6' Sidewalk


Eliot St.
16' Sidewalk
4'
9' Parking lane
10' Drive lane
10' Drive lane
11' Bus lane
2'
6' Bike lane
4'
4'
6' Sidewalk

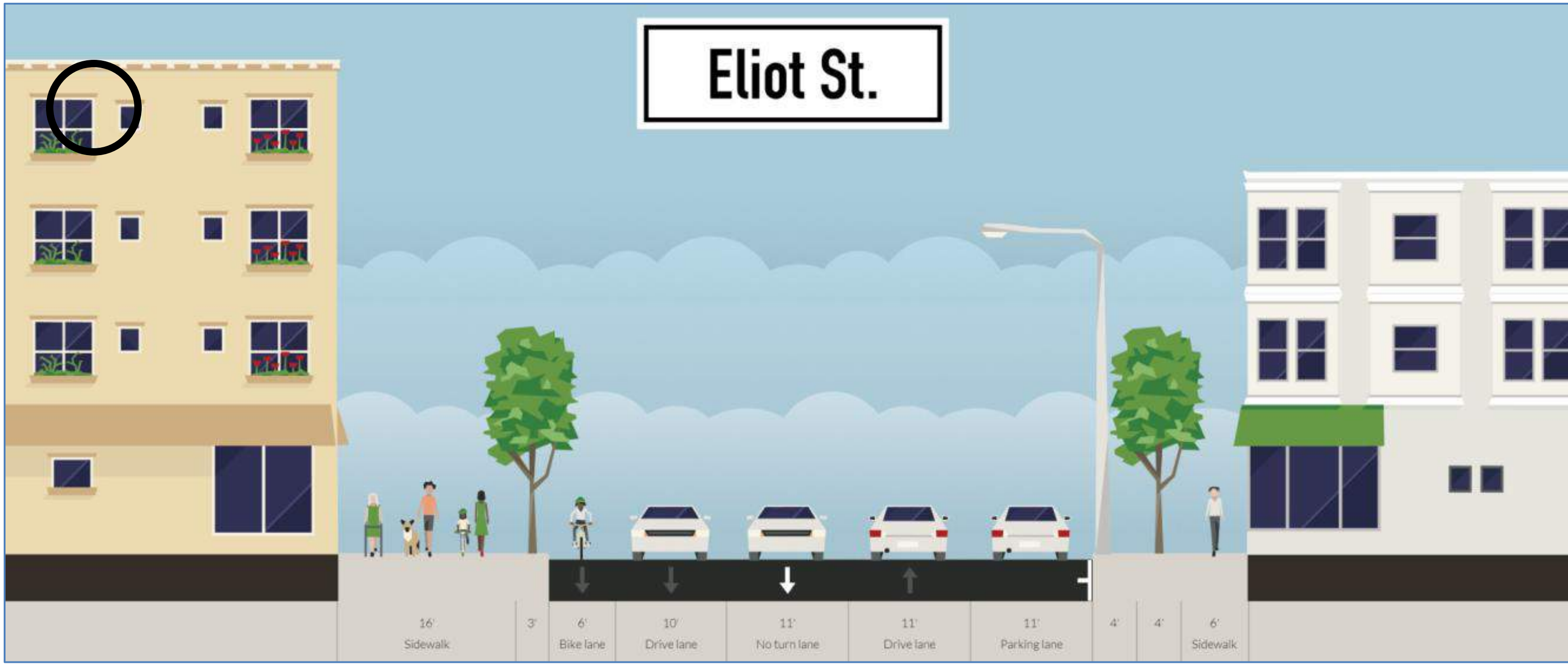

Brattle Theatre
Harvard Square
Mount Auburn Street
Bennett Street
Winthrop Street
John F Kennedy School of Government


Brattle St.
14' Sidewalk
9' Parking lane
6' Bike lane
10' Drive lane
10' Drive lane
6' Sidewalk

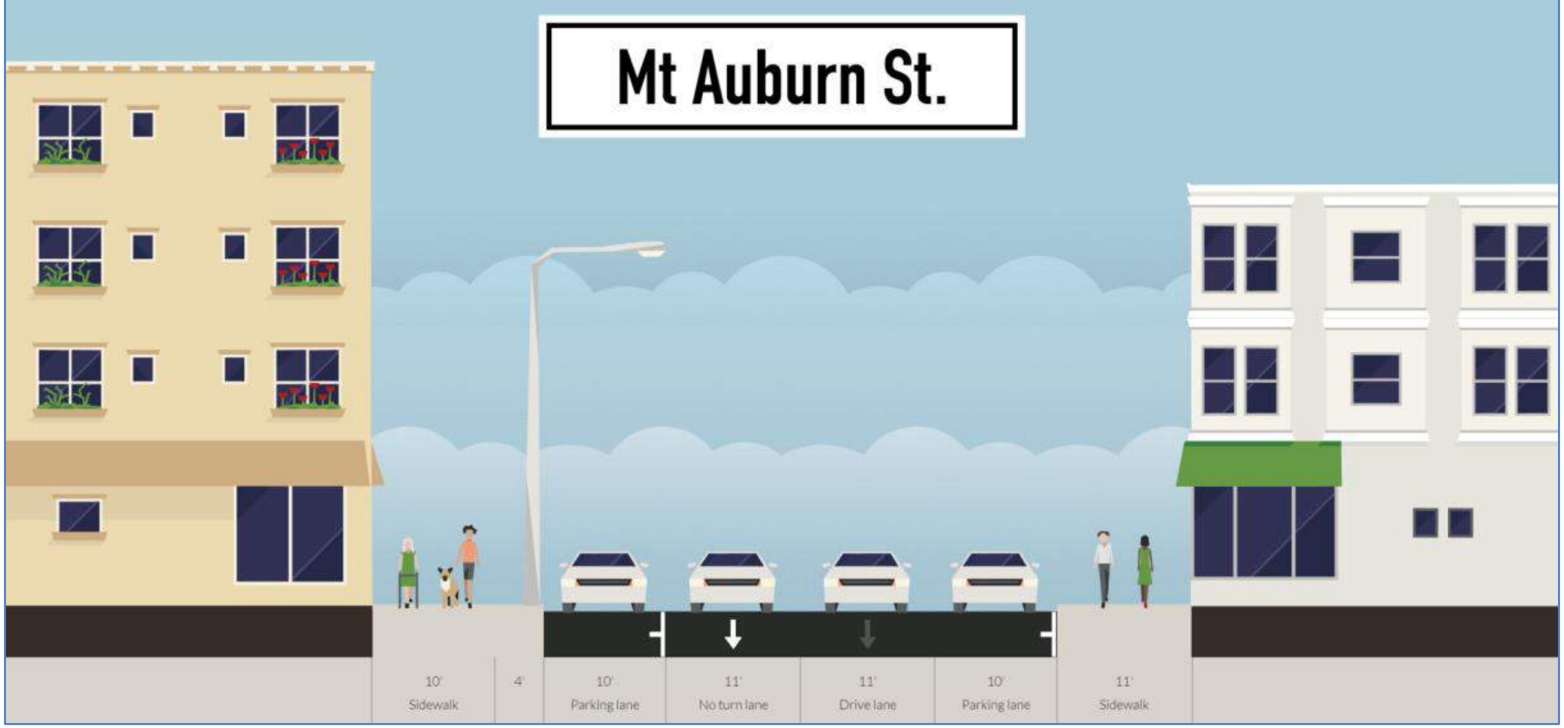

Brattle St.
14' Sidewalk
9' Parking lane
10' Drive lane
1'
5' Bike lane
10' Bus lane
6' Sidewalk

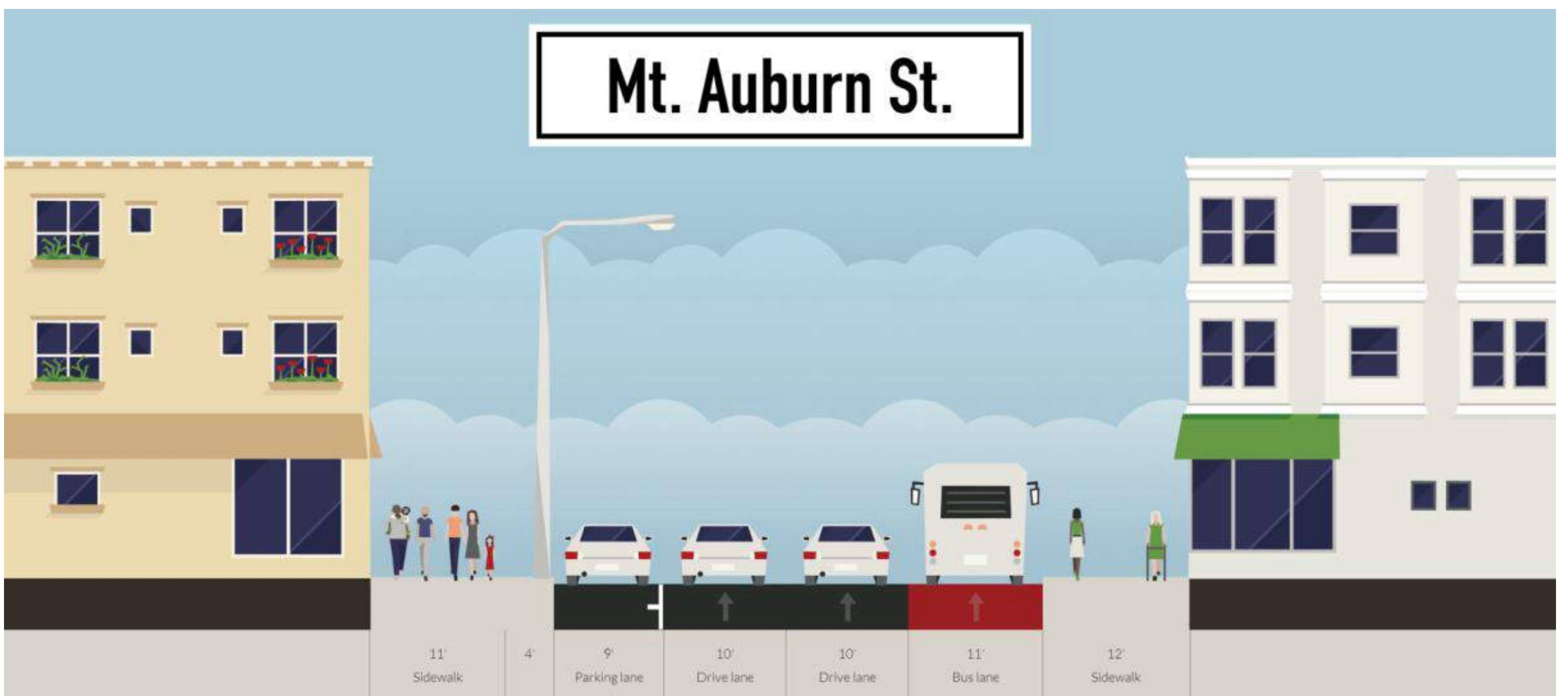

Bennett Alley
5'
Sidewalk
9'
Parking lane
10'
Drive lane
10'
Drive lane
6'
Sidewalk


Bennett Alley
6'
Sidewalk
8'
Parking lane
9'
Drive lane
10'
Bus lane
7'
Sidewalk


Eliot St.
16' Sidewalk
3'
6' Bike lane
10' Drive lane
11' No turn lane
11' Drive lane
11' Parking lane
4'
4'
6' Sidewalk

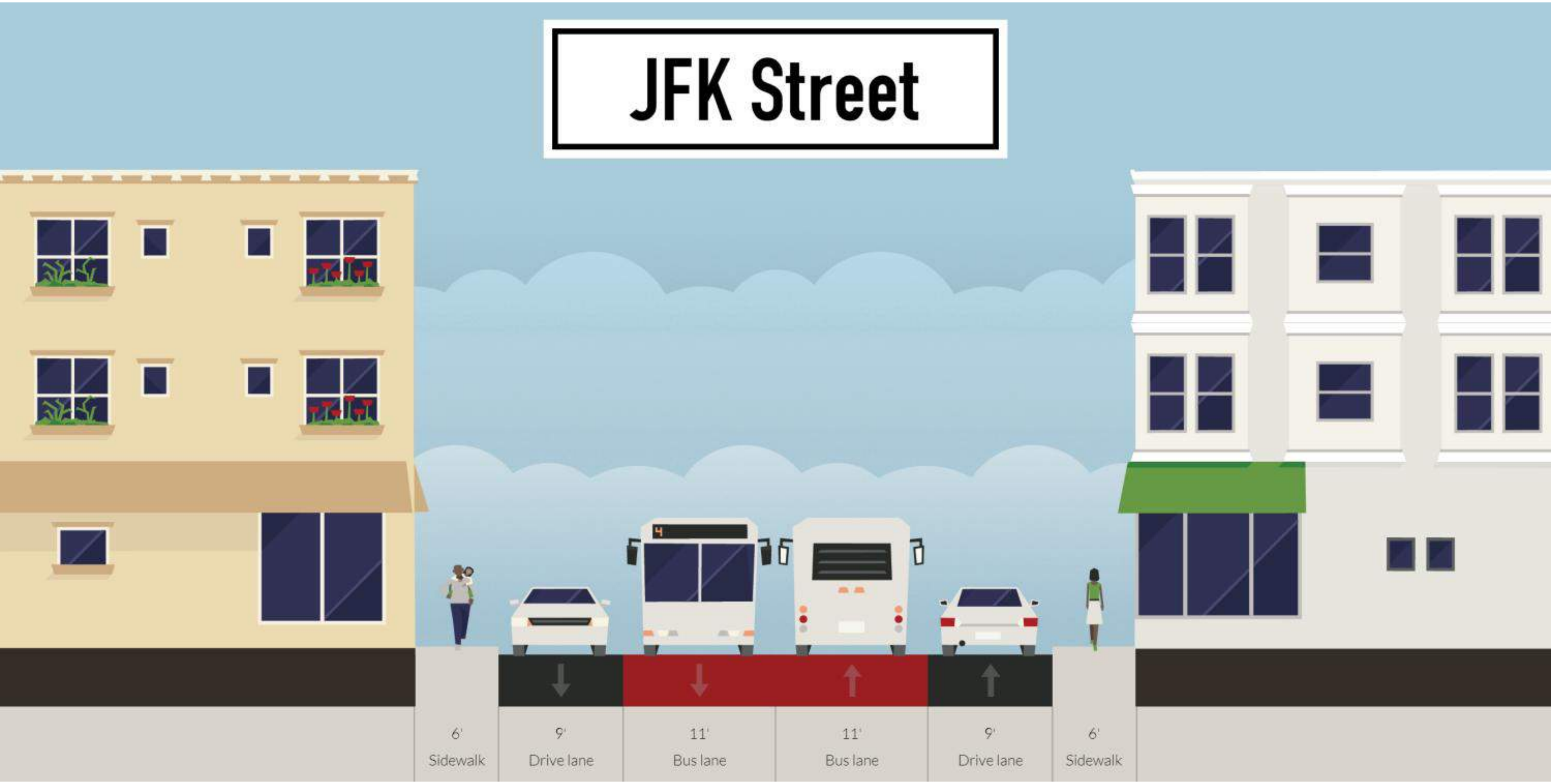

Eliot St.
16' Sidewalk
4'
9' Parking lane
10' Drive lane
10' Drive lane
11' Bus lane
2'
6' Bike lane
4'
4'
6' Sidewalk


Mt Auburn St.
10'
Sidewalk
4'
10'
Parking lane
11'
No turn lane
11'
Drive lane
10'
Parking lane
11'
Sidewalk

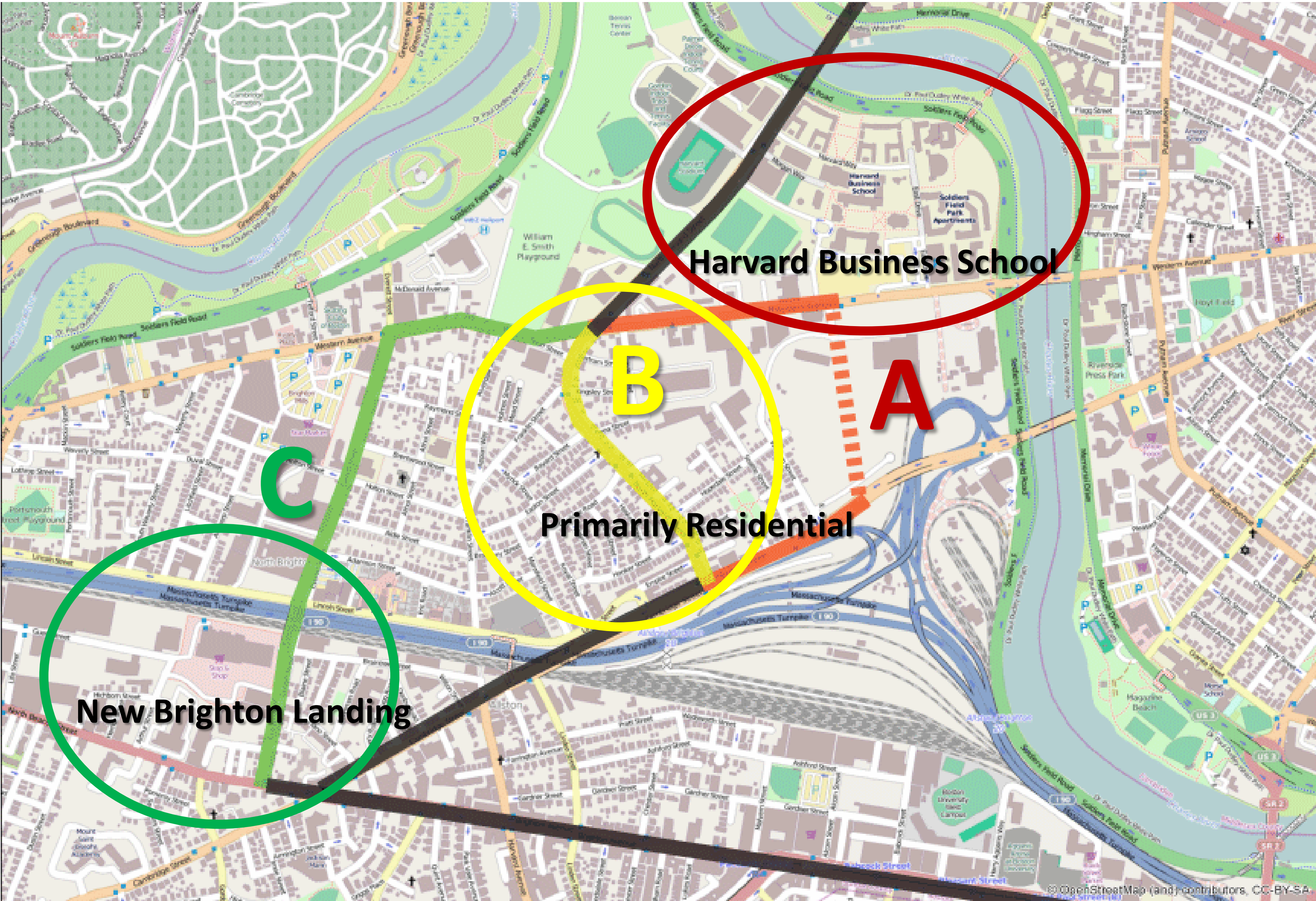

Mt. Auburn St.
11'
Sidewalk
4'
9'
Parking lane
10'
Drive lane
10'
Drive lane
11'
Bus lane
12'
Sidewalk

Preliminary Assessment of Harvard Square to JFK Bridge

- It's possible to get Gold Standard BRT through there if the Harvard Square Business Community and Harvard University and the City of Cambridge support the idea. Most in the area recognize that people should not be driving into Harvard Square and traffic volumes are very low anyway.


JFK Street
4
6'
Sidewalk
9'
Drive lane
11'
Bus lane
11'
Bus lane
9'
Drive lane
6'
Sidewalk

Allston Routing Options



Allston Option A: HBS

Allston Option A: Advantages and Disadvantages

- Better serves planned new Harvard business school developments and connects to Union Square
- Avoids very narrow mixed use stretch of N. Harvard St. which could be difficult to do full BRT. Harvard could maybe give some land for widening the ROW along Western.
- Maybe possible to remove surface parking on Western as huge off street parking reserve
- Benefits 70 and 70a for short section, and the 64 for a longer section.
- Cambridge St. is fine for classic BRT configuration
- Outreach relatively easier: depends entirely on what Harvard Business School is doing and if they would want it.
- But it's fairly indirect…

HBS Development and BRT Routing Options

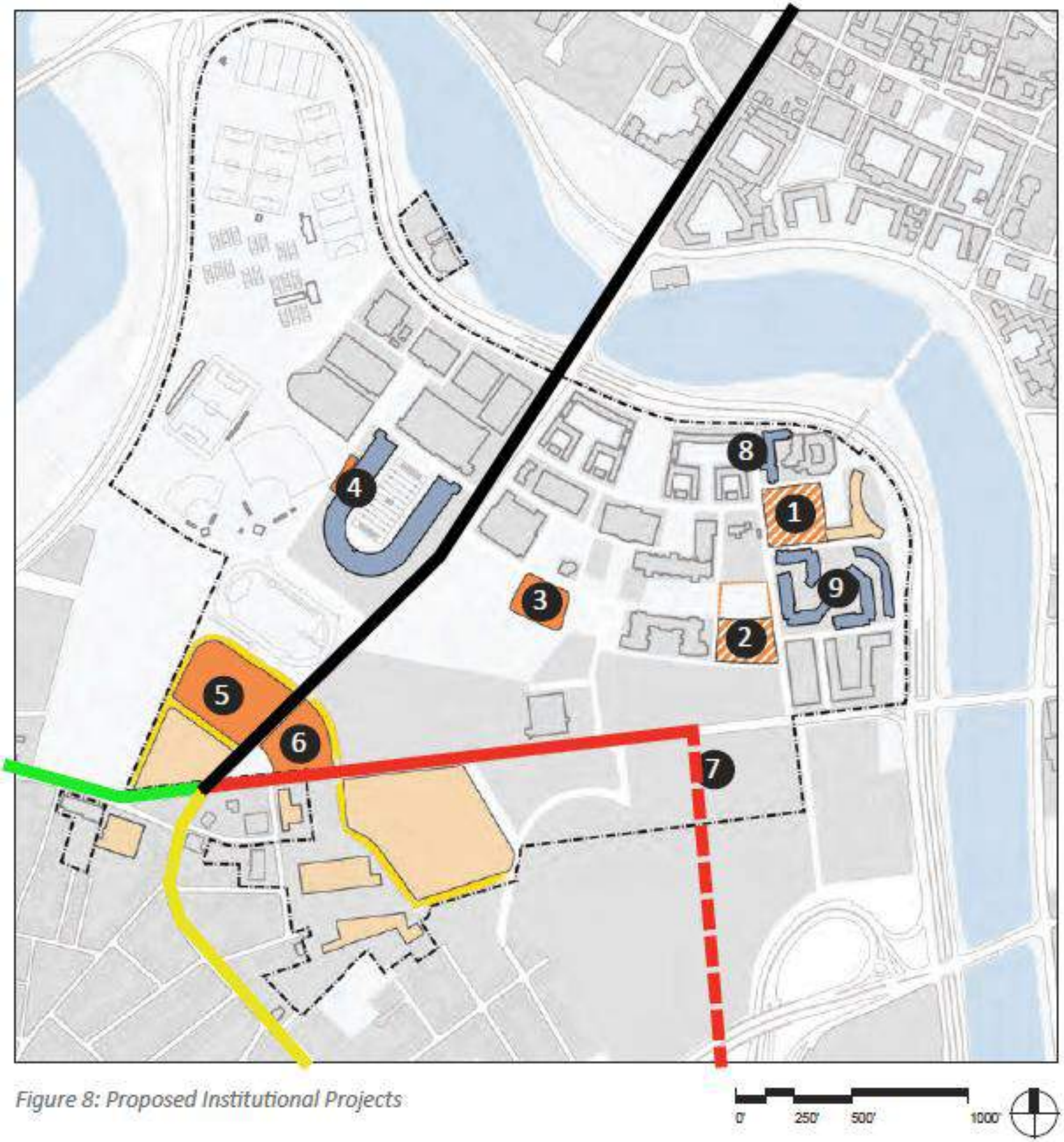
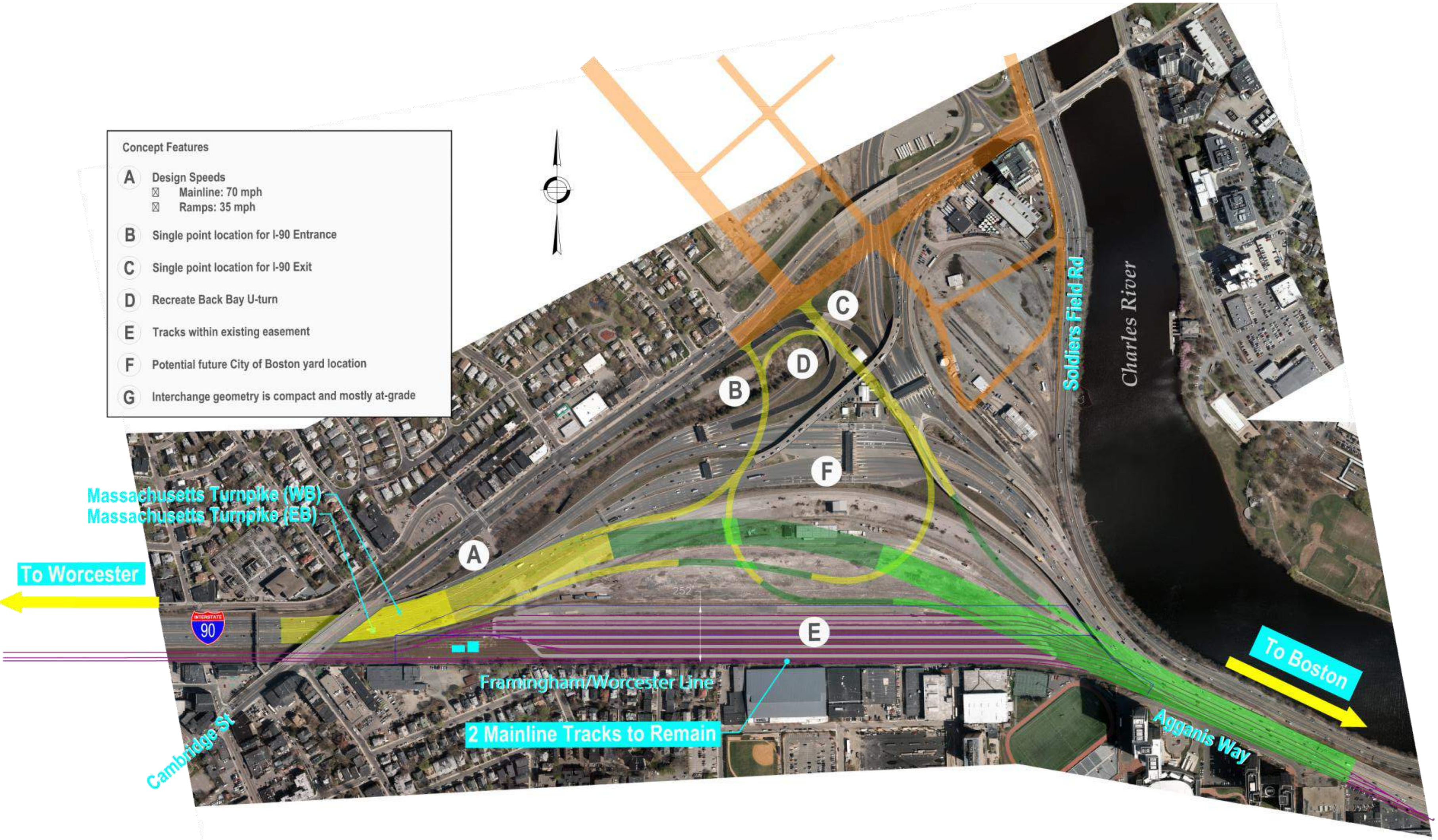


Figure 8: Proposed Institutional Projects



BRIDGE STRUCTURE

ELEVATED ROADWAY

ON GRADE ROADWAY

DEPRESSED ROADWAY

PROPOSED LOCAL ROADWAY NETWORK (HU PLAN)

TRAIN CAPACITY SUMMARY CHART

8-CAR TRAINS AND 1 LOCOMOTIVE – 24-26 CONSISTS

GRAPHIC SCALE

300 0 150 300 600

massDOT Massachusetts Department of Transportation Highway Division

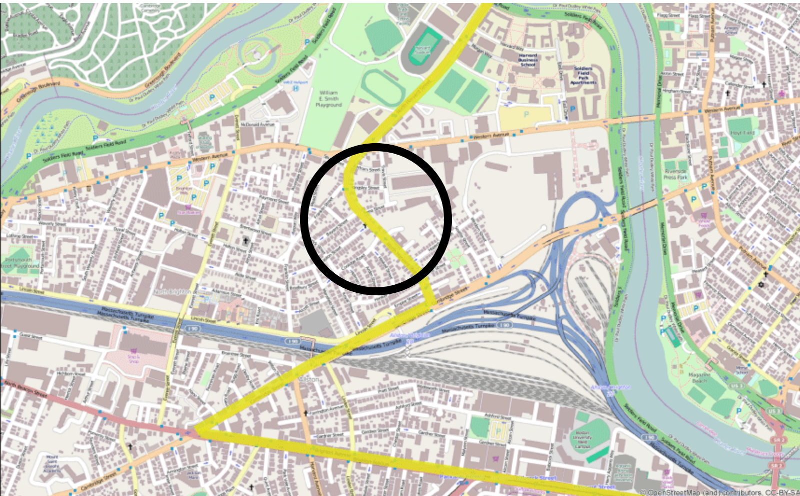
WSP

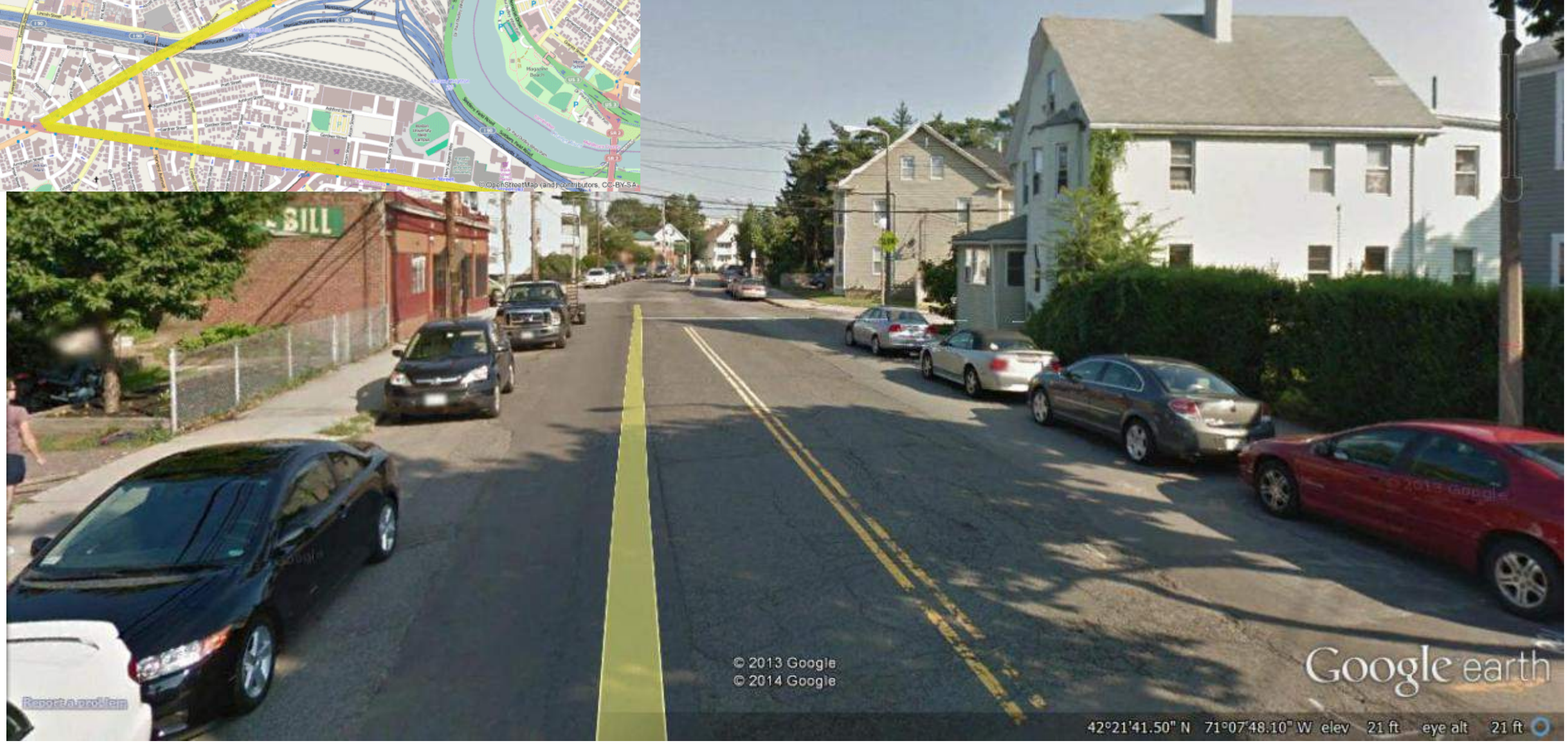
BRIGHTON-ALLSTON

BEACON PARK ALTERNATIVE
8F MODIFIED
CONCEPT PLAN
AUGUST 2013

Allston Option B: North Harvard St

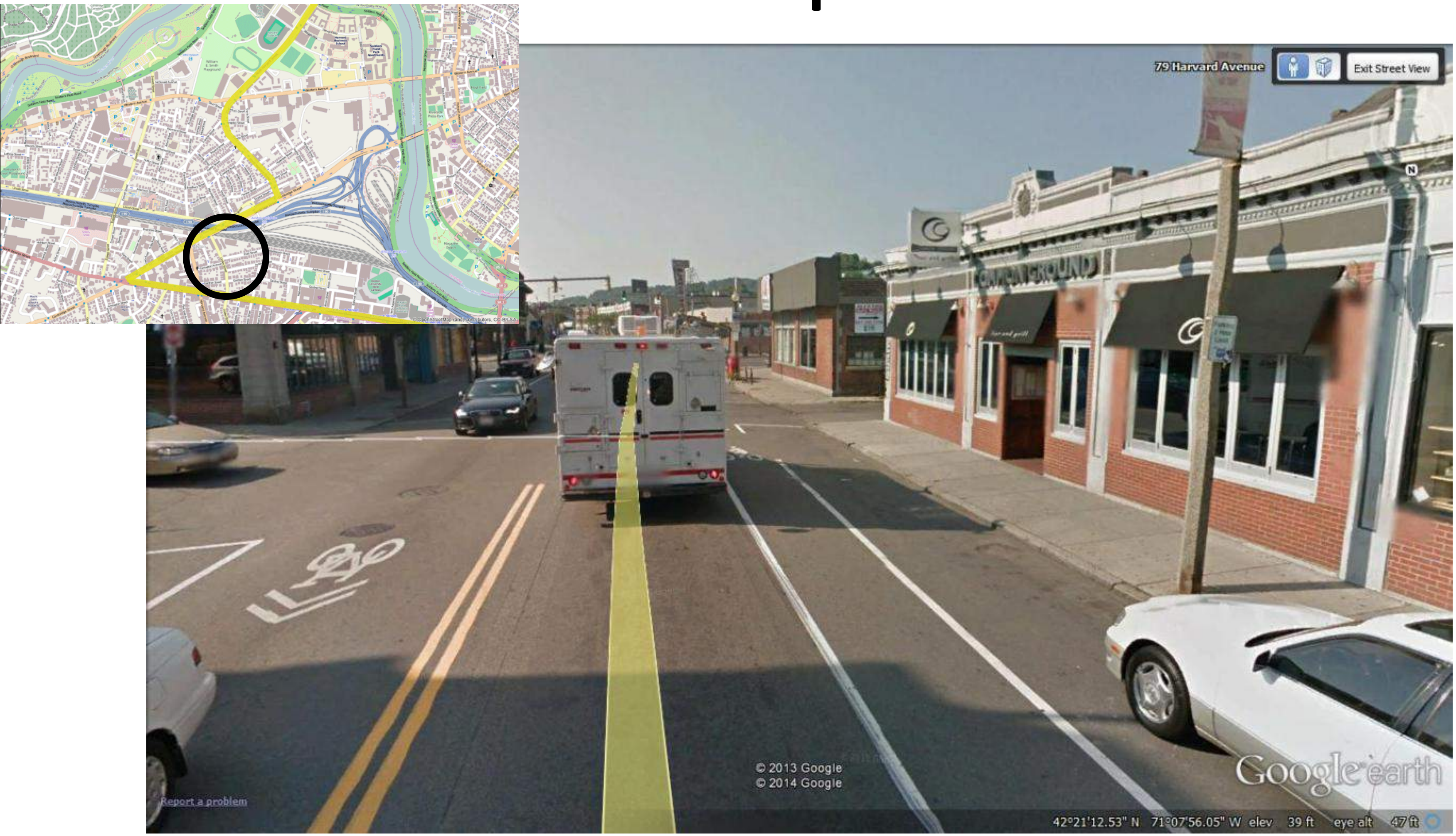
Allston Option B





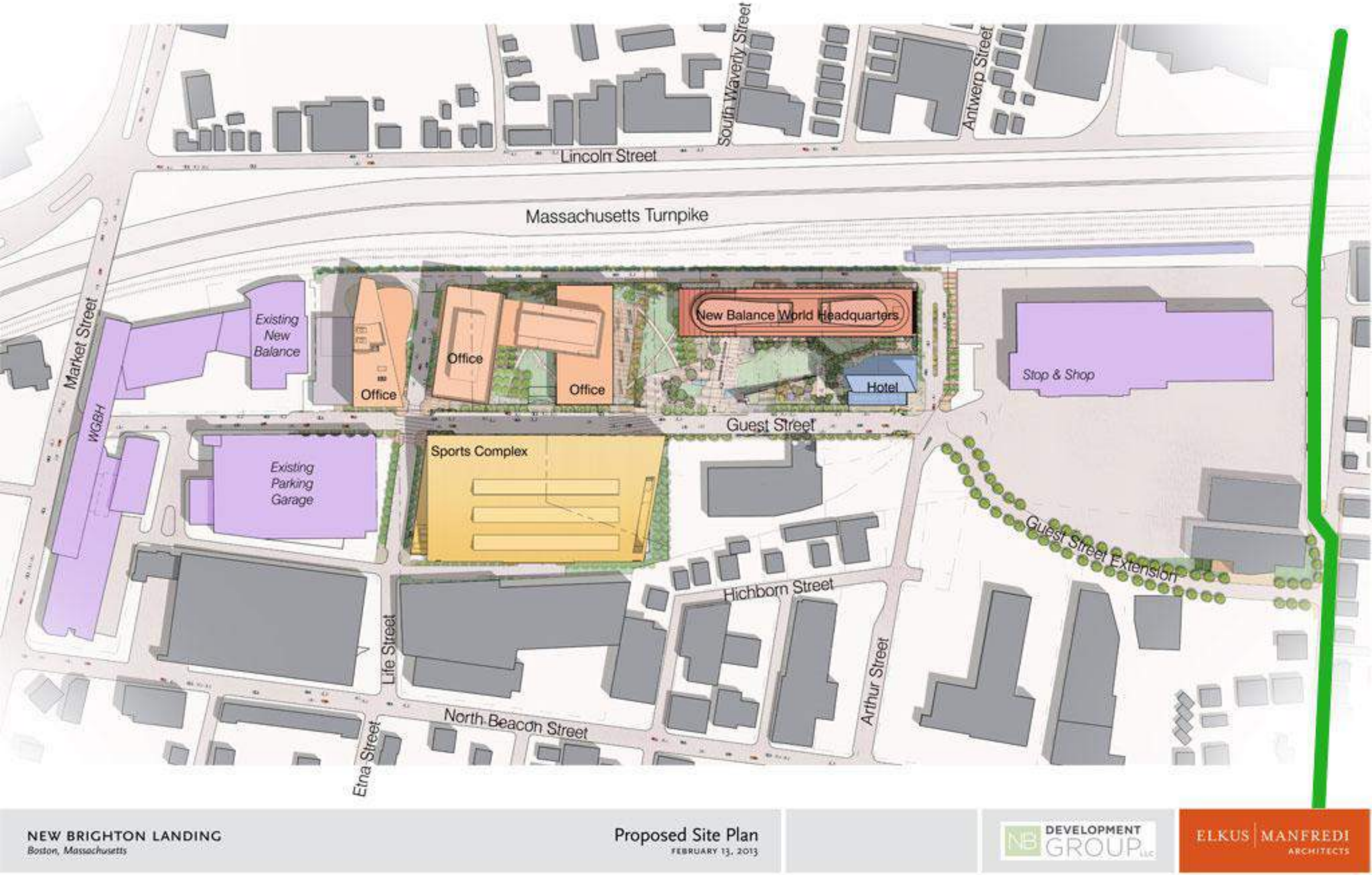
North Harvard St. south of Western has same options as JFK Bridge to Eliot St in Cambridge. Will require removal of on street parking.

Allston Option B



Could serve commercial strip on Harvard Ave if the shops support. Otherwise continue down Cambridge to Allston Union Square

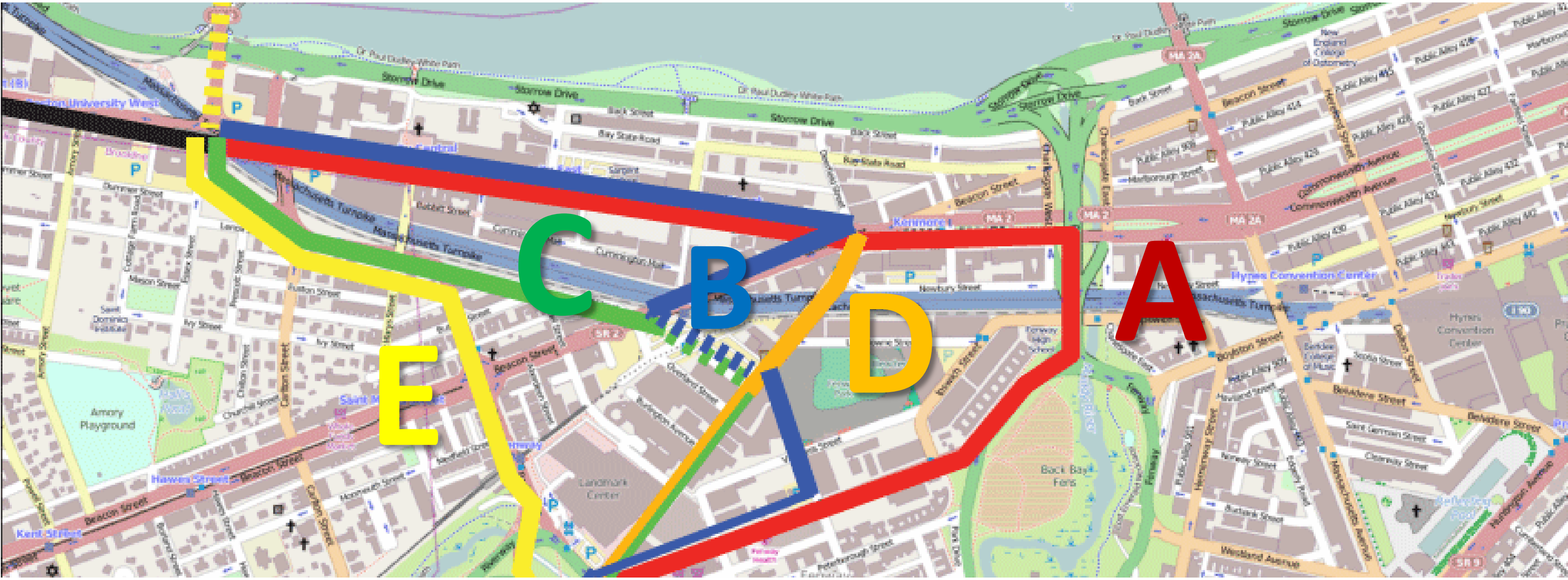
Allston Option C: New Brighton Landing

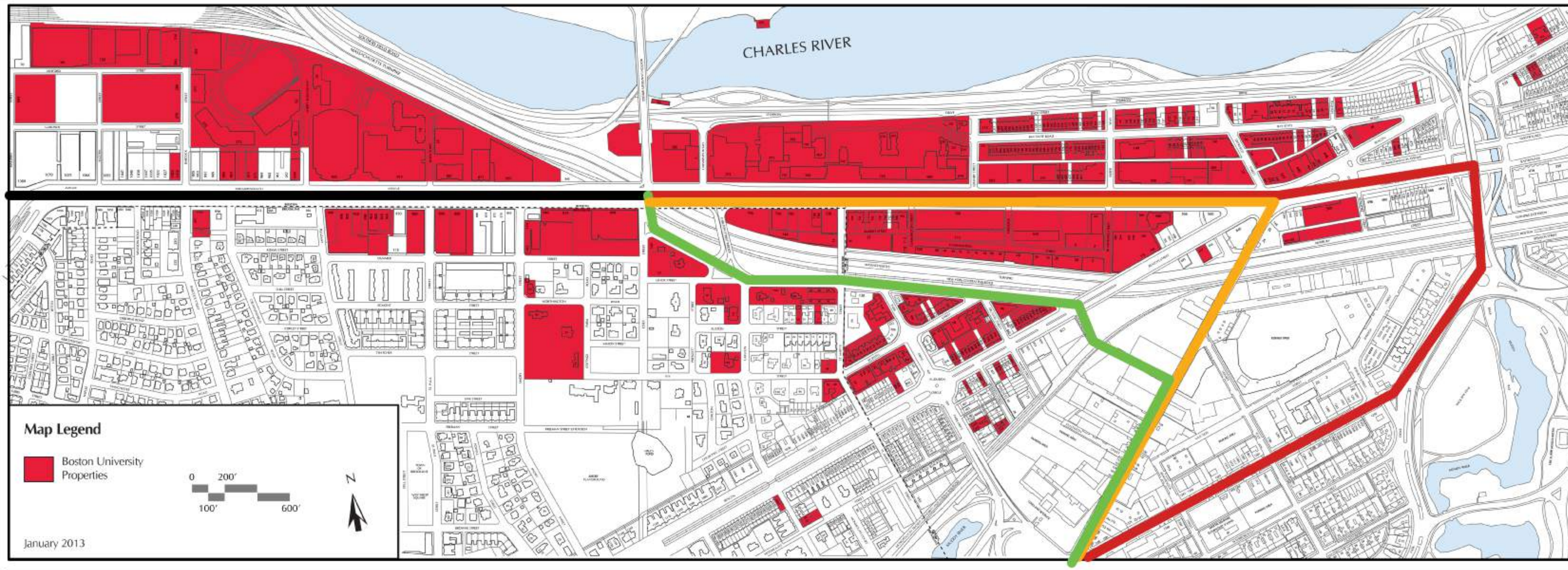


Option C could serve New Balance HQ and new commuter rail station but Everett St is very narrow.

Allston Option C

Fenway Options



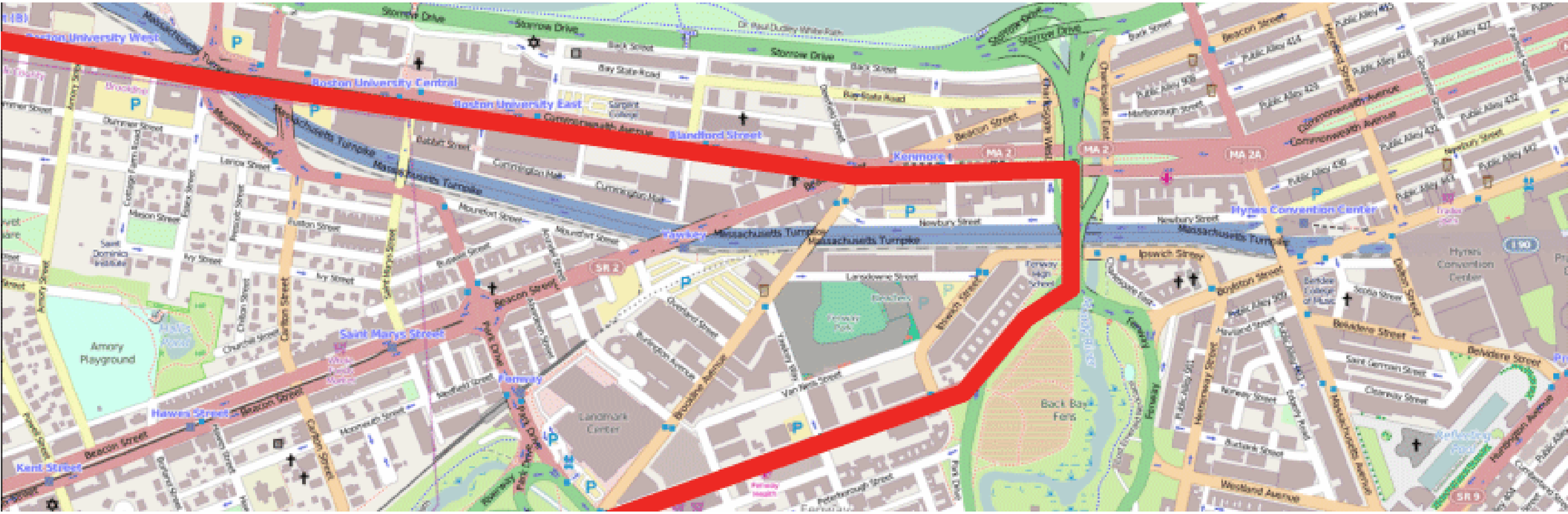


Boston University Charles River Campus
2013–2023 Institutional Master Plan

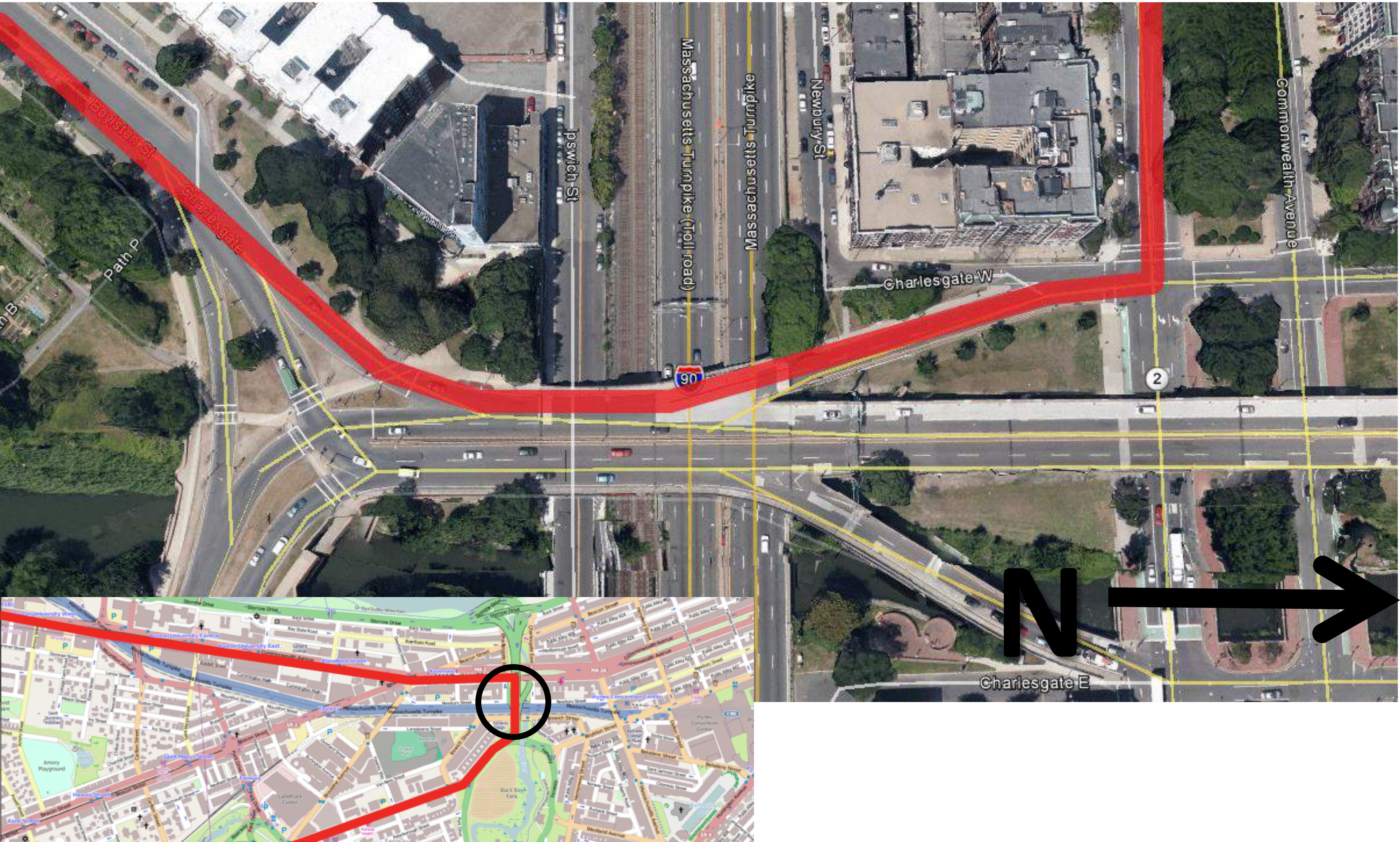
Figure 3-1
Boston University Properties
source: Fort Point Associates, Inc.
3-15

BU owns a large number of the properties in the area.

Fenway Option A:
Charlesgate-Boylston-Fenway



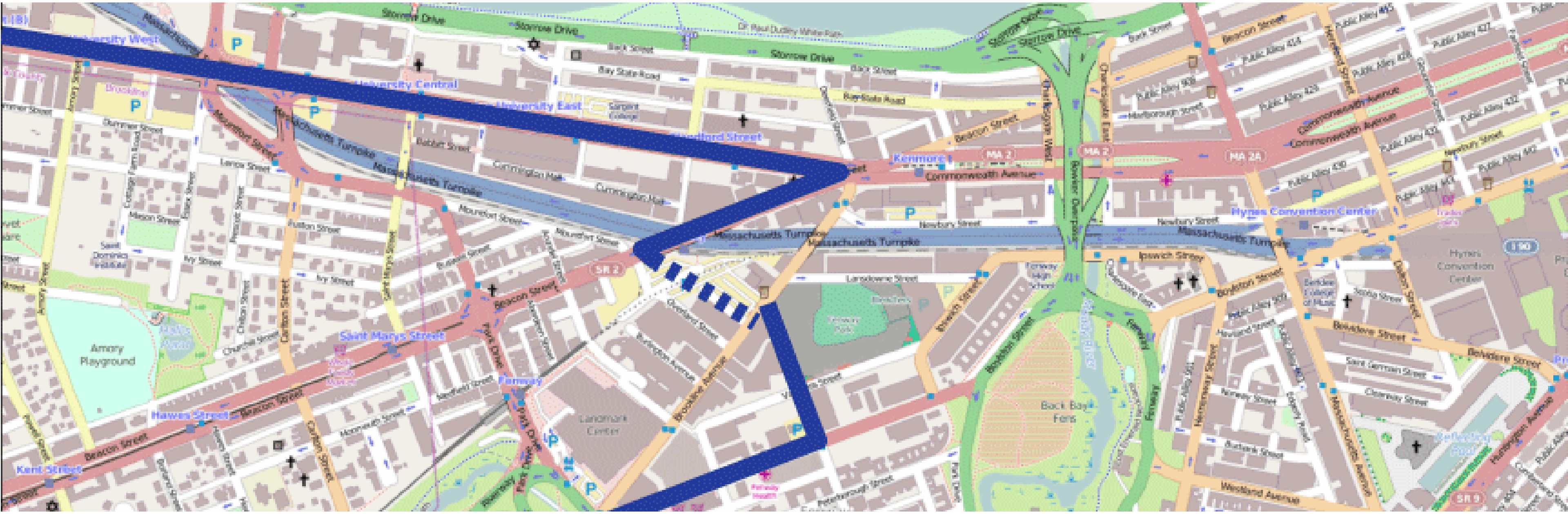
Fenway Option A requires dedicated BRT movement through Charlesgate.



Advantages of Fenway Option A

- Serves Commonwealth Ave 57 bus line longest.
- Charlesgate overpass slated for reconstruction anyway.
- Good access to Fenway without disrupting most popular pedestrian routes from Green Line
- Serves new development along Boylston (but requires City of Boston to freeze Boylston redesign contracts) which currently lacks bus service
- Right of way available for Gold Standard BRT
- Good connectivity with Mass Ave Bridge for rapid access for a new service connecting to Kendall if Corridor 9 moves forward
- Avoids Brookline Ave entirely which we are told is a ‘no go’.
- Needs to be integrated with plans to finish the Emerald Necklace and the Boylston/Fenway/Brookline Ave rotary.

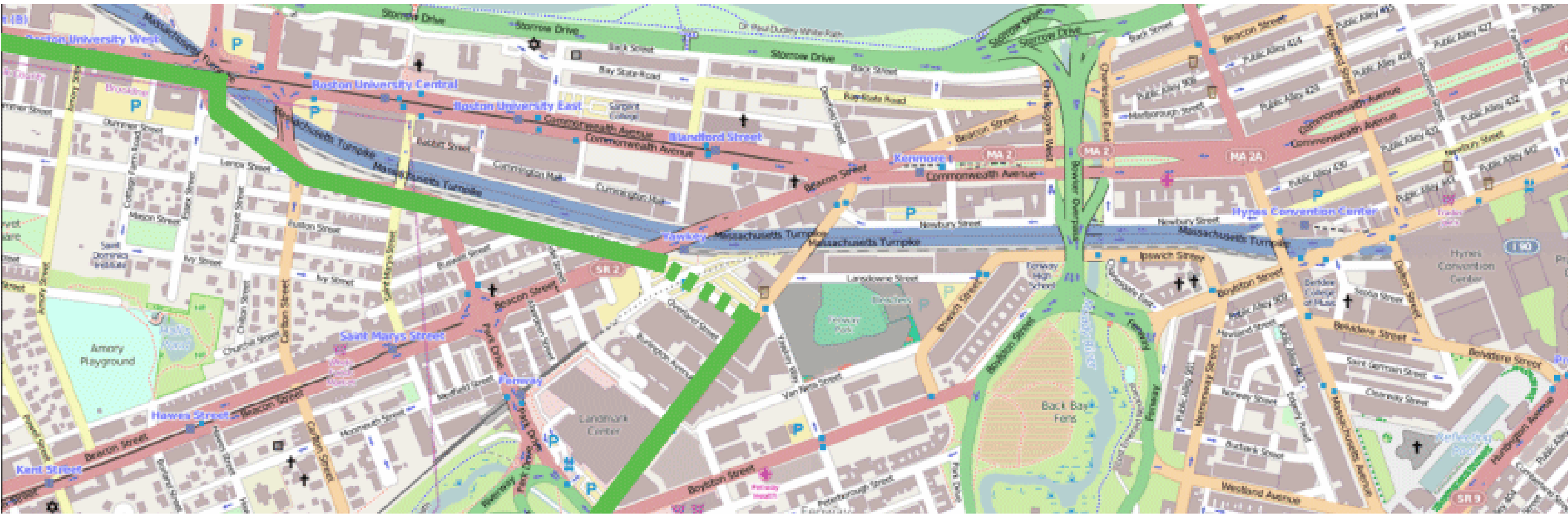
Fenway Option B:
Beacon - Yawkey-Boylston



Advantages and Disadvantages of Fenway Option B

- Better serves #47 bus to Central Sq over BU bridge & existing CT2
- Serves Comm. Ave.
- Provides connection at Kenmore
- Brookline Ave. section also serves #60, #65, #8, #19, CT3
- More direct route from Harvard to Longwood
- Requires new street through parking lot near Yawkey Station

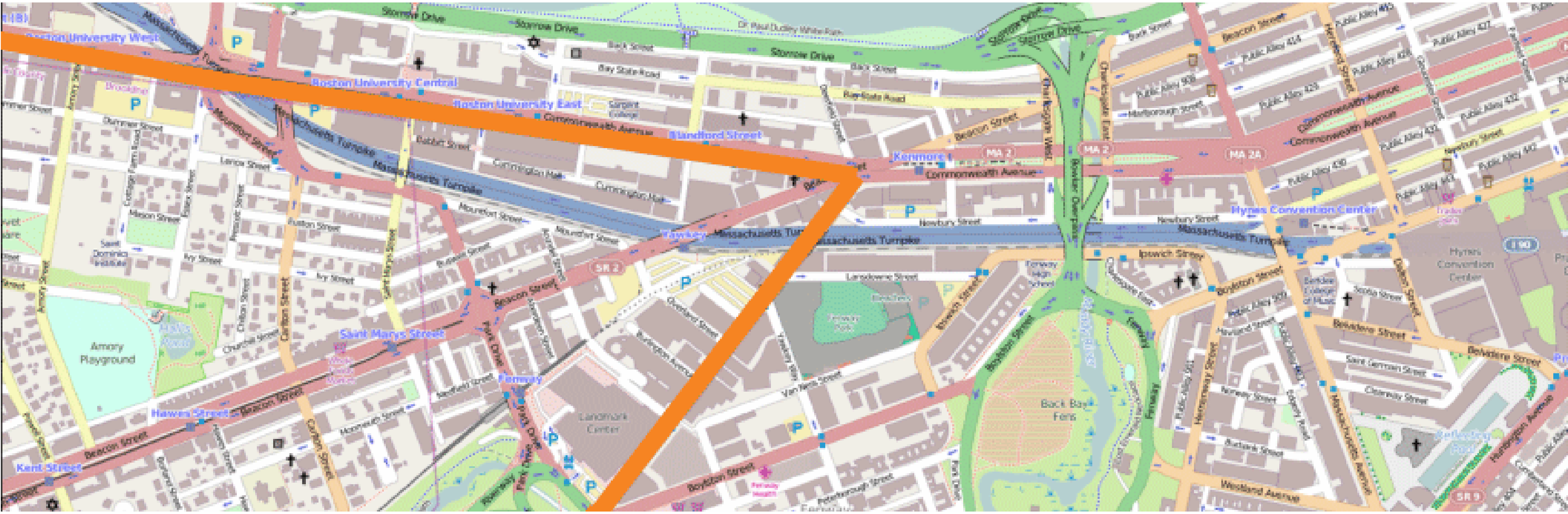
Fenway Option C: Mountfort – Brookline Ave



Advantages and Disadvantages of Fenway Option C

- Better serves #47 bus to Central Sq over BU bridge and existing CT2
- Brookline Avenue section also serves #60, #65, #8, #19, CT3.
- More direct route from Harvard to Longwood
- Misses Fenway and Boylston development area. Misses link to Kenmore T station
- Less Benefit to #57 on Commonwealth
- Requires new street through parking lot near Yawkey Station
- Brookline Ave very difficult politically

Fenway Option D: Brookline Ave



Advantages and Disadvantages of Fenway Option D

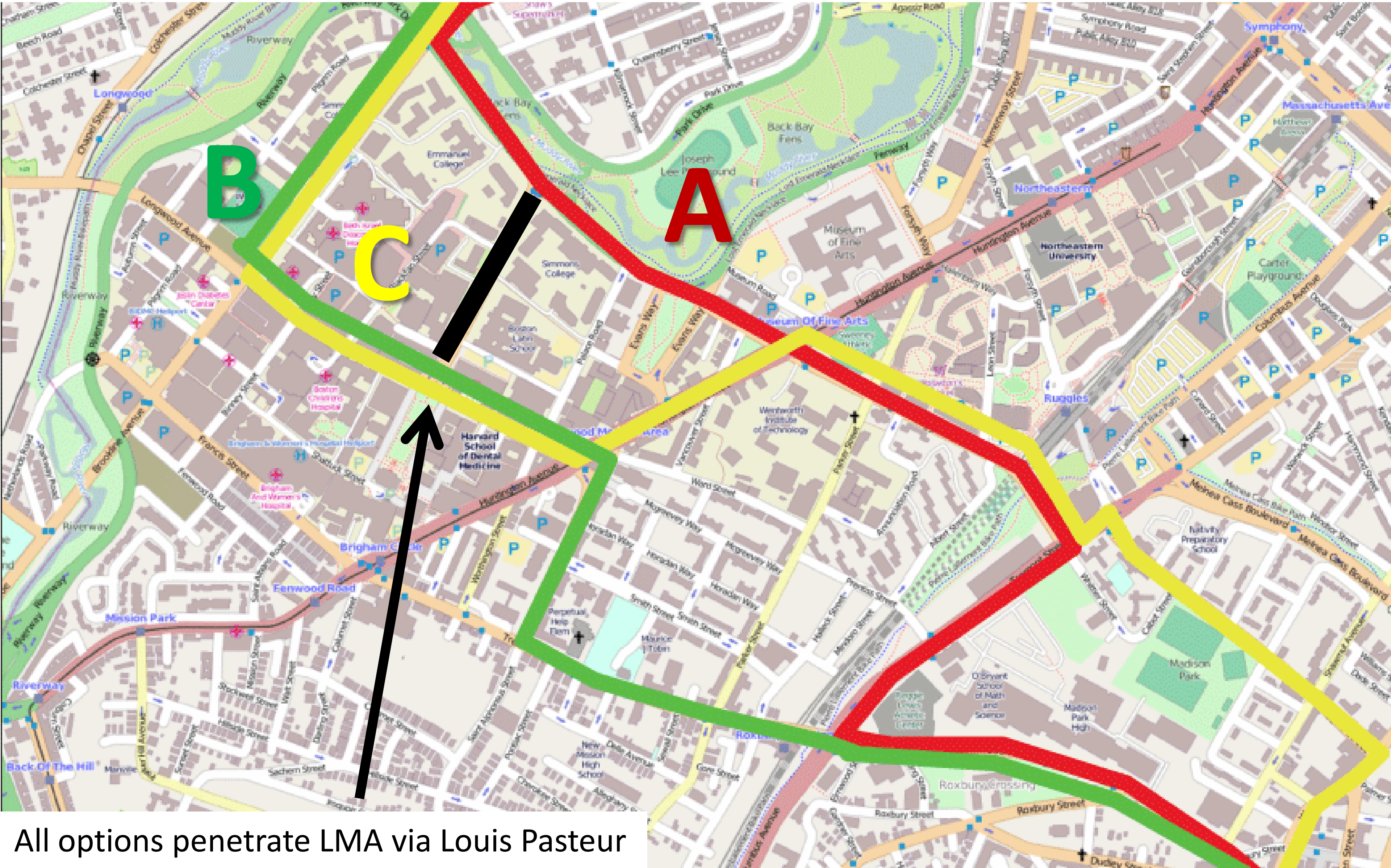
- Better serves #47 bus to Central Square over BU bridge and existing CT2
- Brookline Avenue section also serves #60, #65, #8, #19, CT3.
- More direct route from Harvard to Longwood
- Misses Fenway and Boylston development area.
- Serves #57 on Commonwealth and Kenmore T.
- Brookline Ave very difficult politically

Fenway Option E: Mountfort - Park Drive

Advantages and Disadvantages of Fenway Option E

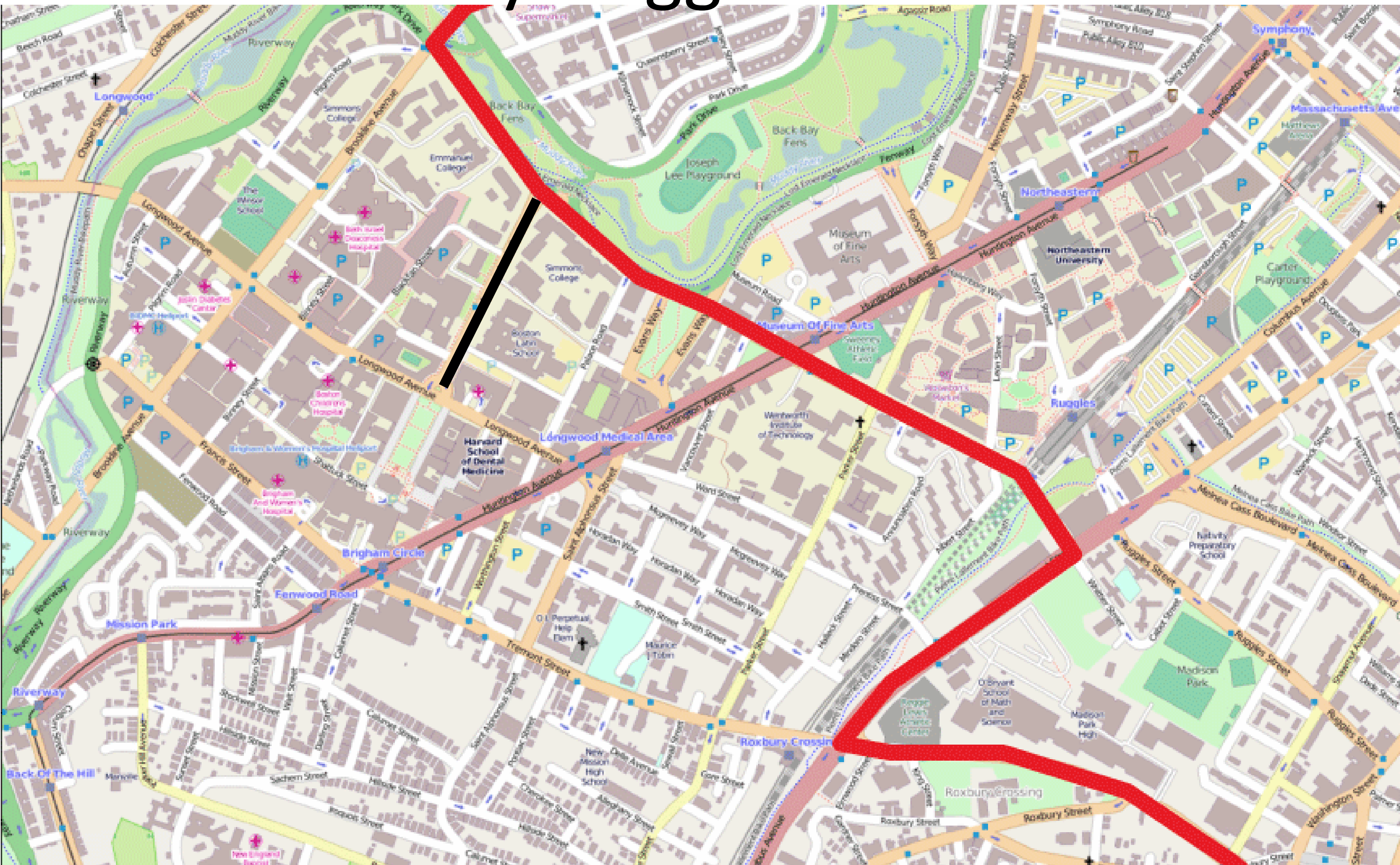
- Provides direct connection to Corridor 9 if BU Bridge option goes forward.
- Misses some destinations along Commonwealth Avenue and Kenmore Square.
- Misses Fenway Park
- Misses new development along Boylston St
- Avoids reconstructed Boylston St if not possible to freeze design process

Longwood Medical Area



All options penetrate LMA via Louis Pasteur

LMA Option A: Fenway-Ruggles-Tremont



Advantages and Disadvantages of LMA Option A

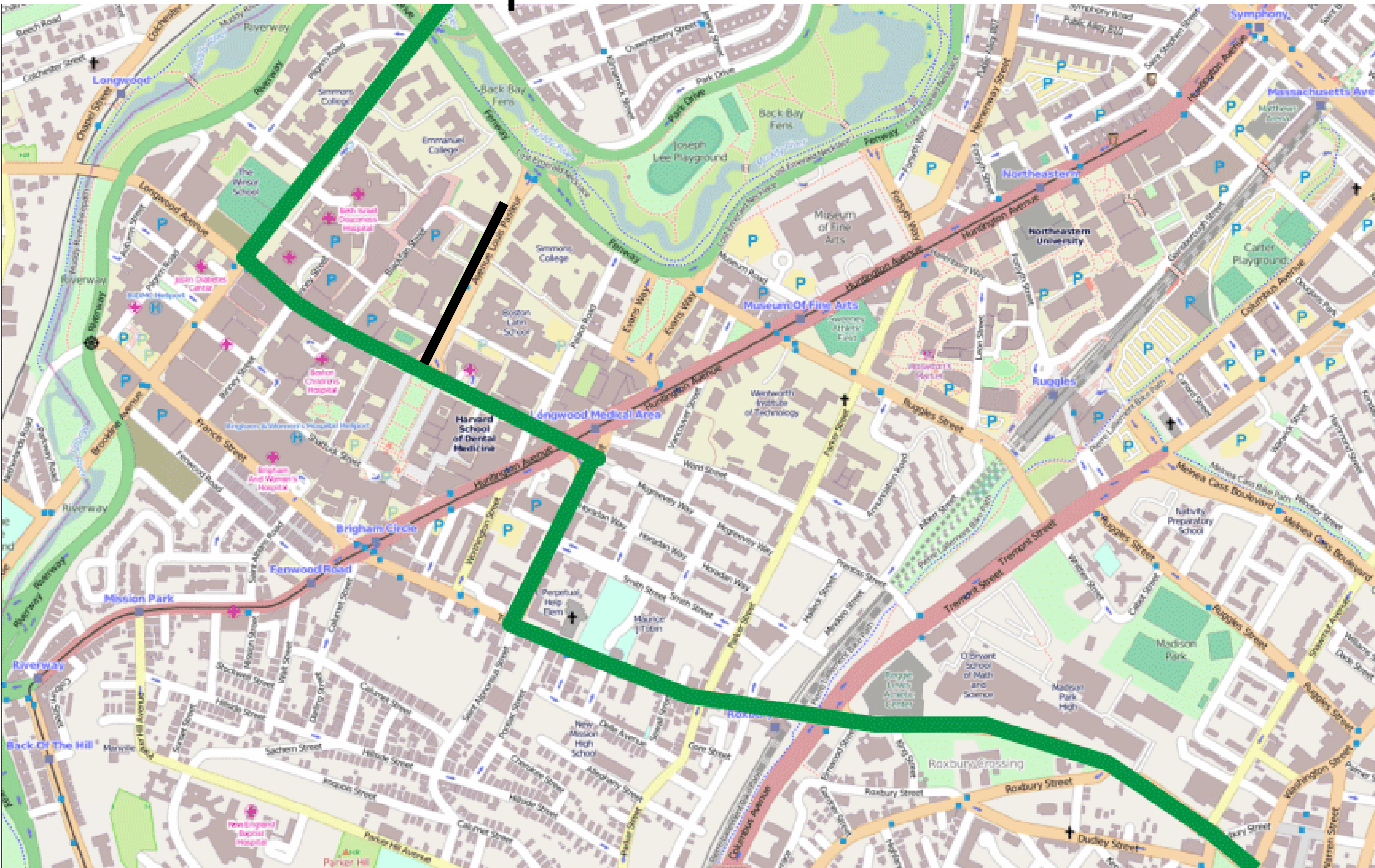
- Bypasses Brookline Ave but serves Longwood.
- All could be Gold Standard BRT though not so easy.
- Serves very high demand on Tremont to Ruggles, and on Malcolm X Blvd.
- Very direct link between Ruggles and Fenway and Commonwealth Ave
- Space is available (though it’s part of the Emerald Necklace)
- Spur into Longwood on Louis Pasteur or it’s a long walk to many of the medical facilities
- Need to turn Fenway back into a two way street.
- Need to see Sears rotary detailed design

LMA Option B: Brookline– Longwood–Huntington-Ruggles

Advantages and Disadvantages of LMA Option B

- Urban Ring Section 2
- Urban Ring study planned for mixed use operations, here we are analyzing Gold Standard BRT
- Uses Brookline Ave & Longwood Ave which are likely to be difficult politically

LMA Option C: Brookline-Longwood-St. Alphonsus-Tremont



Advantages and Disadvantages of LMA Option C

- Slightly better demand on Tremont than on other options
- Challenging ROW
- Uses Brookline Ave & Longwood Ave which are likely to be difficult politically

ITDP

Time Savings Analysis for Five Potential BRT Corridors in Greater Boston

August 2014

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This report was prepared by Annie Weinstock and Chris Van Eyken, on behalf of the Institute for Transportation and Development Policy. It was funded by a grant from the Barr Foundation.

Executive Summary

One of the most important aspects of BRT is its ability to produce dramatic time savings. In fact, many of the elements associated with gold-standard BRT are measures which reduce travel time for buses. Often it is helpful to look at how BRT on a particular corridor can reduce travel times for people already traveling on that corridor. To do this, we perform a "travel time savings analysis."

A travel time savings analysis begins with measuring existing travel times, generally for current bus riders, and determing:
a) how much of that time is simply end-to -end travel time for a bus b) how much of this time is spent at bus stops, at traffic signals, in congestion, etc. BRT cannot reduce travel time from category "a" since BRT is not innately faster than a regular bus. Instead, BRT reduces delays found in category "b" through a series of measures as defined in The BRT Standard.

For this study, ITDP has performed travel time savings analyses on the five corridors in question Dudley to Downtown, Mattapan to Dudley, Dudley to Harvard, and Sullivan to Longwood. The analysis was performed as if a passenger were traveling from one end to the other of each corridor. Although this is rarely the case, it provides a general picture of travel times on each corridor, and travel time reductions if the corridor is built out with gold-standard BRT.

This study provides a crude travel time savings analysis, using the information we currently have and supplemented by some field observations. It is not intended to be a detailed travel time savings analysis, which would require more detailed stop-by-stop, and link-by-link data, and ideally, a full origin-destination matrix, which was not readily available and would take more time and resources to collect and process. Instead, we made several assumptions, based on our experience planning BRT in other cities in the US and abroad, which are all documented in detail in this report.

It is important to note that this study quantifies travel time savings only. However, it is not intended to deemphasize the other important benefits of BRT. In fact, the kinds of reductions in various sources of delay documented in this memo also typically result in increased on-time reliability. And other elements of gold-standard BRT, when done right, are designed to increase comfort and safety for passengers as well as for nearby pedestrians and cyclists. This memo focuses only on the time savings.

Results

In absolutes, the most substantial travel time savings were on the Dudley to Harvard Corridor where the end-to-end travel time drops by 23.9 minutes with gold-standard BRT. However, this is due in part to the fact that Dudley to Harvard is longer than the other corridors. When looking at the percent reduction in travel time from current to BRT scenarios on each corridor, the greatest percentage reductions are found on Dudley to Downtown (45.2%). However, two other corridors – Dudley to Harvard and Mattapan to Dudley – both show considerable percentage reductions in travel times. The Readville to Forest Hills and Sullivan to Longwood corridors show smaller travel time savings than the other three. Below is a chart comparing current and BRT travel times for each corridor (with two alternatives for Sullivan to Longwood), and broken down by source of delay.

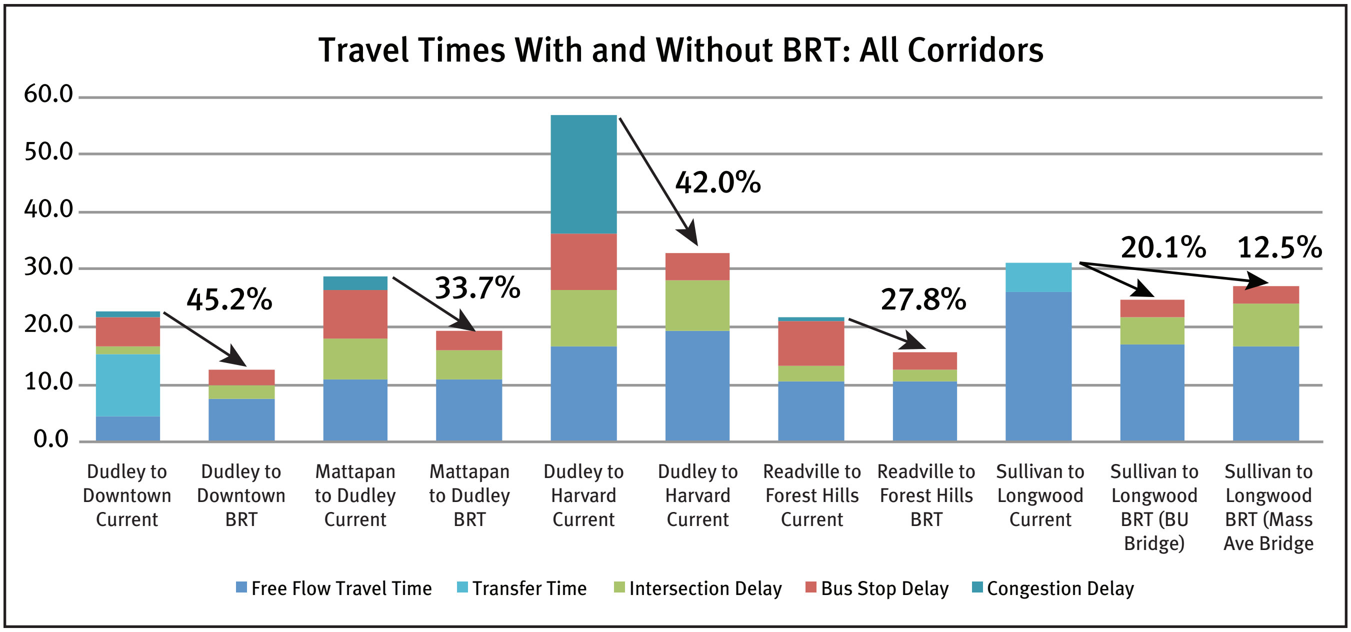

Figure 1: Travel time savings created by Gold Standard BRT

By corridor, this translates to travel time savings as follows:

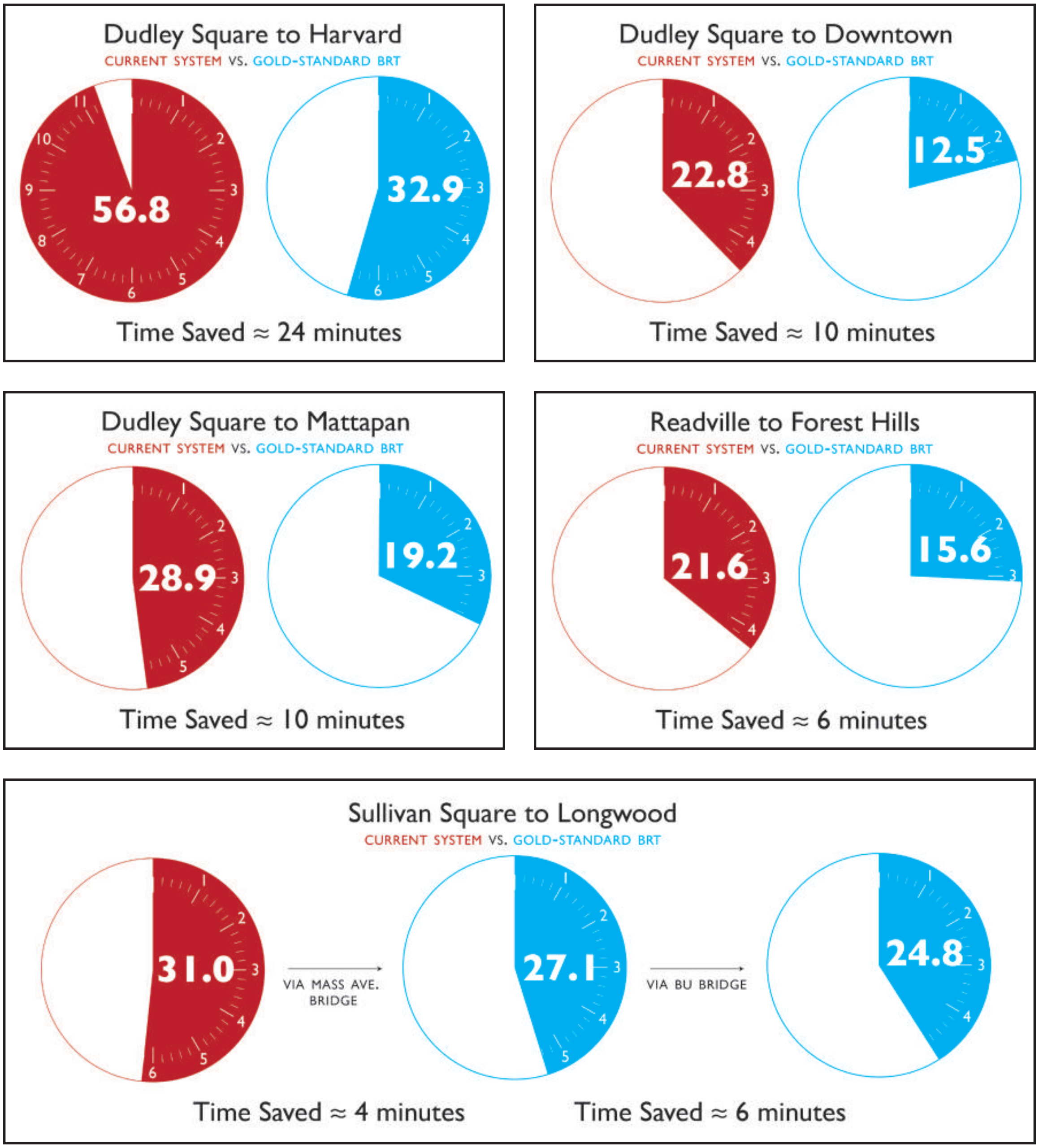

Figure 2: Travel time savings created by Gold Standard BRT

Note, of course, that travel time savings is accrued to passengers, not to buses. It would take a more detailed service planning and origin-destination analysis to determine the aggregate travel time savings for all passengers using these corridors since in fact, most people are not simply traveling end-to-end.

The following report describes in detail the methodology and results for the time savings analysis on each of these five corridors.

Introduction

Whether or not a BRT project can produce time savings is an important consideration when selecting a corridor. If a BRT investment can have considerable benefits for passengers, it may be worth considering. This report provides an end-to-end time savings analysis for each of the five corridors studied by ITDP and the Greater Boston Bus Rapid Transit Study Group as below.

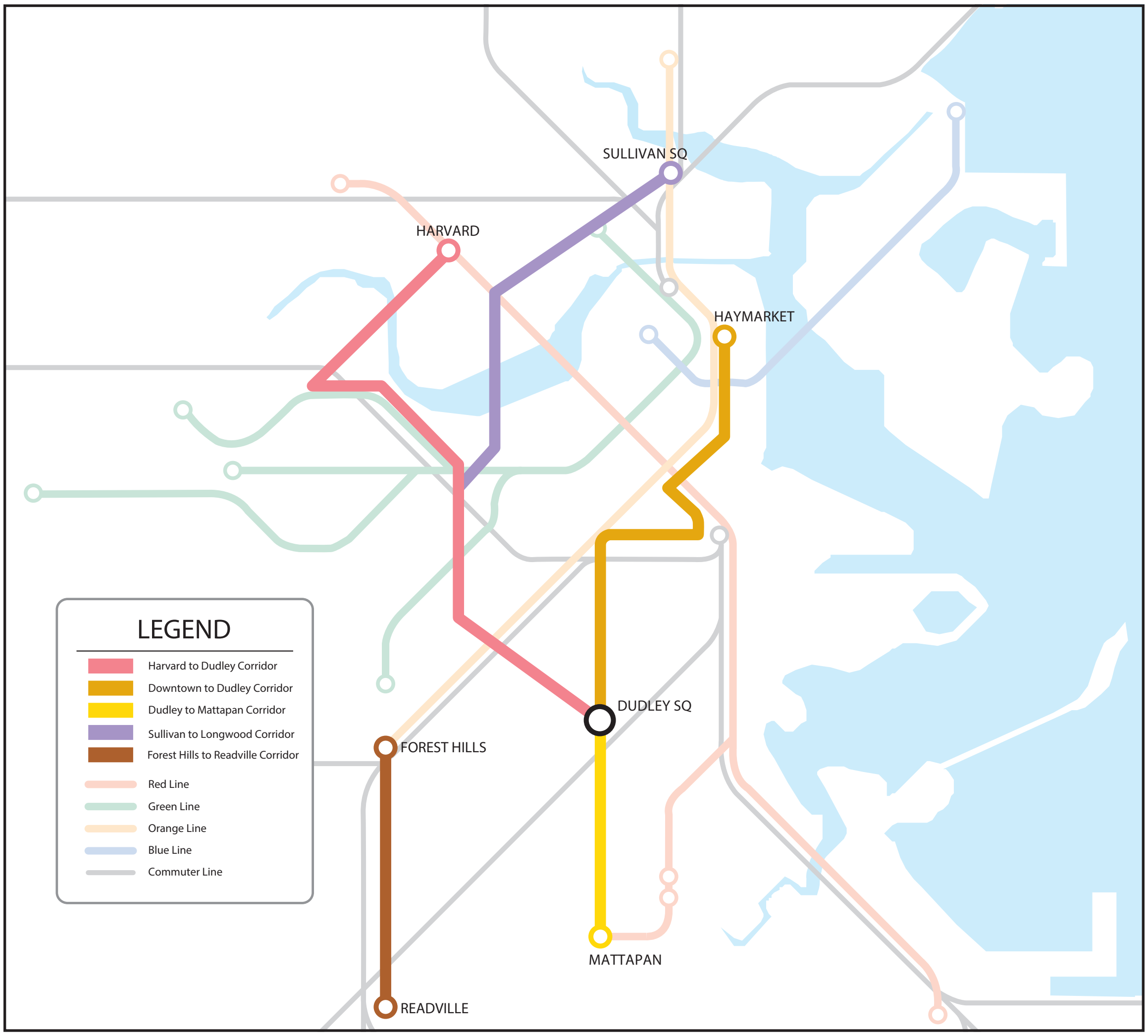

Figure 3: Greater Boston BRT Network Map

The data should also be useful in conveying to the public the relative benefits of gold-standard BRT on each corridor. This analysis begins with an explanation of the baseline conditions for bus services operating on the corridors, and then compares this to the delay reductions that are possible with gold-standard BRT.

Measuring Existing Travel Times

This travel time savings analysis began with a measurement of total current travel times for bus passengers which travel along these corridors from end to end. Since not all of the corridors have bus routes which operate from end to end, the bus routes which most closely mimic the corridors were chosen and adjustments made as below. The average run for those routes during the AM peak (7-8am) became the starting point. This data was obtained through a combination of MBTA's automatic vehicle locator (AVL) data and MBTA's bus schedule information.

• **Dudley to Downtown – 22.8 minutes:** The baseline for this corridor was the travel time of the SL5 which travels from Dudley to Downtown Crossing. However, an important part of this corridor's routing is the fact that it continues past Downtown Crossing, penetrating Downtown Boston, providing a more direct trip for passengers coming up from Dudley Square and Washington Street. Therefore, Haymarket was selected as the terminus in order to make a basic assumption for this analysis.

Today, if a Silver Line passenger wishes to go to Haymarket, the terminus of the Downtown BRT extension, the two most likely options are to transfer to the Orange Line or to walk (there are other possibilities but for simplicity sake, only these two were considered). At a distance of 0.7 miles between Downtown Crossing and Haymarket, and a walking speed of 3 mph (based on the typical U.S. design speed for walkers), the trip, if done on foot, would add fourteen minutes of travel time to a 15.8 minute trip on the Silver Line to Downtown Crossing. If passengers choose to transfer to the Orange Line to reach Haymarket, they will either transfer from the Silver Line at Tufts Medical or go all the way to Downtown Crossing. Looking at scheduled travel times, the trip on the Orange Line from Tufts Medical to Haymarket takes six minutes. The headways on the Orange Line in the peak period are six minutes. So the average waiting time is three minutes. Adding another two minutes to walk to complete the transfer would result in an eleven minute transfer. However, the travel time from Dudley to Tufts Medical Center is 11.8 minutes – four minutes shorter than Dudley to Downtown Crossing. If passengers instead chose to make the transfer to the Orange Line at Downtown Crossing, the trip on the Orange Line takes about three minutes. The average waiting time is also three minutes. Finally, walking down from the street to the subway platform and back up at the other end adds an additional four minutes (approx) to the transfer. This would result in ten minutes for the transfer but 15.8 minutes for the trip from Dudley to Downtown Crossing. While the travel time from Tufts Medical is longer, overall, time would still be saved as the rider would be removed from congestion on the street between Tufts Medical and Downtown Crossing. To be conservative, no "transfer penalty" (i.e., a multiplier due the inconvenience of transferring) was included, although it is common to transit modeling.

Thus, with an 11.8 minute trip on the SL5 and an 11 minute trip from Tufts Medical to Haymarket, the total current travel time for the Dudley to Downtown Corridor was 22.8 minutes, for a trip length of 3 miles.

• **Mattapan to Dudley – 28.9 minutes:** The baseline for this corridor was the travel time of the 28 which travels the full length of the corridor (but continues to Ruggles). The 28's average AM peak run from Dudley to Mattapan was 28.9 minutes, for a trip length of 4.5 miles.

• **Dudley to Harvard – 56.8 minutes:** The baseline for this corridor was the travel time of the 66. There are some variances in the routing between the current 66 and the Dudley to Harvard corridor, namely that the Harvard to Dudley corridor reroutes from Harvard Street in Brookline to the Longwood Medical Area. For the existing conditions, the current 66 routing is used. It is roughly comparable to the conditions on the Dudley to Harvard corridor routing. The 66's average trip took 56.8 minutes, for a trip length of 6.0 miles.

• **Readville to Forest Hills – 21.6 minutes:** The baseline for this corridor was the travel time for the 32 between the Readville and Forest Hills station. The average AM peak run travelled 4.1 miles in 21.6 minutes.

• **Sullivan to Longwood – 31.0 minutes:** For the Sullivan to Longwood trip, a bus route – the CT2 – could be used. However, there is also currently a rapid transit option available - the Orange

Line to the Green Line – which is used by many more passengers making this trip than the CT2. Therefore, the baseline end-to-end travel time for this corridor was the scheduled time on the two rapid transit lines. For the Orange Line from Sullivan Station to Haymarket Station, the in-vehicle travel time is five minutes. The scheduled time from Haymarket to the Museum of Fine Arts (the closest station to the terminus of this corridor) is 21 minutes. An additional three minutes was added for average wait time and an additional two to account for walk time between the Orange and Green Lines within the Haymarket Station. This results in a total travel time of 31 minutes.

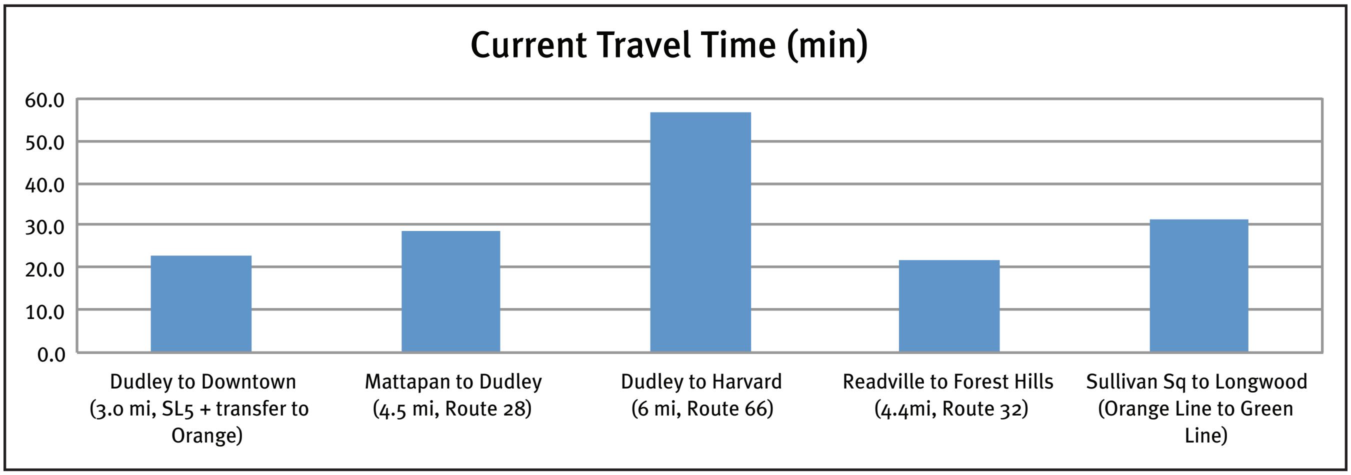

Figure 4: Current end-to-end travel times

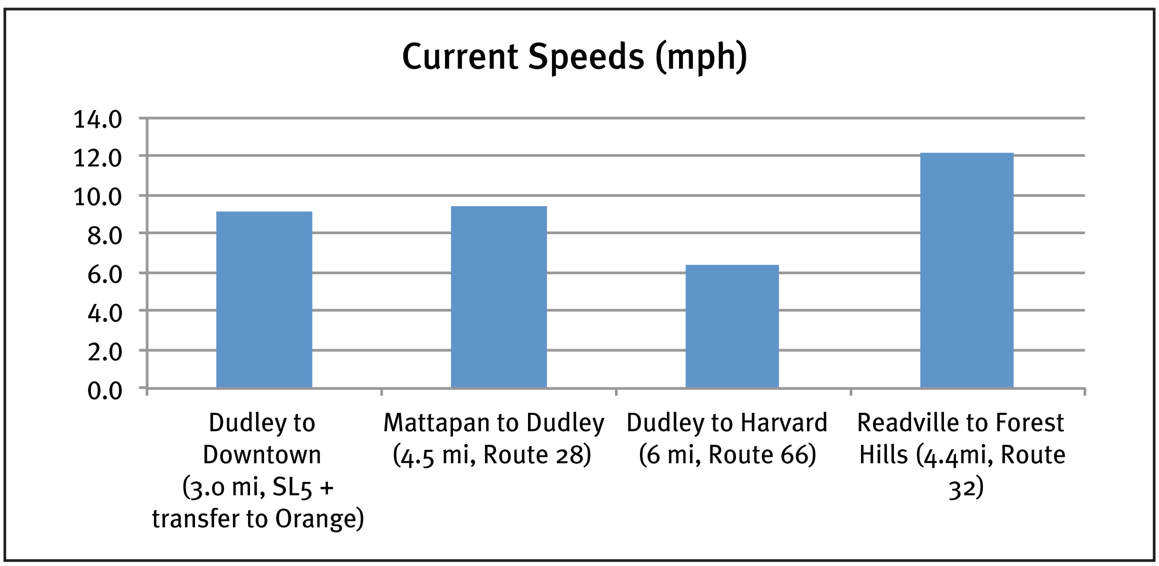

Figure 5: Average speeds from end-to-end

This total travel time for each corridor can then be broken down into “free flow end-to-end travel time” and “sources of delay.”

Free Flow End-To-End Travel Time

Free flow end-to-end travel time is the time it takes a bus to travel the length of the corridor if it does not make stops or get stopped at intersections, and is unimpeded by traffic. This analysis begins with free flow end-to-end travel time as the absolute minimum travel time possible and then adds in sources of delay.

In order to calculate free flow travel time for the corridors where the baseline was a bus route, we begin with free flow speed. We used 24.85 mph as a reasonable free flow speed for buses in an urban environment with moderately wide streets, as we found this to be true in a more detailed travel time savings analysis done in Chicago. A speed of 21.5mph was used for the Dudley to Harvard corridor and the Downtown section of the Dudley to Downtown corridor to reflect the narrower streets and greater number of turns. The end-to-end free flow end-to-end travel time for Sullivan to Longwood (26 minutes) was taken from the calculated trip time for the trip via the Orange and Green Lines.

Using these free flow travel speeds, we calculated the free flow travel time for each corridor based on its length as follows:

Corridor	Length (mi)	Current Travel Time (min)	Free Flow Travel Time (min)	Resulting Sources of Delay (min)
Dudley to Downtown Current	3.0	22.8	4.3	18.5
Mattapan to Dudley Current	4.5	28.9	10.9	18.0
Dudley to Harvard Current	6.0	56.8	16.7	40.1
Readville to Forest Hills Current	4.4	21.6	10.6	11.0
Sullivan to Longwood Current	4.6	31.0	26.0	5.0

Figure 6: Current travel times all corridors - free flow vs all other sources of delay

At this point, the free-flow travel time can be removed from the total existing travel time for each corridor as this travel time savings analysis is more concerned with existing sources of delay. Whatever travel time remains after free-flow travel time has been removed constitutes existing sources of delay.

Sources of delay

Corridor	Free Flow Travel Time	Bus Stop Delay	Intersection Delay	Congestion Delay	Transfer Time	Total Travel Time
Dudley to Downtown Current	4.3	5.0	1.4	1.0	11.0	22.8
Mattapan to Dudley Current	10.9	8.5	7.1	2.4	--	28.9
Dudley to Harvard Current	16.7	9.9	9.5	20.6	--	56.8
Readville to Forest Hills Current	10.6	7.5	2.7	0.8	--	21.6
Sullivan to Longwood Current	26.0	--	--	--	5.0	31.0

Figure 7: Current travel times all corridors - sources of delay by category

Now that we know for each corridor how much delay exists, we can break down the delay by type.

Bus stop delay

Every time a bus stops, some delay is accrued and this affects all passengers onboard the bus. Bus stop delay is made up of two components: fixed dwell time delay and boarding (variable) delay.

Fixed dwell time is the time it takes a bus to pull into the station and stop, open its doors, close its doors, and pull out of the station. We used a value of 10 seconds per stop for fixed dwell time, as fixed dwell time is generally a characteristic of buses and does not vary much from city to city. 10 seconds is recommended in *The BRT Planning Guide*[1].

In order to calculate the total existing fixed dwell time on each corridor, the number of existing bus stops was multiplied by the fixed dwell time value of 10. The number of stops is based on the number of stops that each route currently has on the corridor. The Dudley to Downtown and Dudley to Harvard corridors included the number of stops found on Routes SL5 (13 stops) and 66 (40 stops), respectively, despite the differences in routing. For Mattapan to Dudley, the number of stops (34 stops) was more straightforward as the route mirrors the Route 28. For Readville to Forest Hills, the number of stops on the 32 was used (34 stops). Sullivan to Longwood is left out of the bus stop delay section since only rapid transit travel times were used for that corridor.

Boarding delay is the time it takes each passenger to board. Like fixed dwell time delay, it is a delay that is born by all passengers waiting on the bus. Since every city varies in terms of the length of time it takes passengers to board, on average (generally due to the payment method, age, and health of the bus riding population), peak hour observations were made on several of the routes which operate on the corridors. Observations were made on Routes SL4, SL5, 28, 47, and 66, as well as at Dudley Station. It was found that, on average it takes passengers on these corridors 3.3 seconds to board.

Using MBTA data on total peak hour boardings on the routes that operate on each corridor, these peak hour boardings were multiplied by 3.3 seconds and divided by route frequency. SL5 was used for Dudley to Downtown, Route 28 was used for Mattapan to Dudley, Route 66 was used for Dudley to Harvard, and Route 32 for Readville to Forest Hills. Since total boarding delay is not affected by the number of stops (only total fixed dwell time delay is), the number of stops is not included in the calculations for boarding delay. Boarding delay was calculated by dividing peak hour passenger boardings by route frequency (the number of buses that begin or end service within five minutes of the peak hour).

Intersection Delay

The final source of delay included in this analysis is intersection delay. A detailed intersection-by-intersection analysis, including intersection-specific signal timings, would be the most accurate method of calculating intersection delay. However, given time constraints, this analysis applied a broad assumption that buses will lose an average of twelve seconds per signal where left turns are permitted, throughout the Dudley to Downtown, Mattapan to Dudley corridors, and Readville to Forest Hills. An average of fifteen seconds was used for Dudley to Harvard since, due to the many twists and turns, signal progression (i.e., green wave) is nearly impossible on this corridor.

For Dudley to Downtown, Mattapan to Dudley, and Readville to Forest Hills there are some intersections where left turns are already prohibited or do not exist. At those locations, the average twelve second delay was reduced by four seconds to eight seconds. For Dudley to Harvard, the delay was reduced by four seconds from fifteen to eleven where left turns are prohibited or do not exist. As the Sullivan to Longwood BRT options were compared to a rapid transit ride, there was no reduction calculated.

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[1] Hook, W., & Wright, L. (2007). *Bus Rapid Transit Planning Guide*. New York City: The Institute for Transportation and Development Policy.

Congestion Delay

With all main sources of delay accounted for, the remainder of delay is delay to buses due to being stuck in traffic congestion.

Corridor	Current Travel Time	Free Flow Travel Time	Transfer Time	Bus Stop Delay	Intersection Delay	Resulting Congestion Delay
Dudley to Downtown Current	22.8	4.3	11.0	5.0	1.4	1.0
Mattapan to Dudley Current	28.9	10.9	0.0	8.5	7.1	2.4
Dudley to Harvard Current	56.8	16.7	0.0	9.9	9.5	20.6
Readville to Forest Hills Current	24.6	10.6	0.0	7.5	2.7	0.8

Figure 8: Current travel time all corridors - all sources of delay with resulting congestion delay

Overall, the existing delay by corridor is broken down in the chart below:

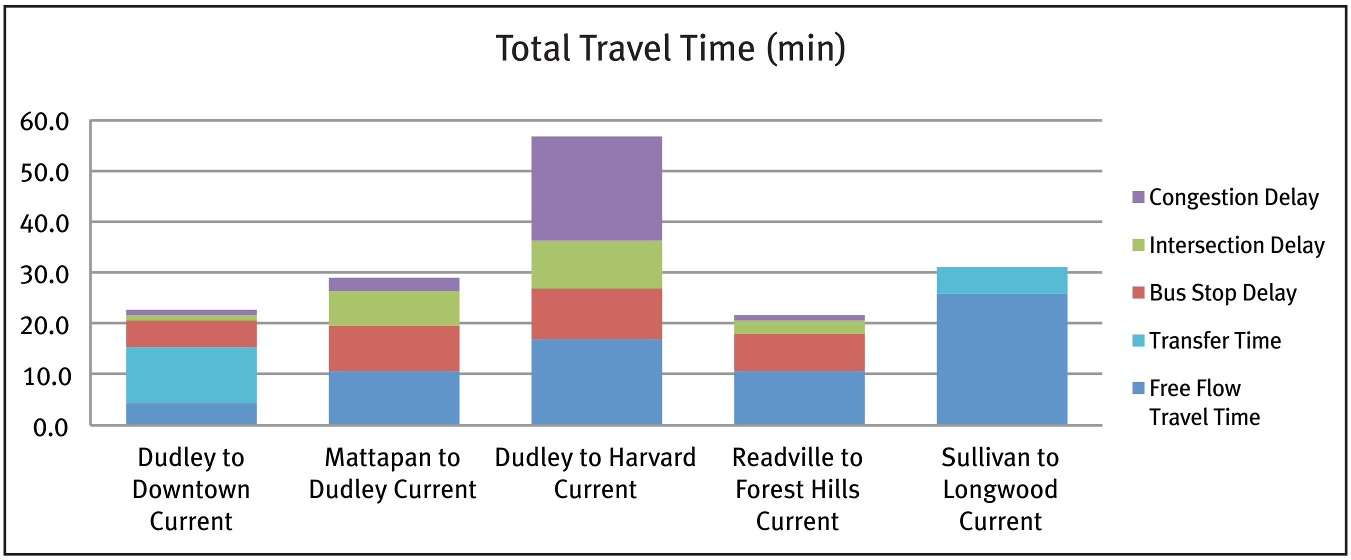


Figure 9: Current travel time all corridors - all sources of delay

A specific discussion of the existing sources of delay by corridor follows:

Dudley to Downtown

The existing sources of delay on the Dudley to Downtown corridor are largely related to high volumes of passengers boarding with no measures to speed up the boarding process. There are also some considerable problems with traffic congestion. Most of this congestion is in Downtown Boston from Washington Street to Downtown Crossing and in the section of the corridor leading into Dudley Square. Some additional congestion-related delay is experienced where vehicles are double parked in the Silver Line bus lane and buses must pull out of the bus lane and travel around double parked vehicles. Finally, with TSP not fully functional on Washington Street and many left turns causing longer signal cycles, buses are also getting caught at intersections.

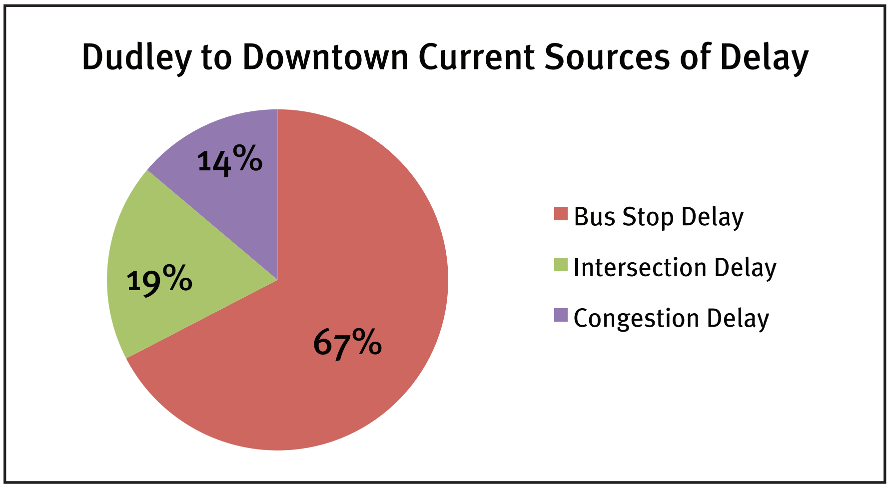


Figure 10: Dudley to Downtown: current sources of delay by percentage

Mattapan to Dudley

Like Dudley to Downtown, the largest source of delay for Mattapan to Dudley is bus stop delay. Large concentrations of boarding and alighting passengers slow travel time for the Route 28 significantly.

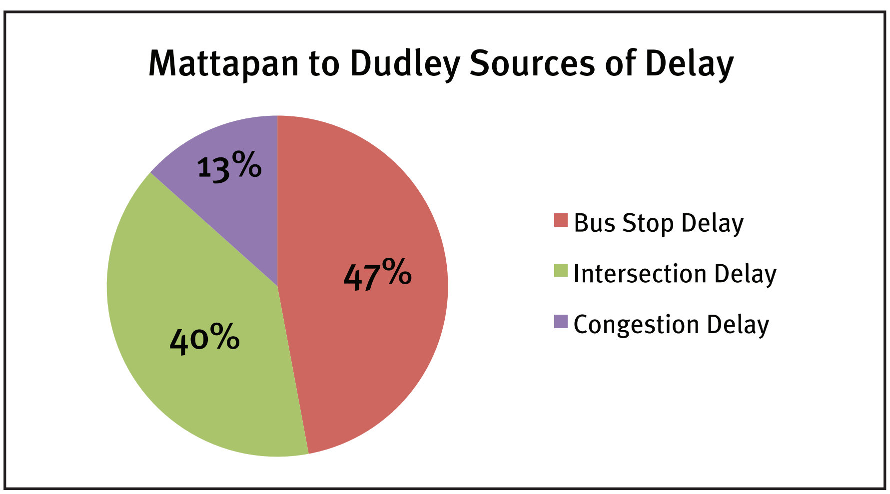


Figure 11: Mattapan to Dudley: current sources of delay by percentage

Dudley to Harvard

While bus stop delay on the Dudley to Harvard corridor is also a major component of the overall delay, the greatest source of delay on the corridor is traffic congestion. While this study focused on the 66 bus route for existing conditions, shared portions of both corridors show extreme congestion. Additionally, congestion levels on the differing parts of the corridors (e.g., Harvard Street in Brookline versus Longwood Medical Area) are comparable. Throughout much of this corridor, streets are relatively narrow, vehicles often double park, and traffic volumes are high.

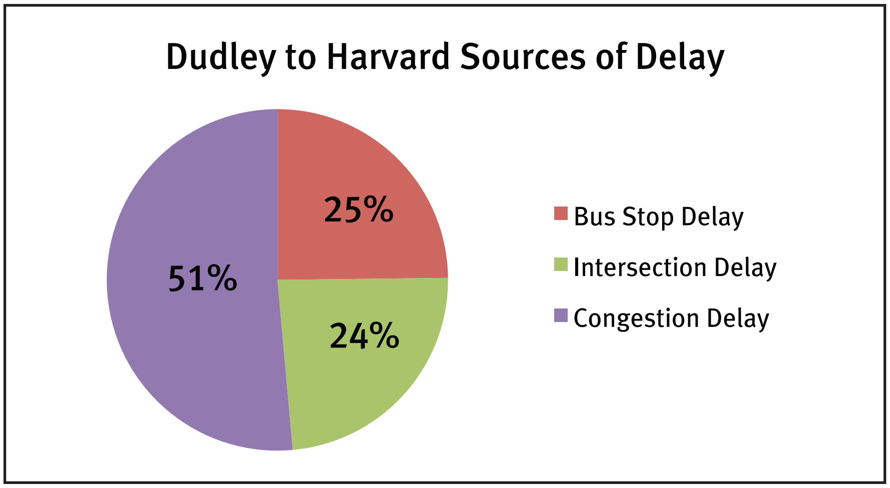


Figure 12: Dudley to Harvard: current sources of delay by percentage

Readville to Forest Hills

Bus stop delay was the most significant factor on the Readville to Forest Hills corridor with intersection delay making up the bulk of the remaining delay time. Congestion delay was less of a factor, most likely due to the corridor's distance from the CBD.

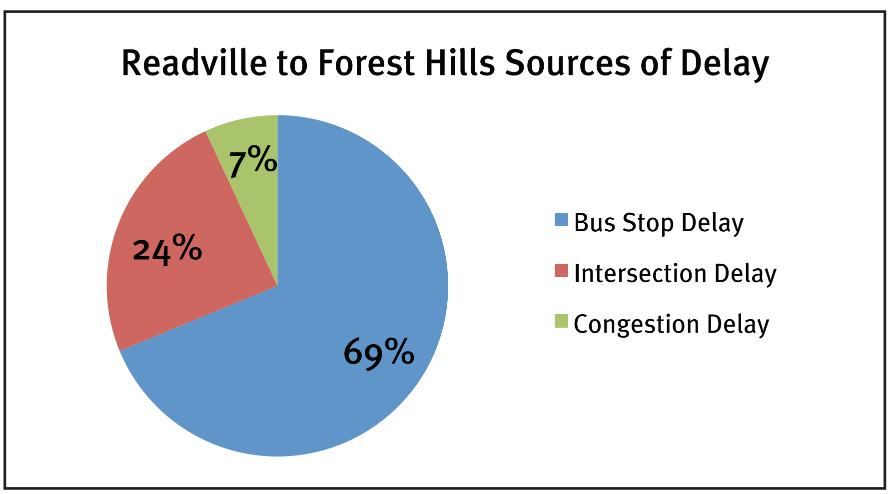


Figure 13: Readville to Forest Hills: current sources of delay by percentage

Sullivan to Longwood

For the Sullivan to Longwood corridor, travel time was compared to the MBTA's scheduled trip time between the two stations via the Orange and Green Lines. It is assumed that any delay, such as stop delay or train congestion, is rolled into the scheduled time which in this analysis, translates to free-flow travel time. Thus, the only delay captured in this analysis on this corridor is transfer delay – i.e., the time it takes to transfer between the Orange Line and the Green Line at Haymarket Station. The six minute headway on the Green Line E's AM peak, translate to a three minute average wait time during the transfer. An additional two minutes were added to account for walk time in the station to make the transfer. Thus, the only source of delay considered for this analysis on the Sullivan to Longwood corridor is the 5 minutes transfer time at Haymarket.

Travel Time Savings with Gold-Standard BRT

A gold-standard BRT can reduce travel time by reducing many of the above sources of delay. This analysis assumes that all gold-standard elements can be implemented. If they cannot, then the travel time savings will be less pronounced.

Free flow end-to-end travel time does not vary between standard bus and BRT and thus will always be the absolute minimum possible travel time on the corridor. However, where certain BRT corridors are of a different length than the baseline route, free flow travel time may vary from the baseline. BRT can reduce bus stop delay, intersection delay, walking delay, and congestion delay in the ways described below, which we incorporated into our analysis.

In order to perform a travel time savings analysis for BRT, we assumed a single BRT service operating from one end of each corridor to the other. In reality, a service plan should be developed, ideally with multiple routes, and travel time savings would be realized by BRT passengers coming from multiple origins and destinations. However, for the sake of this analysis, only one route is assumed which follows the BRT infrastructure directly. The precise routings used to determine travel times for BRT are as follows:

- **Dudley to Downtown** runs from Haymarket south on Congress Street, Arch Street, Chauncey Street, and Harrison Avenue to Kneeland Street until Washington St. It then uses Washington Street all the way to Dudley Square. The length of this corridor is 3.1 miles.

Figure 14: Dudley to Downtown Corridor used in this analysis

Figure 15: Downtown zoom of Dudley to Downtown Corridor used in this analysis

• **Mattapan to Dudley** runs from Dudley Square to Mattapan Station using Warren Street and Blue Hill Avenue. It turns left at River Street to terminate at the Mattapan Station. The length of this corridor is 4.5 miles.

Figure 16: Mattapan to Dudley Corridor used in this analysis

• **Dudley to Harvard** runs on Bennett Alley, Eliot Street, and JFK Street in Cambridge, North Harvard Street in Allston to Cambridge Street. After Cambridge Street, it turns to Brighton Avenue, continuing along Commonwealth Avenue. In the Fenway area, it takes Charlesgate and Boylston Street to reach the Longwood Medical Area. The Fenway is taken through Longwood Medical Area. The corridor passes along Ruggles Street, Tremont Street, and Malcolm X Boulevard before reaching Dudley. The length of this corridor is 6.9 miles.

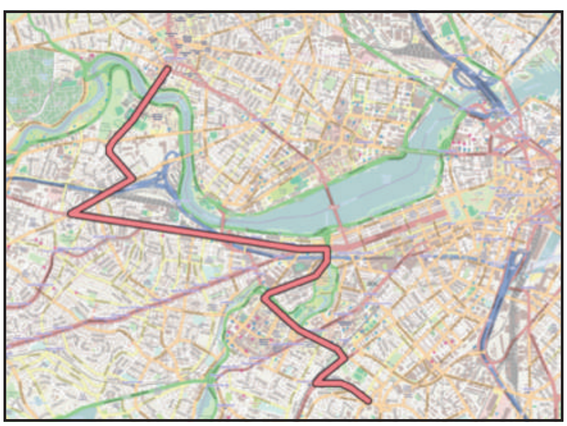


Figure 17: Dudley to Harvard Corridor used in this analysis

• **Readville to Forest Hills** runs for 4.4 miles on Hyde Park Avenue.

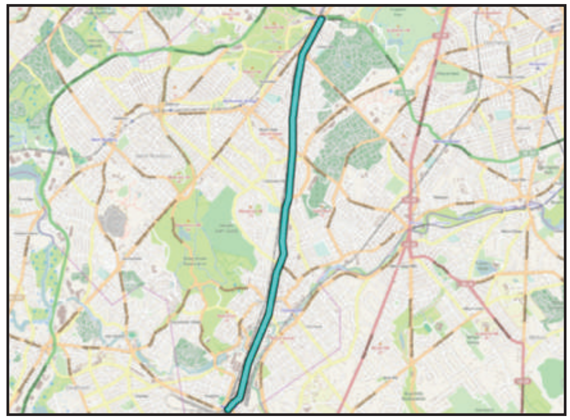


Figure 18: Readville to Forest Hills Corridor used in this analysis

• **Sullivan to Longwood** over the BU Bridge runs for 6.1 miles. It starts at Sullivan Station running down Cambridge Street to McGrath Highway. It turns onto 1st Street then continues on Binney Street. From Binney Street it makes a turn onto 3rd Street and then to Main Street before entering what was the rail right-of-way. It crosses the BU Bridge and then travels down Mountfort Street and Park Drive to reach the Longwood area.

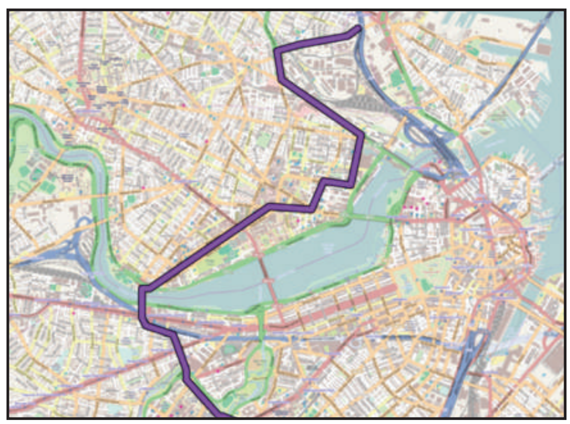


Figure 19: Sullivan to Longwood Corridor (via the BU Bridge) used in this analysis

- **Sullivan to Longwood** over the Massachusetts Avenue Bridge runs for 6.0 miles. It starts at Sullivan Station running down Cambridge Street to McGrath Highway. It turns onto 1st Street then continues on Binney Street. From Binney Street it makes a turn onto 3rd Street and then to Main Street. It then makes a turn onto Vassar Street and then Massachusetts Avenue. Once over the bridge it makes a turn onto Beacon Street. It then passes over Charlesgate. It then travels on Boylston Street to Park Drive.

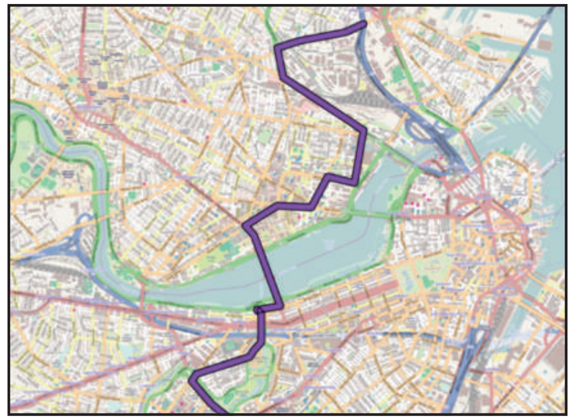


Figure 20: Sullivan to Longwood Corridor (via the Mass Ave Bridge) used in this analysis

Reduction In Bus Stop Delay

Fixed dwell time does not generally vary based on whether a bus is a standard bus or a BRT bus. Therefore, the fixed dwell time remained at 10 seconds per stop for fixed dwell time. However, the number of bus stops does change with BRT, as stop spacings are generally greater with BRT than with standard bus services. Because there are no definitive BRT station placements yet, BRT stops were assumed to be every one-third of a mile. This means that for Dudley to Downtown, 13 bus stops were reduced to 9 BRT stations; for Mattapan to Dudley, 34 bus stops were reduced to 14; for Dudley to Harvard, 40 bus stops were reduced to 21; and for Readville to Forest Hills, 34 bus stops to 14. The number of stops on the Sullivan to Longwood corridor, 14, is based on the number of stops used for the ITDP's Corridor 9 model[2].

For boarding delay, off-board fare collection (one of the most critical BRT elements) has been shown to reduce boarding times to 1.4 seconds per passenger and platform-level boarding (another important BRT element) can reduce the 1.4 seconds to 1.1 seconds per passenger. Both of these important BRT features were assumed for this analysis and thus a 1.1 second boarding time was assigned per passenger.

Using the general assumption (as was used in the Corridor 9 model) that opening year BRT ridership will increase by 30% above existing ridership, peak hour demand on each corridor was increased by 30% in order to calculate future total boarding delay. For the Sullivan to Longwood corridor, the modeled ridership was used. This was 908 riders for the BU Bridge option and 994 for the Massachusetts Avenue option. This number was then divided by peak hour frequency. In order to obtain BRT frequencies, headways were decreased by one minute for each route to accommodate increased ridership. For Dudley to Downtown, the frequency increased from 12 to 15 buses per hour. For Mattapan to Dudley and Dudley to Harvard, frequency increased from 10 to 12 buses per hour. For Readville to Forest Hills, the number of buses per hour was increased from 19 buses to 20 buses. For Sullivan to Longwood a frequency of 20 buses per hour was used as it was in the modeling exercise.

Reduction In Intersection Delay

There are several ways to increase bus speeds at intersections, all of which are aimed at increasing the green signal time for the bus lane. Forbidding turns across the bus lane and minimizing the number of traffic-signal phases where possible are the most important. Transit Signal Priority (TSP) also has some delay reduction utility, but marginally.

For this analysis, left turn restrictions were assumed for at all intersections which currently allow left turns yielding a 4 second reduction in travel time per such intersection.

Reduction In Congestion Delay

A median-aligned dedicated lane for BRT, if properly separated from traffic, can reduce congestion delay to 0. Therefore, congestion delay was assumed to drop from its present value on each corridor to 0 with gold-standard BRT.

[2] Weinstock, A. & Bello, E. "Results of Corridor 9 Modelling," May 2 2014.

Final results

When applying the methodology described above, the following travel time reductions for each corridor with the implementation of gold-standard BRT is obtained.

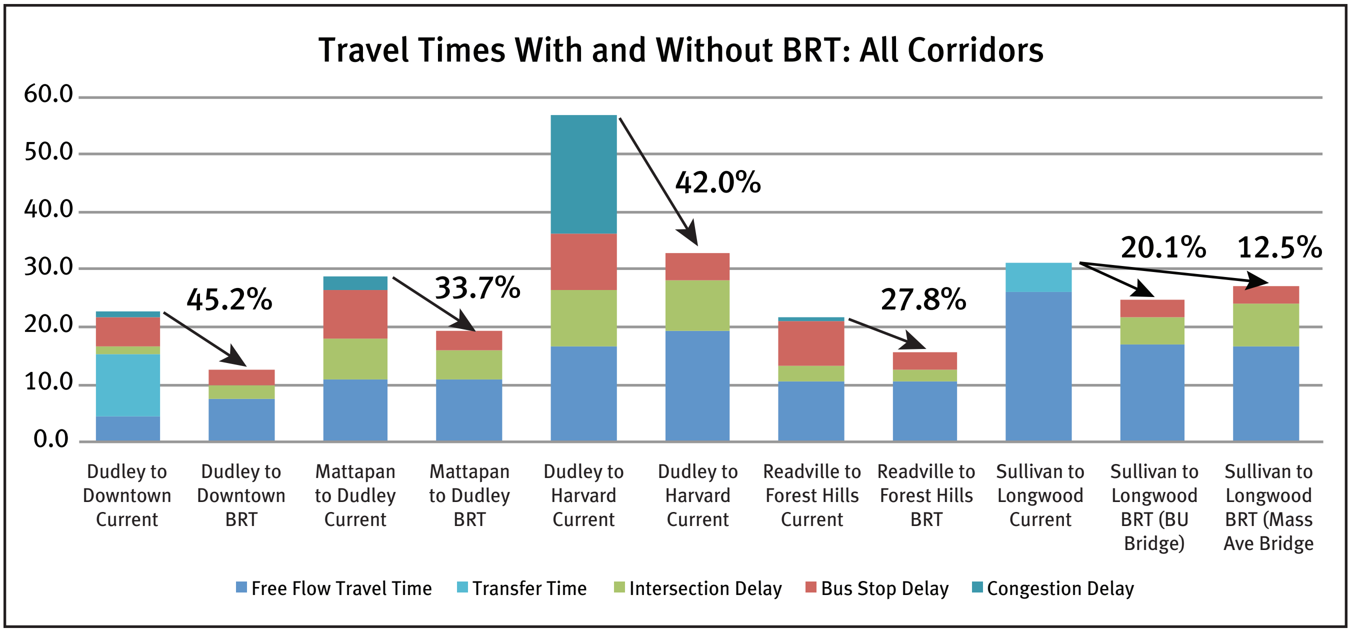


Figure 21: Travel time savings created by Gold Standard BRT

The potential delay reductions are described for each corridor in detail in the following pages.

Gold-Standard BRT on Dudley to Downtown: 10.3 minute reduction

If gold-standard BRT is built on the Dudley to Downtown Corridor, upgrading the Silver Line, adding gold-standard BRT infrastructure all the way into Dudley Square, and a link directly through Downtown Boston, travel time could decrease by up to 45.2%, from 22.8 minutes to 12.5. Much of this is due to the reduction in the time spent transferring to and waiting for the Orange Line by building full BRT infrastructure directly through Downtown Boston. Free flow bus travel time, on the other hand, is longer with BRT since the BRT corridor itself is longer. Through dedication of a median BRT lane, delay related to travelling in mixed traffic along certain portions of the Silver Line is reduced from 1.0 minutes to 0. And by providing limited-stop service and upgrading the stations, including off-board fare collection, and platform-level boarding, bus stop delay is reduced from 5 minutes to 2.5 minutes.

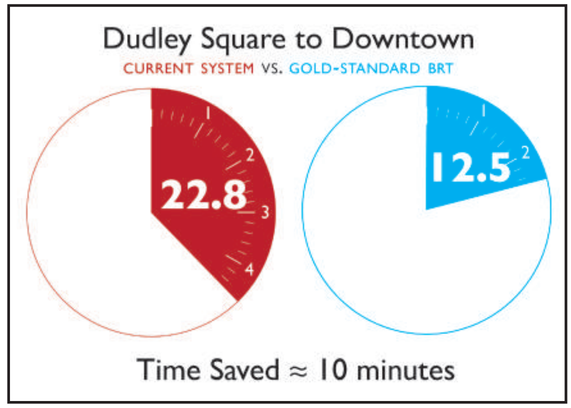
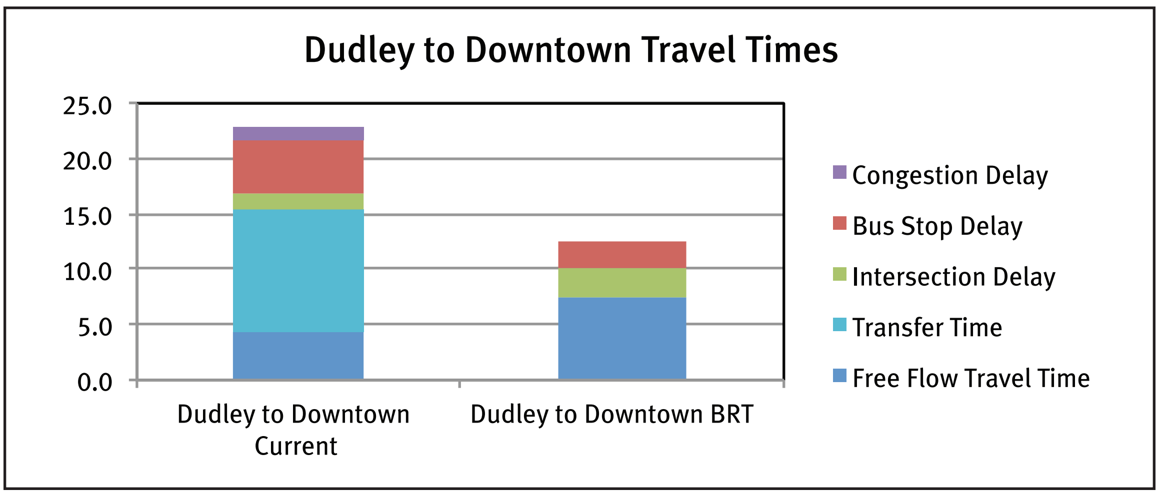


Figure 22: Dudley to Downtown travel times: Current System vs Gold Standard BRT



	Free Flow Travel Time	Transfer Time	Bus Stop Delay	Intersection Delay	Congestion Delay	Total Travel Time
Dudley to Downtown Current	4.3	11.0	5.0	1.4	1.0	22.8
Dudley to Downtown Gold Standard BRT	7.5	0.0	2.5	2.5	0.0	12.5

Figure 23: Dudley to Downtown Travel Time Breakdown with and without BRT

Gold-Standard BRT on Mattapan to Dudley: 9.7 minute reduction

BRT on the Mattapan to Dudley Corridor could result in a 33.7% reduction in travel time as travel times fall from 28.9 minutes to 19.2 minutes. Because of the large numbers of passenger boardings, bus stop delay is reduced from 8.5 minutes to 3.4 minutes through limiting the number of stations, off-board fare collection, and platform-level boarding measures. Congestion delay is also reduced entirely from 2.4 minutes to 0 with well-designed median-aligned BRT lanes. Intersection delay is reduced from 7.1 minutes to 4.9 minutes mainly through the prohibition of left turns across the busway.

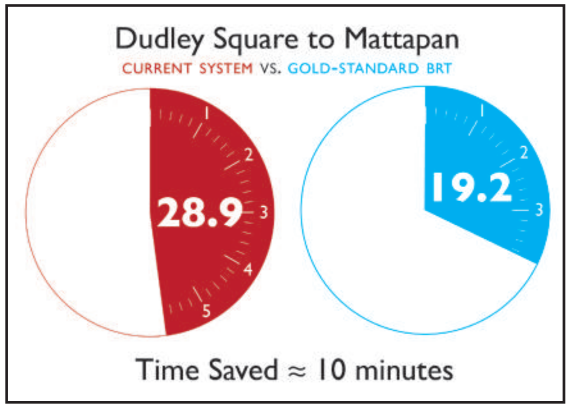
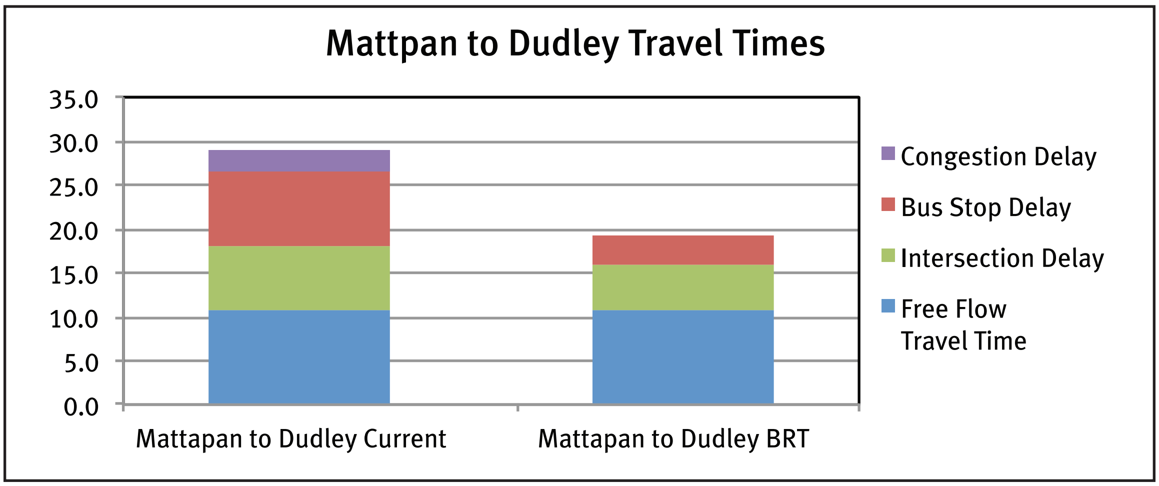


Figure 24: Dudley to Mattapan travel times: Current System vs Gold Standard BRT



	Free Flow Travel Time	Bus Stop Delay	Intersection Delay	Congestion Delay	Total Travel Time
Mattapan to Dudley Current	10.9	8.5	7.1	2.4	28.9
Mattapan to Dudley Gold Standard BRT	10.9	3.4	4.9	0.0	19.2

Figure 25: Mattapan to Dudley Travel Time Breakdown with and without BRT

Gold-Standard BRT on Dudley to Harvard: 23.9 minute reduction

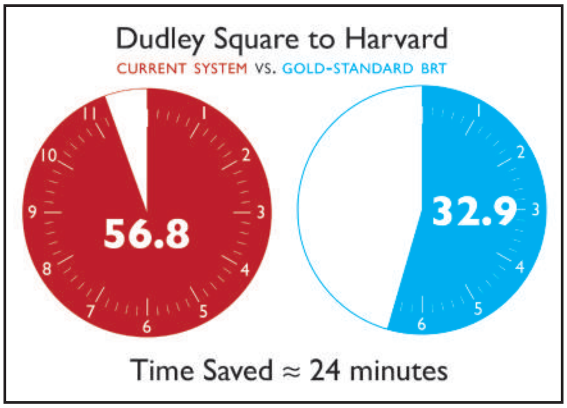
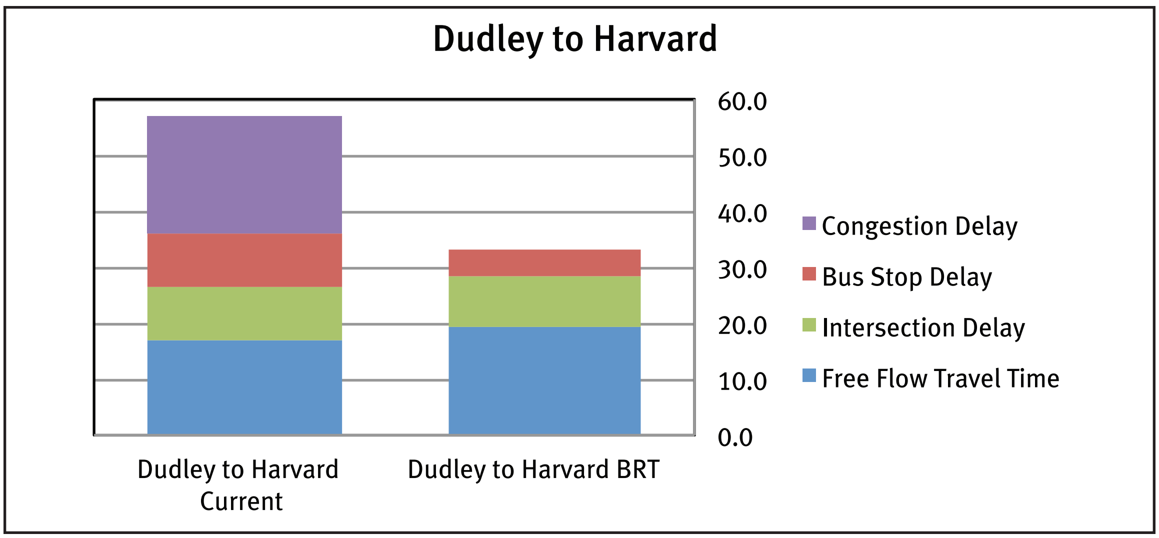


Figure 26: Dudley to Harvard travel times: Current System vs Gold Standard BRT

BRT on the Dudley to Harvard Corridor could reduce travel times from 56.8 minutes to 32.9 minutes. This is a 42.0% improvement. Median-aligned dedicated BRT infrastructure will greatly reduce the 20.6 minute delay associated with congestion. Platform-level boarding will be especially critical for smoothing the boarding process, and reducing boarding times for passengers accessing the Longwood Medical Area.



	Free Flow Travel Time	Bus Stop Delay	Intersection Delay	Congestion Delay	Total Travel Time
Dudley to Harvard Current	16.7	9.9	9.5	20.6	56.8
Dudley to Harvard Gold Standard BRT	19.3	4.7	9.0	0.0	32.9

Figure 27: Dudley to Harvard Travel Time Breakdown with and without BRT

Gold-Standard BRT on Readville to Forest Hills: 6 minute reduction

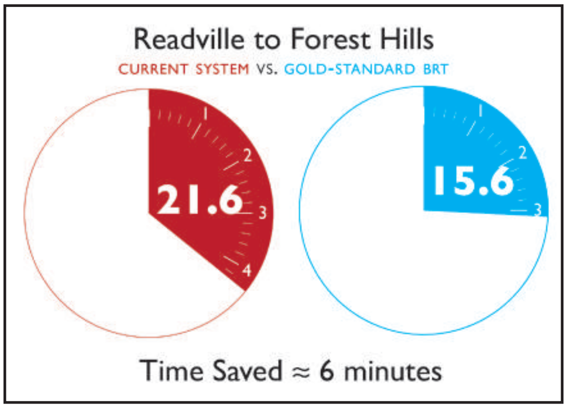
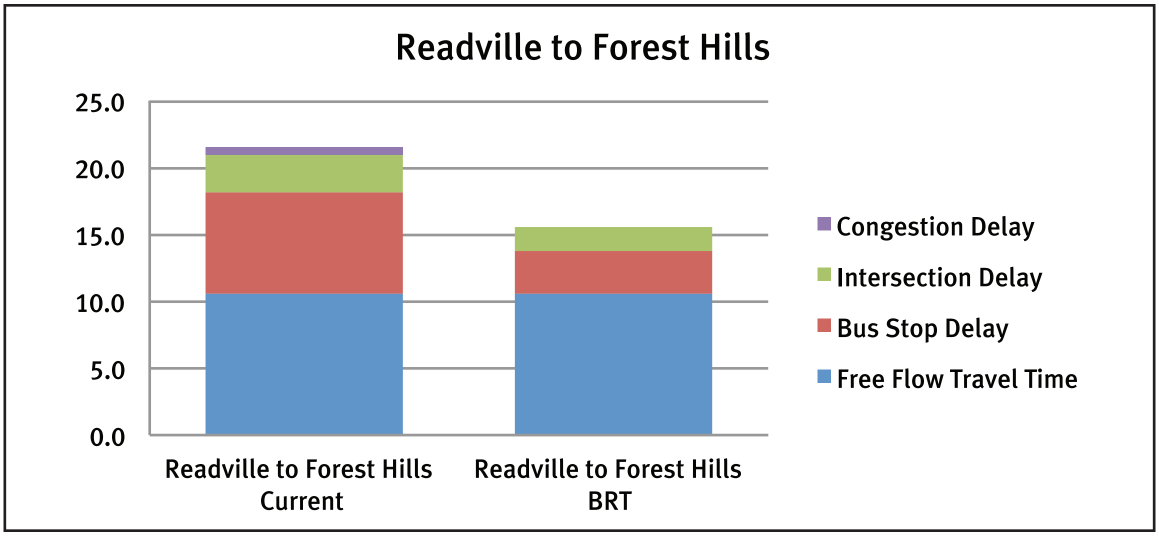


Figure 28: Readville to Forest Hills travel times: Current System vs Gold Standard BRT

A Readville to Forest Hills BRT would reduce travel times by six minutes from 21.6 minutes to 15.6 minutes. This is a 27.8% improvement. Lowering boarding times for passengers, reducing the number of bus stops, and prohibiting left turns would play a great role in creating time savings for passengers here.



	Free Flow Travel Time	Bus Stop Delay	Intersection Delay	Congestion Delay	Total Travel Time
Readville to Forest Hills Current	10.6	7.5	2.7	0.8	21.6
Readville to Forest Hills Gold Standard BRT	10.6	3.1	1.9	0.0	15.6

Figure 29: Readville to Forest Hills Travel Time Breakdown with and without BRT

Gold-Standard BRT on Sullivan to Longwood: 4 – 6 minute reduction

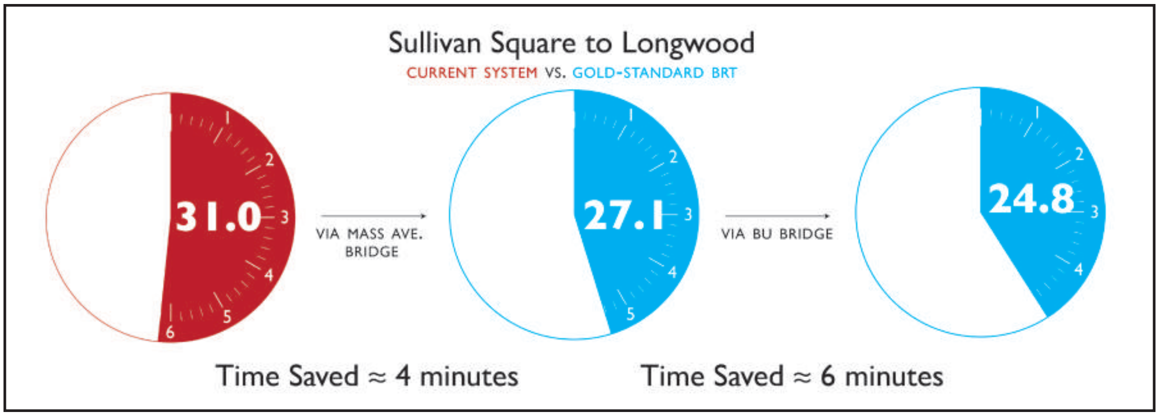


Figure 30: Sullivan to Longwood travel times: Current System vs Gold Standard BRT

A Sullivan to Longwood BRT over the BU Bridge would have a travel time of 24.8 minutes. A Sullivan to Longwood BRT over the Mass Ave Bridge would have a travel time of 27.1 minutes. The difference in travel time between the two BRT options is due a similar length (via Mass Ave Bridge is slightly shorter) but the BU Bridge option encounters fewer intersections due to the brief use of the Grand Junction Railroad right-of-way.

	Free Flow Travel Time	Bus Stop Delay	Intersection Delay	Congestion Delay	Transfer Time	Total Travel Time
Sullivan to Longwood Current	26.0	--	--	--	5.0	31.0
Sullivan to Longwood BRT (via the BU Bridge)	17.0	3.2	4.6	0.0	0.0	24.8
Sullivan to Longwood BRT (via the Mass Ave Bridge)	16.7	3.2	7.2	0.0	0.0	27.1

Figure 31: Sullivan to Longwood Travel Time Breakdown

Conclusion

Gold-standard BRT has the potential to reduce current travel times by transit on each of the corridors by between 20% and 45%. Given that the demand on each of the corridors meets a minimum to justify a gold-standard BRT investment, these findings provide further evidence that gold-standard BRT can be both justified and beneficial in these corridors. While further, more detailed technical analysis is still necessary in order to determine the precise alignment, services, costs, etc., this analysis provides the basic results necessary to confirm the viability of BRT in these corridors.

Which corridor ultimately moves forward must be the result of a strong community-based process. While the technical case for gold-standard BRT is strong, the Greater Boston Bus Rapid Transit Study Group, the local communities, stakeholders, and politicians must now weigh all other factors important when a city makes a new investment and/or changes the streetscape dramatically.

BRT Technical Analysis Endorsement

In September 2013, the Barr Foundation convened the Greater Boston BRT Study Group to explore the potential of gold-standard bus rapid transit in Greater Boston as a complement to the existing transit system. The group members (listed at the end of this document) include local leaders on transportation, economic development, community empowerment, and regional planning. The group started its work by assessing whether there were any corridors in Boston that could
A) carry enough riders and reduce delay sufficiently to justify the investment; and B) physically accommodate the necessary infrastructure for gold standard BRT.

The group also discussed ways that the corridors could contribute to economic, social, environmental, and equity goals for Greater Boston stakeholders and public decision makers.

Barr contracted with the Institute for Transportation and Development Policy (ITDP), a non-profit organization recognized for its expertise and experience with sustainable transportation including Bus Rapid Transit systems, to provide the necessary technical expertise. ITDP first produced an analysis of the current demand and congestion in peak hours on existing bus routes, as well as modeled demand and congestion on a few specific routes without current bus service.

Based on this initial analysis, ITDP identified ten corridors with high demand and delay. For those corridors, ITDP presented the group with potential routing and initial right-of-way analysis. The Study Group then prioritized five of the corridors for further study, based on the level of demand and delay; the apparent feasibility of siting BRT infrastructure; consideration of ongoing MBTA initiatives for improving service; potential for future development to drive demand for BRT; and an initial assessment of potential community interest.

The five corridors that the Study Group prioritized for additional ITDP analysis include, Downtown to Dudley; Dudley to Mattapan; Harvard to Dudley; Sullivan Square to Ruggles; and Forest Hills to Readville.

ITDP then performed additional analysis on these five corridors, including:

➤ Alternative routing for corridors prioritized and selected by the Study Group
➤ Sample cross-section and routing alternatives for BRT infrastructure in key locations throughout the prioritized corridors
➤ A preliminary time-savings analysis on the prioritized corridors

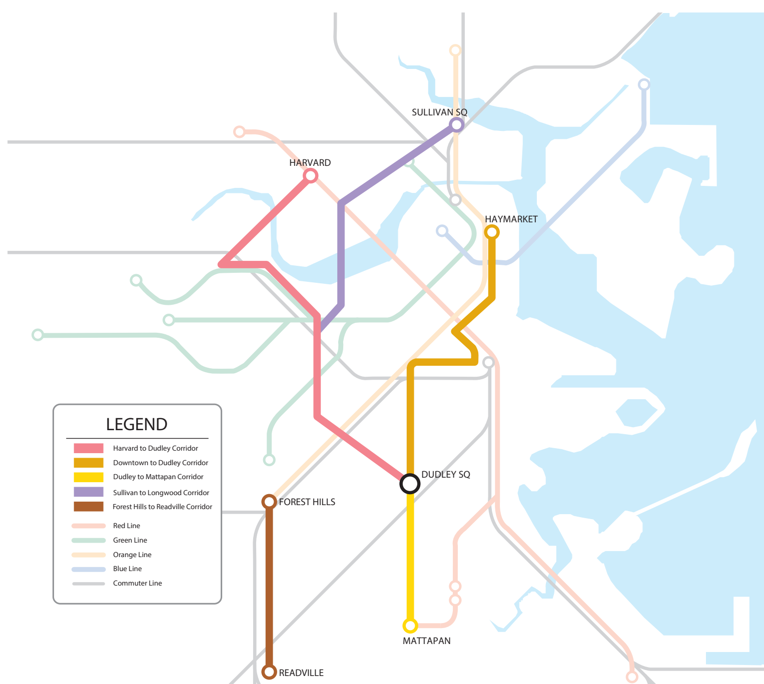
A detailed report on every aspect of these analyses, including methodology, will be available fall 2014.

The Study Group has thoroughly reviewed ITDP's analytic work. Study Group members have asked hard questions and made additional requests of ITDP throughout the process, and generally provided guidance at every step of the development of the analysis.

The Study Group believes ITDP's analysis is a strong starting point for further assessment of the five corridors found to be most technically feasible. The Study Group also strongly recommends additional technical and stakeholder analysis on several key issues for each corridor, including:

➤ Impacts on the existing transportation system from BRT infrastructure and service;
➤ Potential time savings on specific high-demand segments within corridors;
➤ Additional analysis of routing options, and of specific right-of-way segments where gold standard BRT would require elimination of traffic, bicycle and/or parking lanes, or where adjustment of the route might improve travel time or ridership;
➤ Contribution to mobility for the most transit-dependent groups and communities;
➤ Costs and benefits of gold standard BRT relative to other transit/mobility options for each corridor;
➤ Impact on greenhouse gas emissions and other aspects of environmental quality.

In addition, the Study Group will be undertaking outreach and dialogue with public officials, corridor transit riders, and community and business stakeholders to discuss the Study Group's work, explore their interest in BRT, and identify key concerns to be addressed if there is substantial stakeholder interest in further analysis by MassDOT and other public entities. The Study Group's intent is to complement the ITDP technical analysis with a careful stakeholder assessment that can inform the Study Group's final report and recommendations.



Group Members

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Ben Forman* | *MassINC*

Melissa Jones* | *Boston LISC*

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** Indicates that this Study Group member is endorsing the technical analysis in his or her personal capacity, not on behalf of his/her organization.*