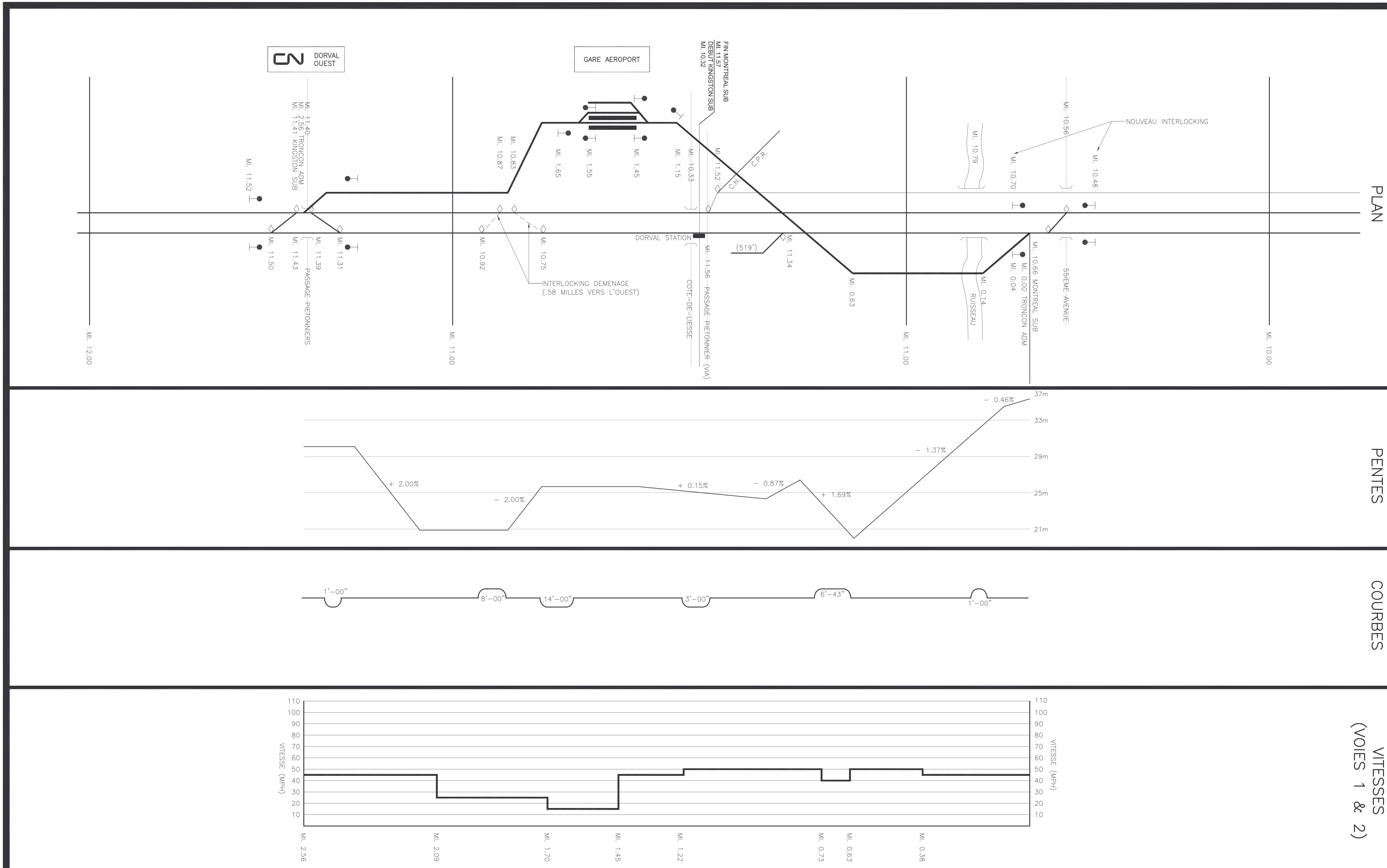
ANNEXE E

PLAN SCHÉMATIQUE DU CORRIDOR PROPOSÉ

Le plan no SK-05 est seulement disponible en version papier dans les centres de consultation.



DORVAL OUEST
GARE AEROPORT
FIN MONTREAL SUB MI. 11.57
DEBUT KINGSTON SUB MI. 10.32
NOUVEAU INTERLOCKING
MI. 11.40
MI. 2.56 TRONCON ADM
MI. 11.41 KINGSTON SUB
MI. 11.52
MI. 10.83
MI. 10.87
MI. 1.65
MI. 1.55
MI. 1.45
MI. 1.15
MI. 10.33
MI. 11.52
C.N.
C.P.R.
MI. 10.79
MI. 10.56
MI. 10.70
MI. 10.48
MI. 11.50
MI. 11.43
MI. 11.39
MI. 11.31
PASSAGE PIETONNIERS
MI. 10.92
MI. 10.75
INTERLOCKING DEMENAGE
(.58 MILLES VERS L'OUEST)
DORVAL STATION
COTE-DE-LIESSE
MI. 11.56 PASSAGE PIETONNIER (VIA)
(519')
MI. 11.34
MI. 0.63
MI. 0.14
RUISSEAU
MI. 0.04
MI. 10.66 MONTREAL SUB
MI. 0.00 TRONCON ADM
55IEME AVENUE
MI. 12.00
MI. 11.00
MI. 11.00
MI. 10.00
PLAN
37m
33m
29m
25m
21m
+ 2.00%
- 2.00%
+ 0.15%
- 0.87%
+ 1.69%
- 1.37%
- 0.46%
PENTES
1'-00"
8'-00"
14'-00"
3'-00"
6'-43"
1'-00"
COURBES
110
100
90
80
70
60
50
40
30
20
10
VITESSE (MPH)
MI. 2.56
MI. 2.09
MI. 1.70
MI. 1.45
MI. 1.22
MI. 0.73
MI. 0.63
MI. 0.38
VITESSES (VOIES 1 & 2)

ANNEXE F

ÉTUDE DES ÉCONOMIES DU DMU

Economics of FRA-Compliant Diesel Multiple Units (DMUs)

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List of Headings

1. In Service Fuel (gallons/mile)
2. Idling at Full HVAC and Lighting
3. Cost Per Gallon of Fuel
4. Cost of Electricity

iii. Maintenance Cost
iv. Operating Crew Cost
v. Purchase Cost

b. Data Used Under ACE Conditions
   i. Operating Conditions
      1. Hours Idling Per Year
   ii. Fuel
      1. In Service Fuel
      2. Fuel Idling at Full HVAC and Lighting
      3. Cost Per Gallon of Fuel
   iii. Maintenance Cost
   iv. Operating Crew Cost
   v. Purchase Cost
c. Calculation of DMU Maintenance Cost per Mile

ABSTRACT

While the economic viability of diesel multiple units (DMUs) has been studied in the past, the advent of an FRA Part 238 compliant DMU makes the evidence all the more valuable. This paper compares the life-cycle costs of FRA-compliant DMU technology with the costs of traditional locomotive-hauled equipment for various consist sizes and levels of service, using data on the Colorado Railcar DMU as well as data supplied by several U.S. commuter properties on the costs of the commonly-used EMD F-40 and F-59 locomotives and the GO Transit-style Bombardier bi-level cars. Comparisons between the initial purchase cost for the rolling stock, the cost of the maintenance facility, and costs for fuel, maintenance, and crew show that the DMU technology is estimated to provide substantial savings for consists of smaller passenger capacity.

INTRODUCTION

Self-propelled passenger cars, also called diesel multiple units (DMUs), have long been in use in Europe, but not since the heyday of the Budd RDC have self-propelled rail vehicles been a major carrier of passengers in the United States. DMUs have long seemed appealing to transit properties in the United States for their potential to save money in specific situations, but up until now a DMU that passed the stricter American strength and safety standards was not available. On July 12, 1999, the FRA's new structural safety standards in 49 CFR Part 238 became effective. Without compliance, DMUs cannot be run on active freight lines without a waiver from the FRA. Colorado Railcar has worked closely with the FRA to demonstrate that the DMU is compliant, including several iterations of meetings with the FRA to improve the DMU per their suggestions. Colorado Railcar's new DMU meets the structural requirements of 49 CFR Part 238. On September 21, 2002, FRA performed a sample car inspection on the DMU, recommending a few minor modifications to safety appliance placement, which the company has implemented.

Description of Locomotive-Hauled Trainsets and DMUs

This study compares the costs of owning and operating locomotive-hauled trainsets vs. DMUs. This section gives a brief description of the two types of rolling stock.

EMD F-40 and F-59 Diesel-Electric Locomotives and Bombardier Bi-Level Coaches
Traditionally, a locomotive is designed to power large capacity trains by pushing or pulling many coaches behind it. A large diesel engine (often 3200 hp) generates electricity to run the traction motors at the wheels. Because of the potential difficulty of restarting the locomotive engine, some transit agencies leave their locomotives idling overnight. Passenger locomotives also have head-end power (HEP) that delivers electricity to the passenger cars. This can either be driven off of the prime mover or off of a separate engine. Locomotives generally operate with a minimum of two coaches to ensure adequate braking.

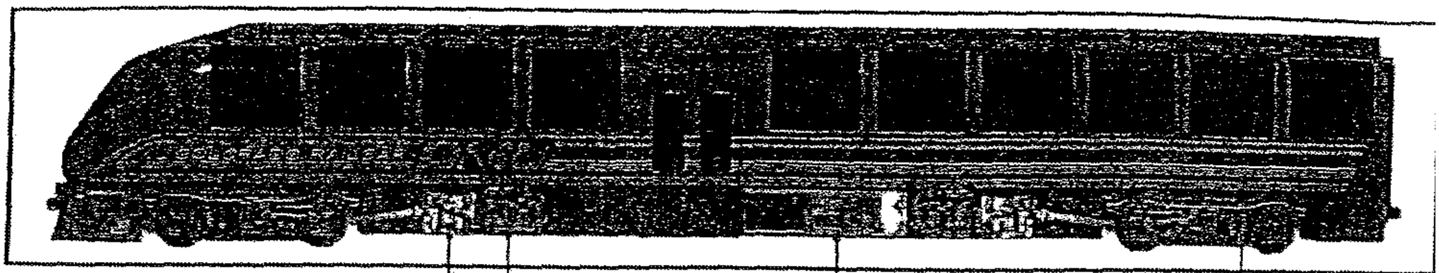
The popular GO Transit style bi-level car built by Bombardier is often hauled by one of the aforementioned locomotives. The Bombardier cars are well known for their low cost per passenger, due to their high passenger capacity.

Colorado Railcar DMUs

Figure 1 presents a drawing of the single-level Colorado Railcar DMU. (More detailed drawings may be found at the company website, www.coloradorailcar.com.) The 92-seat DMU is powered by two 600 horsepower Detroit Diesel Series 60 diesel engines, similar to engines used in highway trucks. A low-maintenance Voith hydrodynamic transmission delivers the power to the drive shaft directly to the powered axle on each truck. Because they are easy to stop and start, the Detroit Diesels may be turned off when the DMU is stationary (such as when the car is in the station for 3 minutes or more), rather than idling. A separate generator provides electrical power to the passenger cabin, or the DMU may be plugged in to 480 VAC station wayside power. Colorado Railcar Manufacturing has also designed a double deck DMU using the same basic components as the single-level DMU. The double-deck DMU, which has 28% more useable floor space than a Bombardier bi-level, seats 185.

The Colorado Railcar DMU differs significantly from the Budd RDC or a European DMU because it can pull coaches. In this way, the Colorado Railcar DMU is a hybrid between a traditional locomotive-hauled train and a traditional self-propelled car and will therefore have economics different from both traditional types of rolling stock. A Colorado Railcar DMU may pull up to two single level coaches or one double deck coach. For larger consists, enough DMUs are added to keep the correct ratio of DMUs to coaches. A DMU train may be operated in either direction with a cab coach, or a single DMU with cabs at both ends could be used.

The Colorado Railcar DMU also differs from locomotive-hauled trainsets in that it is a good neighbor with both low noise and low emissions. The perceived noise from the DMU is substantially lower than that of a locomotive. The Detroit Diesels that power the car already surpass the 2005 locomotive emissions standards: they must meet the emissions standards for truck engines, which are stricter standards than those for locomotives. (More information on emissions is presented in a technical document prepared by Colorado Railcar which is available from the author upon request.) In some cases, these environmental factors can be more important than the actual dollar cost of operating or purchasing rolling stock.



Transmission

Voith T212 BRE Turbo Hydrodynamic Transmission

- 760,000 Miles Before First Major Overhaul

Engine

Detroit Diesel Series 60, 600 hp

- Parts/Service Available at 1300 Outlets Nationwide
- 600,000 Engines in Use Worldwide Running Over a Billion Miles per Week. Engines Are Durable and Easy to Maintain

Generator

175 kw Stadco

- 480 volt, 3 phase
- Deutz Water-cooled Diesel

Trucks

GSI Low Clearance Truck

- Used by METRA, Caltrain and Many Other Transit Agencies

Previous Studies

Prior to the advent of an FRA-compliant DMU, several experts studied the economic viability of DMUs. In 1996, Ken Sislak, of Wilbur Smith Associates, found that DMUs appeared to be a viable technology option along the 32-mile Lakeland-Tampa Corridor, with the major savings coming from fuel economy. The study compared the costs of operating Siemens' non-FRA compliant VT628 with costs based on locomotives and bi-level coaches operated by Tri-Rail, which serves Miami to Palm Beach, Florida. Based on a required seated passenger capacity of about 300, Sislak found that total system operating costs for the DMUs were approximately 17% percent lower than locomotive-hauled services, with savings of 76% on fuel, 36% on maintenance cost, and 31% on crew cost. Mr. Sislak's study did, however, face some data limitations: information on the breakout between locomotive and coach maintenance costs was not available, nor were the DMU maintenance costs per mile tailored to match the conditions under which the Tampa cars would operate. In addition, a compliant DMU was not yet available. (1)

In 1997, Daniel Jacobs of LS Transit Systems (now SYSTRA) and Ann Galbraith of the MBTA Planning Department studied the potential of using DMUs for the MBTA's Fall River/New Bedford route. Jacobs and Galbraith found that DMUs had an operating and maintenance cost advantage for consists with a capacity of between 400-600 passengers when debt service costs were included. The authors recognized certain data limitations (such as ambiguity as to whether maintenance costs included the cost of servicing vehicles) that may have influenced the accuracy of their results. (2)

This study attempts to address some of the data limitations of the above-cited studies. Detailed data on the costs of commuter rail operations have been provided by Tri-Rail, which serves Miami to Palm Beach with peak and off-peak service and by the Altamont Commuter Express (ACE), which runs peak-hour commuter service between Stockton and San Jose, California. Colorado Railcar has developed detailed estimates on the costs of owning and operating its FRA-compliant DMU, including simulations of fuel consumption and maintenance costs under conditions comparable to ACE and Tri-Rail.

Organization of Paper

This paper is organized to first present a description of the data sources. Next, the variable operating costs and purchase costs compared in this study are described. The following section displays comparisons in total variable operating cost and purchase cost for consists of varying passenger capacities in the Tri-Rail and ACE operating environments. The final part of that section gives examples of consists of similar passenger capacity in each of those operating environments, showing in detail how costs differ between locomotive-hauled equipment and DMUs. The next section describes potential cost differences between locomotive-hauled trains and DMUs that have not been quantified in this paper, followed by the conclusion. After the conclusion, the technical appendix gives the detailed data used in the study.

DESCRIPTION OF DATA SOURCES

This section provides a description of the data sources used in this study.

Transit Agencies

Data on the cost of locomotive-hauled equipment was provided by Tri-Rail and ACE for their rolling stock, in response to a detailed 18-page questionnaire developed by Colorado Railcar. A description of the services is provided below.

Tri-Rail

Tri-Rail runs 14 round trips per weekday between Miami and West Palm Beach, plus 7 round trips on Saturdays and 6 on Sundays. A round trip takes 4 hours and covers approximately 144 miles. Tri-Rail operates a fleet of 35 pieces of rolling stock: 9 F-40's built by Boise Locomotive between 1981-1992 and 26 Bombardier bi-levels, built between 1987-1996. During revenue service hours, 27 pieces of rolling stock are in service and the remainder are in maintenance or protect. (Tri-Rail also owns one more F-40 which is not used in service at all and therefore not counted in the figures above.)

ACE

ACE runs 3 round-trips per weekday from Stockton to San Jose (172 miles round trip). The ACE route includes 5 miles at 1.5% grade over the Altamont Pass. ACE operates a fleet of 25 pieces of rolling stock: 5 F-40PH-3Cs received from Boise Locomotive in 1997 and 2000 and 20 Bombardier bi-levels, built in 1997, 2000, and 2001.

Other Agencies

Multiple agencies provided brief data on some of the costs of their operations, including Metrolink, Caltrain, and Seattle Sounder.

Colorado Railcar Manufacturing

Colorado Railcar Manufacturing has made every effort to calculate costs for its DMU that will match the respective operating conditions of ACE and Tri-Rail. As of this date, the DMU has not been run in regular service but has had extensive testing on which the estimates in this study are based. DMU fuel consumption has been simulated for both ACE and Tri-Rail services. Maintenance costs for the single-level and double deck DMUs and single-level and double deck coaches have been projected. Suppliers of major components in the DMU provided detailed costs of operating their components. Current customers of Colorado Railcar shared their costs of operating their single-level and double-deck dome coaches, which use many of the same technologies as the DMU. Industry experts advised on appropriate replacement intervals for items such as windows and wheels. Costs for FRA inspections were based on Colorado Railcar's experience performing daily inspections and 92-day inspections on the DMU.

VARIABLE OPERATING COSTS AND PURCHASE COSTS COMPARED

The following section describes the variable operating costs and purchase costs that are compared in this study. Detailed data on variable operating costs and purchase costs are available in the technical appendix.

Variable Operating Costs Compared

This study compares all the operating costs that may be affected by an agency's choice of either traditional locomotive-hauled trainsets or DMUs. Operating costs include fuel and electricity consumption, maintenance of rolling stock (including overhaul), and operating crew cost. Costs that do not vary with the type of rolling stock have been excluded, such as management cost and maintenance of shop facilities and shop vehicles, and therefore the operating costs are termed 'variable operating costs'.

The author has used the data provided by Tri-Rail and ACE to estimate how variable operating costs change as consist lengths change. Only the conclusions for Tri-Rail and ACE's current train lengths reflect their existing situations' the calculations for other train lengths show projected costs if Tri-Rail or ACE were to change their train lengths. At present, Tri-Rail operates 5 consists with 3 bi-level coaches and 1 consist with 6 bi-level coaches. ACE operates 3 trains with 6 bi-level coaches.

The section below describes the variable operating costs compared.

Fuel and Electricity Consumption
Passenger trains consume fuel or electricity for several purposes: to operate the train in service, to provide electric power to the passenger cabin when the train is stopped either for layover or between arrival and next departure during revenue service, and to keep the prime mover engine idling. Each use of fuel will be described below.

Fuel consumption in service varies by several factors, including speed, grade, curves, adhesion, required acceleration, and the number of cars on the train. Under Tri-Rail operating conditions, locomotive-hauled trains consume more fuel than double-deck DMUs are projected to consume when the passenger capacity is 940 or less, and more than single-level DMUs for 576 seats or less. For ACE conditions at 840 passengers (ACE's current train size), locomotives and double-deck DMUs are projected to use about the same amount of fuel: approximately 2 gallons per train-mile. For passenger capacities below 840, locomotive-hauled trains are estimated to consume more fuel under ACE conditions than double-deck DMUs, as well as for capacities of 940 and higher, because an additional locomotive must be added to reach capacities of 940 passengers, increasing fuel consumption. ACE locomotives also consume about the same amount of fuel as projections for single-level DMUs for passenger capacities of 570 seats. (Data used in the above calculations is available in the technical appendix.)

The amount of fuel consumed by a train to provide electric power depends on 1) the energy efficiency of the train's lighting, heating and air conditioning systems, 2) the number of coaches on the train, and 3) the transit agency's requirements for maintaining onboard temperature and lighting standards. Transit agencies generally require more electric power during the time close to revenue service hours when the passenger cabin temperature must be maintained, and much less during overnight layover.

Fuel to keep the prime mover idling for long periods of time is more often used by locomotives: the DMU's engines can be shut off when the train is stopped for as short as 3 minutes. Locomotive prime mover idling consumes relatively little fuel, however: ACE's prime movers use 1.25 gallons per hour at low idle, Tri-Rail's use 4.1 gallons per hour, and the prime movers on Metrolink's F-59s use 1 to 1.5 gallons per hour at low idle. (Personal communication with Bill Lydon, Metrolink, January 9, 2003) The DMU engines use 1 gallon per hour in idle. Detailed fuel consumption figures are presented in the technical appendix.

Maintenance of Rolling Stock

Maintenance of rolling stock is one of the more costly aspects of operating a commuter rail service, yet one of the most difficult costs to quantify. Maintenance costs can depend on a variety of factors, including the agency's maintenance practices, the conditions under which the vehicles are operated (including hours per day, miles per day, days per year, and temperature), the union representing the workers, and the age of the rolling stock. Added to this complexity is the question of what components the maintenance cost includes, such as cleaning, servicing (refueling, dumping toilets, replenishing water), overhauls, maintenance of shop, and management costs. This analysis calculates variable maintenance cost by including preventative maintenance, repairs, cleaning, servicing, and overhauls. Overhauls are a large cost for locomotives: Tri-Rail's overhauls in 1999 and 2000 cost $700,000 per locomotive. Because of its easily-serviced components, inexpensive overhaul requirements and large passenger capacity, the double-deck DMU has been projected to save on maintenance costs for all passenger capacities under Tri-Rail operating conditions and for capacities of 370 and lower under ACE operating conditions. For passenger capacities of 370 or less, the double-deck DMU is estimated to save more than 25% on maintenance costs under Tri-Rail conditions. The single-level DMU could also save on maintenance costs for Tri-Rail conditions for 380 seats or less and for ACE conditions for 190 seats or less. Detailed maintenance costs are presented in the technical appendix.

Operating Crew Costs

Another major cost of commuter rail operations is the crew costs for engineers, conductors, and fare enforcement officers. These costs may depend on the type of rolling stock being used and the length of the train, as well as any labor agreements in place and the agency's requirements for the number of crew on a trainset at any given time. Detailed operating crew costs are presented in the technical appendix. Both ACE and Tri-Rail are required to have 2 crew onboard regardless of train length, and therefore <u>in this analysis, operating crew costs are assumed to be the same for locomotives and DMUs.</u>

Purchase Costs Compared

This section presents the costs of purchasing rolling stock and the maintenance facility.

Rolling Stock Purchase Cost

The cost of rolling stock depends on the number of trains in revenue service during the day, their passenger capacities, and the number of spare pieces of rolling stock required for maintenance and protect. In this analysis, spare pieces of rolling stock are calculated as a percentage of the total rolling stock (the spare ratio) with a minimum of a certain number of locomotives, coaches, or DMUs. Tri-Rail has more spares as a percentage of its rolling stock (8 spares out of 35 total pieces of rolling stock) than does ACE (4 out of 25). The number of DMU spares assumed in each of those cases therefore allots more spares to the Tri-Rail service. The makeup of the DMU consists also differs between Tri-Rail and ACE: because Tri-Rail's topography is so flat, the DMU is modeled to pull two single-level coaches behind it, but for ACE's steeper route Colorado Railcar has modeled a 2 to 3 ratio of DMUs to single-level coaches, and a 1 to 1 ratio for double-deck DMUs and coaches. See the technical appendix for calculations of DMU consists and spare pieces of rolling stock.

Maintenance Facility Purchase Cost

The DMU can be maintained in any existing maintenance facility designed for locomotives and coaches. Tri-Rail and ACE already have traditional maintenance facilities. For transit agencies that do not already have maintenance facilities in place, the maintenance facility cost is estimated to be substantially lower for DMU equipment because the DMU facility does not require some of the sophistication of locomotive maintenance facilities. Colorado Railcar Manufacturing can help transit agencies define a cost-effective maintenance facility. Because Tri-Rail and ACE already have locomotive maintenance facilities (in which the DMU could be maintained), differences in maintenance facility purchase cost are not included in the study analysis.

COST COMPARISONS FOR CONSISTS OF VARYING SEATING CAPACITIES

This section begins with an analysis that identifies the conditions where DMUs are less costly to operate and purchase than locomotive-hauled trains, based on varying passenger capacities. The section then presents example consists for Tri-Rail and ACE to examine the sources of cost differences for consists of similar passenger capacities. The detailed data and assumptions used in this section are available in Tables 1 and 2, which are explained in the technical appendix.

Comparison of DMU and Locomotive-Hauled Ownership Costs by Consist Seating Capacity

The analysis in this section looks at what seated passenger capacity provides the dividing line between when it is cheaper to own DMUs vs. when it is cheaper to own locomotive-hauled trains. Figures 2 and 3 present comparisons of operating costs and purchase costs for locomotive-hauled trains vs. DMUs, by the seated passenger capacities of the trains for Tri-Rail

Table 1. Data Under Tri-Rail Conditions
(See Technical Appendix for Explanations)

Operating Conditions	
Round trips per year	4246
Miles per round trip	144
Annual train-miles of service	611,424
Revenue service hours per round trip	4.0
† Hours idling per year per locomotive (both layover mode and full light and HVAC)	3500
Percent of hours idling per year per locomotive that require full light and HVAC	25%
Power consumed in layover mode as percent of full light and idling	15%

Fuel			
In service (gal/mile)			
F-40 locomotive with 6 coaches	2.52	Single-level DMU	0.55
Each additional or fewer coach	0.025	Single-level DMU + 1 single-level coach	0.86
		Single-level DMU + 2 single-level coaches	1.16
		2 Single-level DMUs + 3 single-level coaches	1.90
		Single-level DMU + 1 double-deck coach	0.96
		2 Single-level DMUs + 3 double-deck coaches	2.13
		Double-deck DMU	0.66
		Double-deck DMU + 1 double-deck coach	1.03
		2 Double-deck DMUs + 3 double-deck coaches	2.26
Idling at full HVAC and lighting (gal/hr)			
F-40 locomotive with 3 coaches	18.00	Each single-level DMU (without prime movers)	2.59
Each additional or fewer coach	6.00	Each double-deck DMU (without prime movers)	3.23
		Each single-level coach	2.17
		Each double-deck coach	2.81
		kW-hr of electricity per gallon (approximate)	19
		† DMU prime movers idling alone (2)	1.0
Cost per gallon of fuel ($):	0.90		
Cost per kW-hr of electricity ($):	0.08		

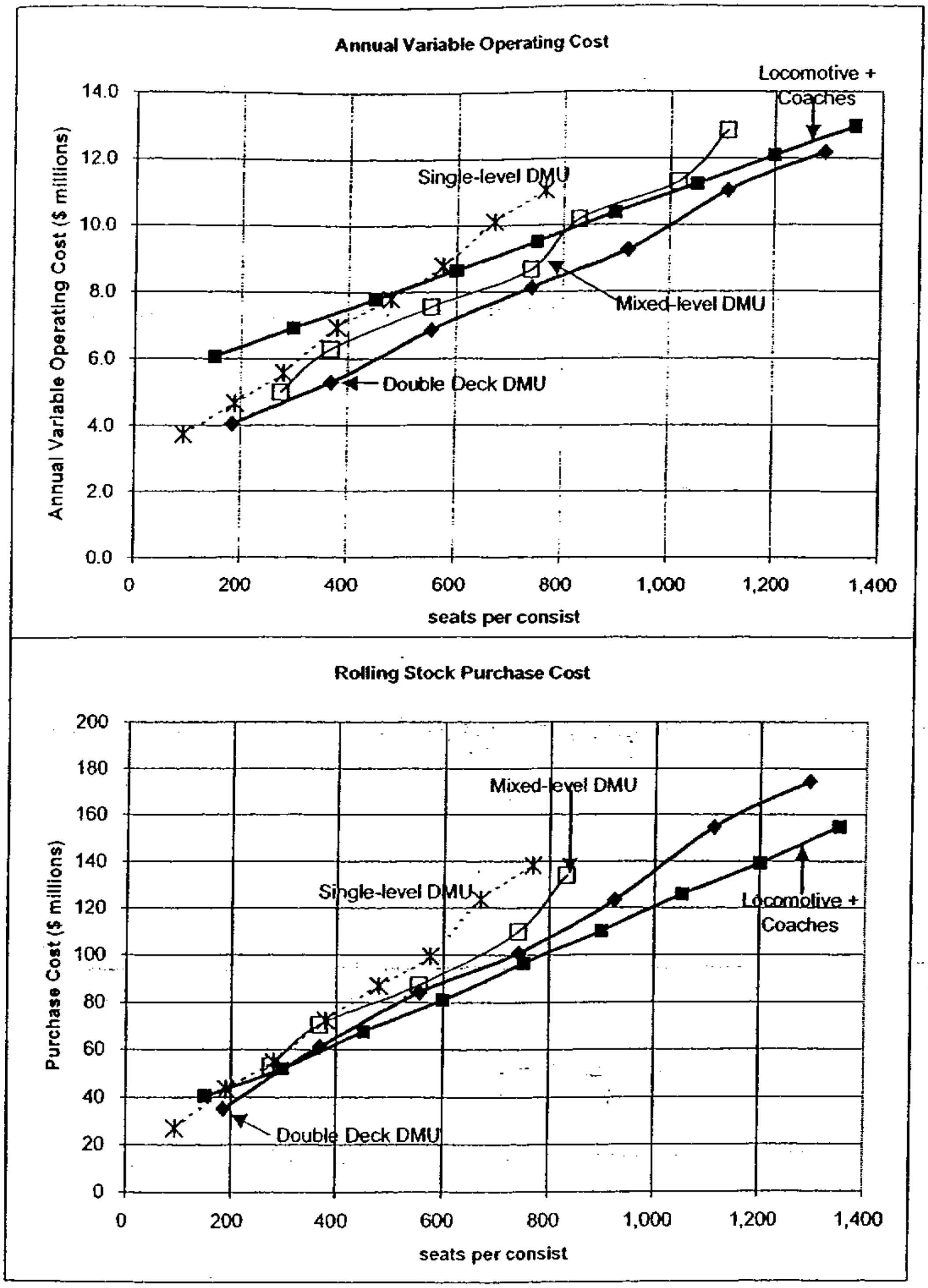
Maintenance Cost: variable cost per mile including overhaul ($)			† min	† max
* F-40 locomotive (1 per train)	2.65	Single-level DMU	1.73	1.80
*Bombardier bi-level coach	1.29	Double-deck DMU	2.13	2.21
		Single-level coach with cab	1.20	1.24
		Single-level coach	1.19	1.24
		Double-deck coach with cab	1.60	1.65
		Double-deck coach	1.59	1.65

*Operating Crew Cost per hour of revenue service ($):	134.40

Purchase Cost			
Number of trainsets in revenue service: 6			
Number of spares: 20% of rolling stock with minimum of:			
Locomotives	3	DMUs	3
Bombardier bi-level coaches	3	Coaches	3
Cost per piece of rolling stock ($ millions)			
Locomotive	2.40	Single-level DMU (92 seats)	3.00
Bombardier bi-level coach (150 seats)	1.90	Double deck DMU (185 seats)	3.90
		Single-level cab coach (92 seats)	1.90
Bombardier bi-level cab coach (150 seats)	2.10	Single-level coach (98 seats)	1.80
		Double deck cab coach (185 seats)	2.90
		Double deck coach (185 seats)	2.80

* See Table 3 in the Technical Appendix for explanation
** See Table 4 in the Technical Appendix for explanation
† See Technical Appendix text for explanation

Figure 2. Variable Operating Cost and Rolling Stock Purchase Cost: Tri-Rail Case



Note: Rolling stock purchase costs are for 6 trainsets plus spare pieces of rolling stock. Locomotive-hauled fleets have a 20% spare ratio, with a minimum of 3 spare locomotives and 3 spare coaches. DMU fleets have a 20% spare ratio, with a minimum of 3 spare DMUs and 3 spare coaches.

and ACE, respectively. The top panel of each figure shows annual variable operating costs (which include fuel, maintenance, and operating crew, as discussed above). The lower panel shows the rolling stock purchase costs, including spares. Included in each figure are four types of consists: 1) traditional locomotives plus bi-level coaches, 2) single-level DMUs plus single-level coaches, 3) "mixed-level DMUs" which are single-level DMUs plus double-deck coaches, and 4) double-deck DMUs plus double-deck coaches. The points where these lines cross show where the costs change from favoring one type of rolling stock to another.

Tri-Rail

Annual variable operating cost: Figure 2 shows that under Tri-Rail's operating conditions, for every passenger capacity presented a DMU consist exists that is estimated to be less expensive to operate than the comparably-sized locomotive-hauled consist. Double-deck DMUs plus double-deck coaches are projected to be less expensive to operate than traditional rolling stock for seated passenger capacities of 1300 or fewer. Mixed-level DMUs are less expensive to operate than traditional rolling stock for seated passenger capacities of 740 or fewer. Single-level DMUs plus single-level coaches are less expensive to operate than traditional rolling stock for seated passenger capacities of 500 or fewer. While the operating cost crossover point for single-level DMUs is similar to that found by Jacobs and Galbraith, the crossover point for double-deck DMUs, which have not been analyzed previously, is much higher than any figure reported in existing studies for single-level DMUs. (2)

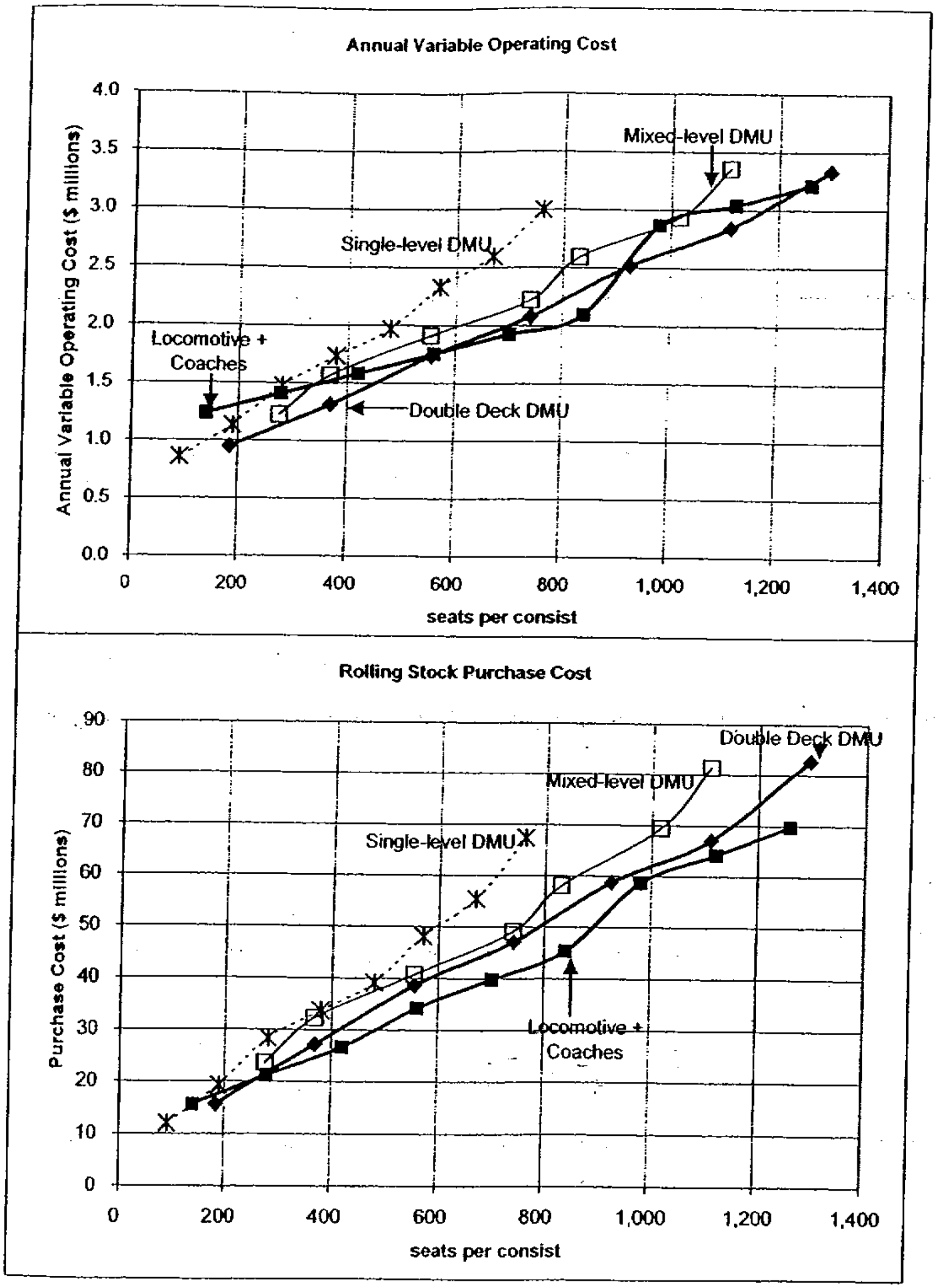
Rolling stock purchase cost: Under Tri-Rail's operating conditions, the system costs to purchase DMUs and locomotive-hauled consists are quite close (within about $5 million) for passenger capacities of 280 to 750 seats. Below 280 seats DMUs offer savings of $10 million or more. Above 750 seats, locomotive-hauled sets have an advantage of approximately $10 to $20 million compared to double-deck DMUs, the most cost-effective DMU.

Result: For seated passenger capacities of 280 or fewer under Tri-Rail's operating conditions, DMUs win hands down: they are both less costly to purchase and less costly to operate. For seated passenger capacities above 280 seats, the results depend on the agency's desire to trade operating cost savings generated by DMUs for higher purchase costs. Each agency will have a different threshold for whether the operating costs saved with DMUs are sufficient to payback the greater initial purchase cost. For example, Tri-Rail could save $1.8 million per year in variable operating costs using two double-deck DMUs plus one double-deck coach (560 seats) rather than a locomotive hauling 4 bi-level coaches (600 seats). The initial purchase cost would be $3 million more for DMUs, which would be paid back within 2 years of operating cost savings. (Data used for the above calculation are available in Table 1, which is explained in the technical appendix.)

ACE

Annual variable operating cost: Figure 3 shows that under ACE's operating conditions, for ACE's current seated passenger capacity of 840 per train, locomotives are less expensive to operate than DMUs. Double-deck DMUs plus double-deck coaches are estimated to cost about the same to operate as traditional rolling stock for seated passenger capacities of 550 and to be less expensive for 370 or fewer seats, as well as for 935 to 1125 seats. Mixed-level DMUs are less expensive to operate than traditional rolling stock for seated passenger capacities of 277 or

Figure 3. Variable Operating Cost and Rolling Stock Purchase Cost: ACE Case



Note: Rolling stock purchase costs are for 3 trainsets plus spare pieces of rolling stock. Locomotive-hauled fleets have a 10% spare ratio, with a minimum of 1 spare locomotive and 1 spare coach with cab. DMU fleets have a 10% spare ratio, with a minimum of 1 spare DMU and 1 spare coach with cab.

Table 2. Data Under ACE Conditions
(See Technical Appendix for Explanations)

Operating Conditions	
Round trips per year	765
Miles per round trip	172
Annual train-miles of service	131,580
Revenue service hours per round trip	4.67
† Hours idling per year per locomotive (both layover mode and full light and HVAC)	1800
Percent of hours idling per year per locomotive that require full light and HVAC	25%
Power consumed in layover mode as percent of full light and idling	15%

Fuel			
In service (gal/mile)			
F-40 locomotive with 6 coaches	2.00	Single-level DMU	0.41
Each additional or fewer coach	0.025	Single-level DMU + 1 single-level coach	0.63
		† Single-level DMU + 2 single-level coaches	N/A
		2 Single-level DMUs + 3 single-level coaches	1.38
		Single-level DMU + 1 double-deck coach	0.71
		† 2 Single-level DMUs + 3 double-deck coaches	N/A
		Double-deck DMU	0.49
		Double-deck DMU + 1 double-deck coach	0.75
		† 2 Double-deck DMUs + 3 double-deck coaches	N/A
Idling at full HVAC and lighting (gal/hr)			
F-40 locomotive with 6 coaches	20	Each single-level DMU (without prime movers)	2.59
Each additional or fewer coach	3.333	Each double-deck DMU (without prime movers)	3.23
		Each single-level coach	2.17
		Each double-deck coach	2.81
		kW-hr of electricity per gallon (approximate)	19
		† DMU prime movers idling alone (2)	1.0
Cost per gallon of fuel ($):	0.9		

Maintenance Cost: variable cost per mile including overhaul ($)			† min	† max
* F-40 locomotive	2.91	Single-level DMU	2.37	2.59
* Bombardier bi-level coach	1.22	Double-deck DMU	2.95	3.19
		Single-level coach with cab	1.72	1.86
		Single-level coach	1.71	1.85
		Double-deck coach with cab	2.30	2.46
		Double-deck coach	2.29	2.44

*Operating Crew Cost per hour of revenue service ($):	129.67

Purchase Cost			
Number of trainsets in revenue service: 3			
Number of spares: 10% of rolling stock with minimum of:			
Locomotives	1	DMUs	1
Bombardier bi-level coaches	1	Coaches	1
Cost per piece of rolling stock ($ millions)			
Locomotive	1.95	Single-level DMU (92 seats)	3.00
Bombardier bi-level coach (140 seats)	1.85	Double deck DMU (185 seats)	3.90
		Single-level cab coach (92 seats)	1.90
Bombardier bi-level cab coach (140 seats)	1.95	Single-level coach (98 seats)	1.80
		Double deck cab coach (185 seats)	2.90
		Double deck coach (185 seats)	2.80

* See Table 3 in the Technical Appendix for explanation

** See Table 4 in the Technical Appendix for explanation

† See Technical Appendix text for explanation

fewer. Single-level DMUs plus single-level coaches are less expensive to operate than traditional rolling stock for seated passenger capacities of approximately 190 or fewer. Note that the estimated cost for locomotives plus coaches jumps up at about 1,000 seats because an additional locomotive must be added to pull the consist over the Altamont Pass. (For illustrative purposes, this analysis has presented a consist with a locomotive and 9 coaches. Under ACE's operating conditions, 8 coaches is the limit on train size.)

Rolling stock purchase cost: Under ACE's operating conditions, the system costs to purchase double-deck DMUs and locomotive-hauled consists are quite close (within about $5 million) for almost all of the passenger capacities shown, and double-deck DMUs are less expensive to purchase than locomotive-hauled consists for a capacity of 185. Mixed-level DMUs are somewhat close to locomotive-hauled consists (within about $10 million) for passenger capacities of 750 and fewer. Single-level DMUs with single-level coaches offer a purchase cost advantage for a capacity of 92.

Result: For seated passenger capacities of 185 or fewer under ACE's operating conditions, double-deck DMUs win hands down: they are estimated to be less costly to purchase and less costly to operate. For seated passenger capacities above 185 seats, the results depend on the agency's desire to trade operating cost savings generated by DMUs for higher purchase costs. Each agency will have a different threshold for whether the operating costs saved with DMUs are sufficient to payback the greater initial purchase cost. An example of this will be explored in the next section. (Data used for the above calculations are available in Table 2, which is explained in the technical appendix.)

Example Consists of Similar Seating Capacity

Figures 4 and 5 present example consists for Tri-Rail and ACE, respectively. These examples take trains of similar passenger capacities and show the differences in costs, broken down by fuel, maintenance and operating crew costs.

Tri-Rail

Figure 4 presents an example consist for the Tri-Rail operating environment. One locomotive with two bi-level coaches (300 seats) is compared to a single-level DMU with two single-level coaches (282 seats). Altogether, the DMU consist is estimated to save 20% on annual variable operating costs, with savings of 50% on fuel and 21% on maintenance. Note that while the savings on a percent basis is greater for fuel than maintenance (50% vs. 21%), the savings on maintenance make up nearly 50% of the total system savings. The DMU fleet has a greater purchase cost by 6%. This purchase cost difference of $3 million can be paid back with a little over 2 years of operating cost savings (which are approximately 1.4 million per year). (For exact explanations of the calculations in Figure 4, please refer to the technical appendix.)

ACE

Figure 5 presents a hypothetical consist in the ACE operating environment. One locomotive with three bi-level coaches (420 seats) is compared to a double-deck DMU with one double-deck coach (370 seats). Altogether, the DMU consist saves 17% on annual variable operating costs,

Figure 4. Example Case: Tri-Rail

	1 locomotive with 2 bi-level coaches 300 seated passengers		1 single-level DMU with 2 single-level coaches 282 seated passengers		DMU Savings ($)
Operating Cost ($)					
Fuel & Electricity					
In service fuel	1,331,681	= 2.42 gal/mile X 611,424 miles X $0.9/gal	637,209	= 1.16 gal/mile X 611,424 miles X $0.9/gal	694,472
Idling at full HVAC and lighting	85,050	= 7875 hrs X 12 gal/hr X $0.9/gal	51,116	= (7875 hrs generator X 6.93 gal/hr + 2190 hrs prime movers X 1 gal/hr/DMU X 1 DMU) X $0.9/gal	33,935
Layover	38,273	= 23,625 hrs X 1.8 gal/hr X $0.9/gal	36,855	= 23,625 hrs X 19.50 kW X $0.08/kW-hr	1,417
Total	1,455,004		725,180		729,824
Maintenance					
Maintenance cost per train mile	5.22	= 1 locomotive X $2.65/mile + 2 coaches X $1.29/mile	4.20	= 1 single-level DMU X $1.80/mile + 1 single-level coach X $1.19/mile + 1 single-level cab coach X $1.20/mile	1.02
Total	3,189,293	= $5.22/train mile X 611,424 miles/yr	2,566,702	= $4.20/train mile X 611,424 miles/yr	622,592
Operating Crew					
Total	2,282,650	(see appendix)	2,282,650	(see appendix)	0
Total	**6,926,947**		**5,574,531**		**1,352,416**
				Annual Operating Cost Savings:	**20%**
Purchase Cost ($)					
Cost per trainset	6,400,000	= 1 locomotive @ 2,400,000 + 1 coach @ 1,900,000 + 1 coach w/cab @ 2,100,000	6,700,000	= 1 single-level DMU @ 3,000,000 + 1 single-level coach @ 1,800,000 + 1 single-level cab coach @ 1,900,000	-300,000
Total for 6 trainsets	38,400,000		40,200,000		-1,800,000
Spares	13,500,000	(3 locomotives and 3 coaches)	14,700,000	(3 single-level DMUs and 3 single-level cab coaches)	-1,200,000
Total	**51,900,000**		**54,900,000**		**-3,000,000**
				DMU Purchase Cost Savings:	**-6%**
				Years to Payback:	**2.2**

Figure 5. Example Case: ACE

	1 locomotive with 3 bi-level coaches		1 double-deck DMU with 1 double-deck cab coach		DMU Savings ($)
	420 seated passengers		370 seated passengers		
Operating Cost ($)					
Fuel					
In service fuel	227,962	= 1.93 gal/mile X 131,580 miles X $0.9/gal	89,339	= 0.75 gal/mile X 131,580 miles X $0.9/gal	138,623
Idling at full HVAC and lighting	16,200	= 1800 hrs X 10 gal/hr X $0.9/gal	10,464	= (1800 hrs generator X 6.03 gal/hr + 765 hrs prime movers X 1 gal/hr/DMU X 1 DMU) X $0.9/gal	5,736
Layover	7,290	= 5400 hrs X 1.5 gal/hr X $0.9/gal	4,399	= 5400 hrs X 0.91 gal/hr X $0.9/gal	2,891
Total	251,452		104,202		147,250
Maintenance					
Maintenance cost per train mile	6.58	= 1 locomotive X $2.91/mile + 3 coaches X $1.22/mile	5.65	= 1 double-deck DMU X $3.19/mile + 1 double-deck cab coach X $2.46/mile	0.93
Total	865,193	= $6.58/train mile X 131,580 miles/yr	743,358	= $5.65/train mile X 131,580 miles/yr	121,835
Operating Crew					
Total	463,249	(see appendix)	463,249	(see appendix)	0
Total	**1,579,895**		**1,310,810**		**269,086**
				Annual Operating Cost Savings:	**17%**
Purchase Cost ($)					
Cost per trainset	7,600,000	= 1 locomotive @ 1,950,000 + 2 coaches @ 1,850,000 + 1 coach w/cab @ 1,950,000	6,800,000	= 1 double-deck DMU @ 3,900,000 + 1 double-deck cab coach @ 2,900,000	800,000
Total for 3 trainsets	22,800,000		20,400,000		2,400,000
Spare rolling stock	3,900,000	(1 locomotive & 1 cab coach)	6,800,000	(1 double-deck DMU & 1 double-deck cab coach)	-2,900,000
Total	**26,700,000**		**27,200,000**		**-500,000**
				DMU Purchase Cost Savings:	**-2%**
				Years to Payback:	**1.9**

with savings of 59% on fuel and 14% on maintenance. Note that while the savings on a percent basis is greater for fuel than maintenance (59% vs. 14%), the savings on maintenance make up approximately 45% of the total system savings. The DMU fleet has a greater purchase cost by 2%. This purchase cost premium of $500,000 would be paid back by 2 years of operating cost savings (which are approximately $250,000 per year.) (For exact explanations of the calculations in Figure 5, please refer to the technical appendix.)

POTENTIAL COST DIFFERENCES NOT QUANTIFIED IN THE STUDY

Several potential cost differences have not been quantified in this study but could have an influence on the choice of rolling stock: single-person operation, track use payments to the railroad, and environmental costs.

Single-person Operation

The Colorado Railcar DMU is designed to be operable by just an engineer. The engineer is able to see the entryways through several cameras positioned strategically. Due to regulations, Tri-Rail and ACE do not have the opportunity to take advantage of single-person operation with either locomotive-hauled trains or DMUs. Single-person operation could generate annual savings on the order of $1,000,000 or $250,000, respectively, as explained in the technical appendix. (Of course, transit agencies would have to address the regulatory and safety issues for single-person operation to become a reality.)

Track Use Payments to the Railroad

Track use payments to the railroad are among the largest costs faced by an agency. (For example, per-train-mile fees cost ACE close to $800,000 annually.) Because the DMU is lighter than locomotives and may result in shorter trains (one DMU takes the place of a locomotive and a coach car), in instances with smaller passenger capacities, agencies may have smaller track use payments if they can negotiate based on either gross-ton-miles or vehicle-miles.

Environmental Costs

Commuter rail operations also face the environmental costs of noise and pollution. While these costs are not readily quantifiable in dollar terms, they can be very influential in purchasing decisions and in garnering public support. As mentioned earlier, the DMU is a good neighbor with significantly less noise than a locomotive and substantially lower emissions.

CONCLUSION

Colorado Railcar DMUs have been forecasted to have operating and purchase cost advantages over locomotives and coaches for a range of passenger capacities. For smaller passenger capacities, DMUs are estimated to have lower operating costs and lower purchase costs than locomotives and coaches, generally for 280 passengers or fewer. For larger passenger capacities, the decision as to whether DMUs make financial sense depends on the purchaser's preference for trading operating cost savings generated by DMUs for a purchase cost premium. Two specific examples, one with approximately 300 seats for Tri-Rail and one with approximately 400 seats for ACE, showed variable operating cost savings of 17% to 20% and purchase cost premiums of 2 to 6% which could be paid back with approximately 2 years of operating cost savings. These conclusions do not include any savings that DMUs might generate in track use payments to the railroad or environmental costs. The inclusion of those items could create greater savings with DMU equipment vs. traditional locomotive-hauled trains.

This analysis also underscores the fact that costs of operating any type of rolling stock depend on the operating characteristics of the system. The author is prepared to produce results based on specific operating characteristics of other transit agencies.

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ENDNOTES

1. Ken Sislak. "Economics of Diesel Multiple Unit Operations" in *Proceedings of the 1996 Rapid Transit Conference of the American Public Transit Association*, pp 81-87.

2. Daniel Jacobs and Ann Galbraith. "A Comparison of the Operating and Maintenance Costs of DMU and Locomotive-hauled Equipment for the MBTA" in *Proceedings of the 1997 Rapid Transit Conference of the American Public Transit Association, vol 2,* pp 157-166.

TECHNICAL APPENDIX

This appendix provides all the data used to reach the conclusions in the main body of the paper. The appendix presents the data used under both Tri-Rail and ACE conditions plus explanations of the calculation of maintenance cost per mile, operating crew costs, and rolling stock purchase costs. Note that all figures and data contained in this appendix are available in electronic form upon request to the author.

Data Used Under Tri-Rail Operating Conditions

Table 1 presents the data used under Tri-Rail operating conditions. Below are explanations of the data.

Operating Conditions

Hours Idling Per Year: Herzog calculated that the average Tri-Rail locomotive spends approximately 3500 hours per year idling. At any given time, 6 consists will be made up and those consists are kept idling at almost all times. (While the locomotives may be plugged in to wayside power overnight, they are generally kept at a low idle to prevent having to redo brake tests. Also, some locomotives will be shut down over the weekend.) The author assumed that for 25% of annual idling hours the train would need full HVAC and light, and the remainder of the time the train would operate in layover mode with reduced HVAC and light. The author assumed that layover mode would require 15% of the power needed for full HVAC and light.

Fuel and Electricity

In Service Fuel (gallons/mile): Herzog estimated that Tri-Rail's locomotives with gear-driven HEP consumed 3.14 gallons per mile and locomotives with Caterpillar HEP used 1.7 to 2 gallons per mile. The author has used the average of those figures, which is 2.5 gallons per mile, and assumed that each additional or fewer coach would use 0.025 gallons per mile.

Colorado Railcar calculated in service fuel consumption for a variety of DMU consists, based on Tri-Rail operating conditions. Fuel consumption for consists larger than those presented in Table 1 may be approximated by summing the figures in Table 1 (so, for example, 2 double-deck DMUs plus 2 double-deck coaches may be approximated as double the fuel consumption of 1 double-deck DMU plus 1 double-deck coach).

Idling at Full HVAC and Lighting: Tri-Rail's prime movers use 4.1 gallons per hour at low idle, and its HEP has been estimated to use 22 gallons per hour. The author has assumed that the amount of HEP used will vary directly with the number of coaches, and therefore, based on an average train length of 3.5 bi-level coaches, HEP will use approximately 6 gallons per hour per coach.

Cost Per Gallon of Fuel: Tri-Rail paid $0.90 per gallon of fuel in the year ending March 30, 2002.

Cost of Electricity: The cost of electricity used by the DMU when plugged into wayside power during layover is assumed by the author to be $0.08 per kW-hr.

Maintenance Cost

Maintenance costs for F-40s and Bombardier coaches, including overhaul, were provided by Herzog. The author has synthesized these numbers into a variable cost per train mile, as presented in Table 3. Note: Coach maintenance costs per mile depend on the ratio of coaches in regular revenue service to the number of spares, because all of the rolling stock must be maintained, and having more spares spreads more costs across the same number of miles. It was not possible, however, to adjust the coach maintenance costs, so for the cases where consists have less than 3 coaches, maintenance costs are likely underestimated, and cases with consists greater than 6 coaches are probably slightly overestimated. This issue does not exist for locomotives because the same total number of locomotives is required in all cases.

Maintenance costs for DMUs and Colorado Railcar coaches were projected by Colorado Railcar. The number of miles per year per DMU changes as the number of DMUs in a consist changes, which affects a DMU's maintenance cost per mile. Therefore, a minimum and maximum maintenance cost is presented to correspond with higher and lower annual mileage. The number of miles per year on a DMU or Colorado Railcar coach ranged from 82,000 to 98,000 under Tri-Rail's requirements for spare pieces of rolling stock.

Operating Crew Cost

The calculation of operating crew cost is presented in Table 4. Tri-Rail employs an engineer and a conductor on each typical train (peak and off-peak). Florida DOT rules require that Tri-Rail have 2 crew members on each train.

Purchase Cost

Costs for locomotives and bi-level coaches were based on data for recent purchases of locomotives and coaches, presented in Table 5. Costs for Colorado Railcar rolling stock were based on a purchase of at least two pieces of rolling stock.

Locomotive-hauled fleets have been assumed to have a 20% spare ratio, with a minimum of 3 spare locomotives and 3 spare coaches. DMU fleets have a 20% spare ratio, with a minimum of 3 spare DMUs and 3 spare coaches (except for consists made up only of DMUs, which did not require spare coaches).

Data Used Under ACE Conditions

Table 2 presents the data used under ACE operating conditions.

Operating Conditions

Hours Idling Per Year: ACE's trains have a long layover during the day in San Jose (up to 9 hours) and during the summer months the HEP must run to provide power to keep the passenger cars cool, as the San Jose layover facility used by ACE does not have wayside power available.

Table 3. Maintenance and Overhaul Costs

	Tri-Rail F-40 locomotives	Tri-Rail Bombardier Bi-levels	ACE F-40 locomotives	ACE Bombardier Bi-levels
Number of pieces of rolling stock	9	26	5	20
Annual miles per piece of rolling stock	68,889	77,000	34,900	43,688
TOTAL annual maintenance budget[1]	$3,763,602		$1,333,000	
Less fixed overhead costs[2]	$700,000		$233,000	
VARIABLE annual maintenance cost	$3,063,602		$1,100,000	
Inspection, Preventative Maintenance, Servicing[3]	$675,000	$1,258,000	$300,000	$800,000
Unscheduled Repairs and Major Changeouts[4]	$167,825	$312,777		
Cleaning[5]	$167,143	$482,857		
Variable annual maintenance per piece of rolling stock	$112,219	$78,986	$60,000	$40,000
Variable annual maintenance cost per mile[6]	**$1.63**	**$1.03**	**$1.72**	**$0.92**
Overhaul cost per piece of rolling stock[6]	$700,000 every 10 yrs	$240,000 every 12 yrs	$500,000 every 12 yrs	$200,000 every 15 yrs
Overhaul cost per piece of rolling stock per year[6]	$70,000	$20,000	$41,667	$13,333
Overhaul cost per mile	**$1.02**	**$0.26**	**$1.19**	**$0.31**
Total maintenance+overhaul cost per piece of rolling stock per year	$182,219	$98,986	$101,667	$53,333
Total maintenance+overhaul cost per mile	**$2.65**	**$1.29**	**$2.91**	**$1.22**

Notes:

1 ACE annual maintenance budget is for 7/1/02 - 6/30/03; Tri-Rail annual maintenance budget is for 4/30/01 - 4/30/02.

2 Tri-Rail fixed overhead consists of Management cost: $450,000; Shop facilities maintenance and tooling cost: $100,000; Uniforms, training, and shop vehicles: $75,000.

3 Servicing refers to dumping toilets and replenishing potable water. The cost of refueling is included in ACE's fuel cost per gallon, and the author has assumed the cost of refueling to be included in Tri-Rail's cost per gallon as well.

4 Unscheduled repairs for Tri-Rail were not provided with a breakout between locomotives and coaches. The author has allocated costs for repairs among locomotives and coaches using their respective proportions of inspection and preventative maintenance costs.

5 A portion of Tri-Rail cleaning cost is allocated to each piece of rolling stock by dividing $650,000 by 35 vehicles (= $18,571 per vehicle).

6 Tri-Rail had a full overhaul performed on 4 locomotives in 99-2000 for $700,000 each, when 3 vehicles were 8 years old and one was 12 years old, which the author calculates would be about $70,000 per year of use, or $1.02 per mile. Tri-Rail also overhauled 5 1988 F40 PHL2s in 94-95 with a top deck-plus overhaul of $400,000. Tri-Rail's coach overhaul program has been costing about $240,000 per coach. ACE, which has not yet experienced overhaul on its locomotives or coaches, provided estimates of the projected overhaul costs.

Sources: Personal communication with Brian Schmidt, Director of Rail Services for Altamont Commuter Express, February 19, 2003; Personal communication with Paul Facer, Director of Finance/Operations Support, Herzog Transit, February 26, 2003.

Table 4. Operating Crew Costs

	ACE 7/1/02 - 6/30/03 1 locomotive + 6 coaches	Tri-Rail 4/30/01 - 4/30/02 1 locomotive + 3 to 6 coaches
TOTAL annual operating crew costs	$979,843	$2,834,000
Less fixed overhead costs	$516,594	$551,350
VARIABLE operating crew cost	$463,249	$2,282,650
Annual hours of revenue service	3,573	16,984
Cost per hour of revenue service	129.67	134.40
Potential savings per revenue hour with single person operation	$64.83	$64.40
Potential savings per year with single person operation	**$231,625**	**$1,093,770**

Variable crew cost is calculated as follows:

Number of engineers	1	1
Engineer wage	$28.14	$25.00
Number of conductors	1	1
Conductor wage	$28.14	$23.00
Engineer plus conductor wage per pay hour	$56.28	$48.00
Fringe benefits (% of wage)	28%	40%
Cost per pay hour including benefits	$72.04	$67.20
Pay hours per hour of revenue service	1.8	2.0
Cost per hour of revenue service	129.7	134.4
Annual hours of revenue service	3,573	16,984
Annual "variable" crew operating cost	463,249	2,282,650

Note: ACE also employs 8 fare enforcement officers at a cost of $45,000 per officer, including all benefits. These costs are not included above, because the decision to have fare enforcement officers would not be affected by the type of rolling stock used.

Sources:

Personal communication with Brian Schmidt, Director of Rail Services for Altamont Commuter Express, February 19, 2003; Personal communication with Paul Facer, Director of Finance/Operations Support, Herzog Transit, February 26, 2003.

Table 5. Purchase Costs for Locomotives, Coaches and DMUs

	Manufacturer	*Model*	*Transit Agency*	*Number Purchased*	*Year Built*	*Cost/Unit*	*# of Seats*	*New?*	*Available?*
LOCOMOTIVES	Boise Locomotive	F-40PH-3C	ACE	3	1997	$1,977,428	0	Yes	Available
	Boise Locomotive	F-40PH-3C	ACE	2	2000	$1,900,000	0	Yes	Available
	Boise Locomotive	F-40P-2	Tri-Rail	2	1981	$1,100,000	0	No	Available
	Boise Locomotive	F-40PHL-2	Tri-Rail	5	1988	$987,000	0	No	Available
	Boise Locomotive	F-40PHM-2C	Tri-Rail	3	1992	$1,500,000	0	Yes	Available
	American Machine	GP-40MC	MBTA	25	1997	$1,579,515	0	No	Available
	Boise Locomotive	F-40PH-2C	Caltrain	3	1998	$2,266,667	0	Yes	Available
	EMD	F-59PH-I	Seattle Sounder	6	1999	$2,666,667	0	Yes	Available
	EMD	F-59PH-I	Oceanside (NCTD)	2	2001	$2,400,000	0	Yes	Available
COACHES	Bombardier	Bi-level	ACE	4	1997	$1,740,836	134	Yes	Available
	Bombardier	Bi-level	ACE	7	2001	$1,761,429	140	Yes	Available
	Bombardier	Bi-level	ACE	4	2002	$1,909,558	140	Yes	On Order
	Bombardier	Bi-level	Tri-Rail	12	1987	$975,000	155	Yes	Available
	Bombardier	Bi-level	Tri-Rail	3	1990	$1,300,000	157	Yes	Available
	Bombardier	Bi-level	Seattle Sounder		2000	$1,800,000	136	Yes	Available
	Bombardier	Bi-level V modified	Metrolink	27	2001	$1,681,019	140	Yes	On Order
	Bombardier	Multi-level coach	Caltrain	15	2002	$1,991,000	148	Yes	On Order
	Bombardier	Bi-level	Oceanside (NCTD)	4	2003	$1,911,605	142	Yes	On Order
CAB COACHES	Bombardier	Bi-level cab	ACE	4	1997	$1,905,186	140	Yes	Available
	Bombardier	Bi-level cab	ACE	5	2000	$2,020,000	140	Yes	Available
	Bombardier	Bi-level cab	Tri-Rail	6	1987	$975,000	154	Yes	Available
	Bombardier	Bi-level cab	Tri-Rail	5	1996	$1,610,316	126	Yes	Available
	Bombardier	Multi-level cab	Caltrain	2	2002	$2,846,000	139	Yes	On Order
	Bombardier	Bi-level cab	Oceanside (NCTD)	2	2003	$2,175,553	130	Yes	On Order
DMUs	Colorado Railcar	Single-level DMU	N/A	2 or more	2003 or later	$3,000,000	92	Yes	Available
	Colorado Railcar	Double deck DMU				$3,900,000	185	Yes	In Design
	Colorado Railcar	Single-level cab coach				$1,900,000	92	Yes	Available
	Colorado Railcar	Single-level coach				$1,800,000	98	Yes	Available
	Colorado Railcar	Double deck cab coach				$2,900,000	185	Yes	Available
	Colorado Railcar	Double deck coach				$2,800,000	185	Yes	Available

Note: Number of seats for Colorado Railcar cars based on a seat pitch of 31 inches, 1 restroom, 1 ADA tie down per passenger car, and no bike storage spaces.

Sources: APTA 2002 Vehicle Database; Personal communication with Brian Schmidt, Director of Rail Services for Altamont Commuter Express, February 19, 2003; Personal communication with Paul Facer, Director of Finance/Operations Support, Herzog Transit, February 26, 2003.

ACE will also sometimes run its locomotives overnight, either in the heat of the summer or the cold of the winter, because the overnight yard in Stockton only has wayside power for two train sets, not all three. This results in 1800 hours per year per locomotive. ACE's locomotives are equipped with HEP by Cummins K19s (3 locomotives) or Caterpillar 3406s (2 locomotives), which on average consume about 20 gallons per hour (including fuel used by the prime mover at low idle). Because ACE does not have wayside power in San Jose and only has wayside power for 2 trains in Stockton, the author has assumed that the DMU would not be able to be plugged into wayside power more often than the locomotive-hauled trains are, and therefore all electrical needs of the DMU are powered by the generator.

The author assumed that for 25% of annual idling hours the train would need full HVAC and light, and the remainder of the time the train would operate in layover mode with reduced HVAC and light. The author assumed that layover mode would require 15% of the power needed for full HVAC and light.

Fuel

In Service Fuel: ACE estimated that its locomotives consumed approximately 2 to 2.4 gallons per mile. The author has assumed that a locomotive hauling 6 coaches would consume 2 gallons per mile, and each additional or fewer coach would use 0.025 gallons per mile.

Colorado Railcar calculated in service fuel consumption for a variety of DMU consists, based on ACE operating conditions. Fuel consumption for consists larger than those presented in Table 1 may be approximated by summing the figures in Table 1. Not all consists from the Tri-Rail cases are used for the ACE cases' these consists are marked with an 'N/A'. Colorado Railcar Manufacturing estimated that consists with a higher proportion of DMUs to coaches would be most likely to meet ACE's operating requirements, and has therefore not included consists with a lower ratio of DMUs to coaches. A more detailed analysis would be required to determine how well the excluded consists would meet ACE's operating requirements. (The fact that in service fuel consumption for ACE is lower than that of Tri-Rail's occurs because Tri-Rail's route requires much more acceleration and deceleration between stops, whereas ACE has longer stretches between their stops.)

Fuel Idling at Full HVAC and Lighting: ACE estimated that its HEP consumed 20 gallons per hour when idling with 6 coaches at levels of HVAC and lighting needed for service. The author has assumed that the amount of HEP used will vary directly with the number of coaches, and therefore HEP will use 3.33 gallons per hour per coach.

Cost Per Gallon of Fuel: In fiscal year 2002/2003, which began July 1, 2002, ACE has so far paid anywhere from $0.63 to $1.16 per gallon of diesel fuel. Two years prior, ACE paid as much as $0.80 to $1.16 per gallon. (ACE's fuel cost includes the service cost of being fueled by truck.) For the purposes of this study, the cost of fuel per gallon will be assumed to be $0.90 for ACE (the average between $0.63 and $1.16).

Maintenance Cost

Maintenance costs for F-40s and Bombardier coaches were provided by ACE. The author has synthesized these numbers into a variable cost per mile, as presented in Table 3. ACE has not yet experienced overhaul on any of its locomotives and has therefore estimated the costs for those overhauls, as explained in Table 3.

Maintenance costs for DMUs and Colorado Railcar coaches were projected by Colorado Railcar. A minimum and maximum maintenance cost is presented because the number of miles per year per DMU changes as the number of spare DMUs changes, which affects a DMU's maintenance cost.

Operating Crew Cost

The calculation of operating crew cost is provided in Table 4. ACE has an engineer and a conductor on each of its trains, as well as a fare enforcement officer. ACE's engineers and conductors are cross-qualified' they may serve as an engineer one day and then a conductor the next. According to the regulations that govern ACE operations, all trains must have at least 2 crew members.

Purchase Cost

Costs for locomotives and bi-level coaches were based on discussions with ACE about the options they hold to purchase additional locomotives and coaches. Costs for Colorado Railcar rolling stock were based on a purchase of at least two pieces of rolling stock.

Rolling stock purchase costs are for 3 trainsets plus spare pieces of rolling stock. Locomotive-hauled fleets have a 10% spare ratio, with a minimum of 1 spare locomotive and 1 spare cab coach. DMU fleets have a 10% spare ratio, with a minimum of 1 spare DMU and 1 spare cab coach (except for consists made up only of DMUs, which did not require spare coaches).

Calculation of DMU Maintenance Cost per Mile

Table 6 presents an example of Colorado Railcar's calculation of maintenance cost per mile, including overhauls, on its single-level DMU for Tri-Rail operating conditions. The upper left block on the table gives the operating life that is used for the DMU based on a 30 year life, including the number of days the DMU will operate, the number of hours the prime mover and generator will operate, and the number of miles the vehicle will drive. The block to the right with labor costs shows the cost assigned to an hour of labor based on who performs the labor. The agency labor rate of $31 per hour is the fully burdened rate for a mechanic in Tri-Rail's shops. The main table lists each system in the DMU and the number of labor hours, cost for labor, cost for parts, and total cost to maintain the system over the life of the DMU, including overhaul. At the bottom right of the table is the maintenance cost for the single-level DMU: $1.78 per mile. Maintenance costs for the double-deck DMU and Colorado Railcar coaches were calculated using similar methods. Table 7 presents the same example for ACE conditions. (A 30-year life has been used for calculation of maintenance cost, however, Colorado Railcar expects DMUs to have useful lives equal to those of locomotives.) Table 8 provides the notes to Table 6 and Table 7. More detailed results are available from the author upon request.

Table 6. DMU Maintenance Cost: Tri-Rail Example

DMU life for analysis (Single-level DMU)			Labor cost ($/hour)	
years	30		Agency	31
days	10,950	(365 calendar days per year)	Detroit Diesel	78
days operating	7,300	(operated 243 days per year)	Stadco	52
hours prime mover	63,913	(2,130 hours/year)	Voith	65
hours generator	90,163	(3,005 hours/year)	HVAC Specialist	75
miles	2,066,670	(68,889 miles/year)		

	Labor hours over DMU life	*Labor cost over DMU life ($)*	*Part cost over DMU life ($)*	*TOTAL labor + part cost over DMU life ($)* [1]	*Source*
Generator[2]	2,811	90,608	29,066	180,596	Stadco/CRM[3]
Prime movers[2]	5,475	202,669	161,029	502,128	Detroit Diesel/CRM
Transmissions[2,4]	1,009	54,127	122,850	198,195	Voith/CRM
Drive shafts[2]	116	3,599	11,463	15,062	Voith
Final drive units[2]	1,001	39,458	41,703	81,161	Voith
Engine cooling	839	26,010	144,450	197,662	CRM Estimate
HVAC[6]	4,234	131,261	237,047	368,308	CRM Customers[5]
Glass[7]	464	14,384	95,487	109,871	CRM Estimate
Exterior paint	1,124	34,844	8,578	49,222	CRM Estimate
Trucks and wheels[8]	1,440	44,640	272,200	510,440	CRM Estimate
Brakes	952	29,512	210,494	240,006	CRM Estimate
End of car[9]	SEE TOTAL COLUMN			6,900	CRM Estimate
Interior[10]	5,423	168,099	84,578	252,677	CRM Customers[5]
Cab	SEE TOTAL COLUMN			14,700	CRM Estimate
Water & sanitation	21	654	6,070	7,724	CRM Estimate
Interior systems & components	3,922	121,574	7,250	130,074	CRM Estimate
Fire suppression	SEE TOTAL COLUMN			2,500	CRM Estimate
FRA inspections[11]	5,751	178,278	0	178,278	CRM Estimate
Cleaning & Servicing	SEE TOTAL COLUMN			638,663	CRM Estimate/ CRM Customers[5]
TOTAL	**34,582**	**1,139,717**	**1,432,265**	**3,684,167**	

MAINTENANCE COST PER MILE (INCLUDING OVERHAUL): $1.78
(Calculated as $3,684,167 lifetime cost divided by 2,066,670 lifetime miles)

See Table 8 for notes to this table.

Table 7. DMU Maintenance Cost: ACE Example

DMU life for analysis (Single-level DMU)			Labor cost ($/hour)	
years	30		Agency	31
days	10,950	(365 calendar days per year)	Detroit Diesel	78
days operating	5,738	(operated 191 days per year)	Stadco	52
hours prime mover	32,532	(1,084 hours/year)	Voith	65
hours generator	86,532	(2,884 hours/year)	HVAC Specialist	75
miles	1,047,000	(34,900 miles/year)		

	Labor hours over DMU life	*Labor cost over DMU life ($)*	*Part cost over DMU life ($)*	*TOTAL labor + part cost over DMU life ($)*[1]	*Source*
Generator[2]	2,378	76,968	27,842	157,370	Stadco/CRM[3]
Prime movers[2]	3,840	137,053	94,019	267,030	Detroit Diesel/CRM
Transmissions[2,4]	577	29,297	61,770	100,173	Voith/CRM
Drive shafts[2]	73	2,254	5,485	7,739	Voith
Final drive units[2]	834	34,275	40,471	74,746	Voith
Engine cooling	839	26,010	144,450	197,662	CRM Estimate
HVAC[6]	2,145	66,498	120,091	186,589	CRM Customers[5]
Glass[7]	464	14,384	95,487	109,871	CRM Estimate
Exterior paint	1,124	34,844	8,578	49,222	CRM Estimate
Trucks and wheels[8]	728	22,568	136,100	275,468	CRM Estimate
Brakes	952	29,512	209,289	238,801	CRM Estimate
End of car[9]	SEE TOTAL COLUMN			6,900	CRM Estimate
Interior[10]	2,747	85,161	42,848	128,009	CRM Customers[5]
Cab	SEE TOTAL COLUMN			14,700	CRM Estimate
Water & sanitation	21	654	6,070	7,724	CRM Estimate
Interior systems & components	3,922	121,574	7,250	130,074	CRM Estimate
Fire suppression	SEE TOTAL COLUMN			2,500	CRM Estimate
FRA inspections[11]	5,074	157,295	0	157,295	CRM Estimate
Cleaning & Servicing	SEE TOTAL COLUMN			463,710	CRM Estimate/ CRM Customers[5]
TOTAL	**25,717**	**838,347**	**999,750**	**2,575,584**	

MAINTENANCE COST PER MILE (INCLUDING OVERHAUL): $2.46

(Calculated as $2,575,584 lifetime cost divided by 1,047,000 lifetime miles)

See Table 8 for notes to this table.

Table 8. Notes to DMU Maintenance Costs in Tables 6 and 7

1. The total of the column "Labor cost over DMU life ($)" and "Part cost over DMU life ($)" will not necessarily equal the column "TOTAL labor + parts cost over DMU life ($)" because certain data was only available as an aggregate of labor and parts. The aggregate system total cost (the latter column) includes all costs of maintenance, whereas the labor and parts breakouts include only those costs which were able to be broken out.
2. Costs for maintenance of off-the-shelf components, such as engines or generators, are specific to the components' application in the DMU. If used differently, these components would have different maintenance costs.
3. CRM refers to Colorado Railcar Manufacturing.
4. Voith costs based on 65,000 annual miles. Costs may increase with fewer miles per year.
5. Data from Colorado Railcar Manufacturing (CRM) customers collected from Princess Tours, Royal Caribbean Cruise Line, Great Canadian Railtour Company, LTD, and Alaska Railroad Corporation. Collectively, these customers have run approximately 6.7 million miles on Colorado Railcar coaches.
6. CRM customer data ranges from $0.02 per mile to $0.18 per mile for double-deck coaches.
7. CRM customer reported $.017 per mile for double-deck coaches.
8. Data on Caltrain truck overhaul costs provided by Steve Coleman, Manager of Maintenance - Rail Equipment on February 14, 2003.
9. Includes coupler, uncoupling lever, grab irons, brake hoses & gladhands, HEP receptical, COMM/MU recepticals
10. Double-deck coach customer costs scaled down for single-level; Customer costs ranged from $0.03 to $0.19 per mile for double-deck coaches.
11. Some inspection costs are quantified within their respective components, such as with the engine or transmission, as opposed to in the dedicated inspection cost rows. To avoid double-counting, those inspection costs will not be included in the inspections subtotal. (It those costs were included, the subtotal would be approximately 60% higher than currently reported.)

List of Tables and Figures

ANNEXE G

HORAIRE ACTUEL DE VIA

Horaire actuel à la Gare Centrale

Trains	Arrivées	Temps d'attente	Trains	Départs
31E	05:50	0:55	31	06:45
53E	06:00	0:55	53	06:55
20E	06:05	0:55	20	07:00
801	06:30	0:10	890	06:40
803	07:37	8:53	802	16:30
805	07:50	9:00	804	16:50
15/17	08:00	0:40	15/17E	08:40
807	08:17	9:03	806	17:20
30	08:30	0:20	30E	08:50
57E	08:45	0:55	57	09:40
14/16E	08:55	9:50	14/16	18:45
21	08:59	0:20	21E>22	09:19
33E	09:05	0:55	33E	10:00
21>22E	09:34	2:56	22	12:30
32	10:54	0:20	32E>35	11:14
61E	10:55	0:55	61	11:50
23	11:15	0:20	23E>24	11:35
32>35E	11:29	3:36	35	15:05
52	11:45	0:20	52E>67	12:05
23>24E	11:50	4:10	24	16:00
52>67E	12:20	4:40	67	17:00
56	14:15	0:20	56E>39	14:35
65E	14:45	0:55	65	15:40
56>39E	14:50	3:10	39	18:00
25	15:40	0:20	25E>26	16:00
37E	15:50	0:55	37	16:45
25>26E	16:15	1:40	26	17:55
34	16:56	0:20	34E	17:16
60	16:56	0:20	60E>69	17:16
600/604	17:15	0:40	600/604E	17:55
60>69E	17:31	0:44	69	18:15
36	18:00	0:20	36E	18:20
891	18:05	0:40	810	18:45
695-69	18:30	0:40	695-69E	19:10
694-98E	19:25	14:25	694-98	09:50
38	19:44	0:20	38E	20:04
64	19:55	0:20	64E	20:15
27	20:43	0:20	27E	21:03
66	20:59	0:20	66E	21:19
68	23:08	0:20	68E	23:28

ANNEXE H

LISTE DESPERSONNES ET ORGANISMES RENCONTRÉES

LISTE DES PERSONNES ET ORGANISMES RENCONTRÉES

André Gravelle,

Directeur de l'ingénierie de VIA

Giovanni Labbiento

Directeur du développement des affaires de VIA

Louis Machado

AMT

Gary Fairbanks

Ingénier senior en mécanique, FRA

Paul Lepage

Conseiller principal, équipement et exploitation

Groupe de sécurite ferroviaire de TC

Tom Peacock

Directeur de l'APTA