Fairmount Line Service Improvements: Potential Use of DMUs

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Prepared for:

EOT

Commonwealth of Massachusetts
Executive Office of Transportation

Prepared by:

JACOBS
Edwards and Kelcey

1. INTRODUCTION

As the MBTA continues its program initiated in 2002 to improve service, facilities and infrastructure on its Fairmount commuter rail line, planners and operations management want to analyze options for service improvements to complement the new facilities when they are complete. The MBTA and the Executive Office of Transportation and Public Works (EOTPW) each conducted studies to understand what Fairmount service improvements would generate the greatest benefit from the facilities and infrastructure investment.

EOTPW is particularly interested in exploring the feasibility, impact and cost effectiveness of using Diesel Multiple Units (DMUs) to supplement or replace services that are presently offered with push-pull locomotive equipment on the Fairmount line. The potential air quality benefits that may accrue from the use of DMUs is of considerable interest to EOTPW. Some stakeholders are also interested in the possible use of DMUs to offer an urban passenger railway service that is closer to rapid transit service in its service features, including faster acceleration, shorter station dwell times and shorter headways.

The EOTPW analysis was conducted in coordination with a separate study funded by the MBTA. The MBTA study focused on the feasibility, impacts and cost effectiveness of potential service improvement options that could be implemented within operational constraints of equipment availability, South Station capacity and layover needs for Southside commuter rail operations. The findings of this separate study, also conducted by JEK, are presented in a separate report.

The age of transportation infrastructure in the Commonwealth requires the maintenance and strategic use of existing assets to be of primary concern to decision makers. Therefore, both Fairmount studies were designed to be consistent with the MBTA's State of Good Repair policy, which seeks to direct resources to projects that preserve existing infrastructure, or assist in maximizing the utility of such infrastructure. These studies are also sensitive to the MBTA's current fiscal climate, where funding for ambitious expansion projects is scarce and all capital expenditure decisions are under increased scrutiny.

The following study of the implications of introducing DMUs to the Fairmount Line includes a survey of existing DMU rolling stock, and a review of operational impacts associated with these vehicles. This survey informs a brief review of the maintenance and storage implications that the introduction of DMUs could have for MBTA commuter rail operations. One finding of the study is that DMU implementation at current service levels would prove to be a very poor investment (due to high capital costs and the need for higher levels of service in order to effectively leverage the benefits of DMUs). Therefore, the study concludes with a detailed evaluation of several specific service options (including those introducing DMUs and those using the MBTA's existing and/or modified fleet of commuter rail rolling stock) and their impacts on ridership, the environment, and operations generally.

2. DMU CHARACHTERISTICS AND AVAILABILITY

DMUs are passenger rail cars with a self-contained, on-board source of motive power, making reliance on a locomotive or electric power distribution system unnecessary. While motive power may be a diesel internal combustion engine or an alternative self-contained, on-board source, all DMUs in common use rely on diesel propulsion. Although DMU vehicles were fairly common in the 1950s (largely due to the manufacture of the Budd rail diesel car, which was a key component of the Boston and Maine Railroad's rolling stock) from the 1960s until very recently, no manufacturers were offering to construct DMUs that complied with Federal Railroad Administration (FRA) standards.

The FRA, which regulates commuter and freight rail service in the United States, sets crash-worthiness standards for all passenger vehicles (including DMUs) operating on the nation's general purpose railroad network. Although non-FRA-compliant DMUs have been developed for use on private, non-general purpose railroads (such as New Jersey Transit's River Line), any DMUs used on the Fairmount Line would need to meet FRA regulations. The weight requirements of those standards proved to be a barrier to the manufacture of new DMUs until a recent increase in transit agency interest in DMU transit. Today, there are five manufacturers (Colorado Railcar, United Transit Systems, Bombardier, Siemens, and Sumitomo/Nippon Sharyo) actively marketing DMUs for the domestic market.

Available DMUs include single and bi-level versions that are available either as individual units or married pairs[1] (see Table 2.1). They are typically powered by two diesel engines with maintenance requirements similar to bus engines. The available DMUs accelerate in the range of 0.8 to 2.4 mph per second (compared to approximately 0.5 mph per second for conventional push-pull service) and operate at maximum speeds of 65 to 100 mph.

Although there are a number of potential benefits of DMUs depending on the operating environment (air quality improvements, the ability to run shorter trainsets thereby better matching capacity to demand) the acceleration characteristics of DMUs have the greatest potential for improving service on the Fairmount Line. DMU acceleration is important on commuter rail lines with a large number of stations and/or speed restrictions because trains spend a significant amount of time accelerating in these environments. On the Fairmount Line, there are currently five stations, and a commitment to add four more. The ability of DMUs to speed travel on this corridor is somewhat constrained by the three speed restrictions currently enforced—at the northern and southern ends of the line as the service enters active yard facilities, and at the Columbia Road overpass due to bridge conditions.[2]

DMUs can also act as "locomotives" and either push or pull trailer cars. However, the addition of trailer cars reduces acceleration performance. With 50% DMUs and 50% trailer cars, performance is still significantly better than for diesel push-pull consists. With 33% DMUs and 67% trailer cars, acceleration at lower speeds remains faster than with traditional equipment, but becomes slower at higher speeds, and from 0 to 60 mph, is slower than traditional equipment.

2.1. Other Rolling Options for the MBTA

[1] Married pairs are two single cars that are permanently connected and operate in pairs or multiples of pairs.
[2] This speed restriction should be eliminated once Columbia Road bridge reconstruction has been completed.

In order to assess the advantages from implementing DMUs, the study evaluates many attributes of a potential DMU service with both the existing push-pull trainsets employed by the MBTA and a modified version of these trainsets.

Conventional Push-Pull - The MBTA currently employs locomotive hauled diesel push-pull equipment for all of its commuter rail operations. Push-pull operations characterize most of the commuter railroads in North America. In this configuration, a diesel electric locomotive is employed to provide propulsion, lighting and HVAC power for the train. The diesel engine drives an electric generator that supplies power to electric motors on the locomotive's drive-wheels. A separate diesel engine and generator typically provides electric power to heat, cool and light the passenger coaches. The typical minimum length for a push-pull train is a locomotive and three coaches. Trains with two cars are occasionally deployed, but are not favored. The typical diesel locomotive is 60 to 70 feet long and weighs 125 tons. The maximum practical train length for a single passenger locomotive is typically 8 or 9 cars.

The passenger coaches for this vehicle type are unpowered trailers. Coaches can be either single-level or bi-level. Regardless of height, the typical coach is 85 feet long. A single-level car generally weighs about 50 tons. A bi-level weighs approximately 60 tons. The MBTA operates a mix of single-level and bi-level equipment but has committed to purchasing only bi-level coaches in the planned future.

At present, all MBTA commuter rail coaches have end vestibule doors. The vestibules have stairs for low-level boarding and a trap that swings down across the stairs for high level boarding. Train conductors manually operate the doors and traps. There is typically one conductor for every two cars that are in service. At each stop, each conductor operates two doors (the end doors of two adjoining cars), or 50% of the total doors. Passengers are only permitted to enter and exit via manned doors.[3]

Modified Push-Pull – In addition to DMUs, another vehicle type is considered as part of this study—modified push-pull trainsets. Also hauled by diesel locomotive push-pull equipment, coaches would be single level with alternate door configurations to enhance passenger boarding and alighting. Coach doors would differ from doors on existing MBTA coaches in two ways.

First, coaches would be equipped with automatic door operation (as on rapid transit, light rail and the MBTA's Old Colony Commuter Rail Line) to allow all doors to be used for boarding and alighting. With the construction of high level platforms at all stations (as on the MBTA's Old Colony Line), this could likely be implemented with the MBTA's existing equipment.

Second, the number of doors would be increased to provide more paths in and out of the vehicles. This would be done through the use of both end vestibule and wide center doors (see Figure 3.1). This door configuration would not only allow for shorter station dwells due to the additional exit/entry paths for passengers during peak travel times, but would also provide the flexibility to serve stations on convex or concave sections of curved track through center or end-vestibule doors, respectively. The MBTA reports that wide center doors could be retrofitted into its existing single-level Bombardier coaches.

[3] Although not permitted by the MBTA, at some busy stations, passengers occasionally operate the doors and traps themselves to be able to board or alight faster.

2.2. Currently Available DMUs

The remainder of this section provides an overview of the DMUs currently being marketed by the five manufacturers identified above. A summary of the available DMUs is provided in Table 2.1.

Table 2.1: Available DMUs

	Colorado Railcar (Single Level)	United Transit Systems	Sumitomo/ Nippon Sharyo	Bombardier DMU (2 cars)	Siemens Desiro USA (2 cars)
					
Configuration	Single Unit	Single Unit	Single Unit	Married-Pair	Married-Pair
First Year of Service	2006	2008?	NA	NA	NA
Passenger Capacity (Seats)					
Seated with 2 x 2 Seating	92	80	87		
Seated with 2 x 3 Seating	116	96	104	199	160
Standees[4]	148	120	NA	174	210
Total	240	200	NA	373	370
Capital Cost (millions)	$3.7	$3.5	$3.6	NA	$8.5
Capital Cost/Seat (3 x2)	$31,900	$36,500	$34,600	NA	$53,100
Engines	2	2	2	4	2
Total Horsepower	1,200	950	690	1,320	1,120
Drive Train	Diesel-Hydraulic	Diesel-Hydraulic	Diesel-Hydraulic	Diesel-Electric	Diesel-Electric
Max Operating Speed (mph)	70	65	80	100	79
Max Acceleration (mphps)	2.4	1.5	0.8	1.5	1.3
Weight (tons)	74	65	71	129	134
Tons/Seat	0.8	0.8	0.8	0.6	0.8
HP/Ton	15	16	10	10	8
Length (feet)	85	85	85	170	167
Height (feet)	15.1	14.4	13.1	13.0	14.4

2.1.1. Colorado Railcar

Colorado Railcar Manufacturing (CRM) is currently producing both single and bi-level DMUs. However, the bi-level DMUs can only be configured for low platform boarding, which would make them incompatible with MBTA operations. A single DMU can accelerate from 0 to 60 mph in 77 seconds, or less than half the 167 seconds for diesel push-pull service.

As currently produced, single level vehicles are configured with two-by-two seating accommodating 94 passengers. With three-by-two seating, seated capacity could be increased to approximately 116 passengers. The vehicles have one set of center boarding doors on each side that are compatible with low or high level boarding (or both). CRM has stated that alternative door arrangements are possible.

[4] Standee figures are those reported by manufacturers (and are generally those for 2 x 2 seating) and are higher than those that are used by most transit systems, including the MBTA.

CRM estimates the useful life of its DMUs at 50 years, with major component overhauls scheduled for 700,000 miles for engines and 750,000 miles or 20,000 hours for transmissions. The capital cost of the single level DMU is estimated at $3.7 million. Presently, the MBTA, like most transit agencies, nominally expects to get 30 years of service from all of its railroad rolling stock in accordance with FTA guidance. However, the MBTA, like most of its peers, sometimes operates rolling stock well beyond its 30 year life expectancy.

To date, Tri-Rail in Miami and Washington County Commuter Rail in Portland, Oregon have purchased Colorado Railcar DMUs. Tri-Rail has purchased a single level DMU, a bi-level DMU, and a bi-level coach for use in a demonstration project. This service began in late 2006. Washington County Commuter Rail has ordered three single level DMUs and two matching single level coaches that are scheduled to begin service in 2008.

2.1.2. United Transit Systems

United Transit Systems, which is a consortium of Tokyo-based Sojitz and Seoul-Based Rotem, had been chosen by the Triangle Transit Authority (TTA) in North Carolina to provide a fleet of single unit/single level DMUs for a new commuter rail line between Durham and Raleigh. This project has since been placed on hold due to funding issues. However, New Jersey Transit has obtained the contract rights to these vehicles and plans to use them on its planned Northern Branch line.

The TTA vehicles were planned to have two-by-two seating for 80 passengers. Presumably, with three-by-two seating, the vehicles could seat 96 passengers. Each vehicle will have two sets of doors on each side designed for high-level boarding. The doors could also be modified to be compatible with high and low level boarding.

Rotem estimates the useful life of the DMU at 30 years, and the cost at $3.5 to $7 million each, depending upon the quantity ordered. (UTS' winning bid for the TTA order was $90 million, or $2.8 million per vehicle, but this bid was viewed as artificially low to enable UTS to enter the American market.)

The UTS consortium is currently producing commuter rail cars for Philadelphia's Southeastern Pennsylvania Transportation Authority, and Rotem is building commuter rail cars for the Southern California Regional Rail Authority.

2.1.3. Bombardier

Bombardier, which is one of the largest rolling stock manufacturers in the world, produces nearly all types of rail vehicles, including non-FRA-compliant DMUs. (Bombardier was part of the consortium that produced the non-FRA-compliant vehicles for New Jersey Transit's River LINE.) To date, Bombardier has not produced any FRA-compliant DMUs, but was an unsuccessful bidder on the TTA procurement described above.

For TTA, Bombardier proposed producing a DMU version of the M-7 electric multiple unit (EMU) that it is now building for New York Metropolitan Transportation Authority's (MTA) Long Island Railroad and Metro-North Railroad. The M-7 DMU would operate in married-pairs.

Each individual unit would have three doors on each side. Vestibule doors at each end could be used for high or low boarding, and the quarter point doors in the middle would be used only for high level boarding. Each married-pair would seat 199 passengers with three-by-two seating.

2.1.4. Siemens

Siemens is another large manufacturer of transit rolling stock that produces most types of vehicles, including non-FRA-compliant DMUs. To date, Siemens has not produced any FRA-compliant DMUs, but did propose on the TTA procurement and in Washington County, Oregon. After Siemens lost to UTS at TTA, it then withdrew its bid in Oregon because it did not believe that it could achieve satisfactory economies of scale without the TTA order.

For the TTA and Oregon projects, Siemens proposed an FRA-compliant version of its Desiro DMU that is in service in Europe, Mexico and Iran. A non compliant low floor variation on this car has been ordered by the North County Transit District in Oceanside, California for a new rail line that is scheduled to begin service in December 2007. This line will be 22 miles long, have 15 stations (one station every 1.5 miles), and will provide service every 30 minutes. Vehicle testing is underway in California.

The proposed FRA-compliant DMUs consisted of married pairs, each of which would have been powered by two diesel hydraulic engines. For the Oregon bid, Siemens proposed a diesel-electric propulsion system (similar to the proposed Bombardier DMU).

Each married pair would have had two sets of center doors configured for low level boarding, and would seat 160 passengers with three-by-two seating. The vehicles are also 60% low floor, meaning that unless the floor height could be reconfigured, they would not be compatible with high level boarding. The capital cost and projected useful life of the FRA-compliant vehicles is not available. However, Siemens bid to TTA in 2004 was for $8.5 million per married-pair. NCTD's cost for non-compliant Desiros, also in 2004, was similar, at $8.4 million per married-pair.

2.1.5. Sumitomo/Nippon Sharyo

Sumitomo Corporation of America, and its partner Nippon Sharyo, have produced single level and bi-level commuter rail coaches for a number of American commuter railroads and transit providers, including the Maryland Transit Administation (Maryland MTA), METRA and Northern Indiana Commuter Rail District (NICTD) in Chicago, CalTrain in San Francisco, New York MTA, and Virginia Railway Express.

Sumitomo was also an unsuccessful bidder on the TTA procurement. There, Sumitomo proposed single unit FRA-compliant DMUs based on the same body used for NICTD's EMUs and Maryland MTA's MARC commuter rail service.

As proposed, the Sumitomo DMUs would have had two end vestibule doors suitable for high or low level boarding. However, NICTD's EMUs also have middle quarter point doors for high level boarding, and the DMUs could presumably be configured in the same way.

The proposed DMUs had two-by-two seating for 87 passengers. The cars could also be configured with three-by-two seating, in which case seated capacity would increase to approximately 104 passengers. Sumitomo's TTA bid in 2004 was for $3.6 million per single car unit.

3. DMU PERFORMANCE EXPERIENCE

To better understand DMU vehicle performance characteristics, JEK conducted a survey of agency operating experience and available research. The relevant findings of that survey, including aspects relating to running times, maintenance and reliability, fuel efficiency and emissions, are described in the following subsections.

3.1. Travel Time Savings

As noted in the introduction, the key DMU characteristic related to desired service improvement on the Fairmount Line, in addition to air quality benefits, is the reduction of running times due to generally faster acceleration than traditional diesel push-pull service. DMUs require less time to accelerate up to full speed from stations stops and slow areas, reducing overall travel times, particularly on a corridor featuring frequent stops such as the Fairmount Line. New DMUs could also be configured with up to three sets of automatic doors, reducing the time trains spend stopped in stations. Currently, MBTA commuter rail coaches have only two doors (one at each end of the car) and during periods of peak passenger loads the number of vehicle exits can act as a constraints to passengers quickly exiting/entering the coach. A DMU with three sets of doors would therefore speed the boarding process during these periods. This benefit is not unique to DMUs, however, as the MBTA's current coaches could be reconfigured with three sets of automatic doors.

Travel Time Savings Due to Faster DMU Acceleration – As discussed, DMUs can accelerate faster than conventional push-pull equipment. The acceleration rates of different vehicles vary, so actual DMU performance would be determined by the vehicle used. For the purposes of this analysis, DMU performance characteristics are presented for single-level Colorado Railcar DMUs operated with a consist mix of 50% DMUs and 50% trailer cars. This vehicle and consist mix was used for the analysis both because actual performance data is available for Colorado Railcar DMUs, and because a 50%/50% mix provides a balance between performance and costs.

Table 3.1: Acceleration Characteristics of DMUs versus Diesel Push-Pull

	Colorado Railcar DMU (50% DMUs/50% Trailer Cars)			Diesel Push-Pull (Typical MBTA)		
Speed (mph)	Time (secs)	Distance (feet	Accel (mphps)	Time (secs)	Distance (feet	Accel (mphps)
0	0	0	0.00	0	0	0.00
5	5	13	1.40	10	37	0.50
10	8	56	1.21	20	149	0.49
15	13	140	1.03	31	340	0.48
20	18	279	0.87	41	619	0.46
25	25	491	0.73	53	994	0.44
30	32	798	0.61	65	1,486	0.41
35	41	1,228	0.52	78	2,113	0.38
40	52	1,819	0.43	92	2,899	0.35
45	65	2,614	0.37	108	3,873	0.32
50	80	3,701	0.29	125	5,074	0.29
55	100	5,224	0.24	145	6,555	0.26
60	123	7,129	0.21	166	8,388	0.23

As shown in Table 3.1, a mix of 50% Colorado Railcar DMUs and 50% trailer cars could accelerate to 30 mph in 32 seconds, versus approximately 65 seconds for existing MBTA equipment. Acceleration to 60 mph would take 123 seconds, versus 166 seconds for existing service. With the addition of more stations to the line, trains would spend more time accelerating, and the acceleration benefits of DMUs would increase.

Using the performance attributes of DMUs and the MBTA's conventional equipment and Fairmount Line operating characteristics, JEK estimated station-to-station running times[5] for: (1) existing service (five existing stations), (2) currently planned improvements with existing rolling stock (four new stations, and improvements to existing stations), and (3) DMU service (also four new stations with improvements to existing stations). As detailed in Table 3.2, the results indicate that DMUs would reduce station-to-station travel times by approximately three minutes once the four new stations are implemented.

Table 3.2: Station-to-Station Running Time Comparison

	Existing Service	Planned Service	Potential DMU Service
Number of Stations	5	9	9
Mode	Diesel Push-Pull	Diesel Push-Pull	DMU
Station-to-Station Travel Times (mins)			
Acceleration/Deceleration Time	7.5	16.0	13.0
Time at Max Speed (60 mph)	8.5	4.5	4.5

[5] "Station-to-station" running times represent only the total vehicle travel time between stations, and do not include the dwell times at stations.

Total	16.0	20.5	17.5
DMU Savings			3.0

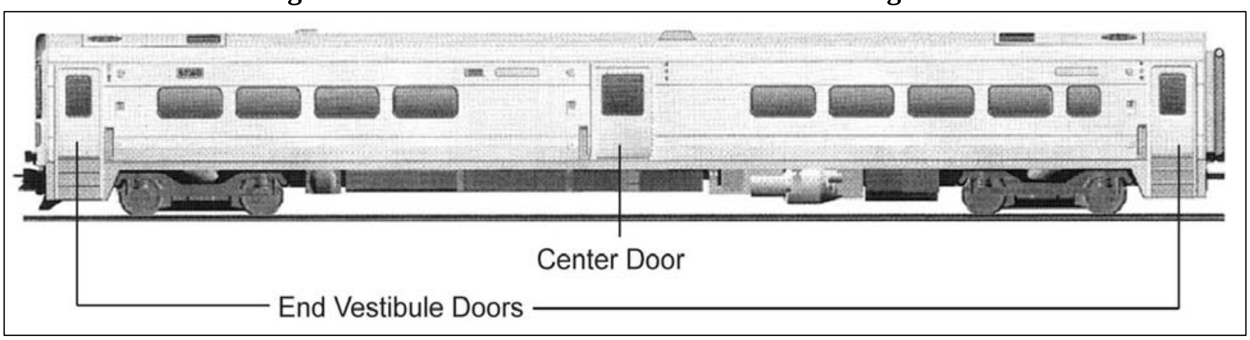
Note: Figures do not include station dwell times.

Travel time savings due to Door Configuration and Operation practices - The second component of total running times impacted by vehicle design would be station dwell times. For existing Fairmount Line service, peak period dwell times are estimated to total approximately three minutes or 23% of the total running time. With the addition of the four new stations and increased ridership, total dwell times are forecast to increase to 10 minutes, or 33% of the total running time.

Dwell times can be reduced in two ways. First, all doors could be used for boarding and alighting. This would require automatic door operation (as on rapid transit and light rail). With the construction of high level platforms at all stations, this could likely be implemented with the MBTA's existing equipment or with DMUs.

Second, the number of doors could be increased to provide more paths in and out of the vehicles. This could be done through the use of both end vestibule and wide center doors (see Figure 3.1). DMUs are available in these configurations. The MBTA also reports that wide center doors could be retrofitted into its existing single-level Bombardier coaches.

Figure 3.1: End Vestibule and Center Door Configuration



To determine the potential dwell time savings of these improvements, JEK researched a number of methods to estimate dwell times based on vehicle and platform characteristics. Of those identified, the most applicable to this analysis was a doorway flow time methodology presented in TCRP Report 13, "Rail Transit Capacity."[6] As would be expected, the number of doors, the type of doors, and boarding levels all impact passenger flow times. High level boarding reduces per passenger flow times by up to 50% (see Table 3.3). Wide center and quarter point doors typically handle two passenger paths in and out of vehicles, compared to one passenger path for end vestibule doors. As a result, the use of wide center doors coupled with end vestibule doors, or the use of quarter point doors, could reduce per passenger flow times by an additional 70 to 80%.

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[6] Fisher, I. & Parkinson, T. "Station Dwells" TCRP Report 13: Rail Transit Capacity. Washington, DC: National Academy Press, (1996). 38-50.

Table 3.3: Passenger Flow Rates per Car (Seconds per Passenger)

Platform Level:	Low Level	High Level			
	End Vestibule Doors; One in Use	End Vestibule Doors; One in Use	End Vestibule Doors; Both in Use	Quarter Point Doors; All in Use	End Vestibule & Wide Center Doors; All in Use
AM Peak	3.6	1.8	0.9	0.4	0.4
PM Peak	3.3	1.8	0.9	0.5	0.5
Off Peak	5.3	2.5	1.3	0.6	0.6

Total Travel Time Savings - In total, the use of DMUs could reduce running times on the Fairmount Line by up to six minutes. Approximately three minutes of these time savings would be unique to DMUs and attributable to their faster acceleration characteristics, and an additional three minutes would be due to more efficient door configurations and the use of all doors. With four new high-platform stations on the Fairmount Line, the use of DMU's would thus reduce forecast total one-way running times of 31 minutes down to 25 or 26 minutes, whereas retrofitted Bombardier coaches (with automatic door operations and a wide center door) in push-pull trains, would yield up to 3 minutes of travel time savings compared with current equipment (or one-way running times of 28 minutes).

3.2. DMU Maintenance and Reliability

This section summarizes the maintenance and service reliability experiences of North American systems that are now operating DMU service. In addition, since "modern" DMUs are relatively new to North America, and operating experience is limited, this report also summarizes the expectations of other agencies that are now planning DMU service. Information was obtained primarily through telephone interviews and email correspondence with representatives of the following surveyed agencies.

- OC Transpo's O-Train service in the Ottawa area (in operation)
- Dallas Area Rapid Transit's Trinity Rail Express (in operation)
- South Florida Regional Transportation Authority's Tri-Rail (in testing)
- TriMet's (Portland, OR) Washington County Commuter Rail (advanced planning)
- TTA's Durham – Raleigh Service (project on hold)[7]

OC Transpo O Train - OC Transpo uses Bombardier Talent DMUs to provide service between Greensboro and Bayview, Ottawa (and presents the service to the public as "light rail"). Service began in 2001 as a three year pilot project. The pilot project was deemed a success and OC Transpo is now working to expand service. The DMUs are maintained by Bombardier at a "semi-permanent" maintenance facility that consists of a metal structure and fiberglass tents located in a large existing rail yard.

7 TriMet and TTA were canvassed on their planning assumptions only

Two of OC Transpo's three DMU train sets are used for daily service and one is used as a spare. Thus, the spare ratio is 33%. For 2006 year-to-date, reliability has been very high, with on-time performance at 99.8%. The spare train's availability has been 71%.

Dallas Area Rapid Transit (DART), Trinity Rail Express - DART's Trinity Rail Express (TRE) service operates between Fort Worth and Dallas. Service has been provided since 1996 and is currently operated with a mix of diesel push-pull and DMUs. The DMUs operate mainly during the mid-day, and mostly between downtown Dallas and Dallas-Fort Worth Airport.

The DMUs are refurbished Budd cars originally manufactured in the 1950s[8] and purchased by DART in 1993. The DMU cars were then completely stripped and remanufactured as part of a 20-month makeover costing approximately $2 million per car. One three-car consist is utilized largely for mid-day service, and operates less than 180 miles per day. A second consist is kept on "hot standby" in case of service failures and/or disruptions.

TRE reported DMU vehicle availability was approximately 86%, and the MTBF was 2,000 miles. Vehicle failures typically do not prevent trip completion because of the high level of engine redundancy (two engines per car). TRE's effective spare ratio for the Budd DMUs is considered to be 25 to 30%.

TRE reported that maintenance requirements for DMUs are similar to those for locomotives except for the DMU propulsion system which uses automotive equipment, requiring tools and knowledge above those used in a facility engaged in locomotive work alone. Because DMU equipment is maintained by a contractor, TRE does not have cost data for maintenance. It is believed that maintenance of a DMU costs more than either a coach or a locomotive, but not more than the two combined.

Both DMUs and conventional push-pull equipment are maintained at the same facilities. A coach shop with a pit inside the rails can accommodate all work except for sand and fuel. A locomotive facility can accommodate all work if a flat track is available for engine changes. There are practical maintenance requirements for TRE's DMUs (e.g. filter change out periods), and although DMU maintenance work is not more difficult when compared to traditional equipment, there are more components to maintain.

Trinity Rail Express reports that there have been no problems with signal shunting.

South Florida Regional Rail Transportation Authority (Tri-Rail) – In late 2006, the South Florida Regional Rail Transportation Authority (SFRRTA) began operating Colorado Railcar DMUs as part of a demonstration project aimed at assessing the service reliability and maintainability of DMUs. The vehicles include one bi-level DMU, one-single level DMU and one bi-level trailer car, and are being used to expand service from 40 to 48 trains per weekday. Tri-Rail's DMU are being maintained by Colorado Railcar. Since the service is so new, Tri-Rail could not provide any information on maintenance history or issues. Tri-Rail reports that there

[8] One of these vehicles was originally owned by the Boston and Maine Railroad and operated on northside commuter rail lines into Boston before first being sold to Via Rail in Canada in the 1960s.

have been no problems with signal shunting. Tri-Rail performed numerous tests before the vehicles went into service, and has not had any problems since service began.

Tri-Met, Washington County Commuter Rail - Tri-Met in Oregon is currently in the process of implementing Washington County Commuter Rail service, which will be a suburb-to-suburb commuter rail service running between Beaverton and Wilsonville. The project is now under construction, and five FRA-compliant Colorado Railcar single level DMUs have been ordered. Service is expected to begin operation in September 2008. Trains will operate every 30 minutes during peak periods. Tri-Met's contract with Colorado Railcar, who was the successful bidder, requires a minimum time between failures for nine major subsystems. Tri-Met did not order any spare DMU vehicles, but does plan to purchase or lease a locomotive to haul DMUs in the event of emergencies or service disruptions.

A new maintenance facility is being constructed to maintain the DMUs. Compared to facilities for traditional commuter rail equipment, the only design elements that are specific to DMUs are those relating to vehicle clearance. Tri-Met's contract with Colorado Railcar includes $2.5 million for systems support (manuals and catalogs, diagnostic test equipment, replacement parts and user education). The user education portion entails $170,000 for the development of an education program outline and the training of maintenance and operations staff.

Triangle Transit Authority Durham – Raleigh Commuter Rail - Triangle Transit Authority (TTA) went through a DMU procurement process for 18 DMUs (with the option to purchase up to 32 vehicles) that it had planned to use for a new commuter rail service between Durham and Raleigh, North Carolina. TTA selected UTS to provide the vehicles, before the project was put on hold due to funding problems. The spare ratio was to be 20% and a maintenance facility was to be constructed at an estimated cost of $6.5 million.

3.3. Fuel Efficiency and Emissions

DMUs and traditional diesel push-pull equipment have significantly different fuel consumption characteristics that impact both total fuel consumption and emissions levels. Fuel consumption for traditional diesel push-pull service is largely related to the operation of the locomotive, and the length of the train impacts overall fuel consumption to only a small extent. Fuel consumption for DMUs, on the other hand, is directly related to the number of cars that are operated. As such, for DMU service, train length is a major determinant of fuel consumption and costs. For train lengths of 5 cars or less, fuel consumption would be lower for DMU service, and at train lengths of 6 or more cars, fuel consumption would be lower for conventional equipment.

Emissions characteristics are related to engine type and total horsepower. As with fuel consumption, emissions levels for traditional push-pull service is affected to only a small extent by train lengths, while those for DMU service are directly related to train length. At all train lengths that would be conceivably operated on the Fairmount Line, DMUs would have lower emission levels than conventional equipment.

Fuel Consumption Rates - Fuel consumption for existing MBTA commuter rail service is approximately 2.8 gallons per revenue train mile, and the average train length is six cars (see

Table 3.4). Based on Colorado Railcar data and factors to include deadhead time and idling,[9] DMU fuel consumption would range from 0.6 gallons per mile for a single DMU to 2.2 gallons per mile for a five car train set with two DMUs and three trailer cars. Using a consist mix of at least 50% DMUs, fuel utilization rates would range from 2.0 gallons per mile for a four car DMU train set to 3.9 gallons per mile for an eight car DMU train set. At these utilization rates, at train lengths of five or fewer cars, DMU train sets would use less fuel. At train lengths of six or more cars, traditional equipment would use less fuel.

Table 3.4: Fuel Consumption Rates[10]

	Revenue Service	Idling & Layovers	Total
MBTA Commuter Rail Fuel Consumption			
Revenue Train Miles	3,847,506		
Revenue Coach Miles	22,152,272		
Average Train Length	5.8		
Fuel Consumption (gallons)			10,804,716
Gallons/Revenue Train Mile			2.81
Per Additional Coach			0.03
DMUs			
Gallons/Revenue Train Mile			
1 DMU Power Car	0.550	0.077	0.627
1 DMU Power Car + 1 Trailer Car	0.860	0.120	0.980
1 DMU Power Car + 2 Trailer Cars	1.160	0.162	1.322
2 DMU Power Cars + 1 Trailer Car	1.410	0.197	1.607
2 DMU Power Cars + 3 Trailer Cars	1.900	0.266	2.166

Emissions Rates - Diesel engine emissions are governed by the U.S. Environmental Protection Agency (EPA), which sets maximum emissions rates for different types of diesel equipment. Diesel locomotives are governed by the EPA's Diesel Locomotive standards, and DMUs are governed by the EPA's Non-road Diesel Engine standards. Allowable emission rates are being reduced over time. This analysis presents impacts for four of the most important pollutants: hydrocarbons (HC), carbon monoxide (CO), nitrogen oxides (NOx), and particulate matter (PM).

While the EPA sets maximum emissions rates, most equipment that is on the market produces fewer emissions than the maximum allowed by EPA. For the purposes of this analysis, the study team compared estimated emissions rates for currently available diesel locomotives and Colorado Railcar DMUs. For diesel push-pull service, diesel emissions were estimated using the EPA's projected actual emissions rates for Tier 2 diesel locomotives.[11] For DMUs, emissions were estimated using the emission rates reported by Detroit Diesel for the Series 60 engines that are used in Colorado Railcar DMUs[12].

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[9] Estimated diesel-electric push-pull fuel consumption rate also includes dead-heading and idling.

[10] Sources: 2004 NTD (MBTA), and "Economics of FRA-Compliant Diesel Multiple Units (DMUs), Christina Rader, Colorado Railcar, prepared for 2003 APTA Rail Conference (DMU).

[11] EPA Circular EPA420-F-97-051, EPA Office of Mobile Sources, December 1997.

[12] These rates, which were initially presented in grams per base-horsepower-hour (bhp-hr), were converted to grams per gallon using the EPA's conversion factor of 20.8 bhp-hr per gallon.

Table 3.5: Emission Rates for Diesel Push-Pull and DMU Service

	HC	CO	Nox	PM
Grams/Base-Horsepower-Hour				
Diesel Locomotive	0.26	1.28	5.00	0.17
DMU	0.07	0.48	2.90	0.06
Grams/Gallon of Fuel				
Diesel Locomotive	5.4	26.6	104.0	3.5
DMU	1.5	9.9	60.3	1.2

As shown in Table 3.5, emission rates for DMU vehicles are 42% to 73% lower than for diesel push-pull service. As with fuel consumption, emission rates for diesel push-pull service is impacted only to a small extent by train length, while emission rates for DMU service increases or decreases in proportion to length. However, at all train lengths that would be operated on the Fairmount Line, DMUs would produce far fewer emissions (see Figures 3.2 through 3.5).

Figure 3.2: Hydrocarbon (NC) Emissions

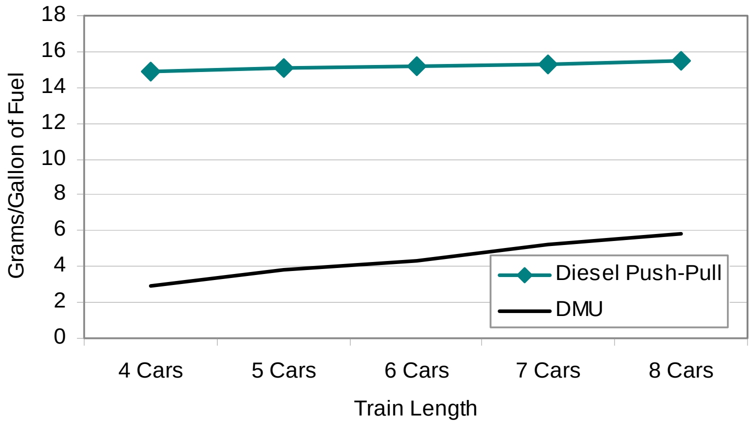


Figure 3.3: Carbon Monoxide (CO) Emissions

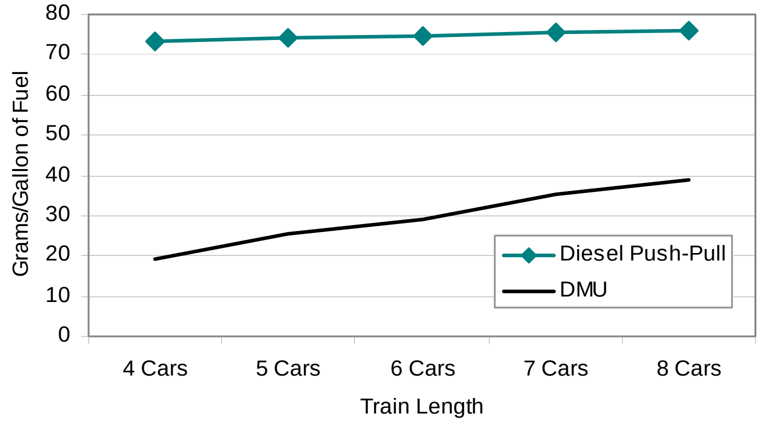


Figure 3.4: Nitrogen Oxide (NOx) Emissions

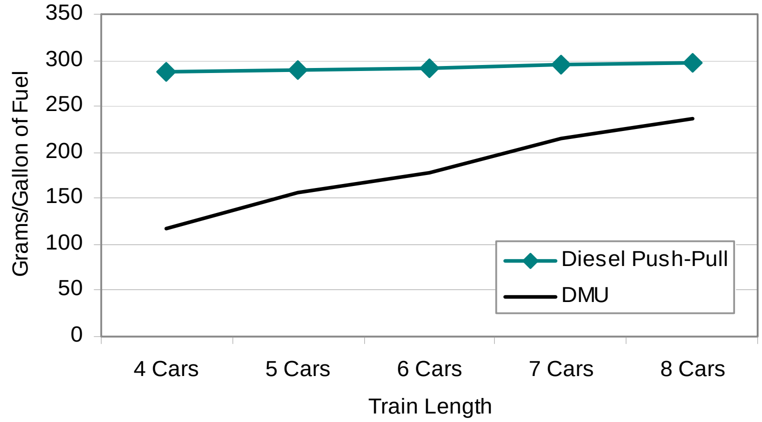
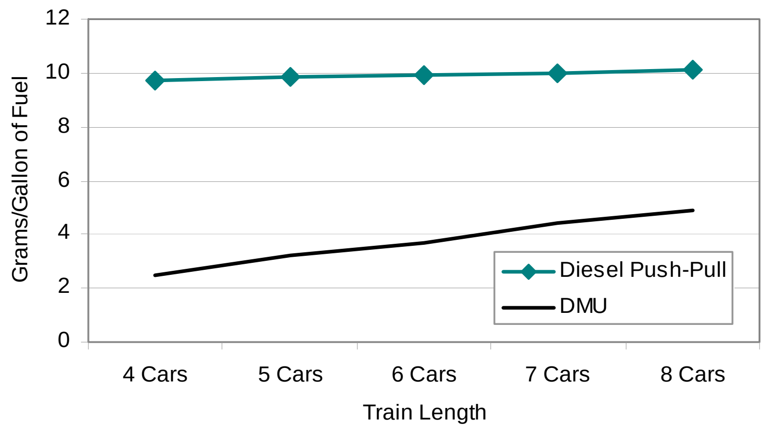


Figure 3.5: Particulate Matter (PM) Emissions



4. SERVICE IMPROVEMENT OPTIONS

JEK explored a number of combinations of vehicle types and service levels to gain an understanding of the costs and benefits associated with DMU service provision and to evaluate the attributes of DMU service relative to other available improvements.

4.1. Vehicle Type

Three types of vehicles were evaluated for operation on the improved Fairmount line: conventional push-pull locomotives and coaches, push-pull locomotives trailing single level coaches with enhanced door operations, and DMUs. Differences in vehicle type affect acceleration profiles, boarding and alighting time and ultimately, trip times. A detailed discussion of these three vehicle options is provided in Section 2 of this report.

4.2. Service Frequency

Three levels of service were considered for the future Fairmount line including, 2030 Baseline frequency, 15 minute peak headway service, and 20 minute peak headway service.

Baseline Service - The assumed Baseline mimics the existing 2006 service plan with the addition of Greenbush deadheads and four new stations at Newmarket/South Bay Center, Four Corners, Talbot Avenue and Blue Hill Avenue.

Running times on the Fairmount line were calculated to increase from the current 20 minutes to 26 minutes in the off-peak period and 30 minutes during peak periods due to additional stops.[13] The current schedule takes advantage of 20 minute running times by scheduling one round-trip per hour per train. The current schedule (one hour round trip) would not be feasible with the longer 26-30 minute running times if the number of consists assigned to the service is not increased. Therefore, a new schedule based on expected running times was created for the Baseline providing an equivalent level of service to the current schedule, while employing the same amount of equipment. The last weekday train would arrive at South Station at 10:45 pm. No weekend service would be provided.

15 Minute Peak Headway – Under this alternative, Fairmount service would be provided at 15 minute headways during the morning and afternoon peak periods and at 40 minute headways during the midday and at night. Two roundtrips would be added to the end of the Baseline's night schedule, and service would be offered on both weekend days

20 Minute Peak Headway – Under this alternative, Fairmount service would be provided at 20 minute headways during the morning and afternoon peak periods and at 40 minute headways during the midday and at night. Two roundtrips would be added to the end of the Baseline's night schedule, and service would be offered on both weekend days.

5. IMPACTS OF SERVICE IMPROVEMENTS

[13] These running times take into account the planned improvements at stations (e.g. high level platforms for easier boarding and shorter dwell times) but not improvements to coach door operation and configuration.

The incremental costs and benefits were estimated for various service improvements employing DMUs and other vehicle types. Costs and benefits are presented relative to the baseline.

5.1. Ridership

The Central Transportation Planning Staff (CTPS) finalized a series of new ridership forecasts for the Fairmount Line in July 2007. As discussed in the previous section, the improvement options differ in terms of vehicle type and service frequency. The baseline, which provides the current level of service once the four new stations are opened, achieves the lowest ridership forecast with 1,760 weekday inbound boardings. The highest ridership forecast (4,250 weekday boardings) was for the option using DMUs and 15 minute peak headways and 25 minute running times.

In general, the results of the ridership were as expected. Given the same frequency of service, shorter running times attracted greater ridership than those with longer running times. For example, with 15 minute headways, DMUs attracted 4,250 riders with a 25 minute running time. Modified push-pull trainsets with enhanced door operations (but lacking the acceleration benefits of DMUs) made the trip in 28 minutes and attracted 3,700 riders. The slowest option employed the MBTA’s current rolling stock. The absence of additional doors on this option resulted in longer dwell times and consequently longer running times (30 minutes) for a decrease in ridership to 3,340.

Ridership results for all vehicle types also increased with greater frequency. For example, even with the benefits of improved door configuration and acceleration, DMUs operating at the current peak headway of 30 minutes performed worse (only 2,000 daily riders) than the MBTA’s current rolling stock without enhanced door operations when they were operated at 20 minute headways (2,760 daily riders). The forecast results show increases in frequency (an operational change that is independent of vehicle type) to increase ridership more significantly than decreases in running time (an operational benefit achieved through introducing DMUs or modified push pull sets).

The ridership forecasts were used to determine required train lengths for each improvement package. Information on train lengths was then utilized in capital and operating cost estimation.

5.2. Capital Costs

The capital cost elements required for implementation of service improvements include new rolling stock and new storage and maintenance facilities.

Rolling Stock – For the purposes of this study it was assumed that bi-level coaches would be procured for operating scenarios that require new coaches without a special door configuration. Where a special door configuration was considered new or modified single-level coaches would be required.

Rather than purchase new single levels for additional Fairmount capacity, it may be possible to retrofit existing MBTA Bombardier (300 series) single level coaches that are slated to come out of the fleet. The single level coaches are to be replaced by new bi-level coaches that are expected to arrive around 2011. The MBTA estimates that the rehabilitation of those coaches to include center boarding doors would cost approximately $1 million.[14] JEK research indicates that new single level coaches typically cost $2.1 million.[15] Rolling stock cost estimates are based on procurement of new single levels, when required, as opposed to retrofitted 300 series cars.

The continued use of the MBTA's current commuter rail rolling stock maintains the status quo of Fairmount operations where no train sets are dedicated to Fairmount service. Fairmount trips are typically performed by vehicles that also operate services on other branches of the MBTA commuter rail network, such as the Franklin and Needham lines. These trains are sized to accommodate their peak load, which generally does not occur on a Fairmount trip. It is important to note that the use of DMUs would free existing MBTA equipment for non-Fairmount use. This reduction in locomotive fleet requirements is reflected in the capital and operating cost estimates.

The use of DMUs or an alternative coach door configuration, would require a shift from the status quo. Because trains would be specially adapted to operate trips on the Fairmount line, they would be dedicated to operating primarily Fairmount service, and scheduling Fairmount trips on non-Fairmount equipment would be avoided. In this case, the adapted trains could be sized specifically to Fairmount ridership levels.

The introduction of DMUs on the Fairmount line is always more expensive than other vehicle types at comparable levels of service. As service levels increase and additional trainsets are required however, the rolling stock costs of using DMUs increases more slowly, due to the fact that these options do not require a new locomotive for each additional trainset. At 15 minute headways, the capital costs for modified push-pull trainsets is $44 million compared to $55 million for DMUs. Using a procurement contingency of 5%, the high end rolling stock procurement cost is $58 million (DMUs operated at 15 minute headways).

Storage and Maintenance Facilities – The estimated cost of constructing new storage and maintenance facilities was based on a JEK survey of related transit agency experience. This survey found costs to be correlated with the number of vehicles that would be stored and maintained at the new facilities. The per vehicle costs of new maintenance facilities (not including property acquisition) was assumed, in this study, to be $538,318.[16]

Due to the present shortage of Southside maintenance and storage facilities, an allowance for new facilities was estimated for improvements requiring additional vehicles. The cost allotted for new facilities was based on estimates of property acquisition and the number of vehicles that would be serviced.[17]

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[14] The MBTA estimates that the unmodified used cars would have a resale value of approximately $350,000. This residual value is <u>not</u> included in the estimates.

[15] Costs are for a single-level cab car as reported by the American Public Transit Authority (APTA). Average New Rail Vehicle Costs, 2005-2006. Retrieved July 23, 2007 from http://www.apta.com/research/stats/rail/railcost.cfm.

[16] New Jersey Institute of Technology and KKO and Associates, *Northern Branch Case Study: Strategic Analysis of the Application of Self-Powered Rail Cars in New Jersey.* Prepared for New Jersey Transit Spring 2004. pp. 48

[17] From the perspectives of maintenance and operational flexibility, options that entail a special fleet of Fairmount equipment, such as DMUs or coaches with a custom door configuration, might add complications to South Side fleet management, increasing overall costs for rolling stock management. Consequently, a 15% contingency premium is added to all operating costs of any options that use specialized equipment.

The parcel directly east of Readville yard on Wolcott Court would be a suitable location for these new facilities. The value of this property, as assessed in 2007[18], plus a 30% contingency was assumed as a placeholder for property acquisition costs.

It was assumed that any incremental conventional push-pull sets, and all DMU and modified push-pull sets would be maintained and stored in the new facilities. For comparison with DMUs, the locomotive was counted as one vehicle in the calculation of train lengths. At all levels of service, DMUs would require less maintenance/storage space, due to the need to accommodate a locomotive in addition to passenger cars for each additional push-pull trainset. DMU service operated at 15 minute headways would require a total of 20 vehicles and be associated with $13 million in new maintenance and storage facilities, which compares with $15.2 million for the 24 new vehicles required for modified push-pull trainsets operating at the same frequency.

Incremental Capital Costs –The total annual incremental capital cost estimates are highest for DMUs given the same level of service. At higher levels of service the gap narrows, as DMUs have incremental capital costs only $10 million greater than modified push-pulls at 15 minute headways ($74 million versus $64 million). However, DMU incremental capital costs are still $25 million higher than the use of current push pull trainsets at 15 minute headways.

Incremental Capital Cost per Incremental Rider – Incremental capital costs and incremental riders were calculated relative to the baseline's estimated capital cost and forecast ridership. Among options that reduce peak headways below 30 minutes, the capital costs per incremental passenger trip were lowest for modified push-pull trainsets at 20 minute headways ($27,000). Incremental capital costs per incremental passenger trip for DMUs were very high when service levels remained at current levels ($196,000 for 30 minute headways) but decreased to the point where DMUs have the lowest incremental capital costs per passenger at the highest levels of service ($29,000 at 15 minute headways versus $33,000 for modified push-pull trainsets and $31,000 for existing rolling stock). The operation of DMUs without increasing service frequency on the line is forecast to be a very poor investment.

5.3. Operating Costs

Incremental operating costs were estimated for the use of different vehicle types at different service levels. Incremental cost estimates were relative to the incremental costs associated with the baseline.[19]

Mechanical Costs – The study team estimated the mechanical costs of coaches and locomotives using MBTA budgeted maintenance costs for additional coaches and locomotives.[20] A recent

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[18] City of Boston (2007). Assessing On-line. Retrieved August 7, 2007 from www.cityofBoston.gov/assessing/search

[19] For MBTA commuter rail, an additive of 16.5% for system administration and management was applied to estimates of incremental costs, based on available National Transit Database reports for the MBTA (2003).

[20] VHB, Inc. & KKO and Associates (April 2004). MBTA commuter Rail Infrastructure Needs Assessment. Submitted to Massachusetts Bay Transportation Authority. Boston, MA.

JEK self-powered rail car (DMU) study for New Jersey Transit[21] provided two similar estimates of the costs for maintaining a fleet of DMUs. The 2004 estimates were:

- $134,064 per unit for agency maintenance
- $134,279 per unit for contract maintenance by Colorado Railcar Manufacturing LLC

Escalating the average of these two values to 2007 at 5% per annum yields an estimated annual maintenance expense of $155,320 per unit.

Incremental mechanical costs for the modified push-pull trainsets were much lower than those for DMUs or traditional equipment at lower frequencies. At higher levels of service this advantage almost disappears--$1.455 million, $1.498 million and $1.546 million at 15 minute headways for modified push-pull, DMUs and traditional equipment, respectively.

Two train sets are dedicated to Fairmount service under baseline service. The locomotives from these two train sets would no longer be employed for Fairmount service if DMUs are used. In order to derive incremental maintenance costs a credit of $364,875, or the cost of maintaining two locomotives, was applied to DMUs.

Transportation Costs – Incremental transportation costs represent the fuel and crew costs above those required for baseline service. Fuel costs are based on vehicle miles traveled and crew costs depend on crew hours worked.

The study team estimated the cost for crew and fuel based on current MBTA unit costs[22]. It was assumed that each train set would be operated by an engineer and that a conductor would supervise the first coach. For push-pull trains with more than one coach, assistant conductors are also required, where each assistant conductor can manage two coaches. For DMUs, which seat fewer passengers than coaches, each conductor and assistant conductor was assumed to manage one DMU and one coach. Crew hours were derived by factoring vehicle hours up by 20%.

Table 5.1: Estimates of Transportation Variable Cost Factors for MBTA Commuter Rail Service

Crew Unit Costs[23] (fully loaded/per hour)	Engineer	$55.01
	Conductor	$46.30
	Assistant Conductor	$39.83
Fuel[24]	Diesel Gallon	$1.92

The fuel consumption rate for DMUs was assumed to be two gallons per mile (for train sets consisting of two DMUs and two coaches, the only DMU trainsets forecasted in the study).

[21] New Jersey Institute of Technology and KKO and Associates, *Northern Branch Case Study: Strategic Analysis of the Application of Self-Powered Rail Cars in New Jersey.* Prepared for New Jersey Transit Spring 2004. pp. 54

[22] Estimates for transportation costs (crew and fuel) for the MBTA and EOTPW service improvement studies were developed with differing methodologies leading to somewhat different findings. The differences in estimates of incremental operating costs between two approaches for similar options are in the range of 28% to 36% less for the MBTA study than for the EOTPW evaluation.

[23] As reported by MBTA's Deputy Director of Railroad Operations, July 2007.

[24] Average price of diesel fuel in the MBTA's 2007 budget.

Because fuel consumption for push-pull trains does not vary significantly with train length, the MBTA's average fuel consumption rate of 2.81 gallons per train miles was assumed for all push-pull options.

DMU fuel costs are lower than those for conventional push-pull equipment at all service levels and the relative advantage increases with service frequency (from a $200,000 annual savings at 30 minute headways to $250,000 at 15 minute headways).

Because the number of conductors required on each train depends on the number of coaches, annual crew costs are dependent on train length as well as the amount of service provided. The use of existing rolling stock does not require a dedicated fleet and would therefore not use train sets that are optimally sized for Fairmount services because these trains would also operate services on other branches of the MBTA commuter rail network where ridership may be greater than on the Fairmount Line.

Since running times are shorter on DMU equipment, less equipment is needed to provide the same number of trips. DMUs have lower annual incremental crew costs at all service levels and the advantage increases as service levels increase (at 15 minute headways, DMUs have incremental annual crew costs of $1.146 million compared to $1.368 million for modified push-pull, and $1.672 million for existing equipment.

Total Incremental Costs – Modified push-pull trainsets offered very little savings in incremental operating costs compared with existing equipment at all service levels. At the highest level of service (15 minute headways), DMUs had lower annual incremental operating costs relative to the baseline ($3.7 million versus $4.4 for both options using push-pull equipment).

Incremental Operating Cost per Incremental Passenger Trip – Options that feature specialized fleets would tend to have lower incremental operating cost per incremental passenger trip because they use less rolling stock per train than status quo operations. The services that would provide the shortest trip times and the most frequent service are also predicted to provide the lowest incremental operating cost per incremental passenger. Therefore, both push-pull vehicle types have increasing incremental costs per incremental passenger trip as service levels increase. DMU costs decrease as service increases, and have lower incremental operating costs per incremental passenger trip at 15 minute headways ($2.73 for DMUs versus $4.17 for modified push-pull trainsets and $5.07 for existing rolling stock).

5.4. Emissions

Table 5.1 presents estimates of incremental emissions for select options. DMUs, even when they provide twice as much service as the baseline, create significantly less emissions than baseline service. Service improvements using push-pull vehicles, on the other hand, continue to increase in emissions created as service levels increase.

Table 5.1: Incremental Emission Relative to Baseline Service

Option	Annual HC (000s lbs)	Annual CO (000s lbs)	Annual Nox (million lbs)	Annual PM (million lbs)

Baseline	-	-	-	-
DMU, 30 minutes	-3.48	-106.75	-11.47	-41.33
Existing rolling stock, 15 min	3.48	92.56	9.63	33.69
Modified push pull, 15 min	3.48	92.56	9.63	33.69
DMU, 15 min	-2.79	-99.93	-11.06	-40.83

6. CONCLUSION

A primary policy focus of EOTPW is the cost-effective, environmentally friendly delivery of transportation options. DMUs, with their potential to increase ridership due to decreased running times gained through faster acceleration, and also to provide air quality benefits, represent a promising option for EOT and the MBTA. This study has evaluated this technology generally, and also looked at ridership and cost implications for potential implementation on the MBTA's Fairmount Commuter Rail Line. The key findings of the study are as follows:

Travel Time Savings – *The use of DMUs on the Fairmount line will result in faster running times at all service levels.* DMUs have been demonstrated to accelerate faster than the conventional push-pull equipment currently employed by the MBTA. This study modeled the performance of a trainset featuring a 50%/50% mix of DMUs and conventional equipment and found that the use of DMUs could reduce running times on the Fairmount Line by up to six minutes. Roughly half of these savings were attributable to vehicle door configuration, and are not unique to DMUs (since the MBTA's current rolling stock could be similarly reconfigured to provide three doors per car). The use of DMU's would thus reduce forecast total one-way running times of 31 minutes down to 25 or 26 minutes, whereas retrofitted coaches would yield a one-way running time of 28 minutes.

Fuel Consumption and Emissions – *The use of DMUs on the Fairmount line will result in decreased fuel consumption and emissions at all service levels.* As the results of this study shows, DMUs use less fuel than traditional push-pull equipment for all but the longest trainsets. DMU fuel consumption for a five car train set with two DMUs and three trailer cars is 2.2 gallons per mile. Using a consist mix of at least 50% DMUs, fuel utilization rates would range from two gallons per mile for a four car DMU train set to 3.9 gallons per mile for an eight car DMU train set. Consumption for existing MBTA service is approximately 2.8 gallons per revenue train mile on trains averaging six cars in length. DMUs would therefore be expected to use less fuel than current MBTA vehicles at lengths of five cars or less. Emission rates for DMU vehicles are 42% to 73% lower than for current MBTA trainsets. Although emission rates for DMU service increase in proportion to length, at all train lengths that would be operated on the Fairmount Line, DMUs would produce far fewer emissions.

Ridership Impacts – *The use of DMUs will result in ridership increases due to faster running times. However, an increase in headways regardless of vehicle type will result in more significant ridership gains than faster running times.* JEK explored several service options (differing in vehicle type and frequency) to determine the ridership impacts of introducing DMUs on the Fairmount Line. At all service levels analyzed, the option employing DMUs had the highest ridership (due to faster running times). The highest ridership result was for a DMU operation offering 15 minute headways during the peak. The daily ridership of 4,250 under this scenario compared to 3,340 riders for the same service level using traditional equipment and 3,700 using traditional trains with modified door configuration. Only 1,760 passengers were expected when current service levels and equipment were used.

Capital Costs – *The introduction of DMUs on the Fairmount line will represent a large capital investment that should only be considered if the MBTA is prepared to increase service levels to a point (15 minute headways) where the additional cost of DMUs decreases as compared to other equipment options.* Incremental capital costs and riders were calculated relative to the baseline's estimated capital cost and forecast ridership. The resulting capital costs per incremental passenger trip range between $27,000 and $38,000, with the lowest figure associated with a 20 minute headway service using existing MBTA push-pull equipment with reconfigured doors. The analysis suggests that introducing DMUs to the Fairmount Line without increasing service frequency would be a very poor investment.

Operating Costs – *The introduction of DMUs results in lower incremental operating costs than other vehicle types when service frequency is increased from current levels.* Incremental operating costs were calculated relative to the baseline's estimated operating cost and forecast ridership. The resulting incremental operating costs per incremental passenger trip ranged from $2.73 to $5.07, with the lowest figure associated with a 15 minute headway service using DMUs. The provision of increased frequency using traditional equipment fared the worst.