IBI GROUP
21 Custom Street – 3rd Floor
Boston MA 02110 USA
tel 617 450 0701 fax 617 450 0702

Memorandum

To/Attention	City of Cambridge	**Date**	December 22, 2016
From	IBI Group	**Project No**	103338
cc			
Subject	Technical Report: Grand Junction Feasibility Review		

Contents

List of Figures

List of Tables

City of Cambridge – December 22, 2016

GRAND JUNCTION FEASIBILITY REVIEW

In September, 2016, the City of Cambridge engaged IBI Group to: review work done to date relating to potential transit use of the Grand Junction Railroad right-of-way in Cambridge in conjunction with a multi-use path; prepare a presentation relating to the Grand Junction to Task Force Meeting #8 of the Kendall Square Mobility Task Force (hereinafter 'the Task Force'); and prepare and help incorporate related materials into the overall report of the Task Force. The presentation was made at meeting #8 of the Task Force on October 25, 2016. The memorandum constitutes the feasibility review.

Background on the Grand Junction

By the 1840s a number of radial railroads had been established between Boston and other cities such as Fitchburg, Worcester, Lowell, Providence, and Portland, ME. Each railroad had its own terminal in Boston or Cambridge. They needed a way to interchange freight traffic. By 1856, the Grand Junction Railroad and Depot Company had been established to move freight cars between the different radial lines and to facilitate shipments to and from local customers. The Union Freight Railroad, along Boston's Atlantic Avenue between what are now North and South Stations, served a similar purpose. As local rail freight traffic diminished in the second half of the 20th century, these links became less important; the Union Freight Railroad ceased operations in 1970, leaving the Grand Junction as the only railroad connection between the north and south 'sides' east of I-495.

Present Railroad Use

The Grand Junction is now primarily used for moving MBTA commuter rail and some Amtrak equipment between North and South Station. There are approximately 3-5 train moves per day, mostly in the evenings. These trains consist of passenger train locomotives and cars being moved between maintenance facilities and storage yards; they do not carry passengers.

A single weekday local freight train has been using the Grand Junction to reach two local customers from Framingham: the Schnitzer Steel scrap yard in Everett and the New England Produce Market. The future of the freight service is uncertain because these customers lie north of the Mystic River and could be served by another carrier from the 'north side'. CSX has sold off its Beacon Park Yard on the south side, from which these customers were previously served.

Even if the freight service is discontinued, at least a single track must remain on the Grand Junction corridor to handle the MBTA commuter rail and Amtrak equipment moves.

The track now in place is not rated for train movement at more than 10 mph due to track condition; this has been sufficient for the present limited use.

In addition, any vehicle that shares this track must either comply with FRA requirements for crash energy management or be strictly separated in time from trains that do comply. There are also advanced temporal separation options that could be employed but would require expensive technology solutions.

Another use of the Grand Junction that must be accommodated is the planned multi-use path that will run alongside the existing tracks in the Grand Junction corridor between the Charles River and North Point and, in the future, the extension of the Somerville Community Path originally proposed as part of the Green line Extension. The Grand Junction Path will provide a continuous pathway for residents, schoolchildren, workers and visitors to stroll, jog, or bike along a linear park connecting several neighborhoods, commercial areas, and community resources such as schools, playing fields, libraries, retail areas and the Charles River in addition to regional destinations including Boston, Somerville and beyond. Over one quarter of Cambridge residents live within walking distance or a half mile of the path. The desired width for the path, the first segment of which has been built in the Grand Junction Park between Broadway and Main Street, is 14’ with 2’ buffers on each side.

Any transit plans for the Grand Junction right-of-way must include this path, ideally requiring the path to cross the transitway as few times as possible.

Minimum Configuration for the Grand Junction

A *minimum* width with a single track for railroad equipment moves and a 10’ multi-use path is 33’ where no platforms need to be provided, as shown in Figure 1. As noted above, 14’ plus buffers is the desired width. The path segment between Main Street and Broadway, which has already been constructed meets these dimensions.

The City is currently doing a right-of-way survey to determine what width is possible in current conditions.

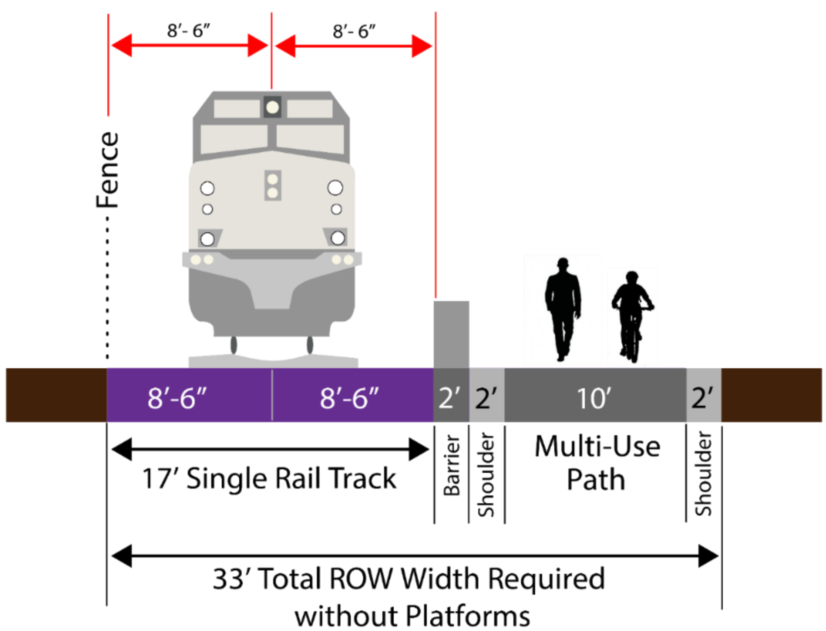


Figure 1: Minimum Configuration Requirements

Connectivity to Kendall via the Grand Junction

The Task Force is interested in using the Grand Junction to improve connectivity to/from the Kendall Square study area. Possibilities for 'ends' – terminals or transfer points – for this connectivity were identified by reviewing prior proposals for transit use on the Grand Junction corridor as well as by soliciting ideas at Task Force Meeting #8 on October 25, 2016.

Prior Proposals

Urban Ring

There has been a significant amount of study of the Grand Junction corridor for transit use. Most of this was done through Urban Ring Bus Rapid Transit (BRT) studies. The Urban Ring studies included ridership forecasts as well as analyses of costs for providing circumferential connections among the existing radial transit lines using BRT, both on exclusive rights-of-way and in mixed traffic on streets. The Urban Ring studies found that there could be value to using the Grand Junction as part of a BRT corridor, but there were a number of feasibility or routing issues, such as the importance of connecting with Lechmere Station on the Green Line. For that reason, the studies did not suggest using or following the Grand Junction corridor north of Main Street. The proposed service is shown in Figure 2. The Urban Ring project is presently inactive because of its cost. As of 2010, MassDOT had concluded that "it would irresponsible to devote significant resources towards continual environmental review for a project so far from implementation", and was advocating implementation of BRT only in "high-value segments".

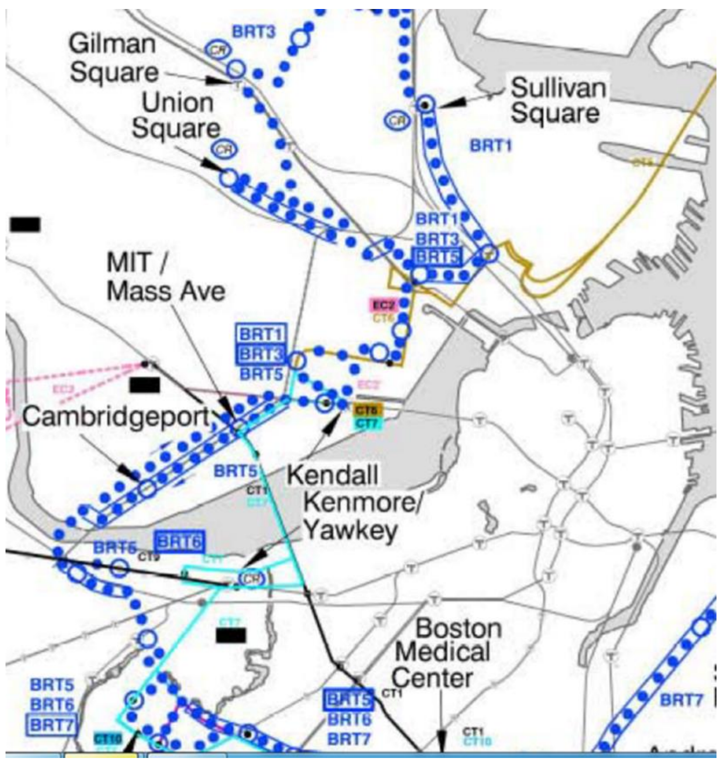


Figure 2: Urban Ring Study Schematic

Worcester Line Commuter Rail

In 2012 the state studied[1] using the Grand Junction to move some Worcester Line commuter rail trains into North Station due to capacity limits at South Station. A schematic of the plan appears as Figure 3. The study also included a stop at Kendall/MIT. This study found that the Grand Junction track would have required an upgrade to support 30 mph movements (the track currently only supports movements of 10 mph). This study concluded that there would not be enough ridership benefits or travel time savings to justify the track upgrade, and noted both high capital and operating costs. The state decided to expand South Station and relieve the capacity constraints there and keep Worcester trains going into South Station.

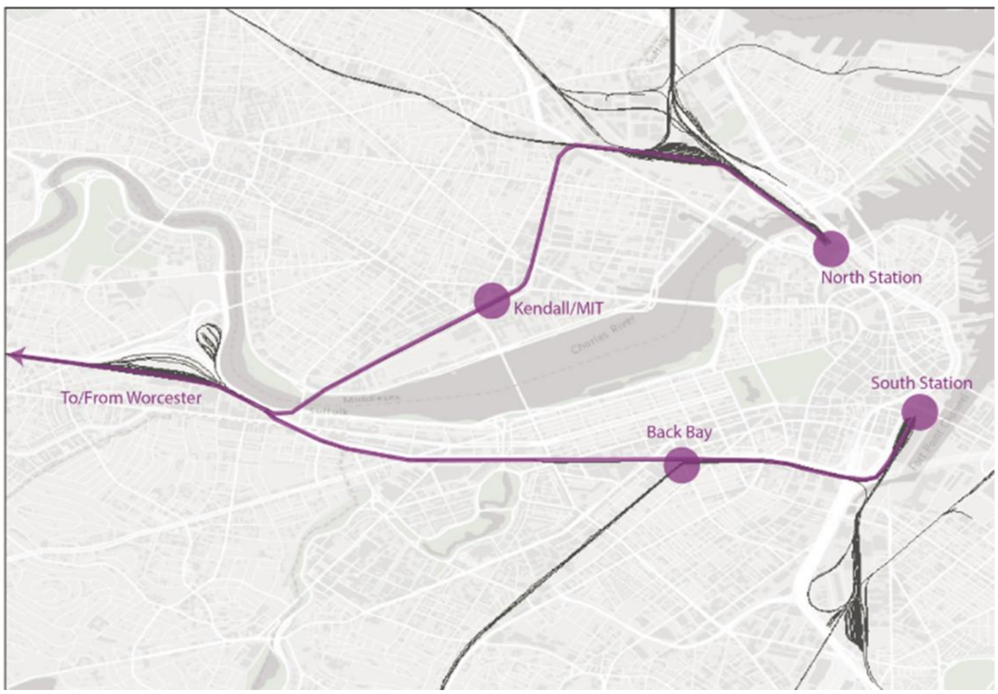


Figure 3: Schematic of Worcester Line Commuter Rail 'Split' Concept to South Station and via Grand Junction to North Station

Barr Foundation / ITDP

In 2015 the Barr Foundation and the Institute for Transportation & Development Policy (ITDP) published a study[2] aimed at exploring where BRT might make sense in Greater Boston. The study was based on existing ridership and speeds of local bus routes to screen where BRT might make sense. The final version of their study included a corridor using at least part of the Grand Junction to connect Sullivan Square and the Longwood Medical Area with BRT, shown as

[1] Central Transportation Staff for Massachusetts Department of Transportation, "Grand Junction Transportation Feasibility Study", July 2012.

[2] The Greater Boston BRT Study Group [Barr Foundation *et al* and the Institute for Transportation & Development Policy], "Better Rapid Transit for Greater Boston", Spring 2015.

a purple line in Figure 4. The report suggested it might have some potential time savings (shown in Figure 5), but their analysis did not develop estimates of either ridership or costs.

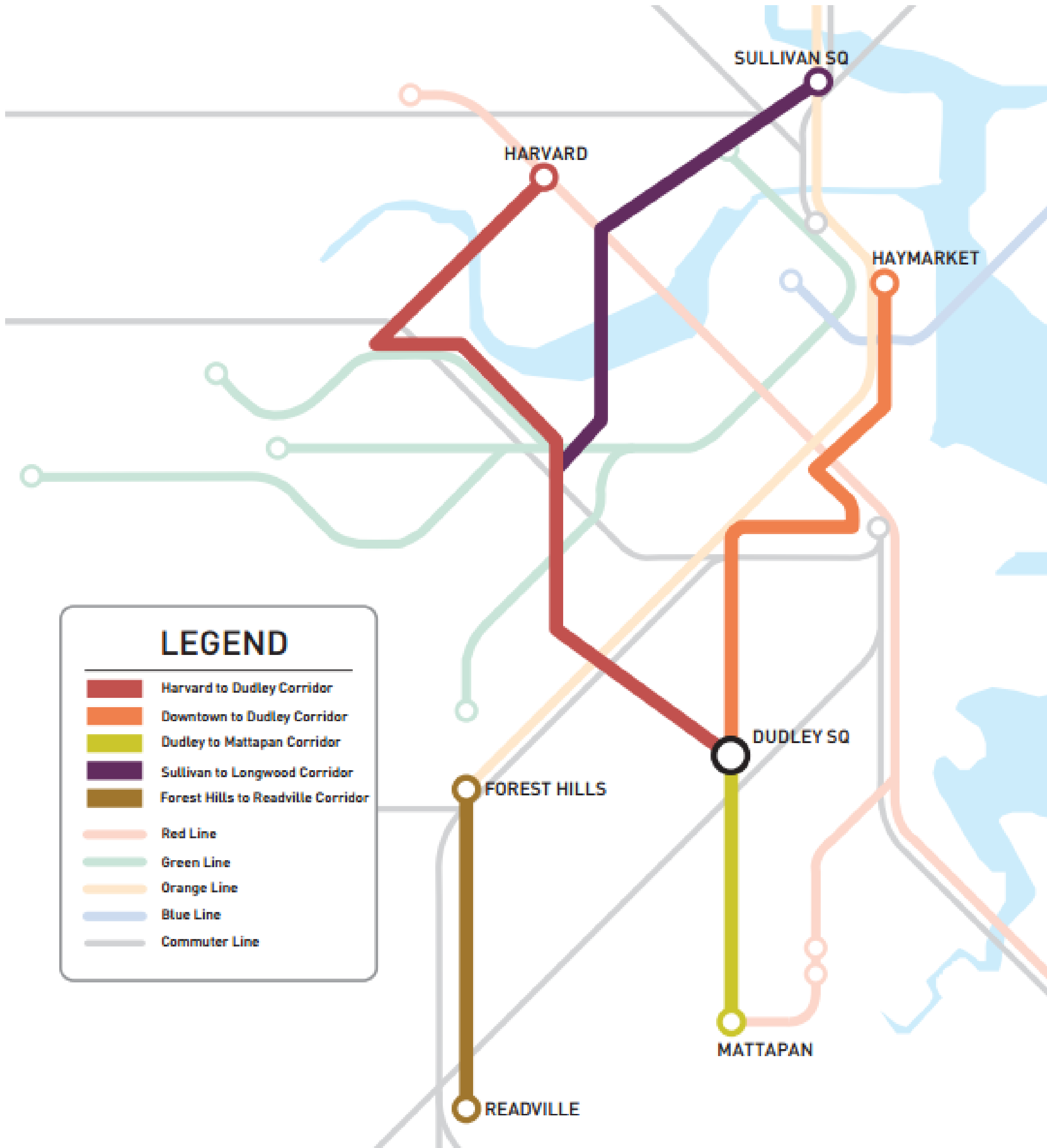


Figure 4: Barr Foundation / ITDP Notional BRT Routes in Cambridge

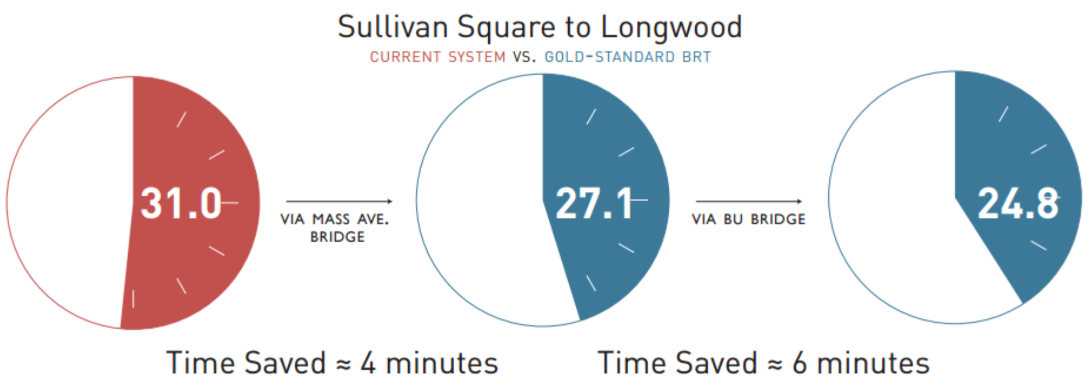


Figure 5: Barr Foundation / ITDP Estimate of Travel Time Savings

Services with Diesel Multiple Units

There have been various proposals for services using Diesel Multiple Units (DMUs) to supplement commuter rail, and these[3] have included a proposal for an operation between West Station and North Station using the Grand Junction, stopping in Cambridge (shown in dark purple in Figure 6. Following some exploration of ordering DMUs for a pilot study, the MBTA's FY2016 Capital Investment Program only contained funds for an overall planning study, which appears to indicate that the operating costs of the DMU plan may have been higher than initially expected. There are presently no plans for moving ahead with DMU services.

The DMU technology is discussed further later in this memorandum. Note than non-diesel, electric versions of this technology would be called Electric Multiple Units (EMUs).

---

[3] As represented in the vision for the year 2024 in MassDOT's Capital Investment Plan for FY2014-2018. This plan included funds to acquire 30 DMUs.

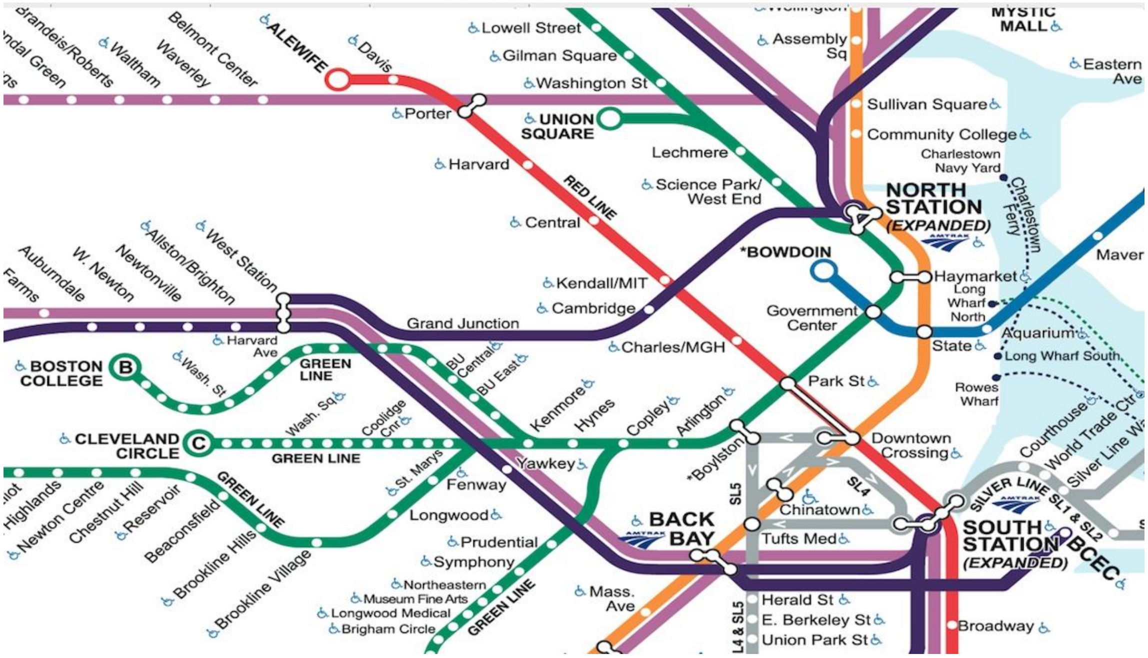


Figure 6: DMU Proposals

Identified by Task Force

At Task Force Meeting #8 on October 25, 2016, there was discussion of whether there might be merit in extending operations from the Grand Junction corridor further west on the MBTA's Worcester Line. A specific suggestion was made that a possible western terminus could be at the MBTA's Riverside Terminal, using the route of a former rail connection. Until the Riverside 'D' branch of the Green Line was established as a light rail operation in 1959, it operated as the Highland Branch of the Boston & Albany (B&A) Railroad. The present MBTA Worcester Line was the B&A's mainline, and a connection existed between them so that commuter trains could loop via the mainline to decrease travel times to and from the outer stations on the Highland Branch. A remnant of this connection still exists, and it in principle could be re-established.

Potential Demand identified in Prior Proposals

Previous studies have attempted to forecast the demand for some of the proposals for service on the Grand Junction. Figure 7 shows a summary of existing and estimated volumes for the daily trips on these services terminating in the study area. The red numbers show the existing Red line daily trips from east and west of the study area. The blue numbers show the existing EZ Ride daily trips from North Station and Cambridgeport.

The purple numbers show the forecasted volumes using the Grand Junction to Kendall for commuter rail services between West Station and Kendall and North Station with approximately five trains in the peak period peak direction. The black numbers are the Urban Ring forecasts for the year 2030 for total boardings at Kendall.

Overall the previous studies did show some ridership benefits for using the Grand Junction for transit, but when compared to the current Red Line numbers, there is nothing to suggest ridership would be at the level of rapid transit volumes.

Additional demand estimates will need to be made to assess the potential demand and effectiveness of transit on the Grand Junction.

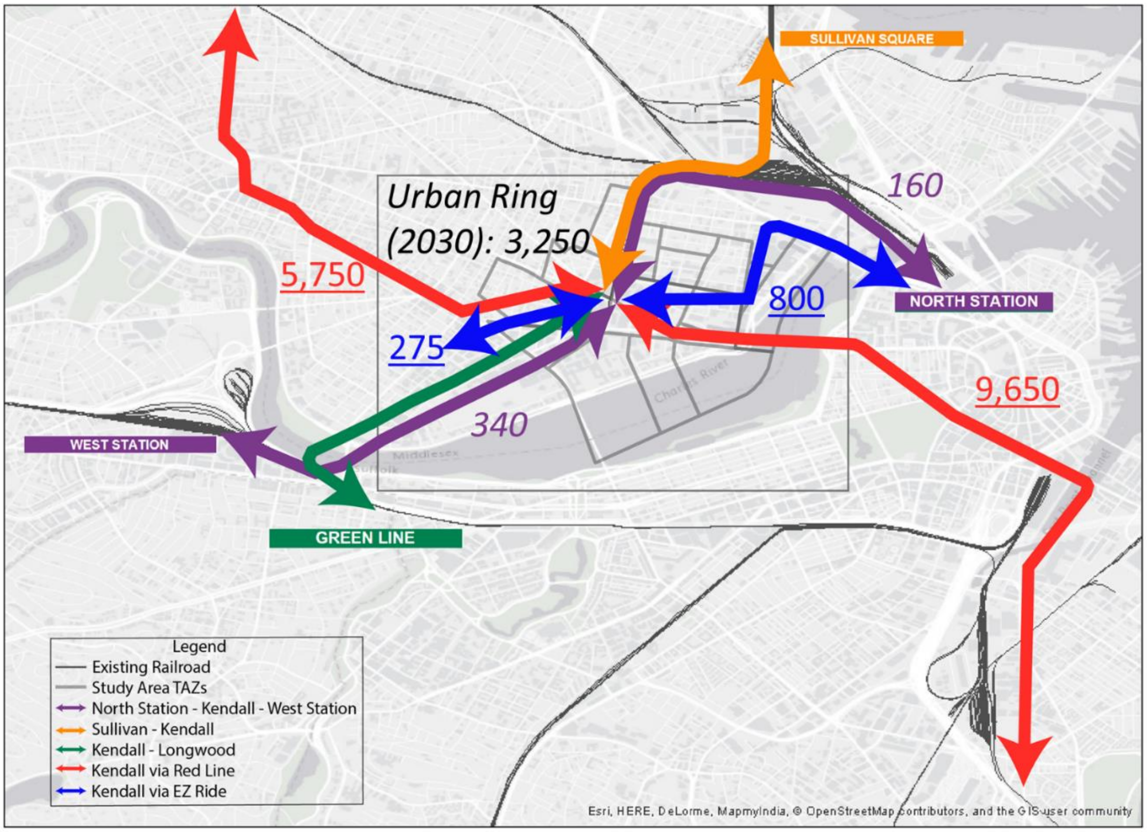


Figure 7: Proposed Transit Uses <u>Existing</u> and *Forecasted*

Service Frequency

For the purposes of this memorandum, three service frequency classes were considered: Regional/Commuter, Intermediate, and Rapid Transit, with characteristics as shown in Table 1.

Regional/Commuter (similar to the Fitchburg Line commuter rail) service frequency ranges from 1-4 trips per hour in the peak (or trips every 25-60 minutes). This frequency class typically has stops or stations two or more miles apart, and at low enough frequencies can operate with a single track or lane in each direction with provisions for passing sidings/lanes and signal control. These services typically average speeds of 25-35 miles per hour because of their longer distances between stops, and because they usually operate in dedicated or exclusive right-of-way. Relatively speaking, the implementation costs can be low to moderate for this type of service because major new infrastructure may not be required.

Intermediate frequency service (similar to the Silver Line Airport bus) ranges from 4-10 trips per hour in the peak (or trips every 6-25 minutes). This class of service typically has stops every 0.2 to 1 mile, and correspondingly lower average speeds of 10-20 miles per hour. They often need a dedicated track or lane in each direction to operate without delays (a total of two tracks or lanes). Relatively speaking, the implementation costs are moderate to high for this type of service because new infrastructure or changes to existing infrastructure are usually required.

The Rapid Transit frequency class (similar to the Red Line subway) ranges from 10-30 trips per hour in the peak (or trips every 2-6 minutes). Rapid Transit services typically have stops every 0.4 to 1.2 miles and almost always need a dedicated track or lane in each direction (a total of two tracks or lanes) to operate at a typical average speed of 15-25 miles per hour. Relatively speaking, the implementation costs are high to very high for this type of service, which often requires major civil works, including grade separations.

Table 1 also shows an indicative range of capacities for each class of service in terms of total weekday capacity each way, intended to be comparable to the demand estimates shown in Figure 7. The ranges are so wide because vehicles may range from a single bus to a train of 6-8 cars or even more. Based on demand estimates from previous studies and the capacity ranges needed to accommodate these potential demands, there is not a strong case for needing the Rapid Transit end of the frequency spectrum. At Task Force Meeting #8 on October 25, 2016, it was generally agreed that the Intermediate frequency class would likely be the most appropriate for transit service on the Grand Junction, but that additional demand forecasts and cost estimates would help support this conclusion.

Table 1: Frequency and Capacity Considerations

Service Frequency Class	Regional/ Commuter	Intermediate	Rapid Transit
Local Example	Fitchburg Line	Silver Line (Airport)	MBTA Red Line
Trips per hour per direction in peak	1-4	4-10	10-30
Dedicated track or lane for each direction?	Sometimes	Often	Almost always
Typical distance between stops (mi)	2 or more	0.2-1.0	0.4-1.2
Typical average speed (mph)	25-35	10-20	15-25
Implementation Costs	Low to Moderate	Moderate to High	High to Very High
Notional Range of Daily Capacity (one way) in the corridor	1,500 – 7,000	3,000 – 15,000	7,000 – 30,000

Applicable Technologies

There are a number of technologies that could be considered for transit on the Grand Junction corridor. However, the frequency of service is more important than technology for determining the width of right-of-way required (number of tracks or lanes), the treatment of street crossings, and the need for expensive structures. Technology is not important to travel time if the maximum speed, alignment, stops, and control arrangements are the same. Technology does relate to: noise, localized emissions, perception, image, and operating cost. For the purposes of this memorandum, there are three principal categories of technology that lend themselves to Regional/Commuter or Intermediate frequency in the corridor: transit buses, compliant DMUs or EMUs, and non-compliant DMUs/EMUs or light rail. These are addressed in the following sections.

Transit Buses

The two most common transit bus types in North America are the nominally 40-foot single unit bus and the nominally 60-foot single-articulated (‘bendy’) bus. The MBTA operates both types in local service. Propulsion options include diesel or compressed natural gas (CNG) as a fuel, and either a direct mechanical drive or a hybrid (*i.e...* diesel-electric) drive.

For services where either or both noise and localized emissions are a concern, electric buses are an option. The MBTA operates electric trolleybuses that draw power from an overhead contact system (OCS). Recent developments in battery and supercapacitor technology now present the possibility of ‘wireless’ electric buses, as shown in Figure 8.

It is not the purpose of this memorandum to compare specific vehicle types. It is sufficient at this stage to recognize that buses are a viable technology that is already in use across the full spectrum of frequency classes.

Figure 8: Battery Electric Bus on Adelaide's 'Tindo' Connector Service

Compliant DMU

Diesel multiple unit (DMU) trains are ones that are both propelled by diesel-mechanical or diesel-electric means *and* are capable of operating either as individual units or in trains of multiple units. Each operating unit (and sometimes these units consist of two or three semi-permanently coupled cars) has its own propulsion system.

In North America, trains that operate on any part of the continent's interconnected railroad system must comply with the requirements of the US Federal Railroad Administration (FRA) or its Canadian or Mexican equivalents[4]. These include specific structural requirements for rolling stock 'crashworthiness'. The crash energy management approaches taken by overseas rail vehicle manufacturers often differ from the North American approach, and therefore many DMUs of offshore origin are 'non-compliant' in this regard. In North America, 'compliant' DMUs can share tracks with other railroad traffic.

The availability of compliant DMUs in North America has varied over time. The Budd Company's Rail Diesel Car of the 1940s and 1950s was widely used for both intercity and Regional/Commuter service, including on both the Boston & Maine ('north side' of Boston) and the New Haven Railroad ('south side'). This product line was discontinued with the large contraction of passenger railroad operations in the US and Canada in the 1950s and 1960s. Over the intervening decades, one Canadian and two US manufacturers have developed prototype products, and have made some deliveries, but have not managed to stay in business. Most recently, Nippon Sharyo, a Japanese firm, has developed a compliant DMU design which it has delivered for both the Union-Pearson Express in Toronto (see Figure 9) and the Sonoma-Marin Area Rail Transit (SMART) service in California. During its exploration of DMUs a few years ago, the MBTA received expressions of interest from another overseas manufacturer.

At this point, the technology should be considered as available. The relatively massive vehicles may be considered noisy compared to others. Although local diesel exhaust emissions have also been a concern with DMUs, the Nippon Sharyo product in Figure 9 is represented by its manufacturer as meeting the present (Tier 4) EPA requirements for emissions from off-road diesel vehicles.

Figure 9: Union-Pearson Express, Toronto, Canada

[4] Transport Canada and the Secretaria de Communicaciones y Trasnporte, respectively.

Non-compliant DMU or Light Rail

Non-compliant DMUs are in use by four US and one Canadian transit agency for local or regional transit service on railroad tracks that are part of the continental network. Each such case requires a waiver of the FRA (or equivalent) requirements based on the specific nature of the operation required. Of these five operations, four operate on the basis of strict time separation, where the tracks are reserved for the exclusive use of the non-compliant vehicles during specific time periods. The other users (generally low-frequency freight service) use the tracks at night or at other hours when the passenger service is not operating. New Jersey Transit's RiverLINE (see Figure 10) uses an Advanced Temporal Separation system to manage joint use in narrower time slices; this requires that all trains that might so operate be equipped with hardware and systems to support this.

Non-compliant DMUs are lighter than compliant ones, and generally are considered less noisy. They are available from several overseas suppliers in attractive styles, and have been referred to by some as 'diesel light rail'. OC Transpo's Trillium Line in Ottawa, Canada, operates the highest frequency of all such services, every 12 minutes.

Figure 10: Stadler GTE Vehicle on New Jersey Transit's RiverLINE

Due to recent developments in battery and supercapacitor technology, a class of electric multiple unit vehicles (EMUs) which might offer an alternative to non-compliant DMUs is becoming commercially available. These are essentially light rail vehicles (LRVs) that have been designed to operate without a continuous overhead contact system (OCS) such as that employed by MBTA's Green Line. These' 'wireless' LRVs (see Figure 11) are designed to rapidly recharge while stopped at stations or terminals. At present, their range and capacity appear suitable for many local purposes; high-speed operation between stations that are separated by longer distances does not yet appear practicable.

The extent to which a non-compliant rail vehicle might be feasible in the Grand Junction corridor would depend on its frequency as discussed above. An operating window long enough for an Intermediate-frequency joint use service (with time separation) could constrain the present rail use of the corridor (for MBTA and Amtrak equipment movements and other non-passenger service) so much as to not be acceptable to the current owner and operators. Higher frequencies would require, or would at least be more reliable with, dedicated tracks separate from FRA-compliant rail traffic.

Figure 11: CAF Urbos 'Wireless LRV' in Kaohsiung, Taiwan

Right-of-Way Requirements

The original right-of-way provision for the Grand Junction was 82.5 feet. During the 20th century, many small parcels of this land were sold by the owning railroads to raise money. The state now has acquired or controls much of the land that was not sold off, and Massachusetts Institute of Technology owns another large segment of the corridor. This right-of-way varies considerably in width (20-40’ generally). Much of what was sold off is now used for parking, open space, and buildings in some cases. The City is currently undertaking a right-of-way survey to determine the exact boundaries of the Grand Junction right-of-way.

Three alternatives were identified at the Task Force Meeting #8 on October 25, 2016. The right-of-way requirements without platforms and other considerations for the three alternatives are described below.

Single-Track Shuttle

A single-track “rail shuttle” (used in this document to refer to a relatively short route with few intermediate stops) could support low frequencies (trains every 20-30 minutes) with a total right-of-way width of between 33-37’ without station platforms. This includes a 10-14’ multi-use path, as well as shoulders and a barrier between the path and the track. This could primarily serve as a Regional/Commuter frequency connection between Kendall and both North and West stations. This would require FRA-compatible DMUs or, most likely, Advanced Temporal Separation between non-compliant rail vehicles and the present railroad uses unless a strict time separation could be arranged with the relevant agencies. The Grand Junction track would also need to be rebuilt for higher speeds (30-45 mph), and one or more passing sidings would be needed for single-track service. Crossing pre-emption for the grade crossings would also be needed; this would include flashers and gates to protect the crossing in advance of (and during) each train movement over a crossing.

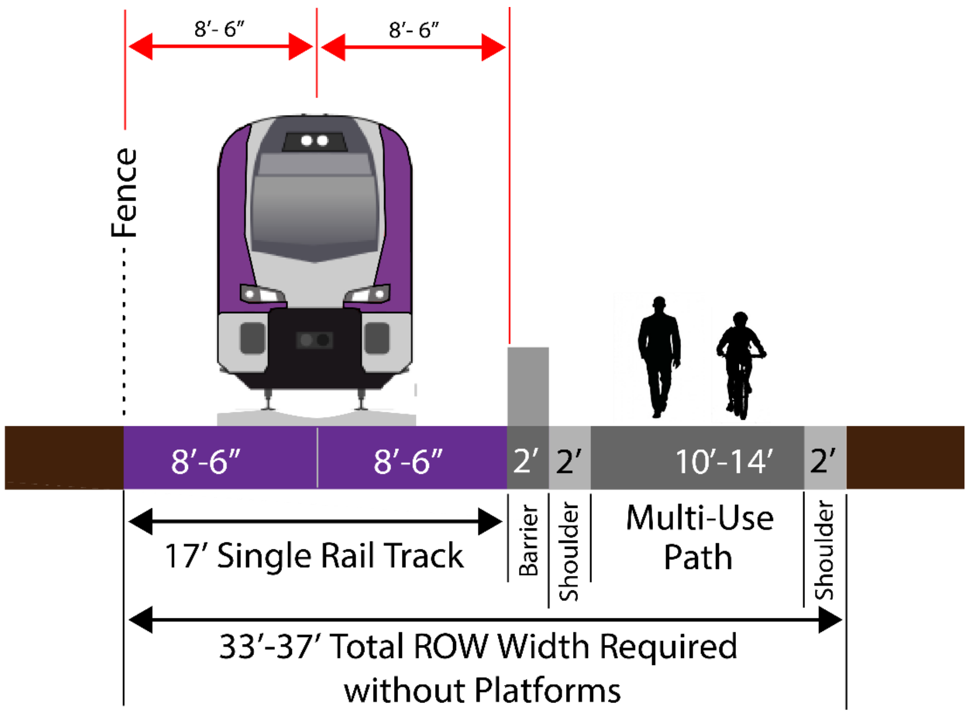


Figure 12: Single Track Rail Shuttle ROW Requirements

Intermediate Frequency with Joint Use

A joint use double-track rail configuration could support moderate frequencies with a total right-of-way width between 47-51' without station platforms. This includes the 10-14' multi-use path, as well as shoulder and barriers between the path and transit. The double track would support the existing passenger equipment and freight movements as well as new transit movements at a Regional/Commuter frequency, or into the lower end of the Intermediate frequency range, with non-compatible DMUs or 'wireless' light rail technology operating with Advanced Temporal Separation or strict time separation. A more robust Intermediate frequency service could be supported with FRA-compatible DMUs.

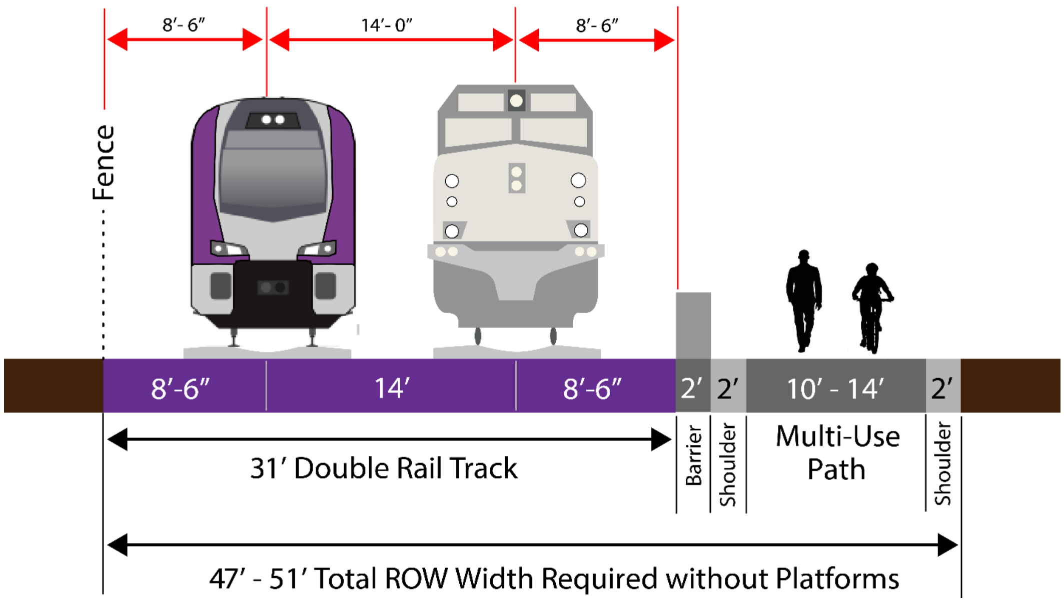


Figure 13: Intermediate Frequency with Joint Use ROW Requirements

High Frequency Separated ROW

A high frequency separated two-way transitway (either rail or bus) configuration could support higher frequencies with a total right-of-way width between 60 and 65 feet without platforms. This includes a 10-14’ multi-use path, as well as shoulder and barriers between the path and the railroad movements, and a barrier between those movements and the two-way transitway. This configuration is only possible south of Main St. in Cambridge due to right-of-way constraints elsewhere in the corridor. This would not require FRA-compatible DMUs or Advanced Temporal Separation between railroad movements and transit operations because the operations would be separated by a barrier. The higher frequencies would, however, require a balance between traffic and/or transit delays at street crossings with pre-emption or other considerations.

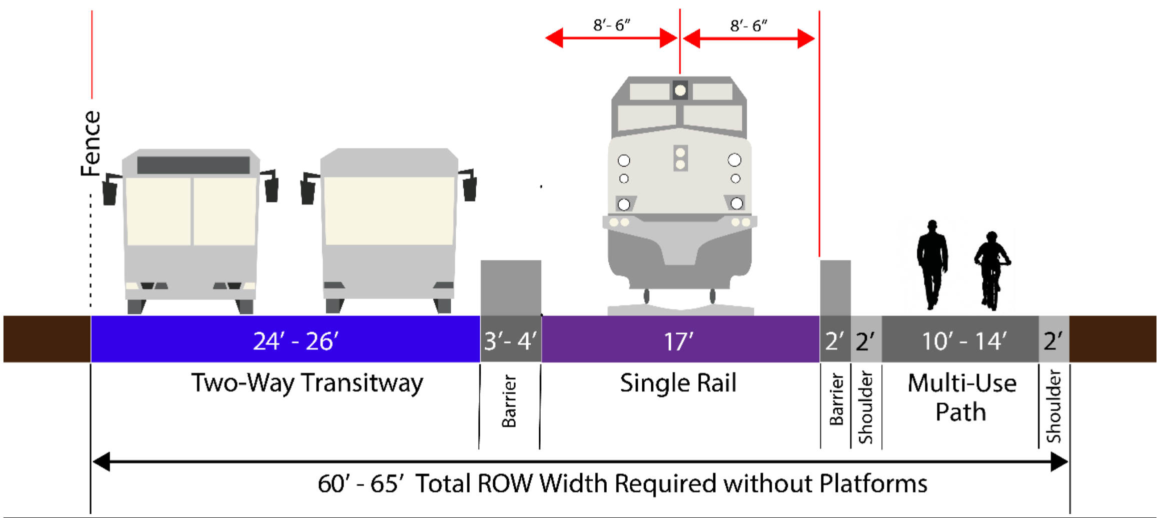
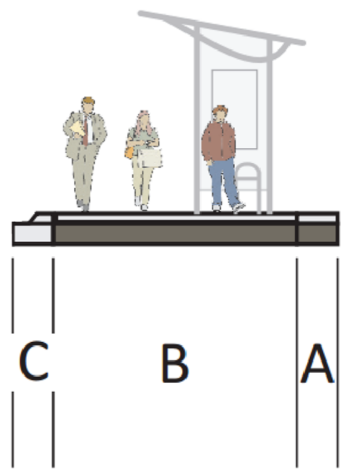


Figure 14: High Frequency, Separate, ROW Requirements

Stations

Passenger platforms at stations will add to the right-of-way requirements. The most common configuration for platforms is one on each side dedicated to each direction of travel. Typical additional width requirements are as shown in Figure 15. For a two-track or two-lane transitway as shown in Figure 14, the total width requirement with the path at a station would then range from a minimum of 74 feet (with a constrained 8-foot-wide path) to an ideal of 93 feet, well outside the bounds of the Grand Junction Railroad's original 82.5-foot right-of-way. Similarly, station provisions for the two-track alignment with joint-use of one track (Figure 13) could grow to 61 to 79 feet with platforms on both sides. A single-track treatment (Figure 12) would require a platform on only one side, with the total width required ranging between 39 and 47 feet.



Designation	Description	Dimension (feet)	
		Preferred	Constrained
A	Buffer	Already provided for	
B	Station	14'	8' to 12'
C	Curb and gutter	Already provided for	

Figure 15: Typical Additional Width Requirements

If the best locations for stations cannot be fit within the available right-of-way, there are some possible ways to reduce the requirement as shown in Figure 16. Staggered platforms are a generally preferred approach, although they complicate the design of the final horizontal alignment. Center platforms offer relatively small savings and require all passengers to cross at least one lane or track. Reducing the transitway to a single track or lane both reduces the ultimate capacity of the line and requires signals or other measures to assure safe operation of vehicles in both directions on the same track or lane. There is North American precedent for all of these arrangements.

It is not likely that there will be so many stations as to have these wider requirements govern the overall path treatment. For a DMU rail shuttle between West Station and North Station, a single ‘Kendall/MIT’ station could well be sufficient. For a BRT treatment, perhaps a second station at Massachusetts Avenue could provide a connection to MBTA’s bus route 1, one of the system’s busiest. The Grand Junction alignment does not appear suitable for a more local service, especially as this would slow it down noticeably from the perspective of passengers connecting from commuter rail services. The multi-use path will already be providing an attractive route for local non-motorized travel within the corridor.

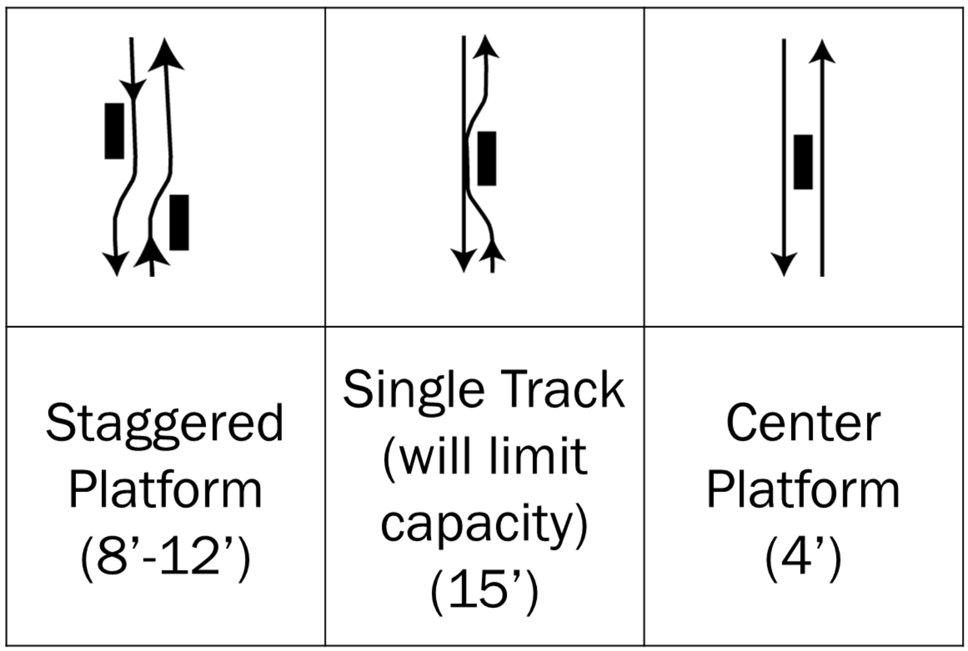


Figure 16: Space Saving Configurations

Street Crossings in Cambridge

There are six at-grade street crossings and two pedestrian crossings in Cambridge as shown in Figure 17. If these crossings were pre-empted *e.g.* with gates and flashers, traffic delays on these streets will increase with service frequency. In the MBTA's Worcester Line study, modest impacts were identified for the infrequent service proposed to/from North Station. Alternatively, if traffic signals were used to stop oncoming traffic, each traffic signal has approximately 40% of the effect on average speed as adding another stop or station. In addition to the delays from traffic signals, the operating speed for DMUs would likely need to be reduced to assure safe braking distances.

Figure 17: Grand Junction Corridor Street Crossings in Cambridge

Cost Considerations

Making Transit Connections beyond the Multi-Use Path

The Grand Junction corridor has been advanced several times for possible transit use, reflecting its ‘opportunistic’ value as a straight, level, and potentially exclusive route in a congested urban setting. To be actually useful, however, a service using it must also provide connectivity to concentrations of trip origins or destinations beyond the corridor. The prior studies of the corridor have not as yet identified such a use that is clearly cost-effective and advantageous. To a significant extent, this has been due to the cost of establishing the connections beyond the corridor.

North End of Grand Junction

At the north end of the Grand Junction as shown in Figure 18, there are some issues that become more constraining as transit service frequency increases. Some of these are related to technology. These include:

- *Access to/from North Station.* At the Commuter/Regional frequencies, a connection from the Grand Junction to the southerly track of the Fitchburg Line could likely be made. The Grand Junction Railroad presently crosses at grade to the north side without making any such connections. However, the tracks and platforms at North Station are regarded as being at or near capacity. Bringing the frequency of compliant DMU service up to an Intermediate level would likely require a treatment such as an additional track and/or platform, and at the high end of the Intermediate range, possibly an additional running track or passing siding between North Station and the Grand Junction. Rapid transit frequency would require dedicated separate runningways between North Station and the Grand Junction, and the terminal arrangement at North Station would require something to be designed outside the present footprint.
- *Crossing the Fitchburg Line commuter rail*. The Grand Junction now crosses the Fitchburg Line at grade. A service based on non-compliant rail technology or buses would need to be grade separated from the commuter rail, and the vicinity is so constrained that this could be very expensive. Compatible DMUs could cross at grade, but in the Intermediate frequency class there would be conflicts and associated delays to both Grand Junction and Fitchburg Line trains.
- *Crossing the Green Line Extension (GLX) to/from Union Square*. Most high-level plans for the GLX have indicated that this Green Line branch would be located north of the Fitchburg Line tracks, making it unnecessary for a DMU service to North Station or Sullivan Square to cross it west of a point where it has joined the branch from College Avenue. Plans are now somewhat in flux because of the re-engineering of the GLX to reduce costs. There does not appear to be width to add a two-lane/track transitway on the surface between the Grand Junction and the point where the two GLX branches merge, so a grade separation would be required for buses or non-compliant rail vehicles at a Rapid Transit or Intermediate frequency.
- *Crossing the Green Line Extension to/from College Avenue*. The GLX will pass over the Grand Junction’s connection towards Sullivan Square on a structure, at a point where both branches will be operating on the same tracks. This does not appear to pose a major obstacle for a service with compliant DMUs, but accommodating a separate facility for buses or non-compliant rail may not be feasible without major expenditures.
- *Access to/from Sullivan Square Orange Line Station.* The present route of the Grand Junction takes it under an overpass for the Lowell Line commuter rail and then jogs to

the east underneath an Orange Line flyover to join the two tracks used by Haverhill Line and Gloucester/Newburyport Line commuter trains. These commuter tracks are directly adjacent to Sullivan Square Orange Line station on the east side, and afford no opportunity to serve as a termination point for a compliant DMU service. However, disused tracks on the west side of Sullivan Square, and site conditions south of the station and west of the Orange Line, suggest that a provision for such a service could be made. The same space might facilitate termination of a non-compliant DMU service or a BRT, if other obstacles are overcome. Finding sufficient width along the route for a separate facility for buses or non-compliant rail vehicles could prove expensive between the GLX crossing and Sullivan Square; at the very least, the relocation or reconfiguration of existing railroad trackage would be required.

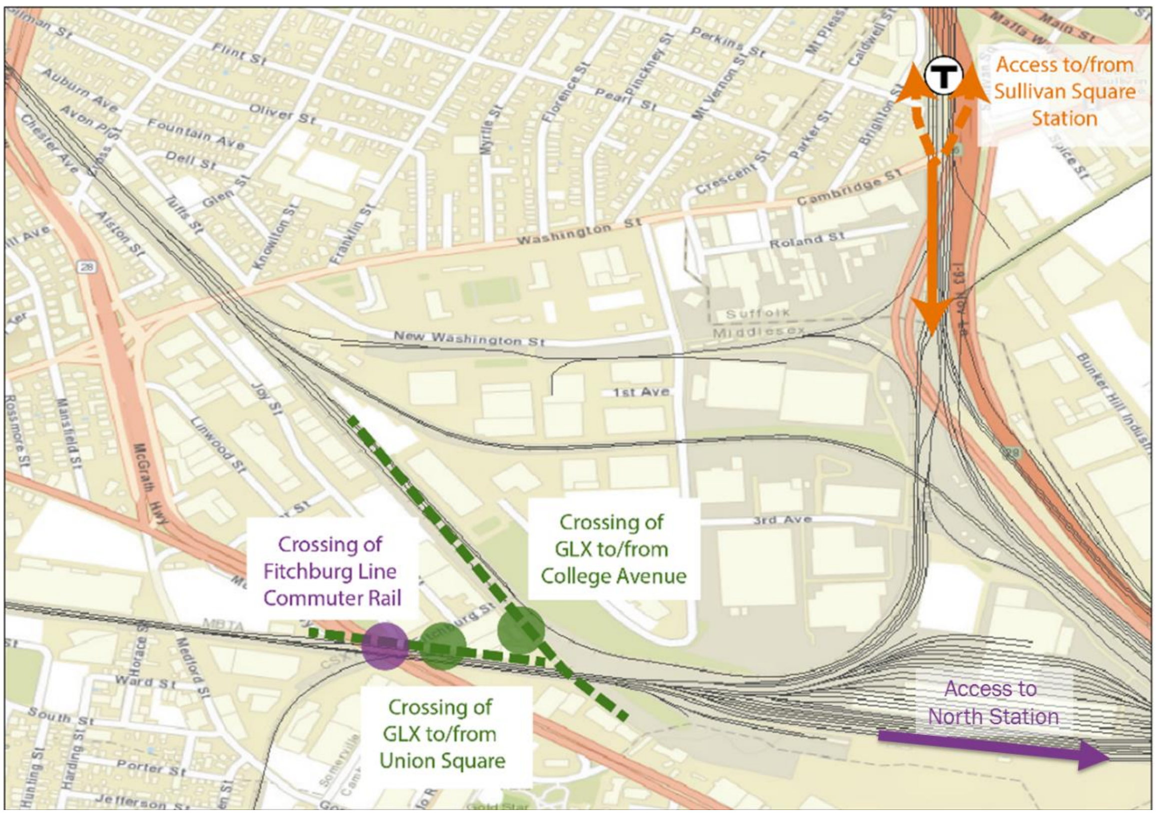


Figure 18: North Issues (Cambridge St to Sullivan Square)

South End of Grand Junction

At the south end of the Grand Junction as shown in Figure 19, there are some issues that become more constraining as transit service frequency increases. Some of these are related to technology. These include:

- *The use of the 'BU' railroad bridge*. This structure is in poor condition, and has required repairs to keep it open to rail traffic. Replacement might be required for even single-track DMU service, and would be even more likely for a two-track solution. Sharing a bridge with non-compliant DMUs or buses is possible in principle, but would require extraordinary control arrangements. A bridge replacement would be very expensive, but could provide for future expansion.
- *Crossing the Worcester Commuter Rail Line*. The present railroad bridge brings the Grand Junction Railroad over the Charles River to make an at-grade connection with the Worcester Line commuter rail. Any alternative terminating south of the Worcester Line would either have to do so via a very expensive grade separation or resort to surface operation on streets, which is what the Urban Ring work concluded was the only practicable alternative. Such a routing can work for a BRT if the delays are acceptable, but DMU operation would not be practicable, and a light rail solution would could be slower than bus for an indirect or circuitous surface route.
- *Access to/from the planned West Station*. The existing track connection could serve a Regional/Commuter frequency. The design of the station has not been finalized; ideally, the design would include provisions (in terms of platform and track arrangements) for a rail shuttle service using the Grand Junction. Higher Intermediate frequencies might require changes the track configuration between West Station and the rail bridge over the Charles River.
- *Where to put the terminal or other stations, especially for any rail concepts*. If a higher-speed crossing of the Charles were effected via a bridge and a grade separation from the Worcester Line, there is no readily available surface alignment to make connections to the Green Line or other Longwood LMA points. The choices would be a very expensive continuation of a grade-separated route, or a very slow on-street solution similar to that shown in the lower left quadrant of Figure 2.

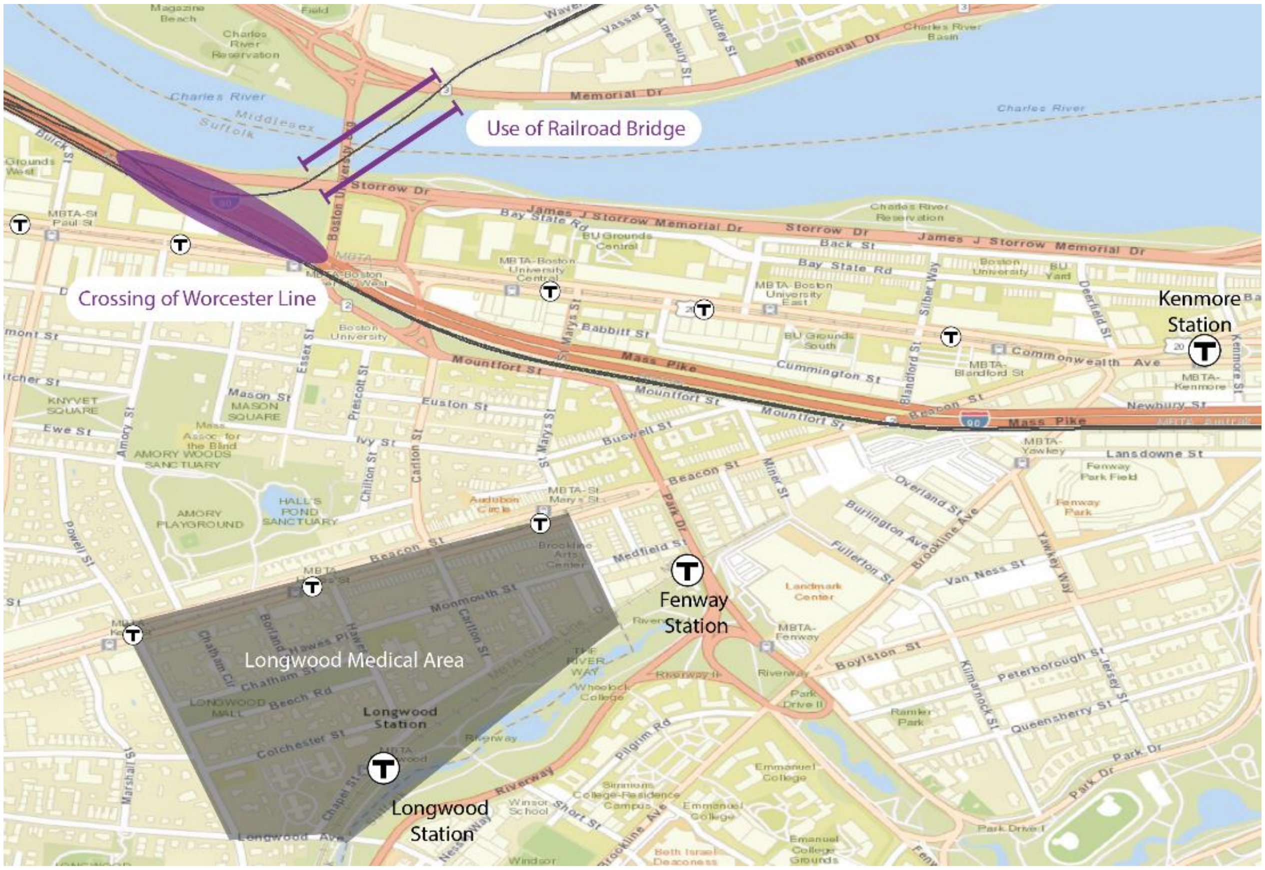


Figure 19: South Issues (MIT to Longwood)

Capital Costs Summary

This feasibility review was not scoped to estimate costs for alternatives. However, in Table 2 we offer some indicative cost levels for some of the different approaches that might be taken to making connections north and south of the Grand Junction, versus costs for a solution along the corridor in Cambridge.

Table 2: Summary of Indicative Capital Costs

Indicative Cost Tier	Longwood-Memorial Drive	West Station - Memorial Drive	Memorial Drive - Main Street	Main Street - McGrath Hwy	McGrath Hwy to North Station	McGrath Hwy to Sullivan Square
Joint Use (Interim 1-track)	N/E					N/E
Joint Use (Ultimate 2-track)	N/E					N/E
High-Frequency Separated (Bus)		N/E			N/E	
High-Frequency Separated (Light Rail)		N/E			N/E	
"N/E" = not evaluated						
		Unlikely to exceed $50 million				
		Unlikely to exceed $100 million				
		Likely to exceed $100 million				
		Likely to exceed $200 million				

Operating and Maintenance Costs

Operating frequency, capacity, and average speed are the primary drivers of operating and maintenance (O&M) costs. Figure 20 provides a *notional (not based on specific data)* view of these relationships for a theoretical five-mile transit link on exclusive transitway with bus rapid transit, light rail, or DMU service either on a single or double track (with one track being used jointly with other rail use such as equipment moves). Note that the single track option has a limited capacity and so can't serve as many passengers as the other options (indicated by the blue line ending before the others). This notional graph also does not take into account the annualized cost of construction and vehicles

All of these types of service have the common trait of O&M cost per passenger-mile decreasing rapidly as the number of passengers increases, because the costs of maintaining the infrastructure (transitway and stations) are spread among more riders. Jumps or sharp increases in costs occur where additional vehicles are needed to provide the capacity to meet demand. The 'joint use' examples (both single and double track) have lower costs because they are assumed to offer either no service or very infrequent service outside the peak periods due to the joint use needs. The higher-frequency all-day operations (BRT and light rail) would cost more per passenger-mile because they would also serve lightly-traveled periods. For comparison purposes, points corresponding to the MBTA's average cost per passenger-mile for 2014 have been shown for BRT (silver), light rail (green), and commuter rail (red).

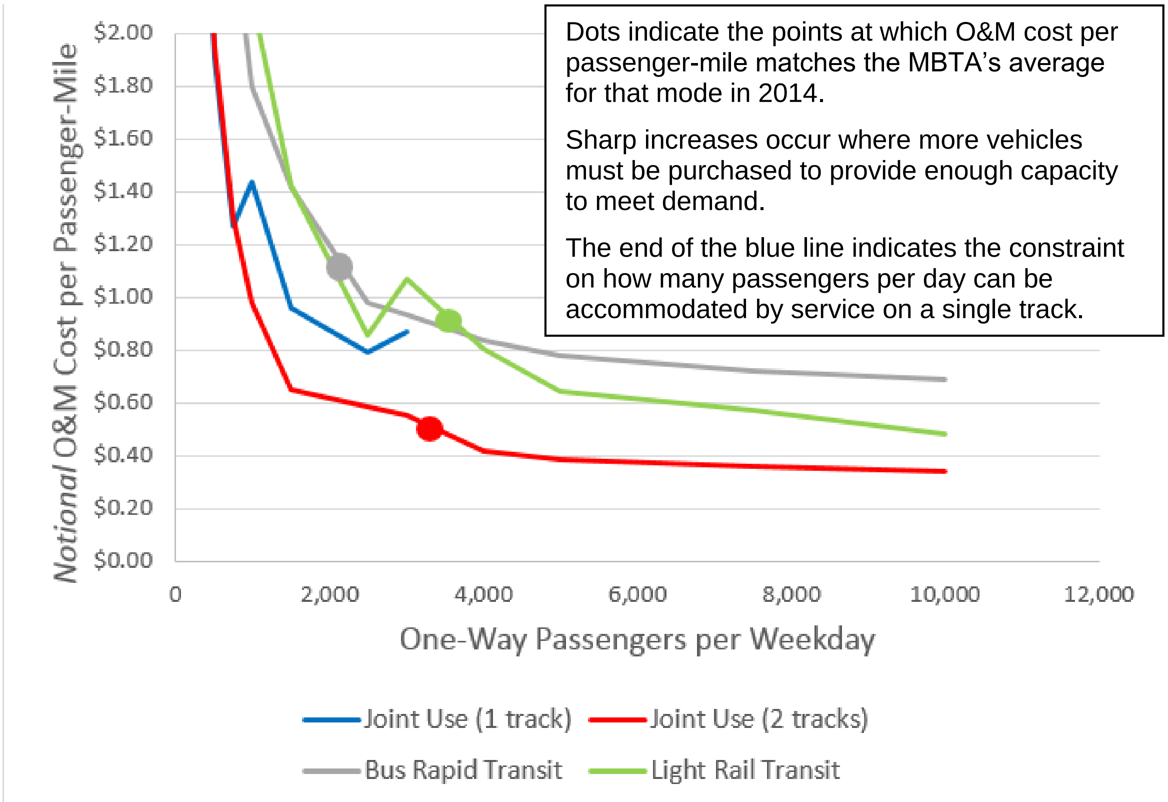


Figure 20: Notional O&M Costs per Passenger Mile

The above graphic is meant to visualize some of the following high level guidance for service on the Grand Junction corridor relative to cost and demand:

- A DMU joint-use rail shuttle (on one or two tracks) operating in peaks only would be less costly to operate per passenger mile traveled than an all day, higher frequency BRT or light rail at these levels of demand.
- Below about 3,500 passengers per weekday, the average cost per passenger mile traveled for DMU joint-use rail shuttle options would likely be higher than the average for MBTA's commuter rail system (indicated by the red dot). This would adversely affect cost recovery for the system as a whole, although the effect might not be significant until demand goes below 2,000 passengers per weekday.
- If the higher costs of all-day service were acceptable (as in the BRT and light rail options), to be competitive with the current MBTA cost per passenger mile, it might be desirable to attract 2,000 passengers for BRT and 3,500 for light rail.

Potential Performance vs. Existing Services

The Task Force recognized that comparing existing travel times to potential travel times for transit alternatives using the Grand Junction could be useful for choosing alternatives to consider further in terms of ridership and costs. This memorandum provides some comparisons for representative connections.

Methodology

The overall time considerations of this review focus on the identified potential connections that might use the Grand Junction. Existing travel times for those origins and destinations via existing services are shown in tables below in plaintext. Estimated times for possible alternatives between the same points are shown in *italics*.

The graphics in the following sections show scheduled times as available in the MBTA's schedule data (via General Transit Feed Specification (GTFS)) in Google Maps, weighting in-vehicle and out-of-vehicle (e.g. wait) times the same. The tables in the following sections show estimates of actual total time and perceived time. These times were determined as follows:

- First Wait: based on scheduled headways and typical observed waiting times for these headways.
- Transfer Wait(s): based on scheduled headways and estimated waiting times for transfers, allowing for missed connections
- Walking: based on 175 feet per minute
- In-vehicle Time: based on actual travel times via Automatic Passenger Counter (APC) and Automatic Vehicle Locations (AVL) times for all weekdays in October 2016 with AM peak conditions for trips arriving Kendall between 8 and 9 am
- Total Time: The sum of the times above
- Perceived Time: A weighted[5] total of the times above or a 'feels like' time in terms of continuous in-vehicle travel.

'Kendall' in all sections below is assumed to be 10 Cambridge Center. This is more or less central to the study area and is about the same distance from the Red Line station and a conceptual stop on the Grand Junction just north of Main Street.

The transit times in the tables in the following sections are generally higher (and more realistic) than Google's because they are based on actual travel times as opposed to the scheduled times in Google.

Riverside Terminal to Kendall

At Task Force Meeting #8 on October 25, 2016, there was discussion of whether there might be merit in extending operations from the Grand Junction further west on the MBTA's Worcester Line. A specific suggestion was made that a possible western terminus could be at the MBTA's Riverside Terminal, using the route of a former rail connection. Existing connections from Riverside Terminal to Kendall are shown in Figure 21.

[5] The following weights (a ratio to in-vehicle time) from the CTPS travel demand model were applied: first wait, 1,10; transfer wait 2.45; and walking time 1.60.

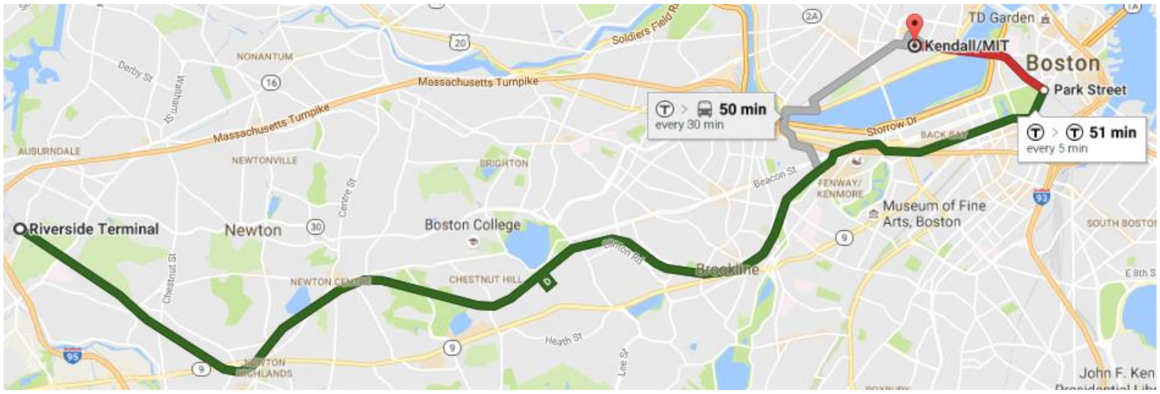


Figure 21: Existing Connections from Riverside Terminal to Kendall

Table 3: Existing and Potential Times from Riverside Terminal to Kendall

Summary (minutes)	First Wait	Transfer Wait(s)	Walking	In-vehicle Time	Total Time	Perceived Time
Green and Red Lines via Park Street	3.4	3.0	8.7	48.9	64.0	73.9
Green Line to Fenway and CT2 Bus	3.4	11.3	9.1	52.3	76.2	98.4
DMU Shuttle Riverside to Kendall	*9.5*	*0.0*	*6.3*	*18.0*	*33.8*	*38.5*

Considered in isolation from the persepctive of Riverside, the one-seat DMU trip from Riverside Terminal to Kendall via the Worcester Line offers a dramatic improvement over present circumstances, as shown in Table 3. However, a number of additional considerations need to be taken into account:

- Ridership on the Worcester Line is predominantly from outside Route 128[6], so that choosing to use the mainline's capacity to move DMU trains between Auburndale and West Station for this service would commit track capacity that could otherwise be used by trains traveling longer distances and taking more vehicle-miles off the highway network. In effect, it could become necessary to eliminate Framingham or Worcester trains from the schedule to make room for trains to/from Riverside.
- The long travel times on the 'Green Line's 'D' branch[7] do not represent the better travel choices that travelers from this vicinity have to Kendall. Riverside Terminal is primarily a park-and-ride facility, so its users have choices, as represented by example in Table 3. This can be understood in the context of the history of the Riverside Line. When people complained about the trains being slow in the late 1960s, the MBTA put on direct buses to downtown which were much faster (*e.g*. 25-30 vs 40-45 minutes). Over the following decades, two things have happened to influence developments: first, Riverside Terminal has become less accessible to much of its original commuter shed because of

---

[6] In 2010, a survey indicated that only 839 of 6,728 daily inbound boardings of the Worcester Line, or just over 12%, originated inside Route 128.

[7] Prior to 1959, the 'D' branch between what is now Riverside and Fenway was a part of the Boston & Albany Railroad, the mainline of which is now the MBTA's Worcester Line. It was possible for local trains to make a loop via the Highland Branch and the main line, so that passengers to/from some of the outermost stations could have faster trips to/from central Boston. When the line was converted to light rail by the Metropolitan Transit Authority (the predecessor to MBTA), this connection was broken.

increasing congestion on Route 128 and Masspike; second, there have been major improvements to the Worcester Line service, especially beyond Framingham. MBTA gradually found the direct Riverside-downtown express (route 500) to have low ridership relative to its operating costs, and cut service about in half from a 30-minute headway in 2008. The express bus operation was eliminated entirely in 2012 because of high cost per passenger.

- The demand linkage between Riverside and Kendall is small; about one percent of boardings at Riverside are destined for Kendall (as opposed to approximately 10% at many of the stations on the MBTA's three 'heavy' rail rapid transit lines), and less than two percent of Red Line arrivals at Kendall are from Riverside. Most 'D" branch passengers from Riverside Terminal have left the train before it arrives at Arlington Station.
- A DMU rail shuttle (short, limited stop serivce) between West Station and Kendall operating primarily on two tracks would offer much of the savings of a direct DMU train between points further west of West Station and Kendall (see Table 4). Perhaps more importantly, the large share of travelers from outside Route 128 would have very similar travel times with or without the extension of the rail shuttle service.

Table 4: Existing and Potential Times from Auburndale Station to Kendall

Summary (minutes)	First Wait	Transfer Wait(s)	Walking	In-vehicle Time	Total Time	Perceived Time
Auburndale to Kendall via South Station and Red Line	7.2	3.0	8.7	*18.7*	37.6	52.2
DMU Shuttle Auburndale to Kendall	*9.5*	*0.0*	*6.3*	*15.9*	*31.7*	*44.3*
Auburndale to Kendall via West Station DMU Shuttle (single track)	*12.6*	*6.1*	*6.3*	*15.9*	*40.9*	*54.7*
Auburndale to Kendall via West Station DMU Shuttle (double track)	7.2	6.1	6.3	15.9	35.4	48.7

These considerations apply to any extension of a DMU operation west of a point where a good connection can be made with the Worcester Line (and each option would include a stop at West Station). Most importantly for the consideration of the multi-use path in Cambridge, whether or not the service were to operate further west does not affect the required right-of-way on or east of the railroad bridge across the Charles. Therefore a provision for two rail tracks beside the path would not preclude such an extension.

It is also worth noting that the times with a two-track DMU rail shuttle are not markedly shorter than via South Station. The potential for significant growth by offering this service may be limited; an actual demand estimate might identify results not too far different from MassDOT's study shown in Figure 7.

Sullivan Square to Kendall

At Task Force Meeting #8 on October 25, 2016, there was discussion of extending service on the Grand Junction north to Sullivan Square. Existing connections from Sullivan Square to Kendall are shown in Figure 22.

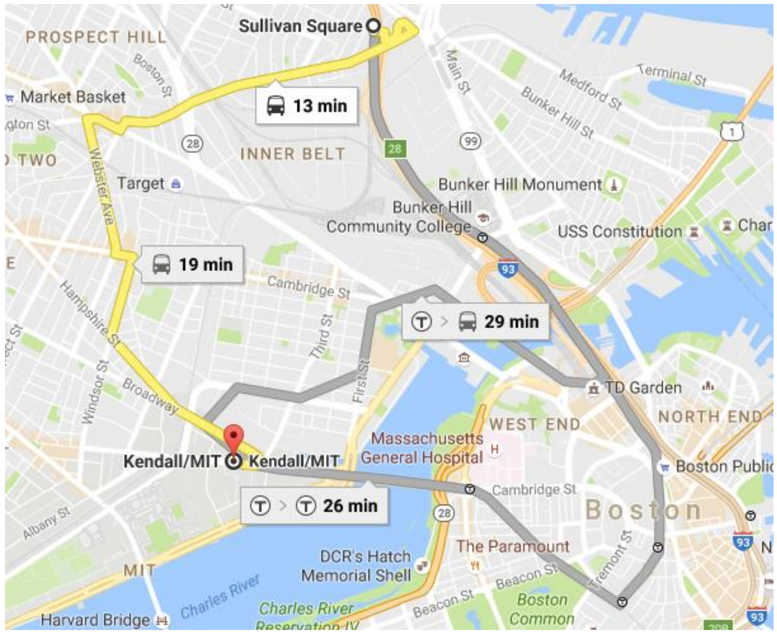


Figure 22: Existing Connections from Sullivan Square to Kendall

The DMU trip from Sullivan Square to Kendall via the Orange Line would offer a dramatic improvement over present circumstances, as shown in Table 5. However, the already proposed ‘CT4’ bus service would have a lower perceived time, and with the improvements envisioned for the Red and Orange Lines by the Focus 40 work, the gap between the DMU service and the path via rapid transit would likely close.

Table 5: Existing and Potential Times from Sullivan Square to Kendall

Summary (minutes)	First Wait	Transfer Wait(s)	Walking	In-vehicle Time	Total Time	Perceived Time
Via Orange Line and EZ Ride	3.4	4.8	10.6	23.0	41.8	55.4
Via Orange and Red Lines	3.4	3.0	13.9	16.1	36.4	49.4
Via CT2 Bus	9.1	0.0	12.3	21.0	42.4	50.7
Via 'CT4' Bus	*5.5*	*0.0*	*7.4*	*14.1*	*27.0*	*32.0*
Via Orange Line and two-track DMU shuttle	*0.0*	*6.1*	*8.0*	*8.8*	*22.9*	*36.5*

North Station to Kendall

At Task Force Meeting #8 on October 25, 2016, there was discussion of using the Grand Junction to connect North Station to Kendall Square. Existing connections from North Station to Kendall are shown in Figure 23.

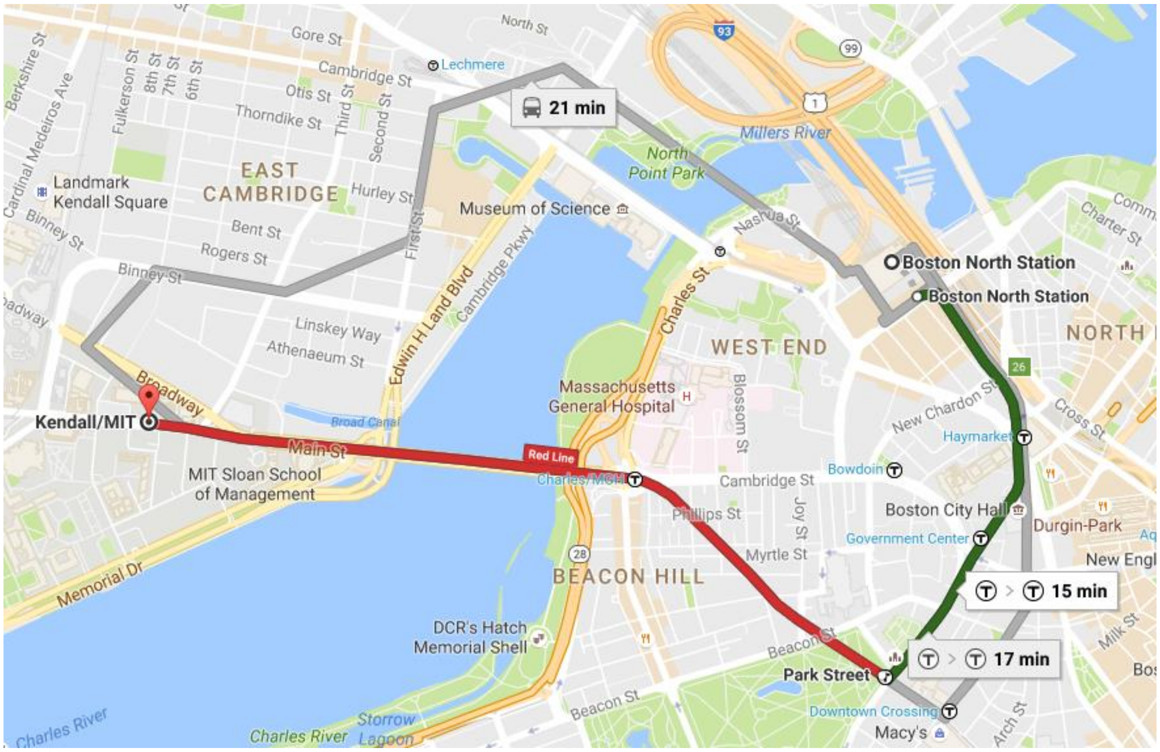


Figure 23: Existing Connections from North Station to Kendall

A DMU rail shuttle trip from North Station to Kendall via the Grand Junction offers a significant improvement over present circumstances that utilize rapid transit via downtown Boston, as shown in Table 6. However, a single-track DMU rail shuttle would not offer much improvement over the present EZ Ride service. The two-track DMU rail shuttle alternative would be competitive or better than the EZ Ride service. Improvements for the Red Line envisioned by the Focus 40 work would likely close the gap between the routes using rapid transit and either the EZ Ride or DMU connections to/from North Station.

Table 6: Existing and Potential Times from North Station to Kendall

Summary (minutes)	First Wait	Transfer Wait(s)	Walking	In-vehicle Time	Total Time	Perceived Time
Via Green and Red Lines	4.1	3.0	13.3	10.2	30.6	43.3
Via Orange and Red Lines	3.4	3.0	13.9	10.3	30.6	43.6
Via EZ Ride	4.8	0.0	5.4	18.7	28.9	32.6
Via single-track DMU shuttle	*12.6*	*0.0*	*8.0*	*3.8*	*24.4*	*30.5*
Via two-track DMU shuttle	*6.1*	*0.0*	*8.0*	*3.8*	*17.9*	*23.3*

It is not surprising that the connection via EZ Ride is preferred by most commuters today; the single-seat ride decreases the perceived time versus connections via rapid transit. The EZ Ride service is slow and unreliable in the peak periods, however, and a DMU rail shuttle might be able to outperform it, even at lower frequencies. The improvements to the Red Line contemplated in the Focus 40 work might also close the gap with the rapid transit connection via Park Street.

Newtonville to Kendall

At Task Force Meeting #8 on October 25, 2016, there was discussion of using the Grand Junction to connect the future West Station to Kendall Square. Existing connections from Newtonville (a proxy for West Station) to Kendall are shown in Figure 24.

Figure 24: Existing Connections from Newtonville (a proxy for the future West Station) to Kendall

Table 7 shows the existing and potential times from Newtonville (a proxy for the planned West Station) to Kendall. A single-track DMU rail shuttle does not offer times savings over the existing service via South Station on the Framingham/Worcester Line and Red Lines. It does offer significant savings over the service via Yawkey on the CT2 bus. A double-track DMU rail shuttle offers the greatest times savings potential. A timed-connection bus service offers a slightly better travel time savings than the single-track DMU service, suggesting that it might merit consideration. In the AM peak, for example, a bus would be scheduled to 'meet' each inbound Worcester Line commuter train, departing a few minutes after it arrives and operating non-stop to Kendall. Return trips in the PM peak would be scheduled with an additional allowance for traffic delay to assure a good connection to outbound trains.

Table 7: Existing and Potential Times from Newtonville to Kendall

Summary (minutes)	First Wait	Transfer Wait(s)	Walking	In-vehicle Time	Total Time	Perceived Time
Via South Station and Red Line	7.2	3.0	8.7	28.9	47.8	58.1
Via Yawkey and CT2 Bus	7.2	11.3	18.3	30.8	67.6	95.7
Via West Station and 1-track DMU Shuttle	*7.2*	*12.6*	*6.3*	*10.0*	*36.1*	*58.8*
Via West Station and 2-track DMU Shuttle	*7.2*	*6.1*	*6.3*	*10.0*	29.6	42.9
Via West Station and Timed-Connection Bus	*7.2*	*4.0*	*9.7*	*22.0*	*42.9*	*55.2*

Suggested Next Steps

From the Urban Ring work and the general extent of the growth of transit passenger travel indicated by the early Focus 40 work, there is nothing to support a conclusion that the connections considered in this memorandum would warrant the Rapid Transit frequency class of service within a typical planning horizon of 20-25 years. Any more specificity in this regard would require conceptual design of a service and estimation of travel demand based on its characteristics.

With regards to the specific connections considered at Task Force Meeting #8, we offer the following observations:

- A high-frequency rapid transit *connection from Kendall Square to Sullivan Square or points north* would require significant capital investment. The Urban Ring work did not identify a fully grade-separated BRT as being warranted or feasible in this section, and for the at-grade solution it identified, did not find it desirable to use the Grand Junction right-of-way north of Main Street because it would miss Lechmere and the connection to the Green Line. The Focus40 work is also pointing to a real potential for improved capacity, travel time, and service reliability on both the Red and Orange rapid transit lines. The competitiveness of a separate route is therefore likely to be diminished in the longer-term future. An alternative that would rely on an on-street solution north of Lechmere would also be subject to increases in travel time with increasing roadway congestion, even if portions of the route were separated from other roadway traffic.
- The linkage between *North Station and Kendall* is deficient in terms of travel time: in the peak, the EZ Ride connection is hampered by traffic congestion, and the two-seat ride by rapid transit is slow and unreliable. It appears that a rail shuttle service with FRA-compatible DMUs might be feasible, to the extent that it would be worth preserving the possibility of providing for two railroad tracks along the path's alignment north of Main Street. Establishing the desirability of this, or a possibly less frequent operation relying primarily on a single track, would require further study of the potential demand and costs. Taking steps not to preclude two tracks along the path's alignment north of Main Street would make it possible to consider a non-compatible EMU or DMU rail shuttle service in the longer term, with appropriate provisions made at North Station.
- The linkage between the *Worcester Line commuter rail at West Station and Kendall* might be satisfactorily provided by a rail shuttle using a single track, but it would be prudent to provide for two tracks between the crossing of the Charles River and Main Street unless it can be clearly established that a single track would suffice and that there would be no other potential transit use (see below). Establishing the desirability of this would require further study of the potential demand and costs. We suggest that any such study include consideration of an express bus service to/from Kendall that would be scheduled to make timed connections with specific Worcester Line trains.
- The connection between *Kendall and the Longwood area and the Green Line* has long been recognized as important, and the Urban Ring work identified a potential for BRT service along the Grand Junction corridor south of Main Street. Although the Urban Ring work did not find a new crossing of the Charles River warranted, or recommend operation in exclusive right-of-way on the Boston side, in our opinion it would be prudent not to preclude either possibility for the longer term.

In light of the above, we suggest that the City explore the feasibility of:

- Developing a 'conceptual' design north of Main Street for a continuous alignment for two railroad tracks as shown in Figure 13. The design should include station locations, allowing for side platforms on each side of the transit alignment where possible, and for staggered platforms where necessary.
- Developing a 'conceptual' design south of Main Street for a continuous alignment for one railroad track and a separate two-directional transitway as shown in Figure 14. This will make ample provision for a two-track railroad, should that be chosen in the future. The design should include station locations, allowing for side platforms on each side of the transit alignment where possible, and for staggered platforms where necessary.
- Advancing the design and implementation of the multi-use path with the goal of not precluding the 'conceptual' designs, while also minimizing the number of path crossings of the future transit operation, and associating such crossings with present street crossings of the railroad wherever possible.

- Advocating that West Station plans not preclude an intermediate frequency service with FRA-compatible DMUs linking West Station, Kendall Square, and North Station.

The City is advised that making provisions to not preclude possible transit futures along the path may require significant engineering effort.

We also suggest that the City assess the desirability of a relatively near-term interim FRA-compatible DMU rail shuttle connection using a single track with one or more passing sidings on the Grand Junction, including the following options:

- A DMU rail shuttle between West Station and North Station stopping at no more than two locations in Cambridge (this may include possible modifications to the EZ Ride service);
- DMU rail shuttle only between North Station and a stop serving Kendall (this may also include possible modifications to the EZ Ride service), and
- A bus service with express operation between West Station and Kendall on existing streets, timed to connect with Worcester Line trains.

The above suggestions are likely to require more study of the following issues:

- North Station platform and track capacity;
- Street crossings in Cambridge;
- Crossing the Green Line Extension to/from Union Square;
- The use of the ‘BU’ Railroad Bridge; and
- Configuration of the planned West Station tracks and platforms.

Finally, we suggest that the City coordinate with the MBTA and MassDOT regarding the re-design of the GLX branch to Union Square so as not to preclude the possibility of FRA-compliant trains moving directly at grade between at least one of the Fitchburg Line tracks and the Grand Junction Railroad in Cambridge.