

**CONGESTION PROTECTION FOR PUBLIC TRANSPORTATION:
STRATEGIES AND APPLICATION TO MBTA BUS ROUTE 66**

A Thesis Presented

by

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to

The Department of Civil and Environmental Engineering

in partial fulfillment of the requirements
for the degree of

Master of Science

in

Civil Engineering

in the field of

Transportation Engineering

Northeastern University
Boston, Massachusetts

August 2008

Abstract

Protecting transit routes from congestion is necessary for improving performance and reliability of bus service. Different congestion protection strategies that have been used across the world are reviewed. A case study of MBTA bus Route 66 in Boston is done to demonstrate how congestion protection strategies can be applied to improve speed on a congested bus route. Using micro simulation analysis, it was found that most of the traffic delay could be eliminated at all of the congestion points identified along the route, by employing congestion protection strategies including exclusive lanes, dual-direction lanes, relocating bus stops, signal priority, and median platforms. Estimated running time savings for the route was 15 minutes per cycle, or approximately 12%.

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1.0 Introduction

Congestion protection for buses is an effective way to solve the ongoing problem of high bus delays. Bus routes are designed to run through streets that serve the most users. Buses often run on the same streets that carry the most private vehicles. The direct result of this is high congestion to roads carrying buses, which increases bus delays. If bus delays become too high, non-captive users may decide to drive to their destination, adding more vehicles to the road. By implementing congestion protection strategies, this vicious cycle can be broken.

Congestion protection for public transport has been utilized for many years. Tunnels and grade separated rail are some of the earliest forms. Building tunnels and rail is costly, and difficult to justify except in cases with high demand for public transport. Physical measures have seen only limited use in the United States over the last 30 years, but they have been used a lot in Europe. The advent of Intelligent Transportation Systems (ITS) offers, in addition, some new methods of giving priority. These methods are easy to implement and not as costly as building tunnels and rail. Some of these strategies are transit signal priority (TSP), conditional priority and electronic fare collection. These strategies will be discussed in the following section.

A bus on a particular route is restricted to the designated path, regardless of the congestion on those roads. When a certain street is congested, private vehicle users may choose an alternate route. Since buses are captive of their path, it is important to protect the streets with bus routes from congestion. When traveling in congestion, buses are slower than traveling in uncongested areas. Slower buses will translate to less reliability.

Traffic signals have been historically designed to serve passenger vehicles, and buses have been grouped in with them in the signal design. Buses have many different travel patterns than private vehicles; such as making frequent stops, and slower acceleration. Therefore they need different treatment than private vehicles at traffic signals.

Since a bus carries many more people than a private vehicle, they deserve priority. This strategy of treating buses as a separate entity from private vehicles is a form of congestion protection.

In Europe, congestion protection strategies are more advanced and many of these strategies could be implemented here in the United States. Chapter 2 of this report provides background of physical priority measures taken. Chapter 3 presents examples of traffic reduction schemes that

have already been implemented in Europe. Chapter 4 describes priority strategies at traffic signals. Chapter 5 discusses other congestion protection strategies, such as stop relocation and operation control. Chapter 6 discusses other strategies to improve speed of public transportation, such as off board fare collection and bus stop consolidation.

Chapter 7 covers the background of bus route 66 and examines the problems associated with it. Chapter 8 analyzes each individual “hot spot” along bus route 66 and offers recommendations. Chapter 9 offers other recommendations to improve speed along route 66.

Chapter 10 evaluates the recommendations made for each “hot spot.”

Chapter 11 offers conclusions.

2.0 Physical Priority

The technique of using physical measures to protect transit from congestion is known as physical priority. Some ways to give physical priority to buses are in the form of bus lanes, removing bus stops from hot spots, partial road closures, contraflow bus lanes and bus lanes with a shared intersection approach. These physical priority schemes will be covered in the following sections.

2.1 Grade Separated Right of Way

Having a grade separated right of way for transit is a popular form of physical priority. For buses, grade separated right of way can take the form of exclusive busways, as in Ottawa, Pittsburgh, and Adelaide, Australia. A busway is made exclusive by having barriers (such as a fence, guardrail, curb) separating it from private vehicle traffic. Bypasses, transit tunnels and bridges are used commonly for congestion protection. The East Side Trolley Tunnel in Providence is reserved exclusively for buses and the Green Line of the LINK rubber-tire CNG trolley system.

2.2 Reserved Transit Lanes

A reserved transit lane aims to give priority to transit in places where roads are congested. Reserved transit lanes have become a common practice across the world. Entire roads can be designated as transit lanes, such as Oxford Street in London which allows only buses, taxis and delivery vehicles. Transit lanes are often separated from the private vehicle lanes by physical barriers.

Some physical barriers commonly implemented on reserved transit lanes are raised pavement, roughly paved, and separated from general traffic by a mountable curb. A mountable curb discourages traffic use, and is a visual separation from the general traffic lane. Private vehicles are able to access the reserved transit lane when a blockage occurs, such as a double-parked vehicle, a broken down vehicle or an accident. If there is only one travel lane in a given direction, double parking will not be as common because vehicles will tend not to block a lane if it is a one lane road. Left-turning vehicles waiting in the reserved transit lane can cause queues to back up and delay the buses. Left turning restrictions may be necessary when implementing reserved transit lanes. An example of a physical barrier preventing left turns is shown in Figure 1.

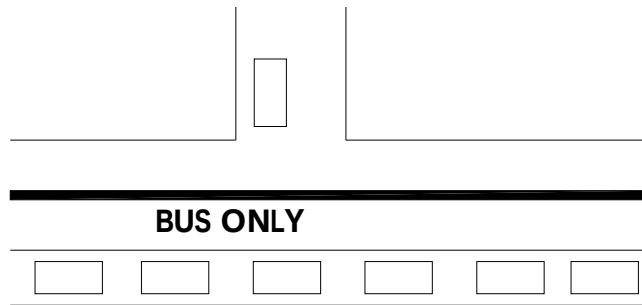


Figure 1 Parking Supply by Parking Designation

Moving violators in a reserved transit lane do not present a major problem to public transport. Stationary violators who are present when a transit vehicle is approaching are a major cause of delay. In Zurich, the two major hindrances to their reserved transit lane were left turning vehicles waiting on the tracks for a gap, and accidents on the tracks, mostly from left turns going across the tracks.

Another common violation of reserved transit lanes occurs when congestion is high. Private vehicles may take over the reserved transit lane blocking the transit vehicles.

Enforcement of reserved transit lanes is difficult because violators generally are not violating for long periods of time. Self-enforcing designs help prevent many violations of reserved transit lanes. The indirect approach to have self-enforcing exclusive lanes is to reduce traffic. A traffic reduction will result in low pressure to trespass into an exclusive lane because not much time will be saved. The direct approach is to make entering the exclusive lanes difficult, by using physical barriers and imposing left-turn restrictions.

Median busways are used in South America in Bogota, Quito and Sao Paulo. A special design for high volume bus traffic is shown in Figure 2. As can be seen from the sketch, the busway is in the center of the road network, and the stops are offset from each other. By offsetting the bus stops, the required width of the median bus lane is decreased. Crosswalks allow for safe crossing for pedestrians to the waiting area. Two lanes in the vicinity of a bus stop allows for overtaking. If both local and express bus routes are present, overtaking is essential to reduce delays.

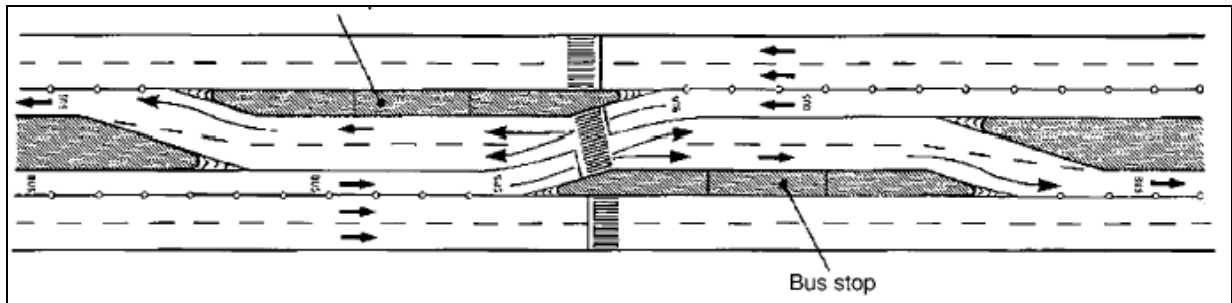


Figure 2 Median Busway Design

Contraflow lanes are used in San Juan, Puerto Rico on Avenida Juan Ponce de Leon and are self-enforcing because the bus lane is traveling against the flow of vehicle traffic (Figure 3). They can be built on one-way streets, going against the general traffic. Buses can use them in the opposite direction, and can share the right of way in the traffic lane in the other lane.

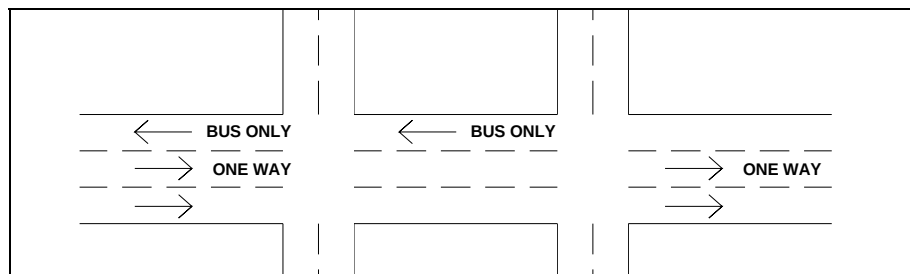


Figure 3 Contraflow Lane

A one-side design in Dublin, Ireland has also shown to be self-enforcing (Figure 4). This design puts both directions of the public transport on the same side of the street. Parking is prohibited on this side, and the buses do not have to pull-in to the platform at stops in either direction. The outside lane is going the in the opposite direction of the adjacent traffic lane, increasing the risk to potential violators. The number of platforms built in the street is limited, and traffic can still cross the lanes to enter and exit driveways, making it compatible with a commercial area.

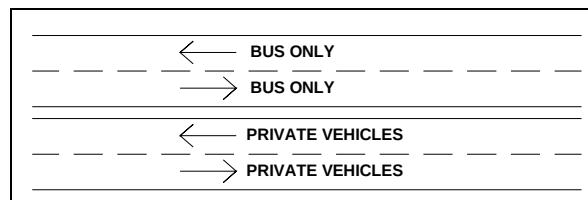


Figure 4 One-Sided Design

A queue bypass lane is a smaller form of a reserved bus lane that allows for a bus to bypass the queue at an intersection by proceeding to the stop line without any vehicle in front of it. This strategy is only successful if the queue length does not exceed the length of the queue bypass lane. Otherwise a bus will be prohibited from entering the queue bypass lane. In Zurich, a queue bypass lane is successfully used because of high technology queue estimation. An example of a queue bypass lane is shown in Figure 5. A buffer space is determined, which is the length beyond which would block the queue jump lane. A detector estimates the queue length and is compared to the buffer space, and green time is added to the approach until the queue length is safe for a bus to enter the queue bypass lane.

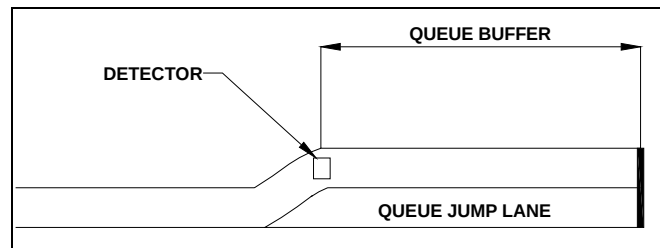


Figure 5 Queue Bypass Lane

Another way to enforce a reserved lane is by use of video cameras. An aggressive video enforcement system is used in London, England. London is a congested city due to its narrow roads and high population. Reserved bus lanes run freely while private vehicle lanes are highly congested. If a private vehicle uses the bus lane, a picture of their license plate will be taken and a fine will be sent to the driver via mail. The revenues from fines can then be used to contribute to improvements to the enforcement system.

These physical barriers mentioned above do not guarantee private vehicle users will not use reserved transit lanes, but they do help to discourage them from doing so.

2.3 Priority in Assigning Space

Reserved transit lanes require space on an existing road. This space could be generated from removal of parking, or eliminating existing travel lanes.

When removing existing parking spaces, several factors need to be taken in account. On street parking spaces have different levels of import depending on whether they are in a residential area, commercial area, or a transfer-type area.

If the parking spaces being removed are in a residential area, gaining public acceptance is unlikely. Residents need to have access to on street parking for long periods of time.

If the parking spaces being removed are in a commercial area, it is easier to convince people to remove parking because many of the drivers attracted to commercial areas do not stay all day and night, as could be the case with residential areas. Providing parking spaces should be the responsibility of the businesses more than the general public.

Removing parking spaces from commuters is the easiest to justify. As is the case with commercial areas, commuters should find private parking and should not rely on available public parking.

Space for reserved transit lanes can also come from taking away from existing travel lanes. Removing a lane and devoting it to public transportation takes away from private vehicle capacity, but can add tremendous value to public transportation. When transit ridership is high, replacing a private vehicle lane with a reserved transit lane the improved service and reliability far outweighs the negative impacts to private vehicles.

3.0 Traffic Reduction Schemes

Several schemes have been used in Zurich in order to reduce congestion on roads with public transportation. Two forms of congestion protection are confining through traffic to routes that do not interfere with public transport, and the other is keeping public transport routes off traffic-bound roadways. When a transit route is already in place, it is not likely that the route will change.

In Zurich, three motorways approach the city, but end short of the core. Three major axes of through traffic connect these motorways to the city. Zurich confines these through routes to roads that are not used by public transport as a congestion protection measure. Public transport is given priority at intersections where it crosses the through routes [1].

Brussels has major through traffic routes leading toward the center from where the E411, E40 (both sides), A201, and A12 motorways spill their traffic onto surface roads. Traffic exiting the tunnel from the E40 is confined by means of turning restrictions for almost one km to the Schuman rotary. One block away, STIB routes 12, 21 and 28 enjoy relatively uncongested travel on the parallel street, Ave. Franklin.

In Brussels, bus line 12 is an example of keeping public transport routes off traffic-bound roadways. It winds along relatively uncongested small streets for Pl. Luxembourg to Schuman Rotary to NATO and the airport, bypassing several congested through traffic roads.

Measures can be taken both regionally and site-specific in order to reduce traffic.

3.1 Regional

Regional schemes to reduce traffic are limiting parking, diverting through traffic, investing in high quality public transport, and periphery metering.

3.1.1 Limiting Parking

By limiting parking opportunities in areas where public transport is an option, vehicle owners are discouraged from driving to their destination if it is located along a public transport route. Limiting parking will not affect through traffic if it is the best available route. With limited parking at a destination, the option of public transportation becomes more appealing, and more users will tend to choose public transportation over driving.

Although limiting parking does not affect through traffic, bypass roads can be used to divert through traffic on roads not used by transit. This technique has proven successful in Brussels, as mentioned above.

3.1.2 Investing in High Quality Public Transport

Speed and reliability are the two most important factors for public transportation. Some examples of high quality public transport are commuter rail, subway and express bus. Improved bus service can be a contributor to a quality public transport system, but good bus service can be hurt by a bad commuter rail system. With a good commuter rail system, not as many private vehicles are competing with the bus service. In conclusion, different public transport modes can help each other.

Another important contributor to high quality public transport is the accessibility to and from stops. If stops are located within reasonable walking distance to dense commercial areas, more people are likely to use public transportation.

3.1.3 Traffic Metering

Traffic metering is used to limit the number of vehicles in the busiest areas of a city. In order to be fit for successful traffic metering, a city must have certain characteristics. Cities where most of the traffic can be traced to a limited number of key arterials are good candidates for traffic metering. The idea is that it is better to have a little more traffic on the edge of the

city than in the center. If the city center is clear of traffic, public transportation can flourish.

In London, congestion charging is the scheme used to meter traffic. A small part of the inner city is protected successfully, but in the outskirts of the city the older roads are still heavily congested. The operating cost is expensive, with nearly half of the revenues from private vehicles going into operating the system.

Traffic metering is much less obvious to the public in Zurich, and is much more successful than in London. Traffic is limited at traffic signals at the periphery of the city. Approximately 80% of the incoming traffic is metered by adding time to a pedestrian phase, or reducing cycle time thus reducing the green time. The 20% of the traffic that is not metered by these periphery signals comes into the city through local streets that are not metered. This scheme results in higher queues in the periphery of the city, and nearly zero queues in the city center.

Traffic metering has been applied locally in Greater Boston, near Alewife Station. Traffic is limited on Route 2 eastbound by a long red phase.

3.2 Site-Specific

Some local measures to reduce traffic are limiting traffic on bus routes, confining traffic on through routes, and protecting transit from pedestrians.

3.2.1 Limiting Traffic on Bus Routes

Keeping through traffic routes and bus routes as separate as possible is important for congestion protection. Through traffic routes should not interfere with bus routes. If the two intersect with each other at any point, the public transport route should be given priority.

3.2.2 Confining Traffic on Through Routes

Confining traffic on through routes can be done by having turning restrictions on them, essentially not allowing vehicles on the through route to have easy access to a road where public transport exists. An example of this strategy is in Brussels, where traffic exiting the tunnel from the E40 freeway westbound is confined by having turning restrictions until it reaches a rotary over a half mile away. The bus route runs parallel to this road only a block away, and is uncongested, while the through road backs up for many blocks.

In order to limit traffic on bus routes, vehicles should be discouraged from driving on the road. Several measures can be implemented to discourage

private vehicles from bus routes. Keeping bus routes on minor streets and off of major roads is one solution seen in Brussels. Bus line 12 travels on many minor streets with low congestion and bypasses several major through routes.

Closing short distances of certain streets to private vehicles where public transport exists is another solution to limit traffic on bus routes. Figure 6 shows an example of a short segment closing to benefit transit. If a traveler is aware a street is closed for a small segment, they will likely seek an alternate route. This will result in leaving the street much more uncongested upstream as well as downstream of the street closing.

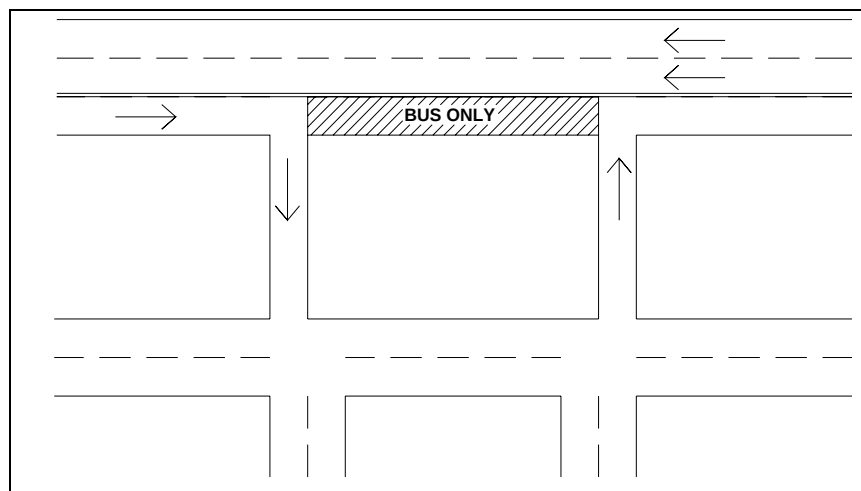


Figure 6 Short Segment Street Closing

This strategy is inadvertently tested when construction areas cause a temporary road closure. If traffic conditions were not impossible during a temporary road closure, one can be confident closing a road for a short distance to vehicles is possible. In Zurich, this was discovered by accident when construction forced street closings to general traffic on the Limmatquai for several months and traffic conditions did not worsen much.

In Brussels, several tram lines have been protected by closing the Ave. Louise crossing at Blvd. de la Cambre and Av. Legrand. These closings result in making these roads useless as through routes, while protecting public transport.

These above examples show that traffic is much more flexible to road or lane closings than it is perceived to be.

3.2.3 Limiting Pedestrian Caused Congestion

Public transport needs to be protected from pedestrian caused congestion. Pedestrians can easily worsen traffic conditions at intersections. In areas with high pedestrian usage, they can block right turns at an intersection when crosswalk placement is beyond the stop line. Typically the right lane is where buses are located, so it is evident that pedestrians can delay buses greatly. Figure 7 shows an example of crosswalk placement in order to limit pedestrian caused congestion. A bus that is going through the intersection is much less likely to be inhibited by a right turning vehicle when the crosswalk is offset from the intersection. In order to prohibit pedestrians from crossing, a fence is put up as a physical barrier at the intersection.

Although not standard procedure in Paris, pedestrian caused congestion has been limited near Place St. Michel. The crosswalk has been moved away from the busy intersection, leaving a buffer zone big enough to allow right turning vehicles to exit the intersection while pedestrians are crossing.

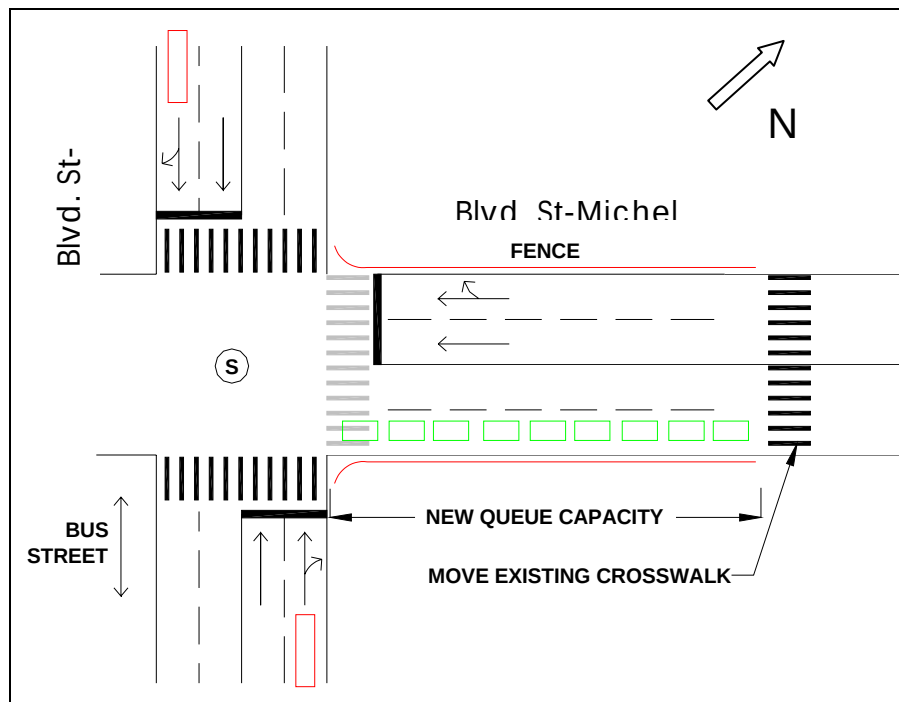


Figure 7 Crosswalk Placement Limiting Ped Caused Congestion

Another way to reduce pedestrian caused traffic congestion is moving the bus stops located near side at an intersection to the far-side or mid-block. When a bus stop is located near side, they are only able to access the stop during a through green phase. Many times, by the time a bus

closes its doors and is ready to proceed, the green phase has ended and the bus must wait an entire cycle to clear the intersection. By placing these stops on the far-side of the intersection, the above mentioned cause of delay will not occur. Figure 8 shows a schematic of mid-block stop placement in order to limit pedestrian caused congestion. This scheme is useful on a street where right turns are prevalent where many pedestrian crossings take place on the turning road.

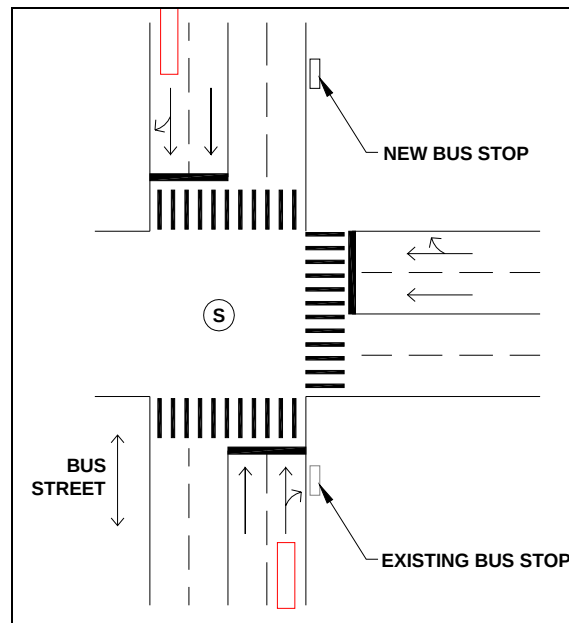


Figure 8 Stop Relocation Limiting Ped Caused Congestion

4.0 Priority at Traffic Signals

Traffic signal timings are typically concerned with minimizing total delay to all vehicles at an intersection. Minimizing vehicle delay may not be optimizing total person delay at an intersection. Total person delay better represents the impacts to everyone using an intersection. Giving priority to transit vehicles is more likely to reduce total person delay and will also maximize the capacity of an intersection.

Some signal priority strategies are passive and active. Each of these strategies will be discussed in the following section.

4.1 Passive Priority

Passive priority schemes use static signal settings favoring streets that carry buses. Some forms of passive priority are allocating more green time to transit routes, shorter cycle lengths, dual realization and signal coordination.

Allocating more green time to the road with transit reduces transit delays. A longer green phase will make it more likely that a transit vehicle arrives during the green phase, and the average wait time at the intersection for transit vehicles will decrease. By slightly adjusting these signal timings to favor the bus street, bus delays can improve while keeping existing traffic delays on the other approaches nearly the same.

Shorter cycle lengths can reduce delays because average wait times will be less for transit vehicles, and all other vehicles. The negative result of shorter cycle lengths is reduced capacity of the entire intersection because of an increase in lost time, since the all red phase will be more frequent. Reducing cycle lengths may increase delays if the intersection is near saturation, but if the intersection has excess capacity, delays on individual vehicles will decrease.

Dual realization is the process of having a green phase for transit twice in the same cycle. An example of dual realization is instead of having one 40 second split; two 20 second splits are given through the course of a cycle. Lost time due to transitions between phases is a disadvantage of this strategy. The average waiting time at a signal is reduced because the red period is cut in half for the phase being replaced with dual realization.

Signal coordination is used not only to benefit private vehicles, but it also can be designed to benefit transit vehicles. Progressions can be timed to match transit vehicle speed instead of private vehicle speed. Transit vehicles may not always successfully get a wave of green signals because of variability in dwell times at transit stops.

Passive priority strategies make intersections less efficient, because they are designed to reduce transit delays. If frequency of transit vehicles is low, then the timings will not be optimal most of the time.

One passive strategy that does not make an intersection less efficient is in the form of pre-signals. A pre-signal is located upstream of an intersection. The goal of a pre-signal is to hold back a queue without limit capacity or increase delay. A pre-signal is appropriate in areas where buses experience delays when attempting to merge from either a stop or another road. Buses are essentially given priority without delaying the existing traffic whatsoever.

4.2 Active Priority

Active strategies allow for signal adjustments in real-time to reduce delay to a bus. Buses are detected upstream of an intersection and different priority strategies can be granted. Having active priority does not

guarantee a vast improvement in service. The way the strategies are implemented is what matters most.

The four actions that can be granted to a bus are green extension, red truncation, insertion of signal phase and signal preemption.

Green time extension is used when a bus is approaching an intersection near the end of the green interval. The green time is extended to allow the bus to clear the intersection. Without green time extension, the bus would have to wait a complete cycle to clear the intersection.

Red truncation, also known as early green, is useful to buses when another approach has their green interval. The green time for another approach can be shortened in order to give green time to the bus approach.

Inserting a signal phase when a bus is detected can be used when a bus arrives at an intersection during a red signal. When the current phase ends, a bus may receive its own green signal to clear the intersection. The signal will then return to its normal timings, with little interruption.

Signal preemption occurs when a signal cycle is immediately interrupted to give priority to bus. This is often used for emergency vehicles, and has shown to be effective. As soon as the bus clears the intersection, the signal returns to its normal timing system.

Implementation of these strategies can be simple, or complex. Simple tactics are commonly seen in the United States, where priority at a traffic signal does not require any additional programming beyond the standard controller. Complex tactics allow for more intelligent programming.

Simple, non-aggressive tactics can result in very little time saving. The AC Transit system in Oakland installed transmitters on 21 buses equipping 62 intersections allowing a 10 second window for early green and green extension. Late buses are granted priority, and the resulting time savings was only 9%, falling short of the 20% time savings goal [2]. The reason for the less than expected results can be partly attributed to the small window for priority. If the window were increased to 20 seconds, it is expected the time savings would be closer to what was expected.

4.2.1 Absolute Priority and Conditional Priority

Absolute priority gives priority to a transit vehicle under any conditions. A bus could be four minutes ahead of schedule and it is still given priority. The advantage of absolute priority is it requires only the detection of a transit vehicle at the intersection. In transit systems with limited capabilities

without AVL where conditional priority measures cannot be implemented, absolute priority is the only option of giving active priority.

The obvious negative impact of absolute priority would be an increase in delays to passenger vehicles in adjacent approaches, and in most cases it is minimal, but it is still important to measure the impacts. If delay to adjacent approaches becomes too high because of absolute priority, conditional priority is an effective method that will reduce delays to adjacent approaches while maintaining priority for the buses that need priority the most (late buses). Absolute priority on one approach can delay buses in an opposing approach, but this also is usually minimal.

Absolute priority has been implemented in Los Angeles at over sixty intersections and has proven to be successful. Some features of the service are early green, green extension, and phase call. Bus headways range from 3-10 minutes. Los Angeles DOT found 22-27% reductions in bus run times. This time savings is attributed to a package of measures including limited stops, low floor buses, and signs encouraging passengers to exit the buses from the rear. Project officials credit approximately 10% of the savings to signal priority [3].

With conditional priority, buses are only given priority if they are running late by a certain threshold. The idea of holding early buses results in preventing buses from getting too far ahead of schedule. Conditional priority could also be given if the headway between two buses is greater than a certain threshold. If implemented properly, this method has little impact on vehicle delay compared to no priority, but greatly improves schedule adherence [4]. If vehicle delay is an issue for a certain jurisdiction implementing TSP, conditional priority is an effective method to reduce vehicle delay. In order to utilize conditional priority, the buses must be equipped with AVL or with onboard computers tracking schedule deviations [5].

One concern with all priority schemes could be the negative impacts it has on the recovery of networks after priority is given. Because priority is not given every cycle, it becomes easy for these networks to recover. For example, if a signal cycle time with priority is 60 seconds, and bus headway is four minutes during the peak period, at worst priority will be given every four cycles, if every bus was behind schedule.

Compared with absolute priority, conditional priority is much more beneficial for recovery for several reasons. Conditional priority impacts can be reduced at critical intersections by increasing the lateness threshold at upstream intersections and decreasing the threshold at the

critical intersections. This will reduce the likelihood of the bus arriving at the critical intersection late, thus reducing the likelihood of a priority request at the critical intersection [6].

The first city to use conditional priority is Eindhoven, which is located in the Netherlands. Combined with other creative congestion protection strategies, public transport has experienced near-zero traffic delay.

4.3 Complex Strategies Used in Zurich

Complex tactics are used in Zurich, where each specific intersection is programmed. Transition between stages is capable of following any desired logic. The inputs used for this programming are gap detections, public transport detections and queue length estimates. The cycle lengths are fixed, but the phases can be adjusted each cycle.

On every approach at an intersection, three to five detectors are used for public transport. These prevent any bad calls from happening. When a stop is located near-side, the closing of the doors triggers a message to the controller in order to call for green. The controller then will decide whether to extend the current green, insert a short public transport stage, or switch to a stage allowing both public transport and its parallel counterpart to pass.

Advance detectors are used sometimes to allow for green phases for pedestrians or other approaches, so the time a tram arrives at the intersection the signal can switch to give a green phase to the tram.

Zurich approaches signal priority very aggressively. Short cycles at intersections guarantee lower delays to trams. Two unique features of their control system are short, tram-only stages, and holding the tram signal in red. If a tram calls for green while the cross street is running, the tram will be given a quick five second green and the timings will then return to their normal sequence, going back to the green at the cross street if it had not had most of its allocated green time yet. This tactic wastes overall capacity but is not much of a concern because it is used at intersections that do not operate at capacity.

Holding the tram signal in red even when the parallel traffic is green until a tram is detected is another unique feature. The beginning of green for the tram is strategically timed so it must slow down slightly as a safety measure. This tactic restricts trams from speeding when approaching intersections.

The aggressive and complex tactics used in Zurich have resulted in almost zero delay at most signalized intersections to public transport.

Active priority strategies are constantly being developed and will continue to improve as time goes on.

5.0 Other Congestion Protection Strategies

Some other congestion protection strategies are stop relocation and real time adjustments to a route using automatic vehicle location (AVL). Relocating stops to less congested areas is a basic form of congestion protection. Making adjustments to a route such as giving conditional priority or sending an extra bus are possible strategies also.

5.1 Stop Relocation

Several factors are taken into account when locating stops. Stop locations must allow for safe street crossing and stop locations should also reflect demand. In the inner city it is expected that stops are located closer together, while in rural areas stops should be farther apart. Stop location is intended to reduce pull-out delays for buses and also to reduce effects with traffic delay and traffic safety.

Bus stop relocation can have both positive and negative effects. One must be careful when choosing a new stop location. Some reasons for relocating or consolidating stops include steep grades, near side delays, or safety.

Grades steeper than 3% can add eight seconds or more to stop delays. In the case of a steep grade, placing a bus stop on the far side of signalized intersections is always a safe option. Near-side delay can be reduced by shortening queues, which can be done by setting back stops or shortening cycle times [7].

At busy intersections, high bus delays can occur when a stop is located on the near side of an intersection with a high cycle time. If a bus stops to for loading passengers on the near side of an intersection, there is the possibility that the signal is green at the time. By the time the bus is ready to pull out, the signal may have turned red and a bus must wait an entire cycle to clear an intersection. Moving the stop to the far side of the intersection eliminates the possibility of a bus missing the first green phase.

Some safety issues that buses experience could be due to pulling out. If the sight distance is low leading up to an existing stop, buses may be at a greater risk of accidents when attempting to pull out. Another safety issue occurs in busy urban areas where many pedestrians use. At an area of

high pedestrian crossings, stops should not be located in such a way that it becomes unsafe to pull out or where passenger vehicles are free to go around a bus but not able to see crossing pedestrians.

5.2 Operation Control

Some operational control strategies are to have better schedule adherence and also real-time control. Automatic vehicle location (AVL) can be used to improve schedule adherence by determining whether a bus route has an accurate scheduled run time. If the scheduled run time does not match the measured run time, the existing schedule can be updated to reflect actual conditions.

Most bus operators are willing to adjust their operating speeds in order to keep on schedule with AVL. Bus drivers must be convinced that AVL is beneficial to them and not just a tool to “watch” them. Service reliability is not only important to passengers, but bus drivers also appreciate a reliable service. In order to monitor buses, time points are set up along a bus route. These are preset locations used to check schedule adherence. When a bus is off schedule by more than a specified amount of time, an incident message will be sent to the dispatcher workstation. This data is stored and can be used to make schedule adjustments to improve service, or as a tool to keep unwilling drivers disciplined to adhere to the bus schedule [8].

As a result of AVL, an increase in delay to non-priority traffic is inevitable. Minimizing this delay increase should be the goal of those designing the bus improvement strategies. As long as the increased delay to general traffic is not too high, the improvement to bus service overwhelms it. In order to effectively utilize AVL, the belief that public transportation deserves priority must be present among the municipality.

The city of Ottawa currently uses AVL but only for data collection purposes. It is not used for real time applications. The control system technologies that Ottawa has implemented shows improved speed, reliability, safety and security [9].

In real time, adjustments in service can be made as problems occur, such as sending out an extra bus to a route with high demand. For example, if a bus is running behind schedule, the AVL system can monitor this and give a bus conditional priority [10]. Without AVL all buses can either get unconditional priority or no priority at all, as was discussed earlier.

Dispatchers have the option of sending an extra bus to a route that is in need of another bus. This idea is not often utilized because most systems

prefer to include all buses into the schedule rather than reserve a bus for filling in purposes on any given route where unexpected problems arise and real time solutions are required. This strategy is only possible if a bus system is willing to purchase a bus and use it for filling in purposes. Bus drivers will not welcome this idea because of the inconsistency in working schedule. Drivers must be ensured they will only work their scheduled hours, and must know what routes they will be on. One way to ensure drivers of this is to have drivers switch buses when they intersect with each other. One driver could be in charge of beginning and finishing a route. This technique requires good planning, and is not a common tool used.

6.0 Other Strategies to Improve Speed

In order to improve bus speed, off board fare collection and bus stop consolidation have been commonly used historically. These strategies will be briefly discussed below.

6.1 Off Board Fare Collection

Off board fare collection requires customers to purchase tokens or tickets before boarding a bus. This is seen mostly in the form of electronic fare collection. An example of this is seen on the Green Line at Lechmere Station. The obvious benefit of this are dwell time reductions for the route. The negative impacts of this strategy would be complications due to advance purchases for tickets. It is unlikely that there would be an advance purchase location at every stop along a bus route since the cost associated with it is high. Also, dwell times are much more variable as a result of passengers who do not purchase their tickets in advance. It is likely that passengers that are not purchasing tickets in advance are not regular riders; therefore it is difficult to predict their arrival pattern.

The Ottawa bus system has a similar fare collection system to the CharlieCard in Boston. Passengers who do not purchase their tickets beforehand are able to use cash for their ride as well.

Electronic fare collection is increasingly becoming more popular everywhere. In Boston's subway system, tokens are no longer used, and passengers paying cash must purchase a ticket out of a machine before entering the subway station.

6.2 Bus Stop Consolidation

Stops with low boarding and alighting are the most obvious candidates for consolidation. If a stop is under used, the removal of it will improve bus running times. If the amount of passengers affected by a removed stop is low, and if the following stop is easily accessible by walking, then the stop is a good candidate for consolidation.

Although running times would improve by removing stops, this strategy should be approached with caution as it could ultimately lead to a loss in ridership [11]. If stops become difficult to access passengers may decide to choose another mode. When a stop is moved or removed, passengers would experience initial confusion at that particular stop. One would expect this confusion to dissipate after one or two bus trips.

7.0 Case Study Description

This report investigates public transport priority in and around the city of Boston, along the Massachusetts Bay Transit Authority's (MBTA) route 66. Existing conditions of the bus service and problems associated with route 66 are discussed.

7.1 City of Boston

The greater Boston area is popular for public transportation, with commuter rail lines, subway lines, bus routes and even ferry boats. Boston has three public transportation lines grade separated, and a light rail line with varying degrees of separation – from grade separated to in-street. Approximately 31.5% of all trips into Boston are by public transportation [12]. One of the most popular bus routes in Boston is route 66.

7.2 Description of Route 66

Bus route 66 travels from Dudley Station by Brigham Circle through Brookline Village turns along Harvard Street and runs through Coolidge Corner and crosses Commonwealth Ave, turns at Union Square traveling on Cambridge Street and then follows N Harvard Street all the way to Harvard Square passing Western Ave and Soldiers Field Road along the way, as shown in Figure 9. Most riders of route 66 are not traveling along the entire route, but only along segments of the route.

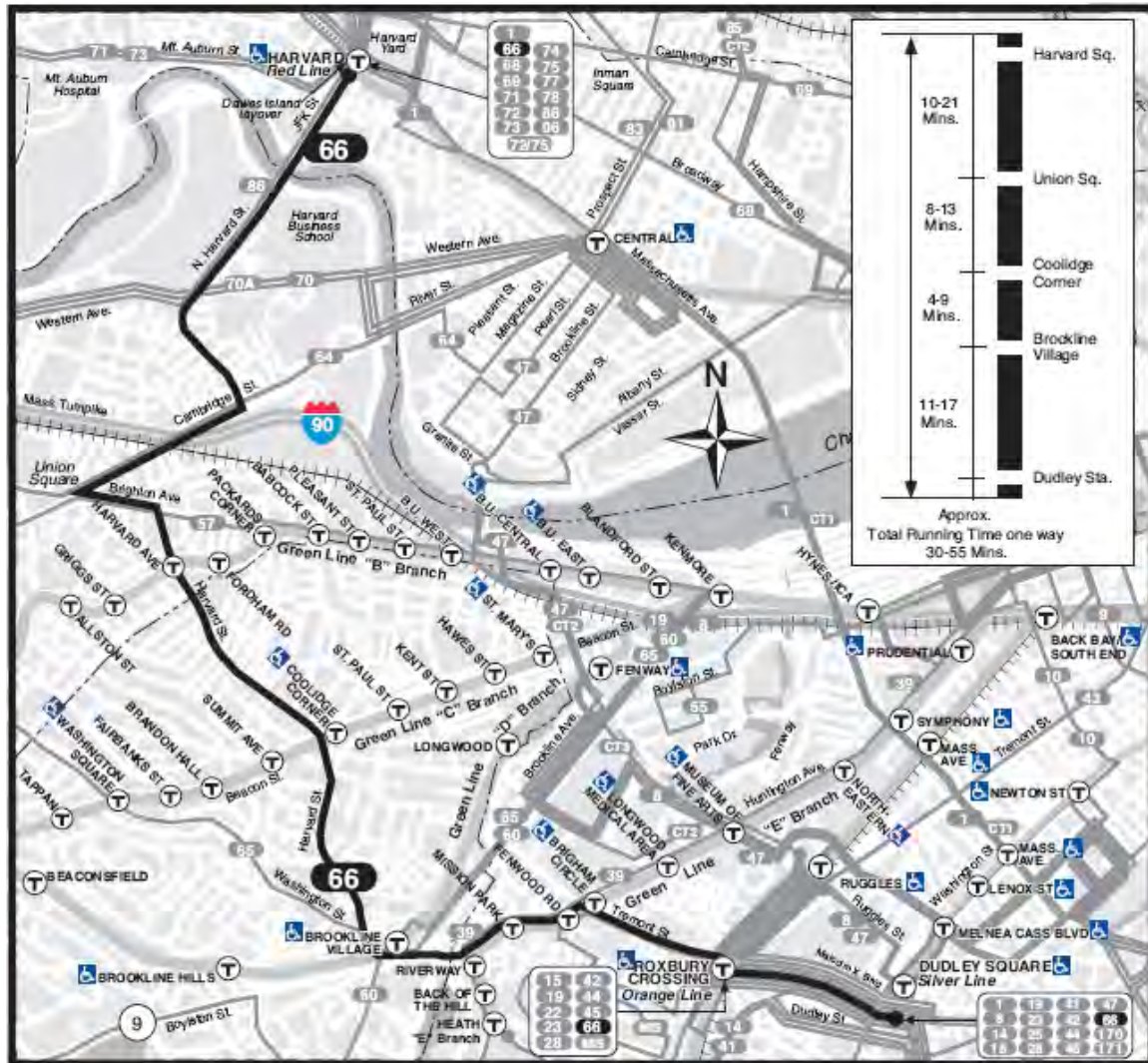


Figure 9 Map of Bus Route 66

Route 66 operates with nine minute service during peak periods and 15 minute service during off peak [13]. Route 66 averages over 11,000 passengers per weekday, which is among the highest utilized bus routes in the MBTA system. The MBTA is currently integrating AVL into their system. It is unclear whether they will be using AVL for congestion protection purposes such as conditional priority, or for scheduling purposes only.

7.2.1 Route 66 Schedule Adherence

In the summer of 2004, the MBTA performed ridechecks on Route 66. The MBTA defines being on time as within 5 minutes past the arrival or departure time.

The schedule adherence of departing buses from the terminal is shown in Figure 10. On route 66, the terminals are at Dudley Station and Harvard Square. Almost every bus departed early or on time with a few exceptions. The buses that departed late could have been due to the bus arriving late from another route, or a driver arriving late to work. The high number of early departing buses is a concern, and is probably due to experienced drivers being uneasy about finishing the route on time, as will be seen with high volume of late arrivals at terminals.

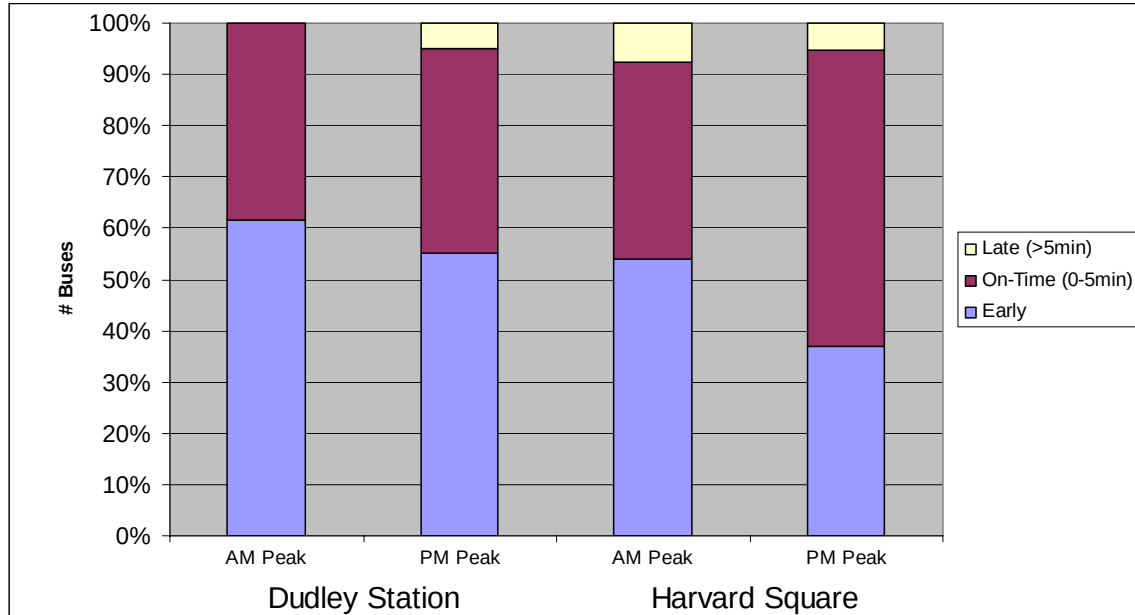


Figure 10 Schedule Adherence of Bus Route 66 Departures

Schedule Adherence of arriving buses at the terminal is shown in Figure 11. Almost all of the buses do not adhere to the schedule. In the morning peak hours, over 70% of the buses were late. In the evening peak period, 83% of the buses were late. Most of these late arrivals can be attributed to congestion along route 66.

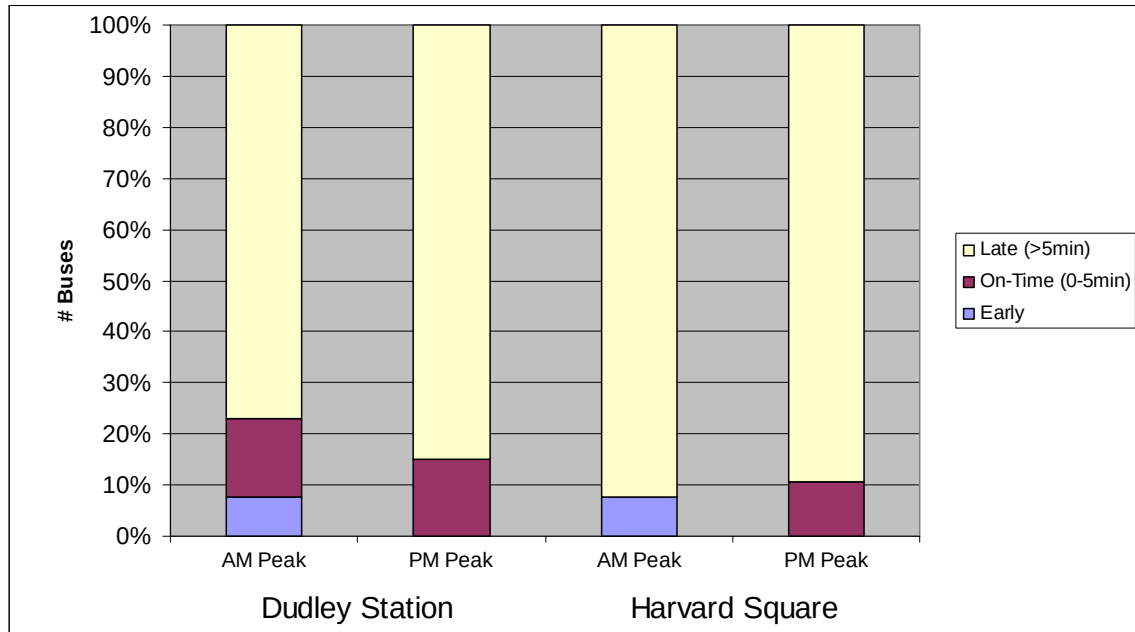


Figure 11 Schedule Adherence of Bus Route 66 Arrivals

7.2.2 Ridership Patterns

Table 1 shows the ridership patterns of route 66 during the weekday peak periods. The critical period occurs during the PM peak period where the most passengers are using the bus route. In the PM peak period, 39 buses are utilized compared to only 26 in the AM.

Table 1 Route 66 Ridership Summary

	INBOUND		OUTBOUND	
	AM	PM	AM	PM
Total Boardings	689	1340	1068	1079
Avg. Boardings/Trip	52.5	67.0	82.1	56.7
Total Trips	13	20	13	19
Avg. 30 min Max Load	37.7	45.0	53.0	47.7

The peak load is typically concentrated between Brighton Ave at Harvard Ave and Huntington Ave at Wait Street.

7.2.3 Fare Collection Issues

Cash purchases cause significant delays to buses. Only one fare collection machine is used per bus, thus allowing only one person to board at a time. The boarding time is further increased due to cash paying passengers who are not prepared with exact change. Riders with little or no experience riding the bus often are confused with the relatively

new fare collection schemes. With more than 60 boardings per bus trip along the route, cash purchases are fairly common along the route. After observing several trips along bus route 66 several times, this assumption was confirmed.

The buses along Route 66 are equipped for CharlieCards and CharlieTickets, a form of electronic fare collection new to the city of Boston. Purchase locations of CharlieCards or CharlieTickets are located throughout the state at all subway stations and also available at select retail locations. These retail locations include supermarkets, convenient stores and are also available to purchase online. Although CharlieCards make boarding on buses quicker, this has not solved the negative impact of cash purchases on a bus.

7.2.4 Traffic Congestion Issues

The high traffic volumes cause long queues at almost all of the 40 signalized intersections along the route, resulting in high delays at signals for both buses and private vehicles. High pedestrian volumes at Brigham Circle, Coolidge Corner and Allston Village are another cause of congestion along route 66.

Double-parked vehicles obstructing lanes are major contributors to bus delays, particularly in Allston Village between Brighton Ave and Commonwealth Ave along Harvard Ave. These double parked vehicles delay all vehicles especially buses, since it is more difficult for a bus to merge into an adjacent lane in order to go around the double parked vehicle. Although this section of Harvard Ave is only one lane in each direction, it is wide enough that vehicles can safely go around a double parked vehicle without going into the opposing lane [14].

8.0 Hot Spots

Along Route 66, several hot spots (congested areas) exist. Figure 12 shows each of these hot spots along the route. These hot spots can be remedied by applying different strategies of congestion protection.

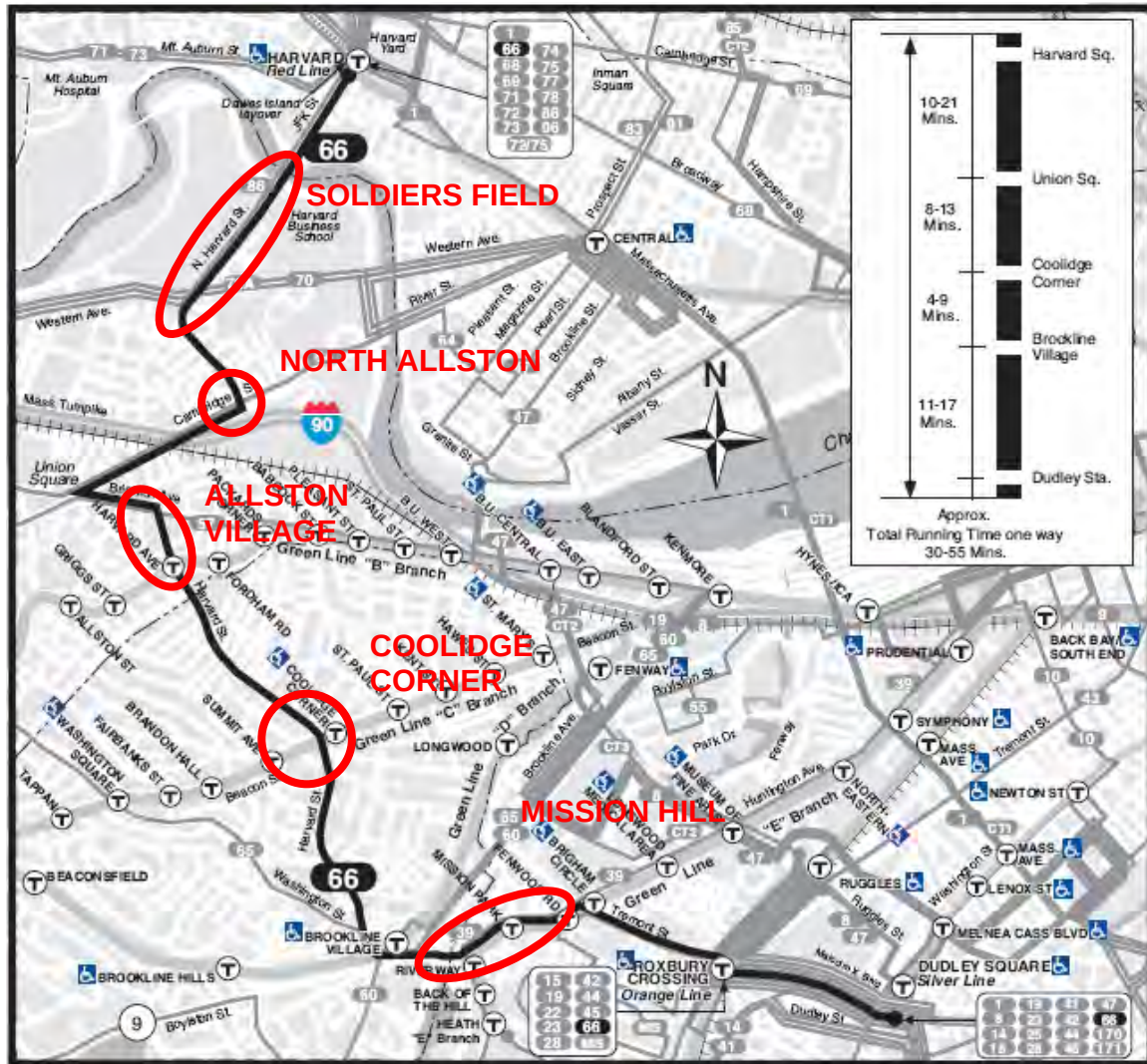


Figure 12 Hot Spot Locations

Buses experience high delays due to private vehicle congestion. These areas are also where the loads on the bus are typically highest.

8.1 Huntington Ave

From Tremont Street to S Huntington Ave

This section of Huntington Ave. is extremely congested at many times throughout the day. The green line operates both ways in the center of Huntington Ave, “at grade” with traffic. The inside lane is used as both a shared through and left turn lane (Figure 13). The buses on this section drop its passengers off at the curb. Trains do not have this luxury because of the existing tracks in the center of Huntington Ave. Although pavement

markings are faded, the outside lane behaves like a 12 foot lane and the inside lane behaves like a 10 foot travel lane.

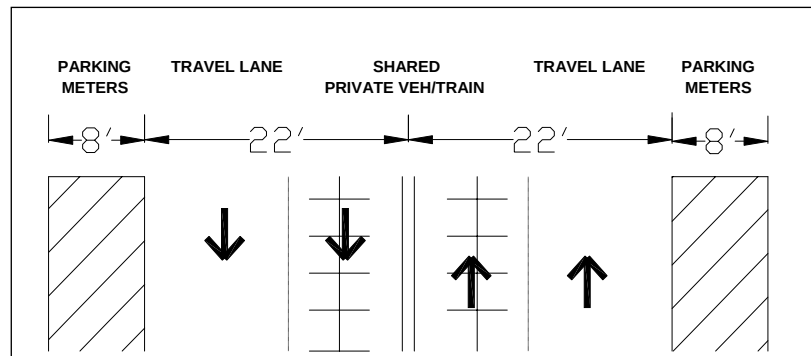


Figure 13 Existing Lane Configurations on Huntington Ave

Two shared bus and train stops are on this section of Huntington Ave. One stop is at Fenwood Road (Figure 14), and the other is at Parker Hill Ave (Figure 15), both signalized. Passengers exit the train at the intersections where they then cross the street from the middle of Huntington Ave. As one would expect, this prehistoric “streetcar” mentality is nearly extinct. Boston may be the only city in the United States still dropping off passengers in the middle of a busy street.

In the inbound direction only, a bus stop is at the intersection of Huntington Ave and Mission Street. Based on the ridechecks that were done by the MBTA in 2005, this stop is much less utilized than both the previous and following stop. Table 2 shows a daily load comparison of these bus stops on Huntington Ave.

Table 2 Weekday Stop Utilization on Huntington Ave INB (Rt 39 & 66)

Bus Stop Huntington Ave &	Boardings	Alightings	Distance to Next Stop (mi)
Parker Hill Ave	137	147	0.13
Mission Street	30	40	0.09
Fenwood Road	28	107	0.05
Brigham Circle	51	231	-

Private vehicles, buses and trains on Huntington Ave experience high delays caused by traffic congestion. During peak periods, private vehicles form long queues along the tracks preventing the trains from flowing freely. Buses also experience delays from pulling out from stops during these periods.

Bus travel times were measured on several different days during the evening peak hour along this corridor between Tremont Street and S Huntington Ave. The average bus travel time toward Dudley Square is 7:30. The average bus travel time toward Harvard Square is 4:20. When flowing freely, these buses could travel along this corridor in 1:30.

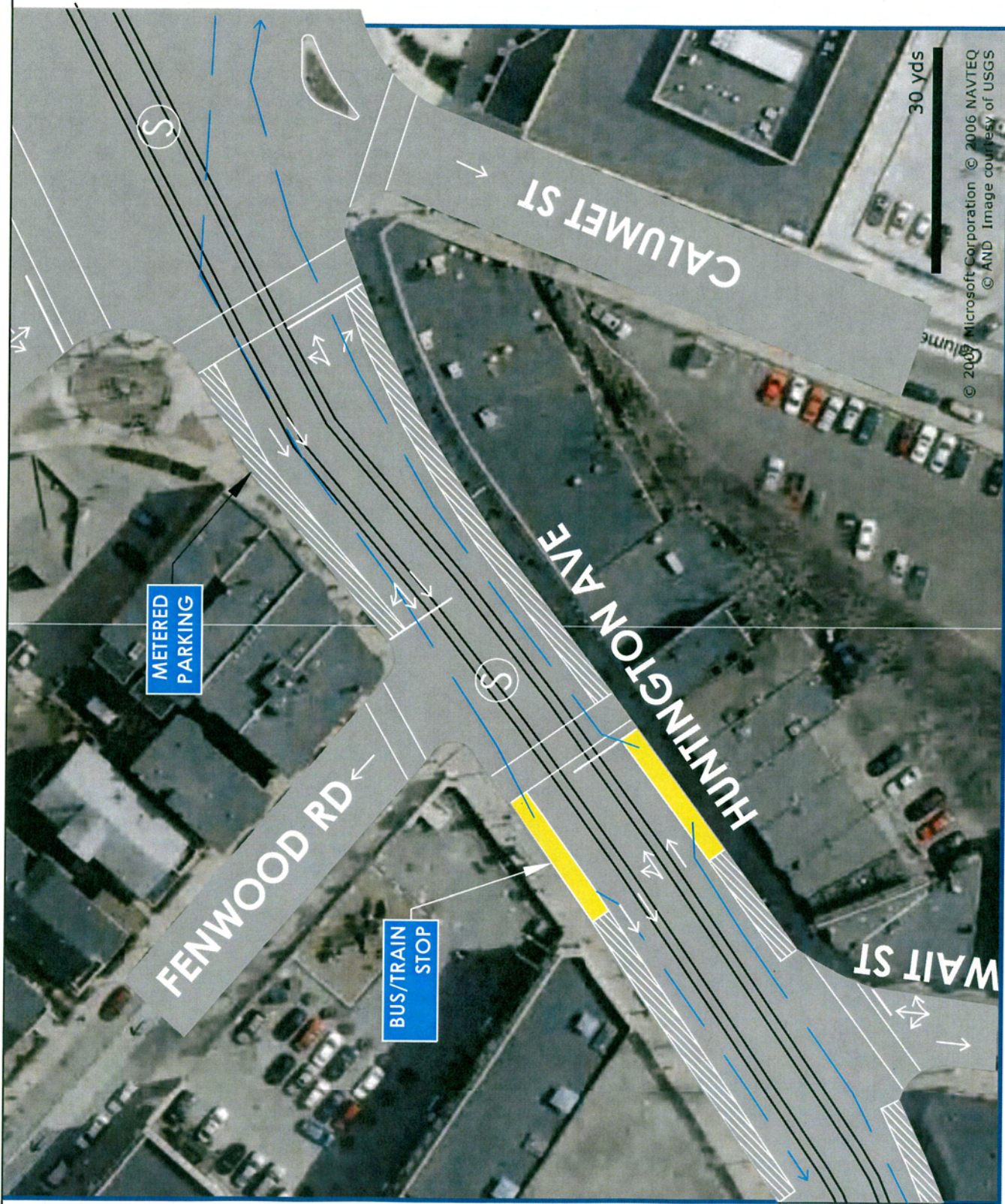


Figure 14
Huntington Ave & Fenwood Road Existing

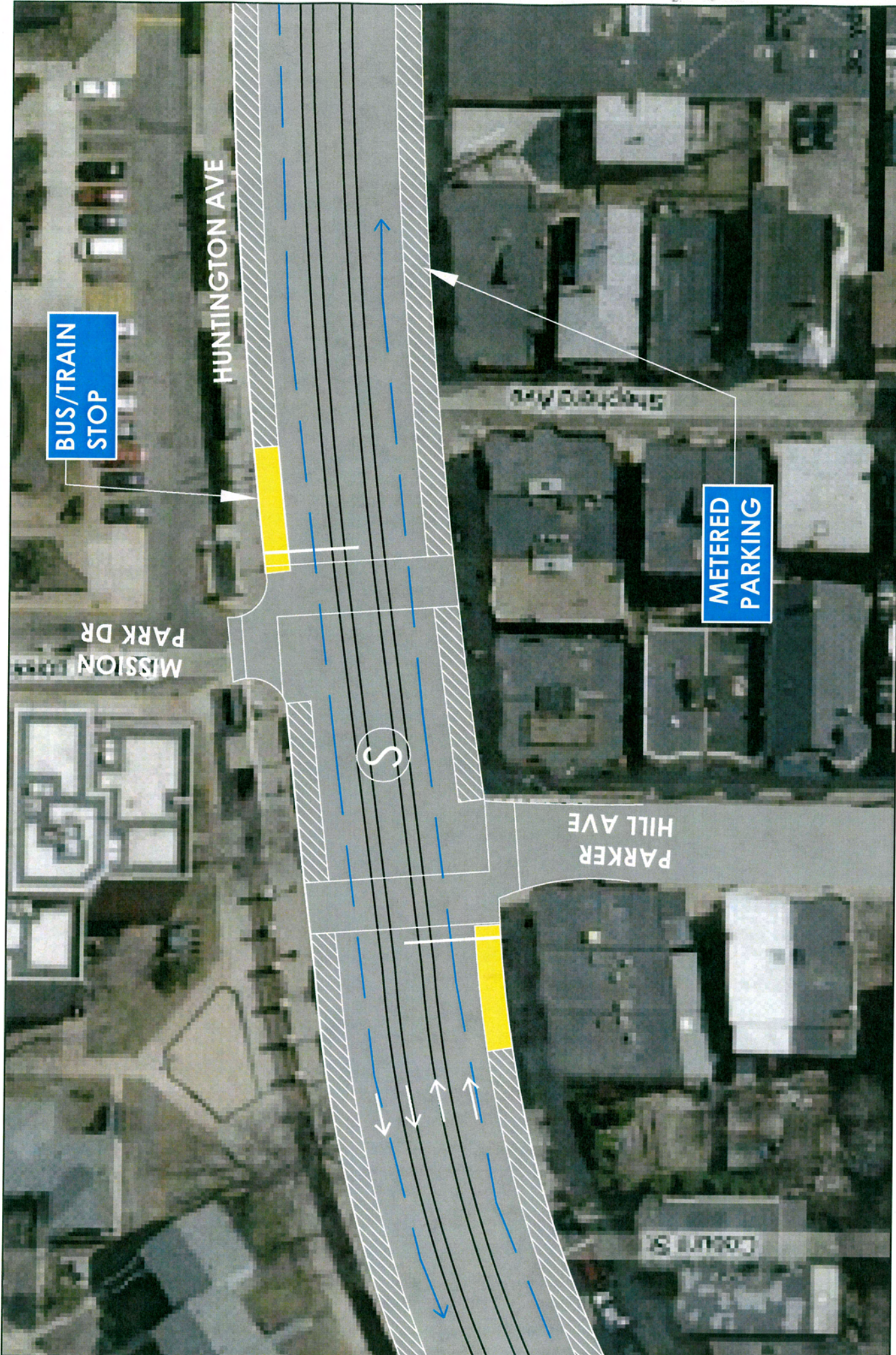


Figure 15
Huntington Ave & Parker Hill Ave Existing

8.1.1 Recommendations

A pair of reserved bus/train lanes in the center of Huntington Ave would allow the buses and trains to be protected of congestion along the entire corridor. Buses will be able to jump the queue on Huntington Ave from Tremont Street to S Huntington Ave.

Safety for passengers boarding and alighting the buses and trains is the most important factor. With a reserved transit lane in the center of Huntington Ave, passengers must be able to cross the street safely. Waiting areas for passengers must have enough capacity to hold waiting passengers. Passengers exiting the buses and trains must be able to safely access the waiting area.

A concern to businesses along this corridor is the removal of parking on Huntington Ave. Very few parking spaces will be lost due to the reserved lane, and these lost spaces will be at the bus stop locations. The few parking spaces that will be removed are a minimal tradeoff to the huge savings in transit delays.

By dedicating the center lane to buses and trains only, private vehicles are reduced to one travel lane. This is justified because the reserved transit lane will carry a comparable amount of passengers to the existing private vehicle lane. Also, as mentioned earlier, the goal is to protect public transportation from congestion, and this is achieved by this strategy.

The person capacity of the reserved transit lane is expected to triple [15]. The existing mode split along Huntington Ave is illustrated in Table 3. The public transportation users along this corridor are comparable to the private vehicle users along the corridor; therefore the recommendation for a reserved transit lane is justified. With greatly improved service, it is expected the bus ridership will increase and surpass the private vehicle users.

Table 3 Private Vehicle Users vs. Public Transit Users on Huntington Ave

Time Period	Private Vehicle Users	Public Transport Users*
AM Peak		
Eastbound	1506	921
Westbound	739	952
Total	2245	1873
PM Peak		
Eastbound	1269	976
Westbound	1163	952
Total	2433	1928

- MBTA Ridership Counts, 2007.
Traffic Solutions Green Line E Branch Ridership Counts.

The person capacity loss as a result of reconfiguring the lanes to have a reserved bus lane shared with the light rail and allowing one private vehicle lane in both directions is large (Table 4). This difference is too large to predict a delay impact based on the usual assumption that traffic volume will be unchanged. There will have to be a significant diversion. The through traffic plus turning lanes at key points that previously used Huntington Ave will seek an alternate route. During construction along Huntington Ave in 2007, the street was reduced to one lane per direction for approximately six months. While congestion on Huntington Ave was severe, the diversion to other streets did not result in noticeable impacts.

Table 4 Huntington Ave Capacity Comparison

Option	Eastbound (veh/hr)	Westbound (veh/hr)
Existing Lane Configurations	2300	2000
With Reserved Bus/Train Lane	1300	1300

It is extremely difficult to accurately predict the run time savings due to a reserved transit lane on Huntington Ave. Simulating the actual conditions and estimating the existing bus delay along this area is a recommended future effort. The bus running time was measured during the PM peak period in both directions (Table 4). The estimated run time savings was calculated by subtracting the minimum run time from the average run time. The minimum run time is a good estimate of what the free flow run time will be with a reserved transit lane.

Table 5 Huntington Ave Bus Run Times

	Eastbound	Westbound
Number of Buses	102	103
Average Run Time (sec)	444	256
Minimum Run Time (sec)	88	99
Maximum Run Time (sec)	733	448
Estimated Run Time Savings (sec)	356	157

Huntington Ave has to serve public transportation well. It is less of a concern that it serves general traffic well because this traffic is not restricted to Huntington Ave and can always seek an alternate route.

Figure 16 shows proposed typical roadway dimensions on Huntington Ave. The reserved transit lane will be at grade with the travel lanes, and will be separated by double yellow lines on both sides. The double yellow lines are used as a means to deter private traffic from the transit lanes. Grade separation is not possible because of the trolley tracks.

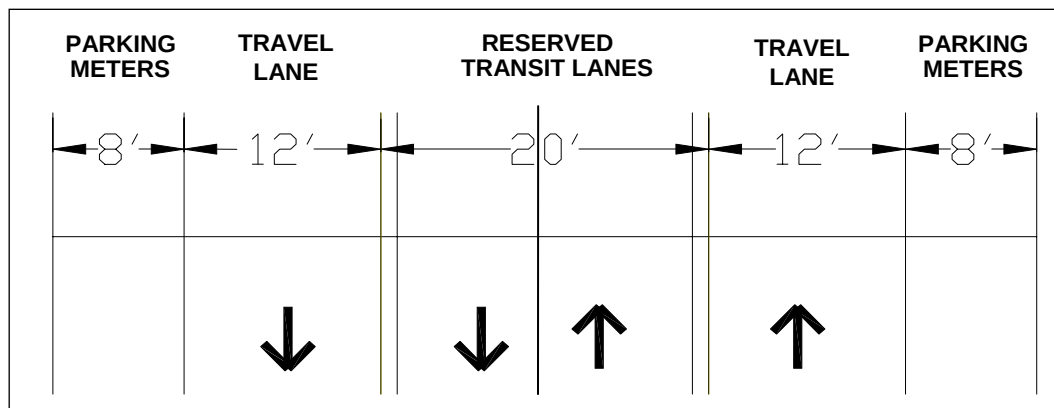


Figure 16 Proposed Lane Configurations on Huntington Ave

The bus stops will be removed and replaced by raised platforms in between the general lane and the transit lane and will be long enough to serve the green line train that carries two cars (75 feet). By replacing the existing bus stops with raised platforms, passengers on the trains will be able to safely enter/exit the trains. Both ends of the raised platforms have crosswalks. In order to protect the passengers from private vehicle traffic, a barrier will be installed on the edge of the platform separating it from the general traffic lane.

With one raised platform serving both buses and trains, it is not possible to serve buses and trains at the same time in the same direction. However, the platforms are designed far enough from an intersection that it will not

block traffic. This will ensure nominal delay to buses when following behind a train and vice versa along Huntington Ave.

The recommendations for each existing bus stop are as follows:

Huntington Ave & Fenwood Road

The design of the bus stop at this intersection is shown in Figure 17. It is important that the waiting areas are accessible on both sides by crosswalk.

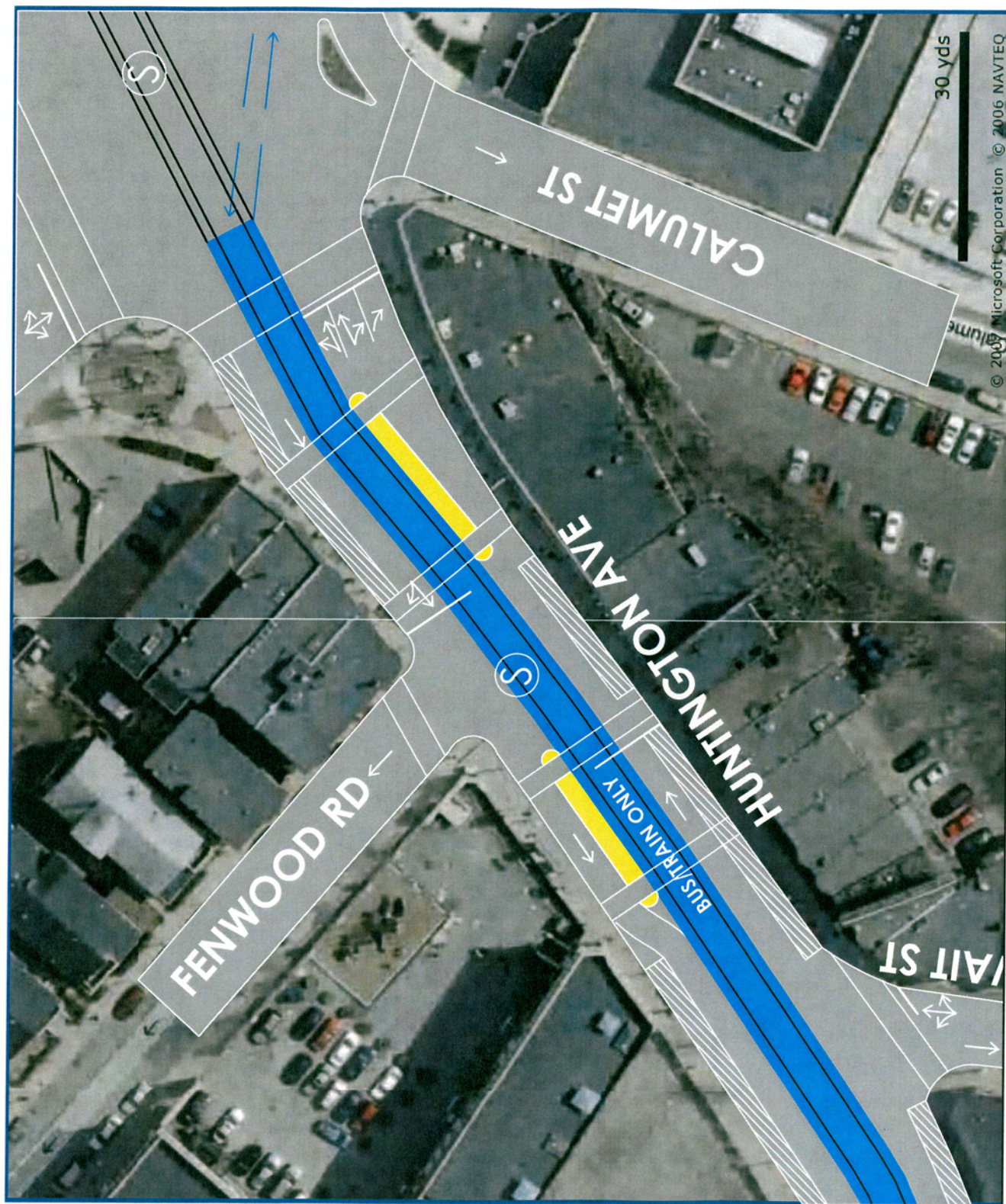


Figure 17
Huntington Ave & Fenwood Road Proposed

Huntington Ave & Mission Street Inbound

Since this stop is not heavily used, it is recommended that it be removed from the route in order to increase bus speed. The previous and succeeding stops are close enough in proximity as shown in Table 2 above. Passengers who previously used this stop would still be within reasonable walking distance to their destination if this stop were removed.

Huntington Ave & Parker Hill Ave

Figure 18 shows a sketch of the proposed design at this intersection. Some of the parking spaces that are being removed as a result of the new location of the bus stops can be replaced in the outbound direction on Huntington Ave where the old bus stop is.

With a reserved bus/train lane in the center of the road, left turns onto Parker Hill Ave and Mission Park Drive is a safety issue. Since the reserved lane is going to be separated by only pavement markings, left turns to and from streets and driveways will not be restricted. Signage needs to be added warning drivers to be aware of the transit lanes in both directions.

In order to reduce long queues on Huntington Ave, a short exclusive left-turn lane (40 feet) is recommended on Huntington Ave westbound for vehicles turning onto Parker Hill Ave. Trains currently safely run down the center of Huntington Ave and no left turning restriction exists. Therefore, it is expected that it will not become a problem with the addition of buses to the center lanes.

Huntington Ave & S Huntington Ave

At this intersection, the green line and bus route 66 split. Bus route 39 follows the path of the green line along S Huntington Ave. Private vehicles turning left onto S Huntington Ave must be aware of the buses that are continuing on Huntington Ave. Adding signage to help make motorists more aware of the end of reserved transit lane is recommended. This signal must be retimed to allow for route 66 buses to get their own signal to have priority over the left turning vehicles onto S Huntington Ave.

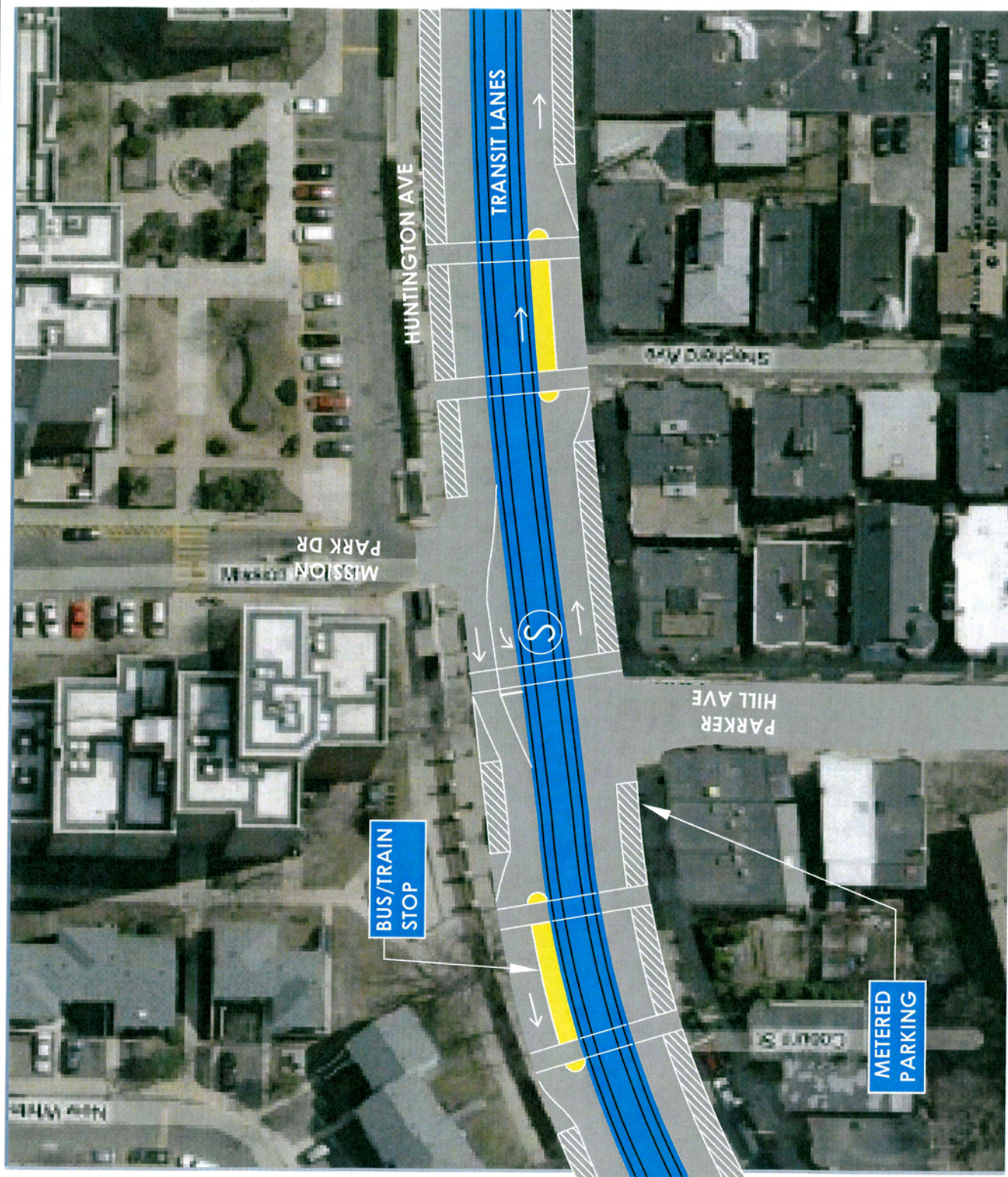


Figure 18
Huntington Ave & Parker Hill Ave Proposed

In order to make room for platforms, some parking must be removed. Table 6 shows the parking impacts along the Huntington Ave corridor. The negative impact of losing parking only eight parking spaces is outweighed by the safety imperative of protecting train passengers.

Table 6 Huntington Ave Parking Impacts

Bus Stop	Net Gain	Net Loss	Total (+/-)
Huntington Ave & Fenwood Road	3	8	-5
Huntington Ave & Parker Hill Ave	0	5	-5
Huntington Ave & Mission Street	2	0	+2
Total	5	13	-8

8.1.2 Transit Lane Operation

Since buses will be sharing the transit way with the green line 'E' train, there will be times when they cause delays to each other. Along the reserved transit lane, buses could get blocked behind a train. This does not have a great impact on delay. In the reserved transit lanes, trains and buses will be moving at the same speed. Since the stops for the green line 'E' train and Bus Route 66 and 39 are located on the same platforms, these delays will not be much of an issue and the overall bus and train run time reduction on this corridor will still be enormous.

8.1.3 Through Traffic

As mentioned earlier in Section 3.2.1, one method of protecting buses from congestion is to limit traffic on bus routes. By downsizing the area of Huntington Ave that bus route 66 travels on to only one private vehicle lane, traffic will have to be limited.

As a result of the decreased capacity on Huntington Ave due to a reserved transit lane, through vehicles are going to have seek an alternate route to get to their destination. Most through traffic on Huntington Ave is heading to downtown Boston inbound, and Brookline Ave and S Huntington Ave outbound. If the through traffic remains on Huntington Ave with a reserved bus/train lane, the corridor will face gridlock.

There is a parallel, high capacity route that excludes buses and trains. This bypass route could be at Fenway Road and Park Drive. Figure 19 shows an aerial view of this through route. In order to make this bypass route more effective, the existing signal timings at Louis Prang/Evans Way/Fenway must be improved. This route was originally intended to be a through route and with some slight improvements to the signal timings it will be successful.

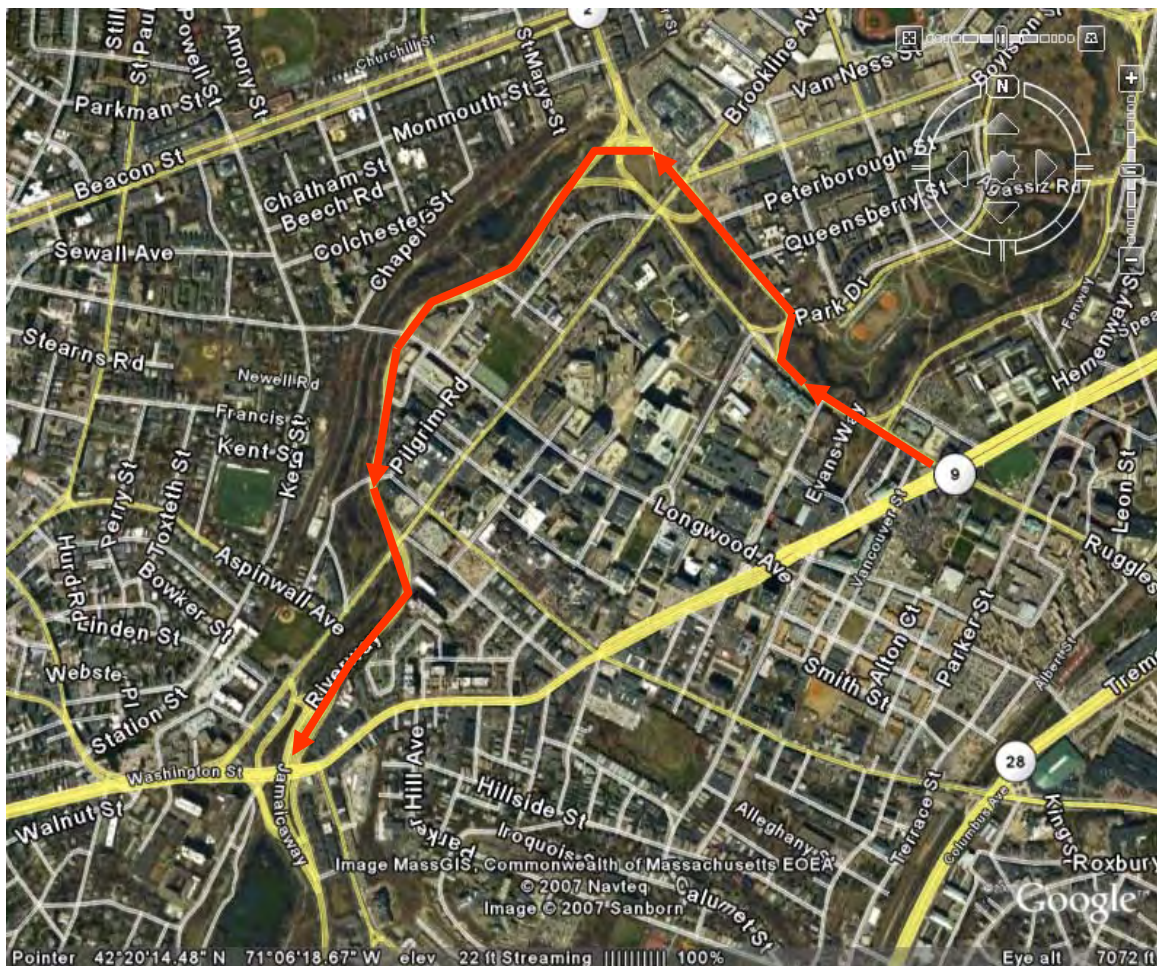


Figure 19 Likely Through Route for Private Vehicles

8.2 Coolidge Corner (Harvard Street/Beacon Street)

Located at the intersection of Beacon Street and Harvard Street, Coolidge Corner experiences significant volumes of vehicular traffic, much of which is through traffic. This intersection is also the location of a stop on the MBTA Green Line 'C' branch, with the 'C' branch running along the middle of Beacon Street. High pedestrian volumes in the crosswalk and impeding right-turning cars blocking the right lane contribute to the high bus delays. High right-turning traffic in both directions also slows down buses. High transit stop use also forces long dwell times at this stop.

This well established transportation network makes Coolidge Corner easily accessible. However, this ease of access is often viewed as being responsible for some of the area's greatest problems. Conflicts between the various transportation modes, congestion, a lack of parking,

deficiencies in the transit system, along with the perceived burdensome nature of regulatory policies and requirements relating to transportation, are all seen as detracting from the area's overall vitality and livability [16].

Figure 20 shows a schematic of the existing conditions in Coolidge Corner. North of Beacon Street, Harvard Street has metered parking on both sides. Approximately 250 feet north of Beacon Street, Green Street intersects Harvard Street. Green Street is a one-way and restricts left turns from Harvard Street.

Route 66 bus stops are located on the near side of Harvard Street at the intersection with Beacon Street. As expected, the volumes along Beacon Street and Harvard Street are high. As a result, buses are often delayed in queue before they are able access the stop, causing frequent triple stops.

South of Beacon Street, Harvard Street is approximately 48 feet wide. At the intersection, there are two through lanes. Longwood Ave intersects Harvard Street approximately 150 feet south of the intersection. South of Longwood Ave, there is a travel lane, bicycle lane and metered parking on both sides.

Beacon Street carries the Green Line along with private vehicles. Buses do not run along Beacon Street. The fact that the Green Line is in a median reservoir is important – it allows for the trains to be separate from the private vehicle traffic, resulting in the non-existence of queues in Coolidge Corner, which is not the case on Huntington Ave. Under the current signal timings, Beacon Street has twice as much green time as Harvard Street, which allows both private vehicle traffic and trains on Beacon Street to experience minor delays at this intersection.

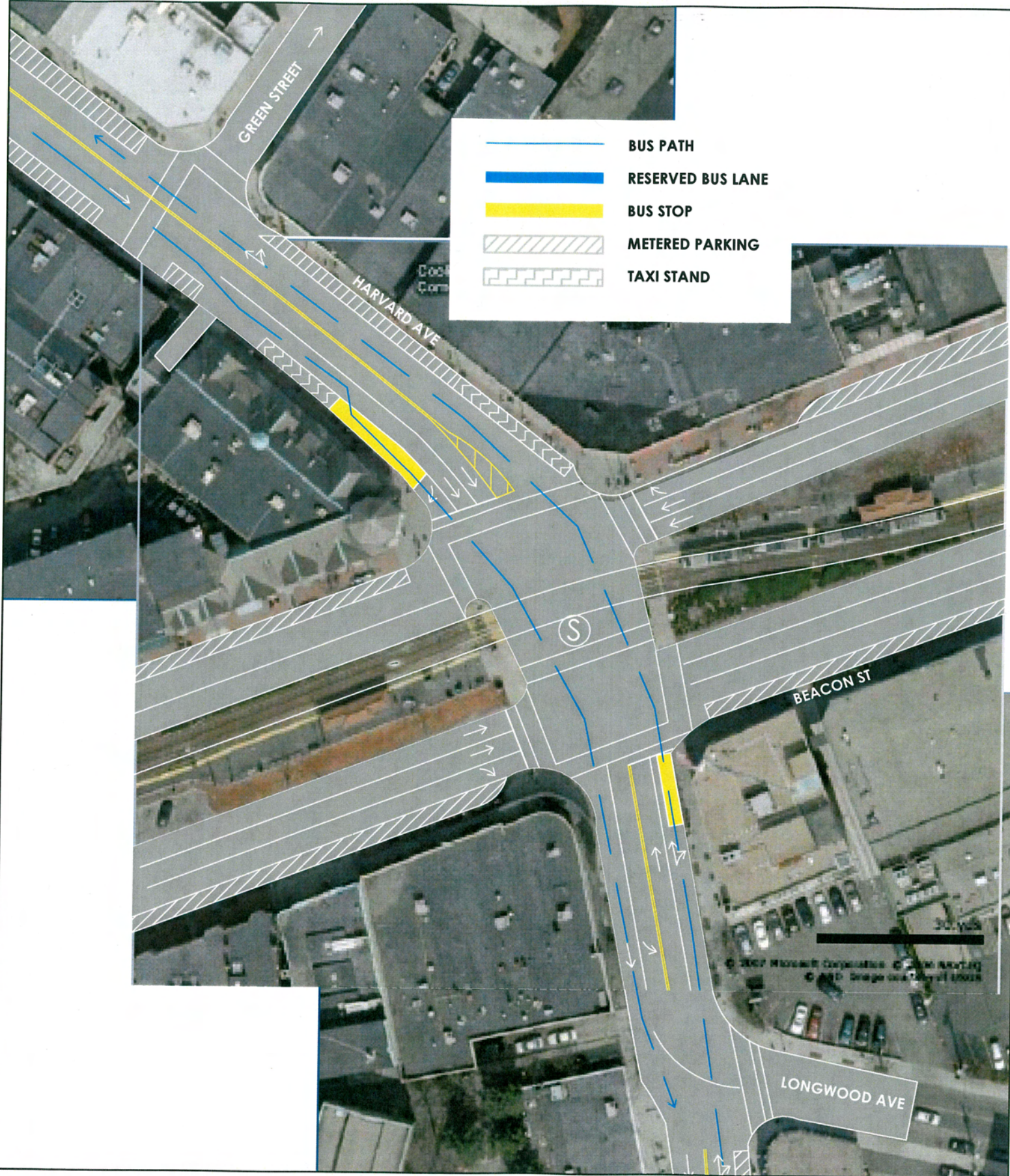


Figure 20
Coolidge Corner Existing

8.2.1 Recommendations

The following is a list of recommendations for Coolidge Corner in order to protect buses from congestion:

- Eliminate near-side stops. In the southbound direction, relocating the southbound bus stop across from Green Street puts it far enough away from the Beacon Street to avoid a triple stop. In the northbound direction, relocating the bus stop to the far-side of Longwood Ave allows for a right-turning queue to extend to further and not block buses from reaching the stop. As long as the queue does not back up beyond Longwood Ave, buses will be able to access the stop without being delayed.
- A multi-use right lane allowing only buses and right turning private vehicles in both directions along Harvard Street. This lane will serve as a queue jump lane, removing the problem of long queues preventing the buses from access to the bus stops (Figure 21). By allowing private vehicles to use this lane, intersection capacity is greater. Only one parking space would be lost by implementation of this recommendation. There is a societal concern for short-term parking and a taxi stand, so it is important to maintain the taxi stand and as much parking as possible. The existing taxi stand will be relocated further away from Beacon Street adjacent to Green Street.
- Bulb-out curb at the southbound bus stop on Harvard Street. This saves buses pull-in time and allows for safer pull-outs.
- Signal Priority
 - o Passive Option:
 - Allocate more green time to Harvard Ave. Buses are delayed waiting in queues, while the Green Line is not. By allocating more green time to Harvard Street, buses will be more likely to arrive at the intersection during the green phase, thus reducing delays.
 - o Active Option:
 - Priority to bus – early green, green extension. Early green time is going to be limited by the minimum pedestrian crossing time needed.
- Signalize Harvard Ave & Green Street to prevent general blockage on Harvard Ave. This would promote safer pedestrian crossings further away from the core of Coolidge Corner. Since the pedestrian crossing at Green Street will be behind the bus, buses will not have to wait for the pedestrians crossing the street in front of the bus, and will be allowed to proceed to the intersection in the queue jump lane.

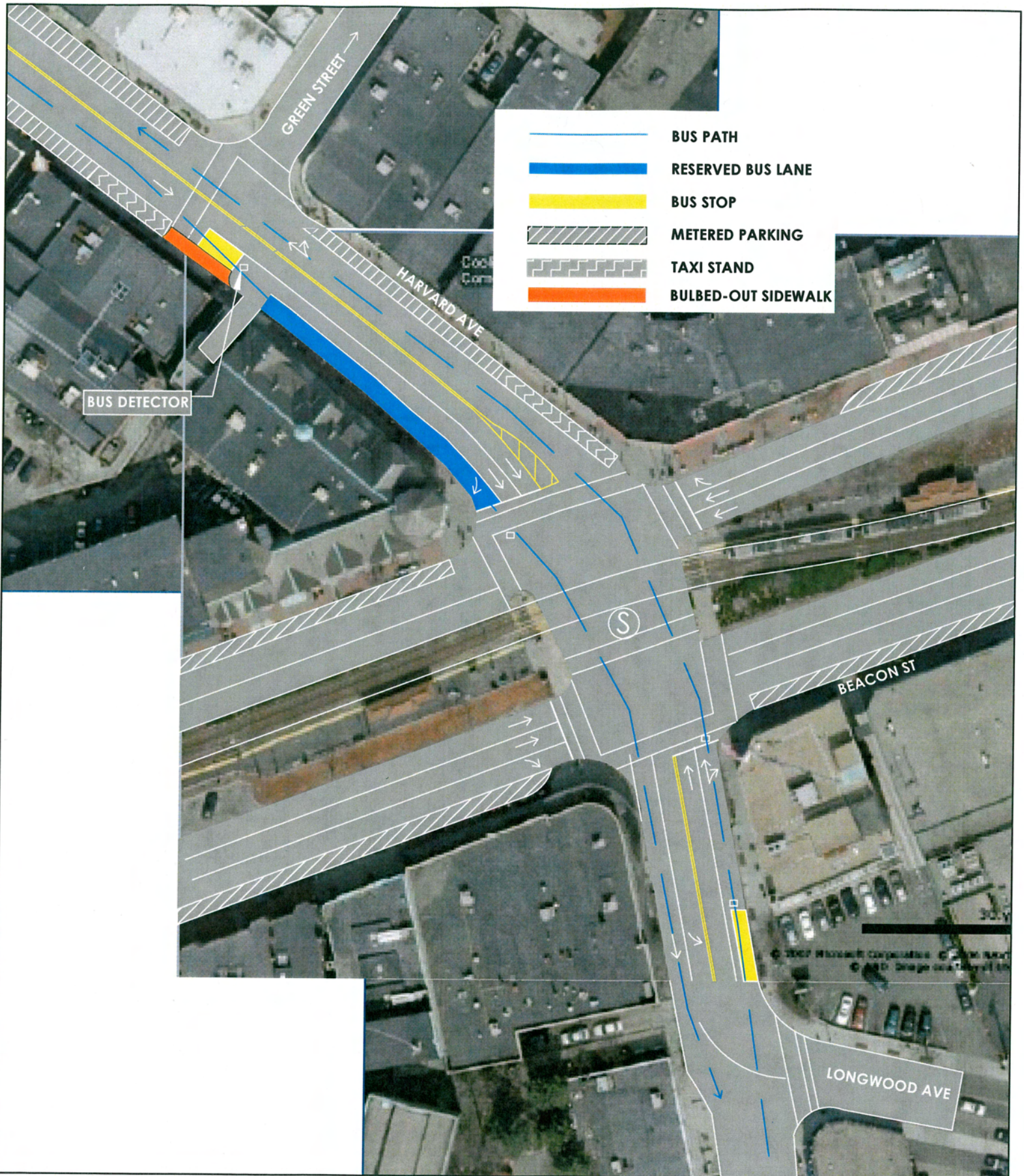


Figure 21
Coolidge Corner Proposed

In order to implement these recommendations, the existing parking will be reduced by only four total spaces (Table 7). By relocating the taxi stand, three parking spaces will be lost. One parking space will be lost as a result of the queue bypass lane on Harvard Ave north of Beacon Street.

Table 7 Coolidge Corner Parking Impacts

Location	Net Gain	Net Loss	Total (+/-)
Prop. Taxi Stand	0	3	-3
Prop. Queue Bypass Lane	0	1	-1
Total	0	4	-4

8.2.2 Evaluation

Implementing a queue jump lane, transit signal priority, bus stop relocation and some minor improvements should protect buses from congestion. A comparison of these bus delays is shown in Figure 22. The average bus delay is reduced from about 75 seconds to approximately 20 seconds.

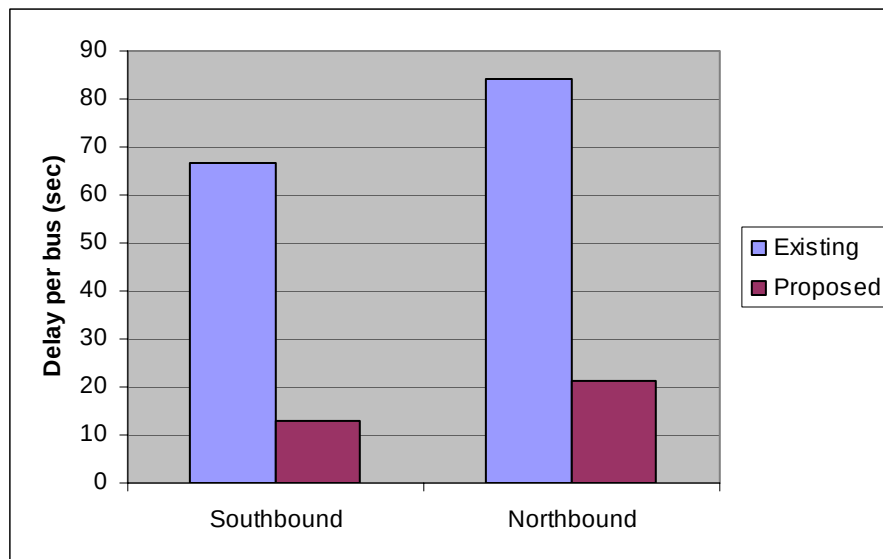


Figure 22 Coolidge Corner Delay Comparison

8.3 Allston Village

Harvard Ave from Brighton Ave to Commonwealth Ave

This entire block is often congested during peak hours, with an approximate average travel speed below five miles per hour. It often takes two or three signal cycles for a vehicle on Harvard Ave approaching northbound to clear Commonwealth Ave. Figure 23 shows

the existing lane configurations along Harvard Ave between Brighton Ave and Commonwealth Ave.

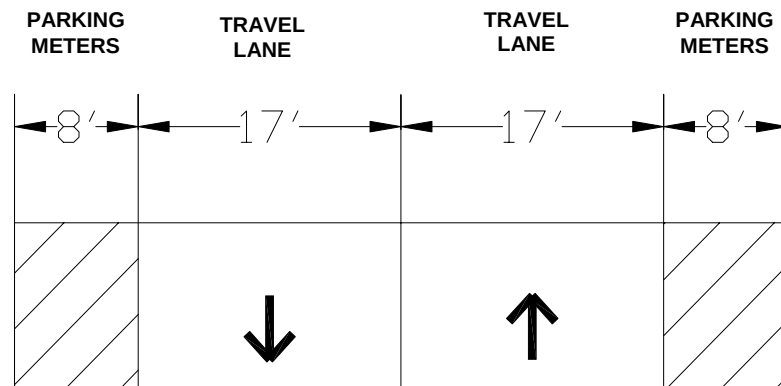


Figure 23 Existing Lane Configurations on Harvard Ave

Allston Village is mostly a commercial area, and although there are several parking meters in the area, double parking by commercial vehicles is a common problem on Harvard Ave. The lane configurations almost invite double parking; since vehicles can easily go around double-parked vehicles without crossing the double yellow centerline. Buses typically travel in the right part of the wide lane due to the location of bus stops, and often encounter a double-parked vehicle. As one would expect, it is more difficult for a bus to go around a double-parked vehicle than it is for a typical passenger vehicle.

In addition to double parking, the queues along Harvard Ave in Allston Village can be unbearable at times, detracting from area.

Harvard Ave & Commonwealth Ave

Figure 24 shows the existing lane configurations at this intersection. The bus stops are located near-side, which increases the likelihood of a “triple stop”, as mentioned earlier. A major reason for the long queues is left-turning vehicles. Approximately 25% of the Harvard Ave northbound traffic turns left onto Commonwealth Ave, delay through and right turning vehicles tremendously.

Harvard Ave & Brighton Ave

Figure 25 shows the existing lane configurations at this intersection. Buses are often experiencing high delays due to the near-side stop locations.

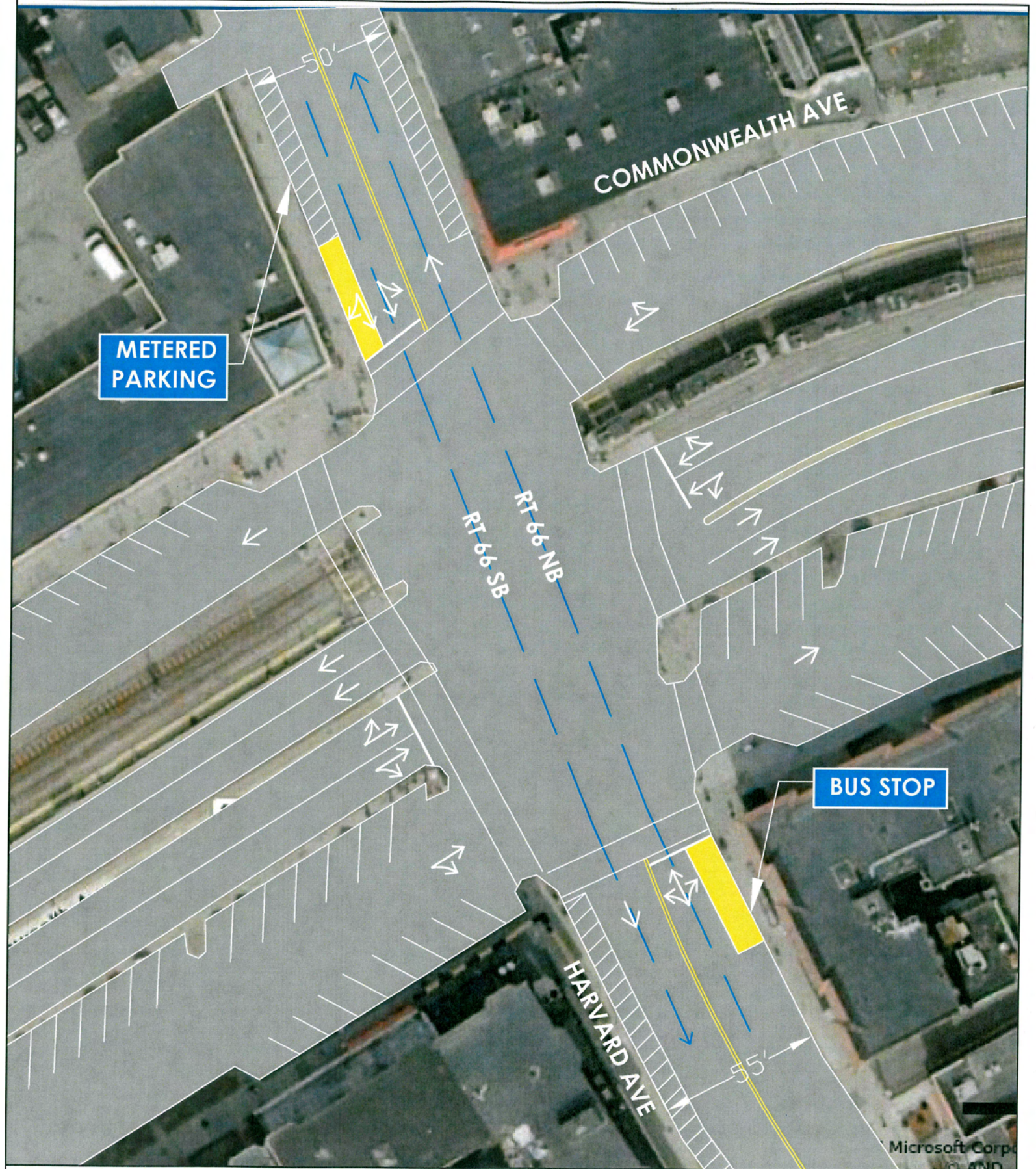


Figure 24
Harvard Ave & Commonwealth Ave Existing

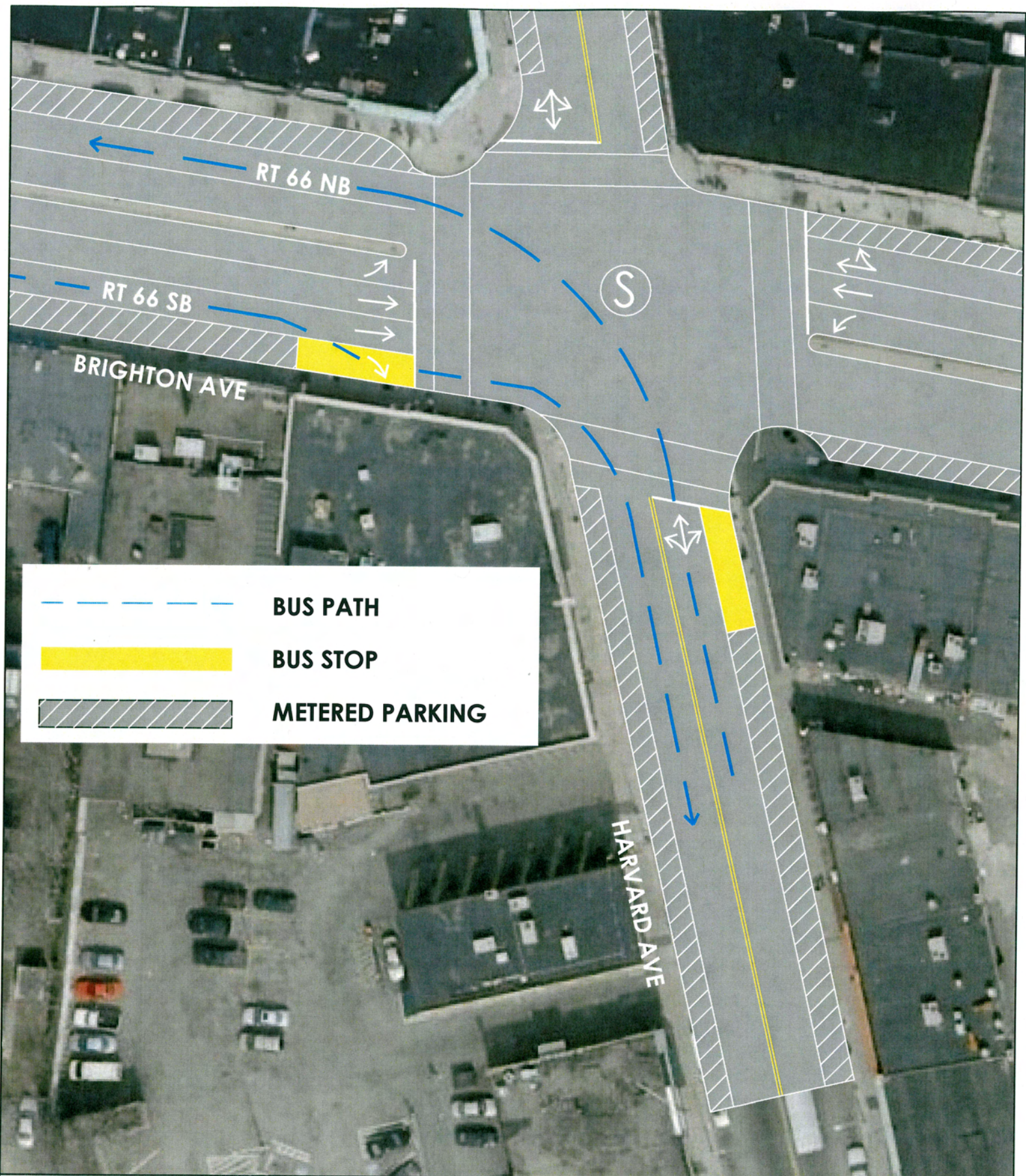


Figure 25
Harvard Ave & Brighton Ave Existing

8.3.1 Recommendations

The following is a list of recommendations for Allston Village in order to protect buses from congestion:

- A reserved bus lane on Harvard Ave, which would allow buses to jump the long queues on Harvard Ave. This reserved bus lane would only be successful if double-parked vehicles did not interfere with the reserved bus lane (Figure 26).
- Because there is not enough space for bus lanes in both directions, the bus lane will be one-way depending on the intersection approach.
- A four inch mountable curb will separate the bus lane from the travel lanes. By making the curb difficult to mount, double parking will be prevented. The curb is designed to be mounted only during emergency situations (e.g. a vehicle breakdown).
- The existing bus stops will be moved to the far side of the intersections in order to protect buses from the triple stop. Since buses will be in the center lane, access to the curb is much easier if the stops are located on the far side of the intersections (Figure 27-Figure 28). By placing the stops far-side, buses will be able to make a call to the signal to request priority sooner than if the stop was located on the near-side.
- Left turns will be prohibited in areas on Harvard Ave between Commonwealth Ave and Brighton Ave. This will make Harvard Street safer and also allow help protect the reserved bus lane queues resulting from left turning vehicles. Harvard Ave and Beacon Street is a perfect example of how prohibiting left turns will work in this area.
- The curb at the relocated bus stop on Brighton Ave westbound will bulb out similar to the proposed configuration in Coolidge Corner in order to reduce pull-out delays to buses. Left turning vehicles from Harvard Ave still have a lane to safely turn.
- The route 57 bus stop should be moved to the far side of the intersection (avoid triple stop) to eliminate interference with the route 66 bus, and to reduce delay for route 57.
- Signal Priority
 - o Passive Option
 - As on Beacon Street, buses do not run on Commonwealth Ave, and the trolleys are protected. Therefore, allocating more green time to Harvard Street is recommended. Also, shortening the cycle lengths at both intersections would help to protect buses from congestion. Implementing actuated control would also improve delays to all vehicles.

- o Active Option
 - Priority to bus – early green, green extension. Early green time is going to be limited by the minimum pedestrian crossing time needed.
- Adding more loading zones on Harvard Ave would help to prevent double parking.

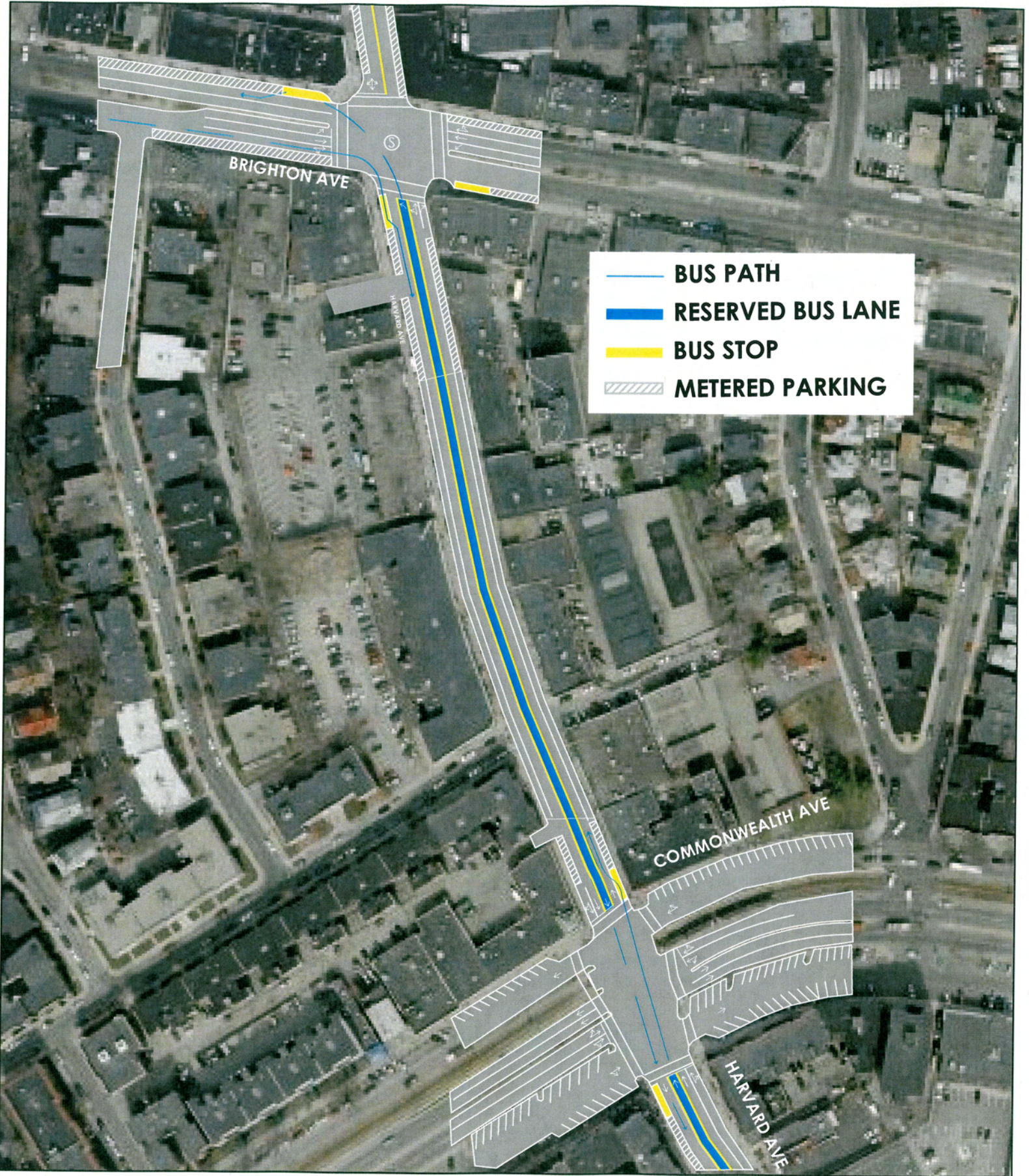


Figure 26
Allston Village Proposed Alignment

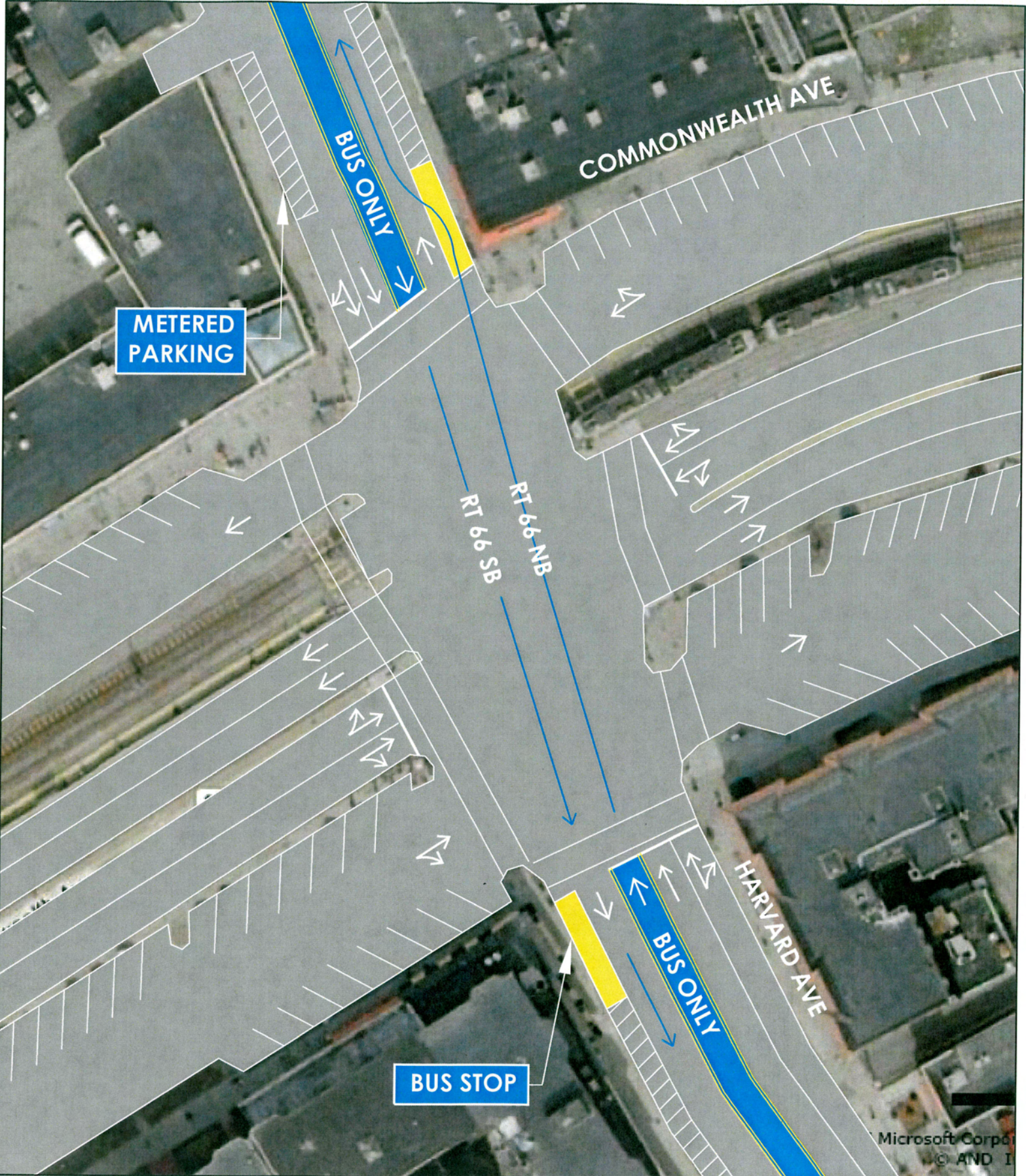


Figure 27
Harvard Ave & Commonwealth Ave Proposed

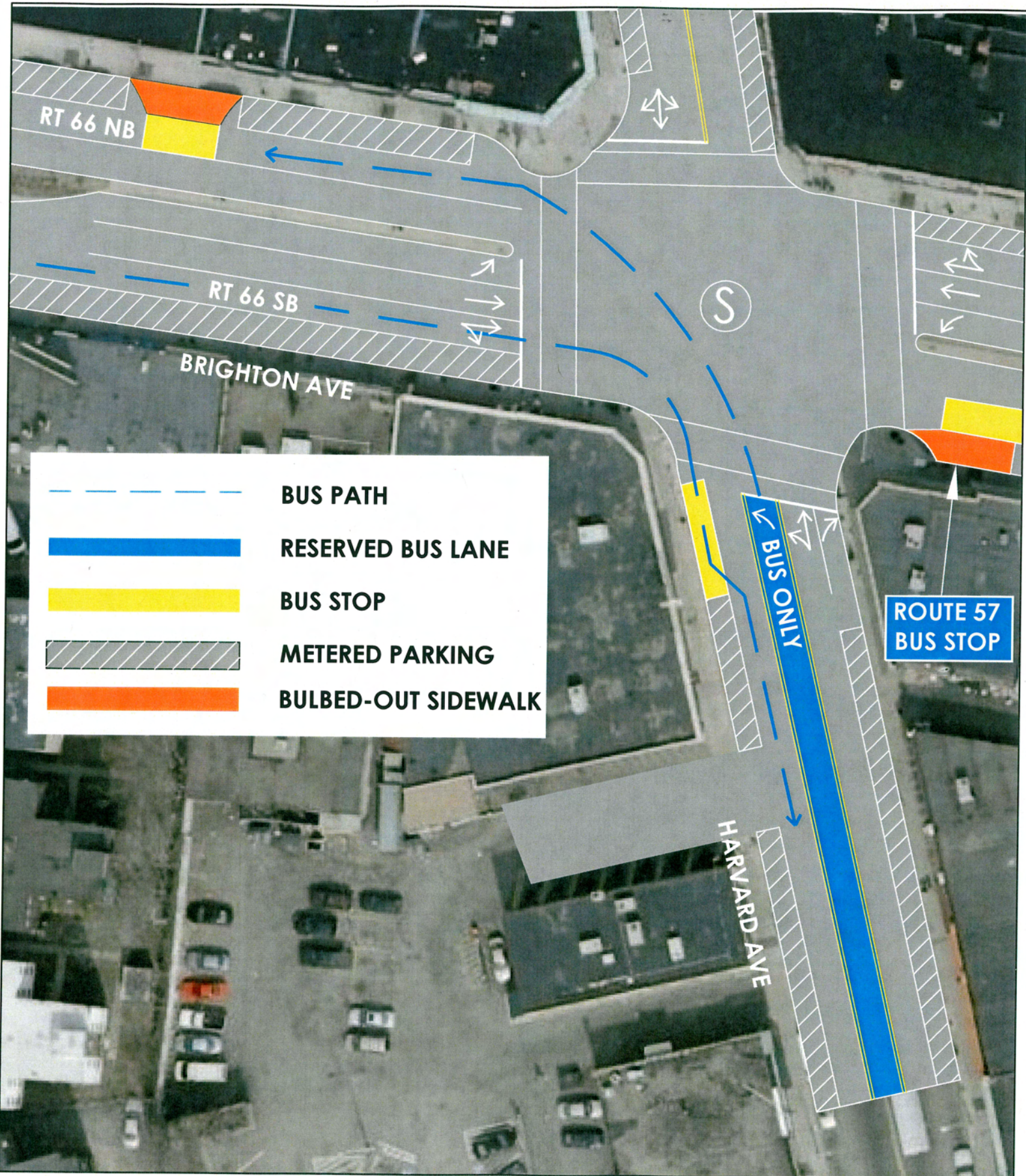


Figure 28
Harvard Ave & Brighton Ave Proposed

Eight parking spaces will be lost in Allston Village as a result of the recommended congestion protection strategies (Table 8). For the amount of savings buses will experience, this is a relatively minor loss.

Table 8 Allston Village Parking Impacts

Bus Stop	Net Gain	Net Loss	Total (+-)
Harvard Ave & Commonwealth Ave	0	-4	-4
Harvard Ave & Brighton Ave	2	-6	-4
Total	2	-10	-8

8.3.2 Evaluation

By adding a reserved bus lane to serve both directions, far-side bus stop relocation, left turn restrictions, signal priority and other minor improvements, buses on Harvard Ave experience much lower delays. Figure 29 shows the delay reduction due to congestion protection at the intersection of Harvard Ave and Commonwealth Ave. The average delay per bus has been reduced from approximately 45 seconds (southbound) and 90 seconds (northbound) to less than 20 seconds in both directions.

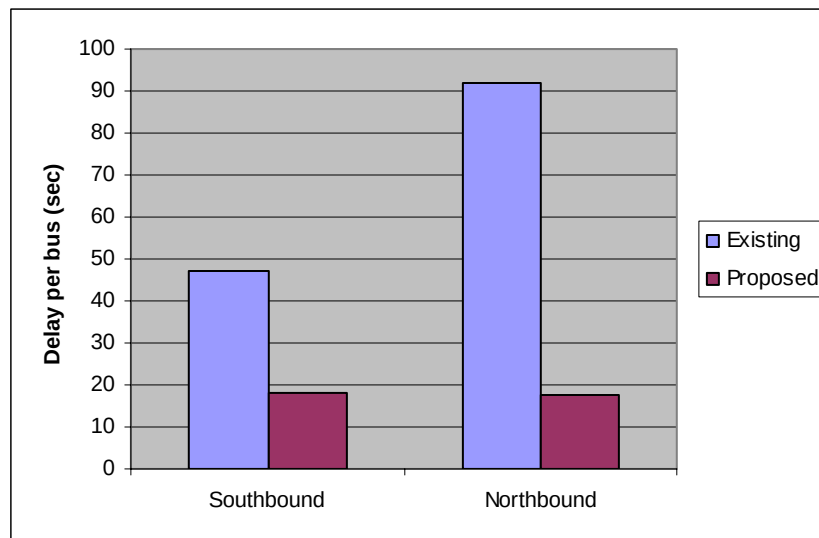


Figure 29 Harvard Ave & Commonwealth Ave Delay Comparison

Figure 30 shows the delay reduction due to the congestion protection measures mentioned above at the intersection of Harvard Ave and Brighton Ave. The average delay per bus has been reduced from approximately 40-55 seconds to approximately 20 seconds.

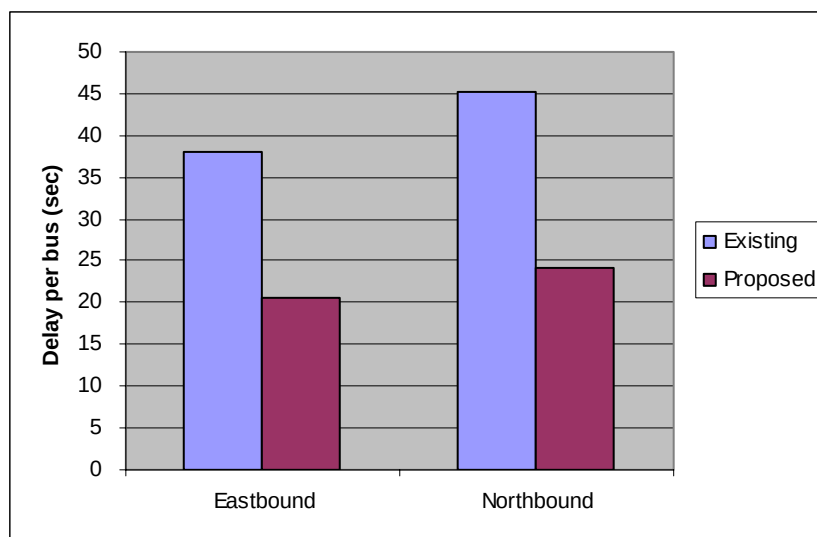


Figure 30 Harvard Ave & Brighton Ave Delay Comparison

With all of the congestion protection strategies recommended in Allston Village, bus delays will be reduced considerably. It will be impossible to get zero delay due to long pedestrian clearance times.

8.3.3 Conflicts

Due to left turning restrictions, vehicles entering and exiting driveways must make right turns. Glenville Ave, which intersects Harvard Street approximately 250 feet from Commonwealth Ave, will also restrict left turns. Figure 31 shows an example of a worst-case scenario route a vehicle will experience as a result of the left turning restriction.

A northbound vehicle on Harvard Street will have a difficult time getting to the municipal lot. One option would be permitting left turns in what is currently used as an exit in the southernmost part of the lot (circled in blue).

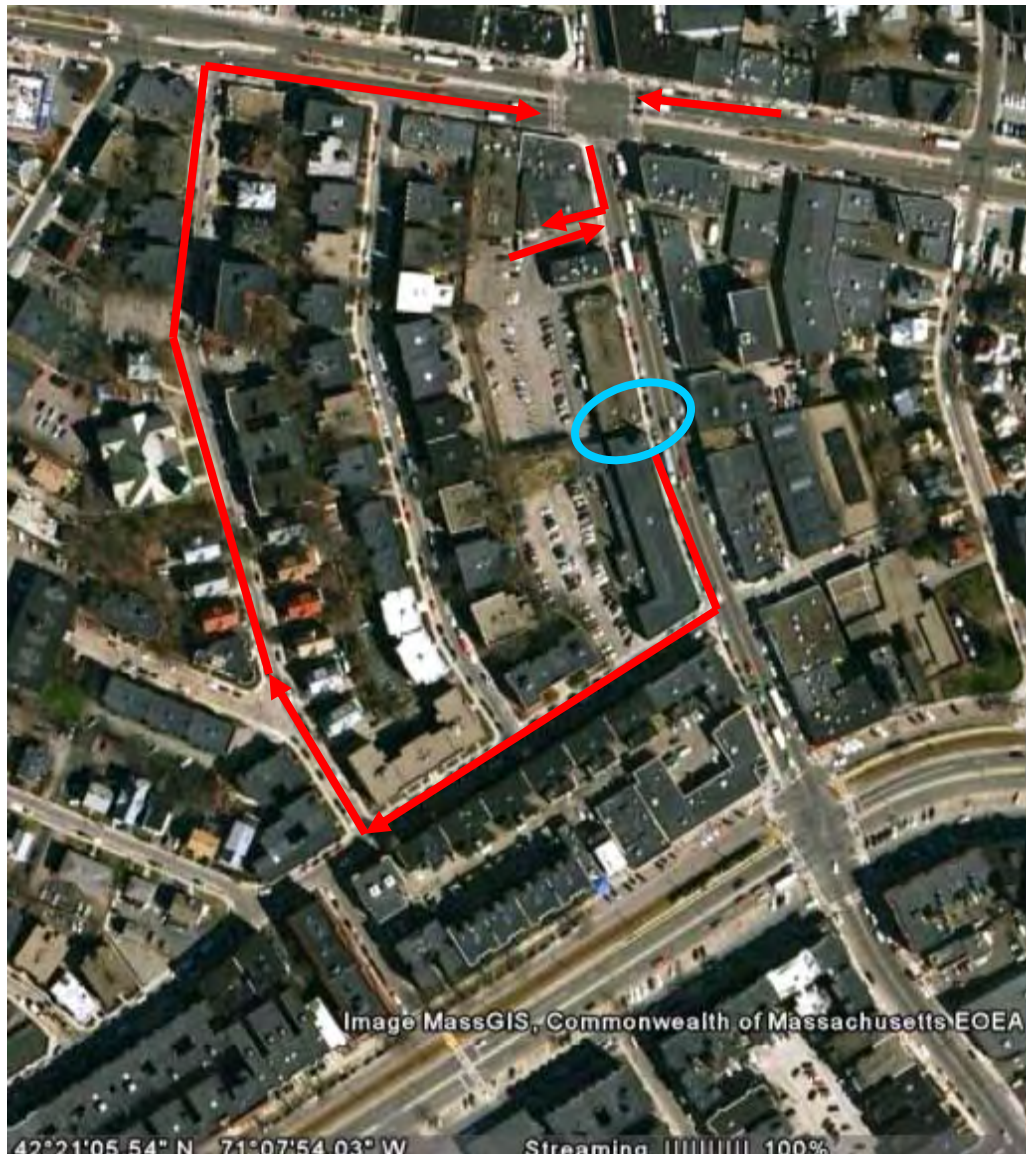


Figure 31 Proposed Veh Path due to Turning Restrictions

Another conflict resulting from the proposed bus lane is the possibility of double parking. As has been shown in Brussels, mountable curbs do not work in commercial areas, because they encourage double parking. The solution to this is a 4-inch mountable curb at a sharp angle to the street, it is possible for private vehicles to enter into the reserved bus lane when a double-parked vehicle is blocking the private vehicle lane, but it is difficult to do so and will only be done during emergency situations (Figure 32). This scenario is not expected to occur often, since the lane will only be 11 feet wide.

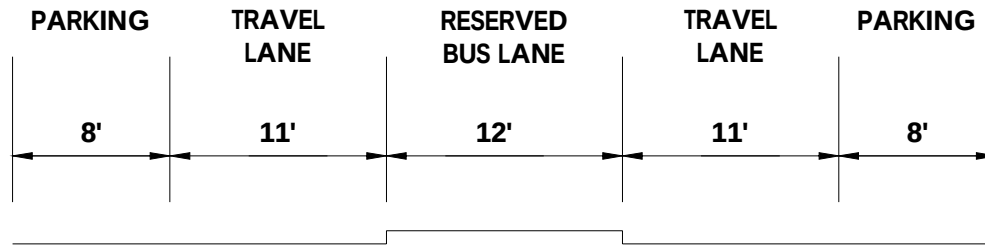


Figure 32 Cross Section of Four Inch Mountable Curb

8.4 Cambridge Street/N Harvard Street

Outbound buses approaching turn left onto N Harvard Street from Cambridge Street experience high delays due to large volumes of left turns which, in spite of long green times, sometimes overflow. The existing conditions at this intersection are shown in Figure 33. On Cambridge Street, left turns are protected with a turning pocket accommodating approximately 11 cars. Cambridge Street has four lanes in each direction.

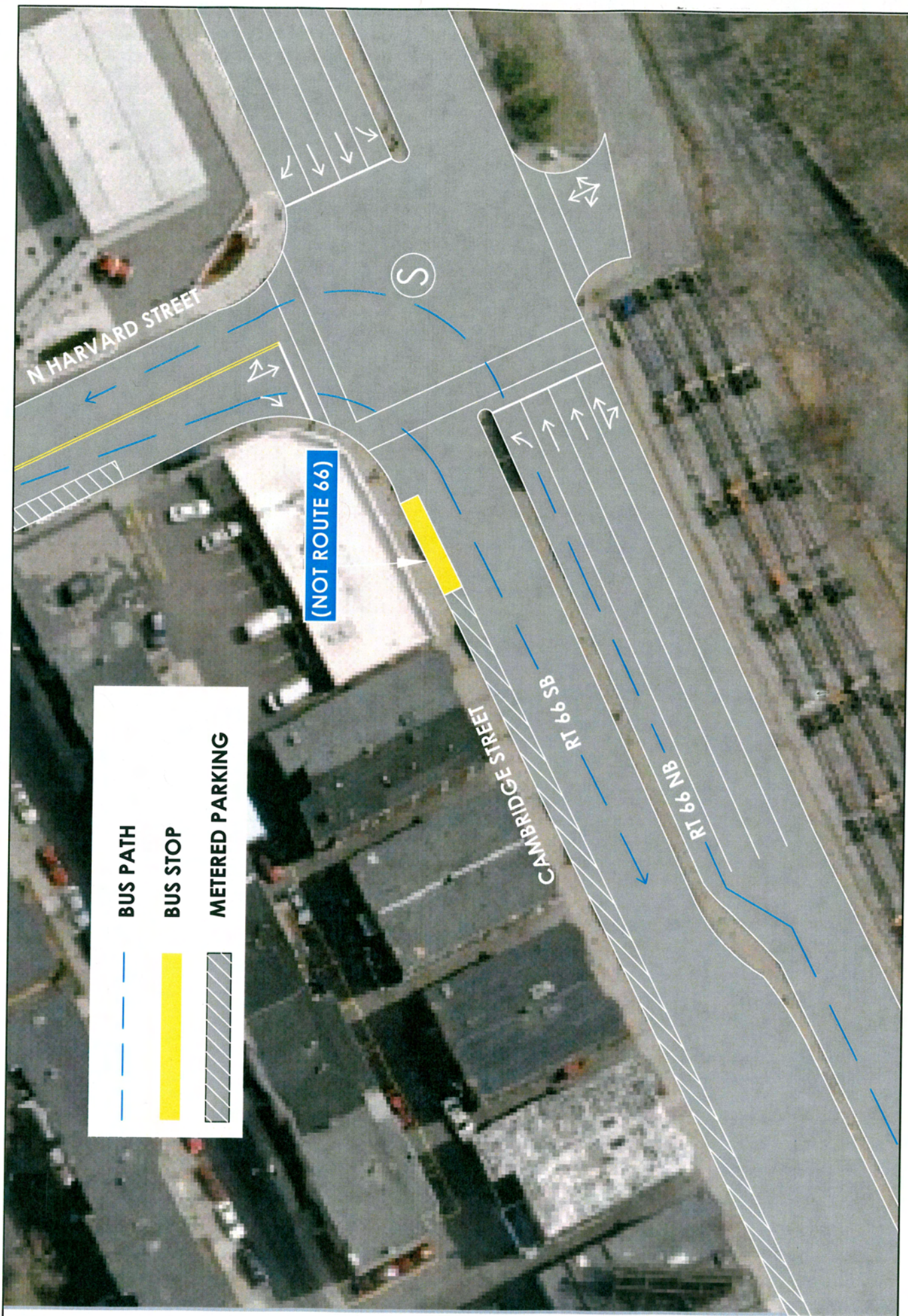


Figure 33
Cambridge St & N Harvard St Existing

8.4.1 Recommendations

The following is a list of recommendations for the Cambridge Street/North Harvard Street intersection in order to protect buses from congestion:

- A queue jump lane on the eastbound approach of Cambridge Street for left-turning buses (Figure 34). The location of the lane will be strategically placed to protect buses from being blocked entry into the lane. Through traffic, which currently is accommodated with three lanes, will be reduced to two. If the queue jump lane were located in the innermost lane, buses could potentially be blocked by vehicles in the through lane.
- A bus detector will be placed near the end of the left-turn lane in order to protect the buses from being blocked behind the queue. When the queue is backed up to the detector, the controller will be notified and the left turn lane will receive priority in order to clear the lane.
- Signal Priority
 - o Passive Option
 - Allocating more green time to left turns from Cambridge Street is recommended. Implementing actuated control would also improve delays to all vehicles.
 - o Active Option
 - Priority to bus – early green, green extension. Early green time is going to be limited by the minimum pedestrian crossing time needed.

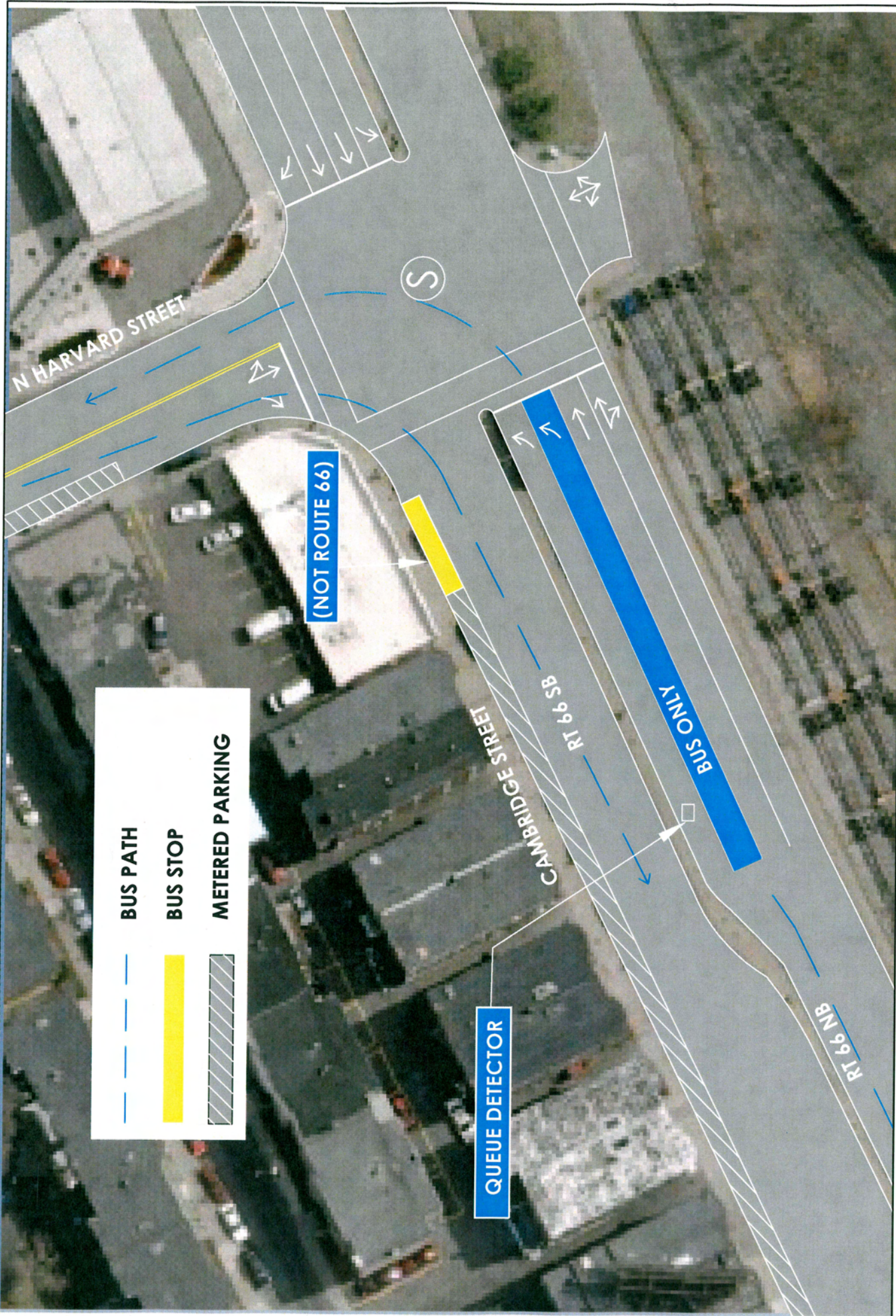


Figure 34
Cambridge St & N Harvard St Proposed

The proposed recommendations in North Allston will not have any impact to parking. All of the existing parking spaces will be retained.

8.4.2 Evaluation

By implementing a queue jump lane in the eastbound direction, along with transit signal priority and actuated control, bus delays on Cambridge Street have been reduced from over 45 seconds to less than 10 seconds (Figure 35). The existing delay in the southbound direction is already low because there is not a left turn involved, as is the case in the eastbound direction. The resulting bus delay associated with the left turn has been eliminated.

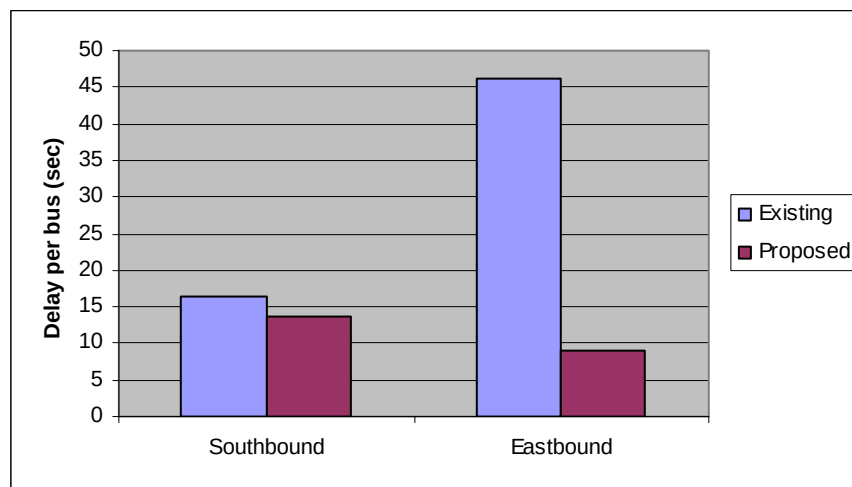


Figure 35 Cambridge Street & N Harvard Street Delay Comparison

8.5 N Harvard Street

Buses are congested as a result of long queues stemming from left turns from N Harvard Street turning onto either Western Ave or Soldiers Field Road (Figure 36). These left turning vehicles inhibit through travel for not only buses, but all traffic.

N Harvard Street & Western Ave

The bus stops are located north of Western Ave mid-block. Bus route 86 travels along N Harvard Street north of Western Ave and on Western Ave west of N Harvard Street. The lane configurations are the same in each direction of N Harvard Street, a left-turn only lane and a through/right shared lane.

N Harvard Street & Soldiers Field Road

The existing signal timings have four phases, and the green time for buses in the northbound direction is only 30 seconds, while the cycle length is 105 seconds. Buses are often stuck waiting in queues due to a single lane containing both through and left turning traffic.

The lane configuration on N Harvard Street northbound has recently been changed to a shared through/left lane and a right turn only lane. In the southbound direction, there are two shared through lanes. With approximately 50% of the traffic turning left onto Soldiers Field Road, the left lane essentially serves as a left turn only lane, leaving only one lane for through traffic. There are currently no bus stops located near this intersection.

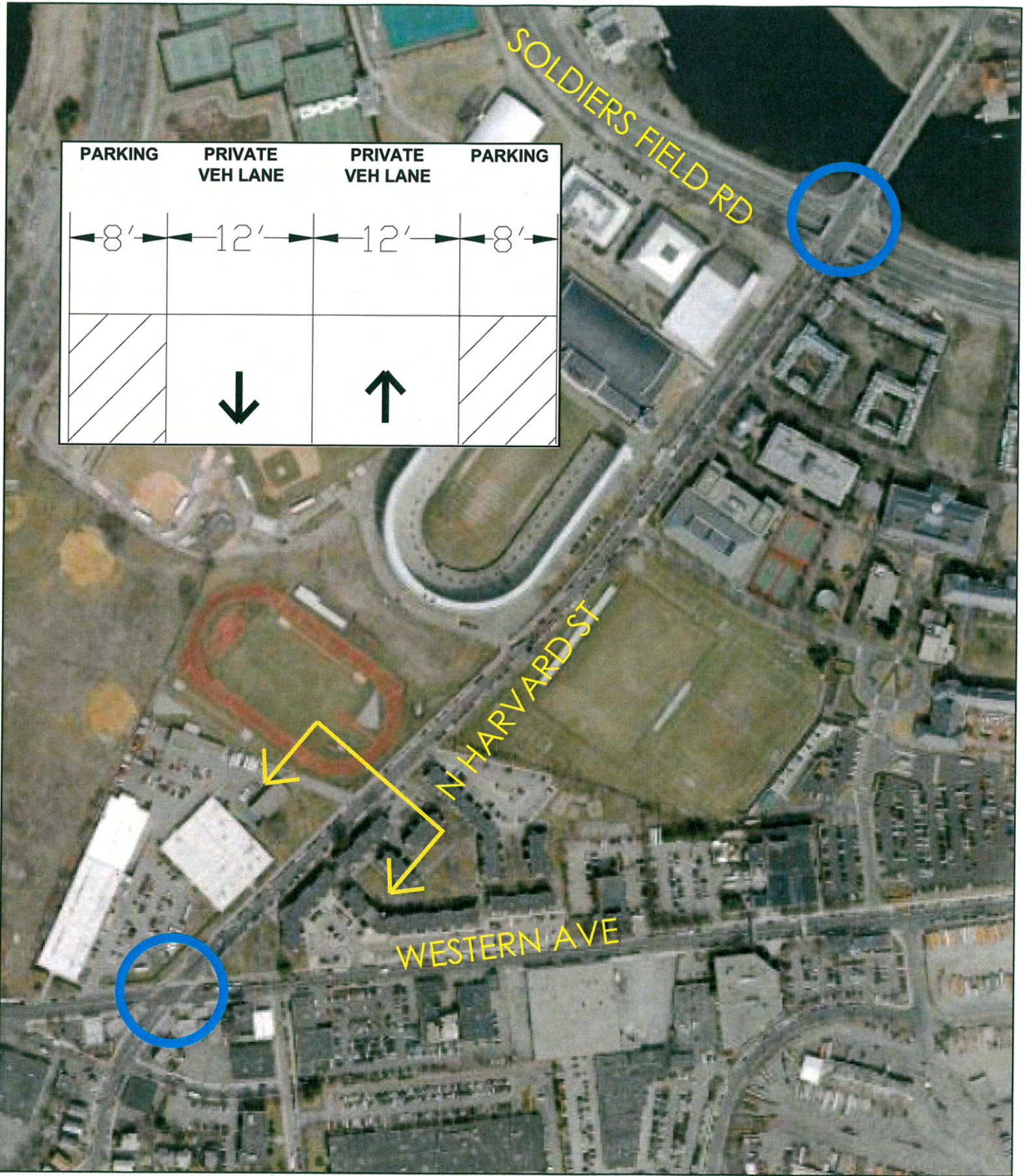


Figure 36
Soldiers Field Existing

8.5.1 Stop Spacing Analysis

Table 9 shows the utilization of the bus stops between Western Ave and Soldiers Field Road. Based on the short distance between stops and low utilization rates, the current stop spacing is inefficient. In order to improve bus speed, eliminating some bus stops from N Harvard Street is an option. Removing the two underutilized bus stops on N Harvard Street at 175 N Harvard and at Stadium Gate 6 is recommended.

Table 9 Weekday Stop Utilization on N Harvard Street

Stop: N Harvard &	Inbound		Outbound		Distance Between Stops (mi)
	Ons	Offs	Ons	Offs	
Western Ave	182	93	95	200	0.08
175 N Harvard	29	28	45	37	0.18
Stadium Gate 6	20	8	13	26	0.05
Gate 2 Harvard Stadium	39	23	46	59	

8.5.2 Recommendations

The following is a list of recommendations for Allston Village in order to protect buses from congestion:

- A reserved bus lane on N Harvard Street in the northbound direction allowing for buses to jump the long queue at the intersection with Soldiers Field Road. The bus lane could begin anywhere between Western Ave and Soldiers Field Road. A queue analysis is recommended to determine the best location of the beginning of the bus lane. The bus lane would be grade separated by a sharp 4-inch mountable curb similar to the situation in Allston Village until approximately 100 feet from the intersection. By ending the mountable curb 100 feet from the intersection, the lane could be used by private vehicle traffic at the vicinity of the intersection, saving some capacity. It will add a little delay; but without it, queues could extend beyond Western Ave, hurting buses there. In order to have enough space for a reserved bus lane, parking spaces must be removed. Since the parking being removed is commuter parking, there will not be much outrage by their removal.
- Transit Signal Priority
 - o Passive Option

- Shorter cycle times as well slightly increasing the green times on N Harvard Street will help to protect the buses from congestion.
- o Active Option
 - Giving early green and green extension, buses would experience lower delays.

The proposed lane configurations are shown in Figure 37. Northbound buses will experience near zero delays throughout this corridor. In the southbound direction, buses do not experience high delays on N Harvard Street and it is recommended to leave the lane configurations as is.

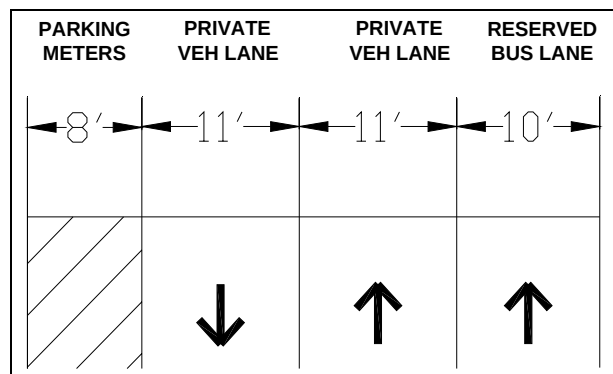


Figure 37 Proposed Lane Configurations on N Harvard Street

The impacts to the parking supply will be determined by the location of the start of the bus lane (Table 10). The parking supply on N Harvard Street is mostly used by commuters, and depending on a queue analysis on N Harvard Street, the extent of the effects to these parking spaces will be determined.

Table 10 Soldiers Field Parking Impacts

Location of Start of Bus Lane	Cumulative Parking Spaces Lost
Harvard Way	9
Albert H Gordon Road	28
Hefferan Street	60
Western Ave	72

8.5.3 Evaluation

The bus delay on both routes 66 running along N Harvard Street and 86 running along Western Ave will be reduced by having a reserved bus lane in the northbound direction on N Harvard Street and transit signal priority

on both Western Ave and Soldiers Field Road. Figure 38 compares the bus delay at the intersection of N Harvard Street and Western Ave. This delay includes both bus route 66 and 86. Southbound delays are higher in both existing and proposed conditions. By changing signal timings and giving transit signal priority, bus delays decreased to less than 10 seconds. This small delay is further proof that congestion protection strategies can be implemented anywhere.

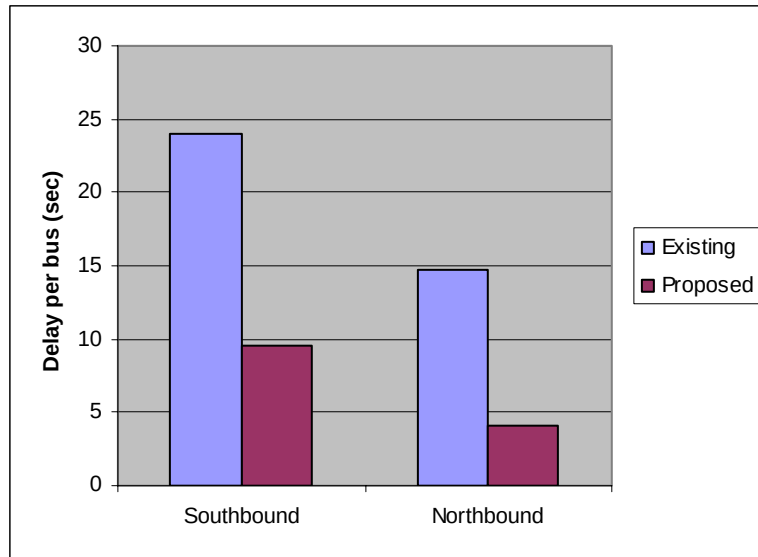


Figure 38 N Harvard Street & Western Ave Delay Comparison

Figure 39 compares the bus delay at the intersection of N Harvard Street and Soldiers Field Road. The existing northbound delays to buses are extremely high and with a reserved bus lane along with transit signal priority, buses will experience near-zero delay in both directions.

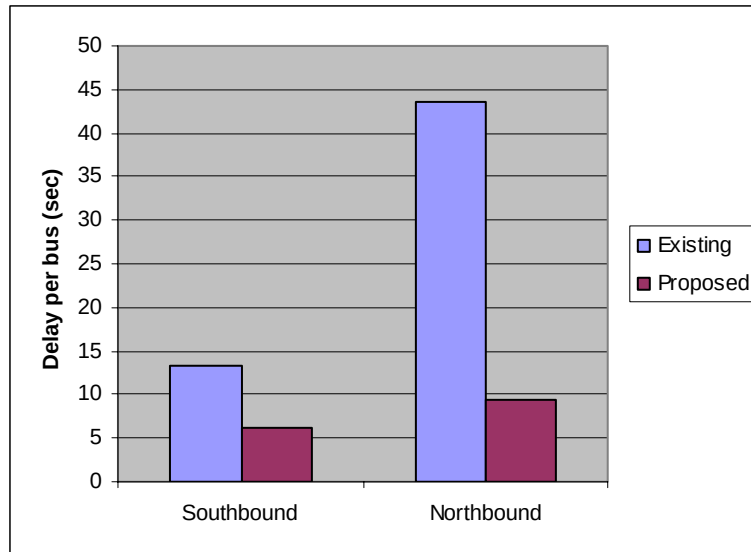


Figure 39 N Harvard Street Soldiers Field Road Delay Comparison

9.0 Other Recommendations to Improve Speed

Based on limited research, there are a few other areas along route 66 where bus speed can be improved by only minor adjustments to existing conditions. These areas along the route are located on Tremont Street and Washington Street. The recommendations to each of these areas will be discussed below.

9.1 Tremont Street

From Brigham Circle to Roxbury Crossing

Tremont Street is a hill with an approximately 2% grade southbound and 3.5% grade northbound. The peak of the hill is at the intersection with Carmel Street. The northbound stops located on the upgrade are at the intersection with Parker St. and at the Tobin Community Center. The bus stop is located on the near side of the signalized intersection with Parker St. The stop at the Tobin Community center is not located at an intersection.

9.1.1 Recommendations

Tremont St & Parker St Northbound

This stop should be moved to the far side of the intersection. The grade on the far side of this intersection is a little less steep, but bus delays will be a little more consistent if the stop is relocated here.

If the bus stop is relocated to the far side of the intersection, some parking must be removed on Tremont St. These spaces can be replaced at the old stop location on the near side of the intersection.

Tremont St & Tobin Community Center Northbound

This stop is not frequently used based on MBTA ridechecks performed in April of 2005. An average of only 33 riders board or alight this stop per day. Compared to the previous stop at Parker St and the following stop at Mission Church, this stop is utilized the least. As a result, it is recommended that this stop be removed from the route in the northbound direction only. Since this stop is underused, not many people will be affected by this stop being removed. Walking to the following stop at Mission Church is a close walk from the Tobin Community Center. Assuming this stop does not have some historical purpose, it is recommended it be removed.

Issuing bus signal priority would also reduce bus delays. If buses do not have to stop at a signal, the delays due to steep grades will be reduced. Signal priority will allow the buses to improve schedule adherence, efficiency and also lower operating costs. It is recommended that the

signals along Tremont St be coordinated and give outbound buses absolute priority at Gurney St and Parker St.

9.2 Washington Street & Pearl Street (Northbound)

This stop is located in the drop-off area of the JFK Building, separated from private vehicle traffic. Route 66 westbound buses pull in to the stop to the right without any impedance. This stop is also used for the bus route 65. Buses pull out from this stop and merge with general traffic approximately 100 feet from the stop line of the Washington Street signal. Washington Street northbound consists of two lanes.

When traffic volumes on Washington Street northbound are high, buses experience considerable delays when trying to pull out of the drop-off area.

If the stop line were moved back, buses would receive priority when pulling out of the stop.

The queue that results from the stop line being moved needs to be evaluated. As long as the new queue is far enough back to impact the existing traffic conditions, the stop line should be moved.

This solution would have an extremely minimal cost and could potentially save minutes of a buses run time, while also making the run time less variable.

10.0 Evaluation of Recommendations

All of the following hot spots except the Huntington Ave Corridor have been evaluated using simulation software (VISSIM). The results from the peak period will be presented in the following sections.

As a result of improved service, it is expected schedule adherence would greatly improve, making route 66 much more attractive to potential customers. Delay reduction will reduce operating cost. On a route with 10 minutes headway, these delay reductions will reduce necessary fleet size by one bus, reducing operating cost by approximately 10%. Delay reduction will also reduce passenger travel time and will improve reliability, attracting more passengers.

Toward Dudley Square, the expected run time savings is estimated to be slightly over eight minutes. Toward Harvard Square, the expected running time savings is estimated to be almost seven minutes. By saving approximately 15 minutes on the bus cycle time, one less bus is required on the route anytime the headway is less than 15 minutes. Over the

course of one year, this equates to approximately \$330,000 of savings to the MBTA.

Table 11 compares the delay for each hot spot. Table 12 summarizes the run time savings for each hot spot.

Table 11 Hot Spot Average Delay Comparison (seconds)

Hot Spot	Existing		Proposed	
	Toward Dudley Station	Toward Harvard Sq	Toward Dudley Station	Toward Harvard Sq
Harvard/Beacon	64.5	85.1	20.1	19.5
Harvard/Commonwealth	73.5	84.8	12.2	12.8
Harvard/Brighton	40.9	53.5	19.5	19.6
Cambridge/N Harvard	10.7	41.5	12.5	11.2
N Harvard/Western	24.0	14.8	9.6	4.1
N Harvard/Soldiers Field Rd	13.3	43.6	6.3	9.4
Huntington Ave	*	*	*	*

*Vissim not used

Table 12 Bus Delay Improvement Summary

Street/Intersection	Toward Dudley	Toward Harvard
Huntington Ave Corridor	350	150
Harvard/Beacon	44	66
Harvard/Commonwealth	61	72
Harvard/Brighton	21	34
Cambridge/N Harvard	-2	30
N Harvard/Western	14	11
N Harvard/Soldiers Field Rd	7	34
<i>Total Savings (seconds)</i>	<i>495</i>	<i>400</i>

11.0 Conclusion

Congestion protection for buses is a relatively new concept in the United States and can be used in many different situations to fix the ongoing problem of high bus delays. Bus routes almost always run through streets that serve the most users. Buses often run on the same streets that carry the most passenger vehicles, resulting in high bus delays.

Congestion protection strategies can take the form of physical priority, traffic reduction schemes and priority at traffic signals. In this study, some of the physical priority measures used is median busways and queue bypass lanes. The major traffic reduction schemes used are limiting traffic on bus routes and limiting pedestrian caused congestion. The signal priority measures recommended in this study include both passive and active options. The passive options include allocating more green time to bus routes, shorter cycle lengths and actuated signalized intersections. The active options include early green and green extension.

A case study of the historical bus route 66 was done in order to showcase congestion protection measures in a real-life situation. After analysis of bus route 66, many hot spots were targeted. By implementing congestion protection strategies at these hot spots along with other recommendations to improve speed, the service of bus route 66 will be improved significantly. Most of the hot spots were evaluated using Vissim, and implementation of these congestion protection measures should reduce buses cycle time by approximately 15 minutes along route 66, which equates to approximately \$330,000 of savings to the MBTA.

This case study of bus route 66 shows that these ideas can be used in any major city around the world and be tremendously successful in reducing bus delays and making operations more efficient while preventing major road reconstruction.

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