DRAFT

25 Kv ac ELECTRIFICATION PROJECT

ASSESSMENT OF ELECTRIC MULTIPLE UNITS

PASSENGER RAIL CARS

TABLE OF CONTENTS

EXECUTIVE SUMMARY

The Peninsula Corridor Joint Powers Board (PCJPB) has determined to electrify the rail line utilized by its commuter rail operations. This particular document reports on the results of a research and evaluation of Electric Multiple Unit (EMU) passenger rail cars and is prepared for the purpose of augmenting a previous evaluation of rolling stock equipment focusing on electrically powered locomotive technology.

Two major assumptions were defined early in the process in order to focus on realistic alternatives. The assumptions were: a) that the cars should be of multi-level design, taking full advantage of existing railroad clearances and increasing system capacity; and b) that the equipment must be designed and built in accordance with all current U.S. Rules and Regulations and Recommended Industry Practices.

Japanese and European equipment were identified and evaluated. While European countries have adopted multi-level EMU cars for commuter services, the Japanese have concentrated on applying the technology to intercity services, meaning higher operating speeds and more comfortable accommodations, such as fully reclining seats and food service equipment, among others. For that reason, this report presents the assessment of these two vehicle technologies from a slightly different point of view, although both are oriented toward the same goals and objectives. More specifically the evaluation of these technologies is intended to determine the applicability of these vehicle and components and/or systems in the technical and regulatory railroad environment in force in the United States.

With regard to European Technologies the report focuses primarily on three modern vehicle technologies in operation or under development, namely the French TER 2N, by Alstom and Bombardier for the French National Railways; the Italian TAF, by Ansaldo-Breda for the newly formed TrenItalia (formerly the Italian National Railways); and the Swiss IC2000 by Adtranz, for the Regional Commuter Rail Authority in Zurich. These three technologies were selected among many others, as the most modern and representative in Europe and most likely to be adapted to the Caltrain services. Also, because they offer the most modern facilities for passenger comfort and safety, with wide entrance doors, low boarding floors, optimum passenger flow through doors, aisleways and stairways, excellent lighting and comfortable 2+2 seats.

All three technologies are basically arranged in the same form, including power, cab and trailer cars. The power equipment occupies the “mezzanine” level of the floor over the trucks, at one end of the car. Passenger seating accommodations are arranged in the low floor section, between the trucks; on the upper floor and in the “mezzanine” level at the opposite end of the car. The control cab for push-pull operations is arranged at one end of the non-powered car. A third car design, a trailer, is available to be coupled between a powered and a cab car, but this consist is rarely used in typical European formations due to acceleration and braking requirements.

The arrangement of the power equipment, floor and stairway layouts, side door location and size and overall dimensions of the cars are features that should be further evaluated for application to the future Caltrain equipment.

With regard to Japanese equipment, the most recent bi-level passenger cars in operation are oriented toward intercity services. Japanese Railway clearances are more generous than those found in the general system of railroads in the U.S., allowing for car bodies six to twelve inches wider. In addition, the structure of the car body is not designed in accordance with U.S. requirements; therefore it is not appropriate to consider these mechanical systems for application in the Caltrain services. As with European equipment, however, a number of other systems, components and equipment offer significant technical and economic potential benefits and should be evaluated in more detail.

We also evaluated technologies recently or currently being implemented in the U.S. While these technologies are not of U.S. origin, they are being adapted to the overall railroad environment, rules and regulations. Two recent EMU procurements are discussed, including the M7 cars for the Long Island Railroad and the Nippon-Sharyo cars for NICTD. Both cars are single level.

The conclusions are that indeed both European and Japanese manufacturers are highly capable and qualified to supply rolling stock equipment to the U.S. market, in accordance with all applicable rules, regulations and recommended practices

However, a word of caution must be expressed, with regard to new developments. For it to be successfully implemented, the following must occur:

- the problem to be solved must be correctly identified. A common occurrence is to find a solution, not knowing what the problem really is;
- correct definition of system performance;
- clearly and reasonably written performance specifications and contractual terms and conditions;
- realistic schedules that allow for development, testing and commissioning;
- a true partnership relationship between the customer and the contractor.

Recent problems with the implementation of high-speed services in the Northeast corridor must be used as a constructive experience and not repeat them.

In addition, it must be remembered that vehicle prices will depend on the total number of cars ordered. Prices of cars in Europe and Japan are usually lower than similar vehicles in the United States. The primary reason is that the number of vehicles ordered is often in lots of 200 to 300 and more. This is generally achieved due to the involvement of large customers, or multiple customers ordering the same vehicle. METRA in Chicago recently placed an order for 300 Gallery style commuter rail cars at a price averaging $ 1.3 million per car, as opposed to the last procurement of 20 Gallery cars by the PCJPB, at an average price of $ 1.65 million each.

With regard to the acquisition of electric locomotives or EMU cars, the decision must be made on the basis of life cycle costs. Unfortunately the economic data, especially maintenance and overhaul costs, does not exist in the format needed in the United States. While energy consumption costs can be simulated in a reasonable accurate manner, other costs will have to be adjusted or assumed and the results will likely be uncertain to permit a clear decision.

For this reason, it is recommended that the bidding process be open to both electric locomotives and EMUs. Under this scenario the most suitable option would include supply and maintenance of the vehicles. The proposals would include initial vehicle prices and maintenance and operating costs. Labor costs would be proposed in terms of man-hours to complete maintenance tasks in order to avoid currency rate differences. Under the locomotive scenario the PCJPB could either ask for prices including new passenger cars or discount the price of the existing level of Gallery cars.

The cost information submitted by the vendor will become binding under the contract and will be the basis for penalties and incentives to the contractor.

There are several factors affecting the decision on procurement strategies. Therefore the above-described process should be considered a concept and further discussions are necessary with the PCJPB, before a final approach is adopted.

1 BACKGROUND AND INTRODUCTION

The Peninsula Corridor Joint Powers Board (PCJPB) has determined to electrify the rail line utilized by its commuter rail operations between San Francisco and Gilroy. This particular Report, prepared as part of the preliminary engineering phase of the 25 kV, 60 Hz ac Electrification Program, addresses electrically powered passenger rail car equipment, specifically Electric Multiple Units (EMU). This evaluation identifies equipment in operation in Europe and Japan, assesses its technical characteristics and explores its potential application in the operating and regulatory environment that prevails in the United States.

2 ASSUMPTIONS AND APPROACH

As discussed in our previous Assessment of Electrically Powered Rolling Stock Equipment, it is assumed that the passenger rail cars to be utilized in the Caltrain services should be multilevel equipment, regardless of power mode. This assumption is based on the fact that railroad clearance conditions permit the use of the largest possible vehicle, within the weight and infrastructure limitations. These allowances permit the overall system capacity to be optimized, within the same length and width dimensions that would apply to single level cars.

With regard to foreign technologies, while European countries have adopted multilevel EMU rail cars for commuter services, the Japanese have concentrated on applying the technology to intercity services, typically operating at higher speeds than those of commuter systems. For that reason, this report addresses European and Japanese technologies from a slightly different point of view, although both are oriented toward the same goals and objectives. This knowledge will allow preparation of sound recommendations to PCJPB and the development of specifications for the most suitable equipment. The purpose of the study is to evaluate the applicability of the Japanese and European double deck EMU technology with respect to North American standards.

3 REFERENCE SOURCES

The sources of information for the preparation of this report were:

- *Library reference material;*
- *Replies to requests for information from Japanese and European Railway operators;*
- *Replies to requests for information from car and propulsion system manufacturers;*
- *Internet searches.*

4. JAPANESE TECHNOLOGY

The approach to the development of new technology for subsystems and trains in Japan is quite different from that in North America. In North America, technology is often developed on a competitive basis and is owned by the manufacturers. Technology development in Japan occurs on a cooperative basis. The transit operators own the design rights, and the train and subsystem manufacturers have a free license to use these designs. On new technology developments, such as the linear motor mini-subway, it is typical that a group of railways, manufacturers, consultants, and university specialists form a task force that participates in the complete development process for a new train. It is the responsibility of the task force to prepare the actual requirements and technical specifications for the new equipment. Generally, all railway cars, propulsion, and other suppliers will participate in the program. For instance, during the design phase, Kawasaki (KHI), Nippon Sharyo, Kinki Sharyo, and Tokyu Car will all work jointly on the design as a subcommittee of the task force. Following approval of the design, the manufacturing of the prototype trains is shared among the manufacturers. As an example, the linear motor Variable Voltage Variable Frequency (VVVF) inverter main propulsion systems for the mini-subway in Japan had prototype equipment on it from Toshiba, Mitsubishi Electric Company (MELCO), Hitachi, and Toyo Denki. This approach provides the railways with a number of manufacturers that are able to compete for contract awards for commercial supply of the equipment and car designs.

In the particular case of the propulsion equipment, a number of manufacturers have supplied equipment for the EMU bi-level cars, including Hitachi, Toshiba, and MELCO. The equipment they supply is identical in form, fit and function and the mechanical and electrical interfaces offer total compatibility. Given the high level of quality required and produced for the Japanese railways, the manufacturers compete on the basis of after-sale service, price, and delivery schedule.

There is a general trend within Japan's railway and transit industry to use VVVF inverter and induction motor drives. The current technology of choice is Insulated Gate Bi-polar Transistors (IGBTs). Within the next few years there is a possibility of evolving to Enhanced Gate Bi-polar Transistors (EGBTs). All the manufacturers use the basic control technology, Vector Field Control, as an effective means of accurately and efficiently controlling both the speed and tractive effort of these drives. While the rating, size, and packaging differ among subway, commuter and high-speed Shinkansen applications, the devices, their configuration, control systems and control methodology are all identical.

A comparison of four Japanese double deck EMUs is presented in Appendix A. The comparison includes information about the following components:

- *Electrical system*
- *Trainset*
- *Performance*
- *Car body*
- *Bogie*
- *Gear Ratio*
- *Principle Equipment*
- *Control*

In regard to the utilization of this type of propulsion system for bi-level EMUs in North America, the rating, size, and functionality required for the Caltrain system are all well within the range of those parameters that have been supplied for transit and railway trains in Japan.

The issue the ability of these technologies and products to conform to North American Standards is addressed in Section 6.

4.1 JAPANESE DOUBLE DECK EMU

The Japanese have extensive experience with double deck EMUs in revenue service, as shown in Table 1.

TABLE 1: EXPERIENCE IN REVENUE SERVICE

	Date of Introduction	Cars in Service
Series 215	1992	285
Shinkansen Series 100	1985	370
Shinkansen Series E1	1994	72
Shinkansen Series E4	1997	80

The most recent Japanese double deck EMUs are the Shinkansen Series E1 and E4 shown in Figures 2 and 3 respectively. The mechanical characteristics and propulsion system are discussed in the following sections.

4.1.1 MECHANICAL CHARACTERISTICS

The mechanical characteristics of the Shinkansen Series E1 and E4 bi-level electric multiple unit cars are almost identical, with a top speed of 240 kph (150 mph). The design of these cars is governed by matching the structure gauge and the track quality standards that have been established for Shinkansen cars. The rate of change of horizontal and vertical curves, minimum vertical and horizontal radii, and levels of super elevation were all determined for the initial series of cars. Consequently, the dynamic characteristics and bogie designs have been constrained to conform to these characteristics. Japanese track characteristics are generally better than typical railroad track quality in North America. Consequently, changes in the design of the cars would be needed to accommodate the North American track quality standards.

Japanese National Railways has been divided into six different companies. The East, Central, and West Japan Railway companies have adopted a design operating philosophy that there will be no crashes. As a result of this they have not incorporated the energy absorption characteristics that are required by the new FRA Standard CFR 238-403. For this reason we have concentrated our evaluation on the merits of the electrical characteristics of these cars, as these are more readily transferable to the North American railway environment.

East Japan Railways Series E4 represents the most modern evolution of the propulsion system design. It has been proven by two years of revenue service.

4.1.2 PROPULSION SYSTEM

The East Japan Railway has designed a propulsion system that has 50 percent of all axles powered. As shown in Table 2, Series E4 Car Configuration, the four-motored cars of the total of eight cars have traction power driving the axles.

TABLE 2: SERIES E4 CAR CONFIGURATION

Car No.	1	2	3	4	5	6	7	8
Item	**Tc1**	**M1**	**M2**	**T**	**T**	**Mp**	**Mc**	**Tc**
Cab	3							3
Pantograph		1				1		
Transformer			1			1		
Converter		2	2			2	2	
Inverter		2	2			2	2	
Traction Motors		4	4			4	4	
Auxiliary Inverter		1					1	

The transformer, converter and inverter change the 25 kV, 50 Hz power supply from the overhead catenary to a VVVF supply. This VVVF is the power source for the induction motors, which have a rated condition of 1850 Vac at 130 Hz. The converter transforms the 25 kV, 50 Hz signal into a fixed dc voltage.

The converter is a fully controlled bridge using IGBTs. This provides an additional element of control allowing the system to respond to fluctuation in the supply voltage. This also provides more options in the control strategy for maximizing the electromagnetic compatibility of the propulsion system with other subsystems in the car and ground facilities.

Figure 1 shows the schematic for the traction and propulsion system for a pair of motorcars. One transformer supplies the power for the propulsion system on a pair of motorcars. As shown in Table 1, each motorcar has two converters and two inverters. Each inverter provides the power of a VVVF nature to the induction motors that drive the two axles of a single bogie. The inverter and converter are packaged into one unit, providing more flexibility for the mechanical designer in achieving weight balance on the car. The drive torque from the induction motors is transmitted to the axles by a parallel Cardan drive with a gear coupling.

There are two auxiliary inverters installed in each 8-car train.

Further details of the major propulsion system components are discussed in Appendix B, where a tabular comparison of four Japanese propulsion systems is also presented:

- *Supply*
- *Inverter*
- *Drive Method*
- *Control System*

· *Protection*
· *Traction Motor*
· *Braking System*

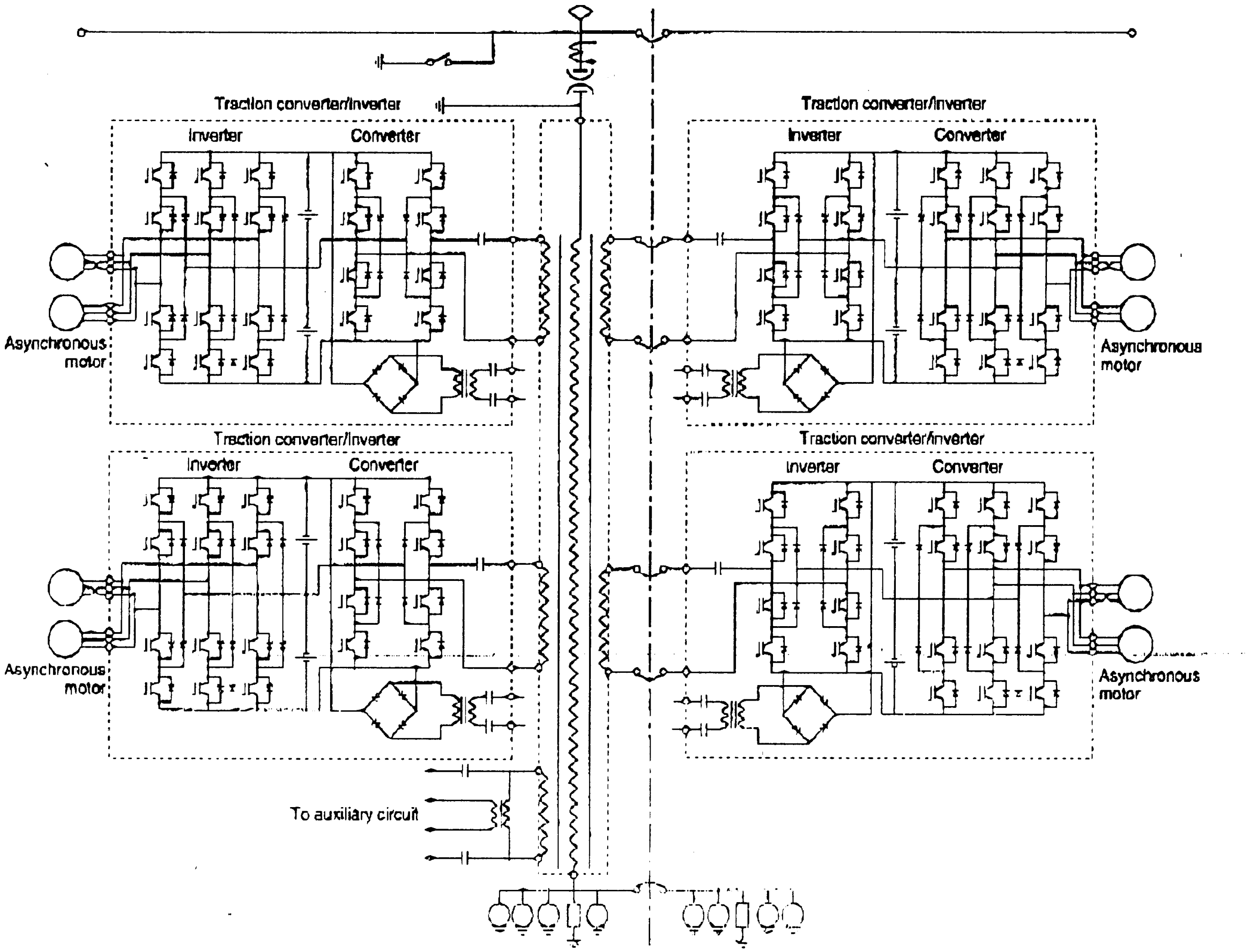

FIGURE 1: SERIES E4 TRACTION CIRCUIT DIAGRAM

4.1.3 TRACTION TRANSFORMER

Traction transformers are mounted on the floor. The main converters controlling the traction motors are installed in the left and right side machine rooms provided on both sides of the center aisle in the rear vestibule of all M cars. The converter and inverter sections for the two main converter sets are integrated together and housed in the same machine rooms. This is advantageous because the wiring running along the center aisle can be omitted and the weight of the right and left side machine rooms can be balanced. This integration makes the system more compact and lightweight.

A single traction transformer provides the electrical power to the four main converters for two cars. It consists of four secondary coils and one tertiary coil for an auxiliary circuit. A polyamide film and an aluminum coil are used to insulate the element wires of the primary and secondary coils, keeping them compact and lightweight. These features minimize total weight.

4.1.4 CONVERTER

The converter is a phase control, full wave bridge. As such, it is one element of a three-level converter/inverter control system that reduces the higher harmonics of the primary current and the ripple effect on motor current. The converter solved the problem of higher harmonics affecting ground facilities, and greatly reduced the audible noise emitted from the traction transformers and motors. An IGBT with a self-protective function increases the reliability of the main circuit elements.

For cooling, two redundant fan sets are used for the converter.

4.1.5 INVERTERS

The inverters change the dc power produced by the converters to ac power. They produce a VVVF output that provides the means to control both speed and traction torque efficiently. One inverter provides power to two induction motors that drive the two axles of a truck.

Three sets of inverters are used to ensure optimum cooling and high availability for operation.

4.1.6 CONTROLS

The inverter is controlled by a 32-bit microprocessor based traction control unit. The traction control unit has the following functions:

- *Decoding the driving commands from the cab*
- *Acceleration / deceleration control*

- *Forward and reverse control*
- *Rollback protection*
- *Load compensation*
- *Jerk control*
- *Slip/slide control*
- *Controlling braking chopper for regenerative/rheostatic blended brake*
- *Interface with friction brake*

Since a 32-bit Large Scale Integration (LSI) digitally controls the inverter frequency, there is no temperature drift. The operating frequency of the LSI is 32 MHz.

The motor torque and speed are controlled by the Vector Field Control method. This achieves smooth acceleration and enhances the ride quality for the passenger.

The Vector Field Control also achieves quick and precise control of motor torque when the wheels slip in motoring or skid in dynamic braking. This slip/slide correction with the Vector Field Control is applied to each inverter, which thereby corrects the spin or slide on the two axles of a bogie. It maximizes the adhesion between wheels and rails to stabilize the train acceleration and braking, and avoids the damage to wheels and rails in slipping or locked wheels.

The logic control unit is provided with a fault logging function. A fault in the traction inverter system triggers fault data logging. The fault annunciation and the detailed logged data are transmitted to a vehicle monitoring system.

4.1.7 TRACTION MOTOR

Insulated bearings, allowing operation of 900,000 km or more without an overhaul, are used in the traction motor. They are compact in size, lightweight, and maintenance free. The design of the bearing structure allows lubrication without requiring disassembly of the traction motor.

TABLE 3: SUPPLY RECORD OF PROPULSION INVERTER

No	Country	Transit Name	Contact Name / Tel	Performance Record	Supply Quantity
1.	USA	Northern Indiana Commuter Transportation District	Mr. Daniel J. Gorstein +1 219 874 4221	Under the running test / manufacturing	54*
2.	USA	Port Authority of New York and New Jersey	+1 212 435 7000	Under manufacture	64*
3.	Canada	British Columbia Rapid Transit Company Ltd.	Mr. Christopher B. Morris +1 604 520 3641	Under manufacture	120*

TABLE 4: SUPPLY RECORD OF AC TRACTION MOTOR

No	Country	Transit Name	Contact Name / Tel	Performance Record	Supply Quantity
1.	USA	Northern Indiana Commuter Transportation District	Mr. Daniel J. Gorstein +1 219 874 4221	Testing	8

TABLE 5: EVIDENCE OF AUXILIARY ELECTRIC SYSTEM IN-SERVICE PERFORMANCE

Item	Transit Name	Contact Name / Tel	Car Series	System Voltage	No. of Units (GTO)	No. of Units (IGBT)	Year of Supply	Performance Record
1.	Chicago Transit Authority	Mr. Walter R. Keevil +1 312 664 7200	EMU	DC 600V		1	1996	Approx. 100,000 miles
2.	Metro North	+1 212 340 3000	Subway Car	DC800V, AC13800V	70	1	1996	Approx. 200,000 miles
3.	New York City Transit Authority	Mr. Leonard Chimelewski +1 718 694 4506	Subway Car	DC 600V		346	1999 -*	Under manufacture and testing
4.	New York City Transit Authority	+1 718 330 3000	Subway Car	DC 600V	638		1985	Approx. 800,000 miles
5.	Northern Indiana Commuter Transportation District	Mr. D. Gorstein +1 219 874 4221	EMU	DC 1500V		14	2000-2001*	Under manufacture
				Total	**708**	**362**		

Remarks: * = Under Manufacture

4.2 JAPANESE EMU SUPPLIERS

There are a total of four Japanese rolling stock companies currently manufacturing bi-level or Gallery style EMUs.

- *Kawasaki Heavy Industries*
- *Kinki Sharyo*
- *Nippon Sharyo*
- *Tokyu Car Corporation*

In addition, four companies are currently manufacturing electric propulsion systems for bi-level EMUs.

- *Hitachi Limited*
- *Mitsubishi Electric Corporation*
- *Toshiba Corporation*
- *Toyo Denki*

With many manufacturers capable of producing equivalent products, North American authorities can be assured of receiving competitive bids from a number of suppliers. Appendix D provides some background on each of the above suppliers.

5 EUROPEAN TECHNOLOGIES

European countries have embraced both the electrification of railways and the adoption of multi-level passenger rail cars almost unanimously. Trains comprising passenger cars hauled by electric locomotives or electric multiple units, are common approaches to solve transportation problems in most major cities.

Rolling stock and equipment suppliers have responded aggressively to the demand for new, modern and safe technologies.

The approach to the development of new technology for subsystems and trains in Europe is quite different from that in the U.S. Here technology is often developed on a competitive basis and is owned by the manufacturers. In Europe the technologies are developed for national railways and to suit particular national requirements and environment. It occurs on a cooperative basis between the transit operators and the train manufacturers. The ownership of the design resides usually with the particular manufacturer. Thus, the design and certainly the manufacturing rights are proprietary and when a particular design is reproduced by a different manufacturer, such as the case with the Gallery cars, the new contractor must undertake new engineering work.

This approach precludes the railways from having a number of manufacturers that are able to compete for contract awards for commercial supply of the car designs. To large extent, this was not an issue as the manufacturers were selected to support the national interest in having a viable manufacturing industry. There are now, however, trends within the European Community to completely open the award of contracts to competition among the European manufacturers and to discourage national purchasing preferences.

For the propulsion equipment, the same technology development and purchasing policies apply. The principal propulsion manufacturers and their locations are listed below.

PROPULSION MANUFACTURERS

Company	Country
Siemens	Germany
Alstom	France
Adtranz	Germany
Holec	Holland

However, the recent mergers have provided more trans-European content in the propulsion equipment manufacturing. Hence, competition for this type of equipment is stronger and has a broader base in keeping with European Economic Community (EEC) directives.

There is a general trend within the Europe's railway and transit industry to use VVVF inverter and induction motor drives. The current technology of choice is Insulated Gate Bi-polar Transistors (IGBTs).

In regard to the utilization of this type of propulsion system for bi-level EMUs in North America, the rating, size, and functionality are all well within the range of those parameters that have been supplied for transit and railway trains in Europe.

5.1 EUROPEAN BI-LEVEL EMUS

The Europeans have significant experience with EMUs in revenue service. A few examples are shown below.

EXPERIENCE IN REVENUE SERVICE

Model	Country	Date of Introduction	Cars in Service
M12N	France	1992	210
TER 2N	France	1995	152
BR 445	Germany	1996	1 preseries 3-car trainset
TAF	Italy	2000	

In November 2000, it was announced that a consortium comprised of Bombardier Transportation and Alstom Transport has received a firm order from the French National Railways, Societé Nationale des Chemins de fer Français (SNCF) for 72 TER 2N NG (New Generation) electric multiple unit trainsets. The contract has options for an additional 426 vehicles. First deliveries are scheduled to begin December 2003.

5.1.1 MECHANICAL CHARACTERISTICS

The mechanical characteristics of these European bi-level cars are driven by the commuter rail application. The trains will operate at speeds of 90 mph. on lines generally dedicated to passenger traffic. This dedicated operation permits the maintenance of high track standards.

Consequently, changes in the design of the suspension systems would be needed to accommodate the North American track quality standards.

The EEC directives require the incorporation of energy absorbing design features. The railways, in cooperation with the manufacturers, have undertaken an ambitious program, including simulations and actual tests, to understand the dynamics of accidents. The results will be incorporated on standards that will apply to new rolling stock equipment. It is important to note that the outcome is not expected to create significant changes on the general philosophies, but will likely allow to produce better and safer vehicle designs. The requirements are different from those of the new FRA Rules, CFR 49, Part 238-403, which is governed by the mixed passenger and freight usage.

5.1.2 PROPULSION SYSTEM

The overhead catenary has a variety of supply conditions:

- 1,500 Vdc
- 15 kV, 16 2/3 Hz ac
- 25 kV, 50 Hz ac
- 50 kV, 50 Hz ac

This VVVF is the power source for the induction motors. The converter transforms the 25 kV, 50 Hz signal into a fixed dc voltage.

The converter is a fully controlled bridge using IGBTs. This provides an additional element of control allowing the system to respond to fluctuation in the supply voltage. This also provides more options in the control strategy for maximizing the electromagnetic compatibility of the propulsion system with other subsystems in the car and ground facilities.

5.1.3 INTERIOR ARRANGEMENTS, PASSENGER COMFORT AND AMENITIES

The European cars described in this report offer modern and attractive interiors and boarding accessibility. All cars evaluated for instance, have two large 50" to 52" wide doors per side and boarding is at the low floor, in the range of 25 to 27" from top of rail; the 2+2 seating, allowing for clear and safe aisleways; accommodations for the handicapped; large windows and excellent lighting. These features offer safe and comfortable access to the on-board facilities and amenities. With regard to the height of the low floor of the car, it is technically feasible to bring it down to 17" from top of rail, improving the access to the car in a safe manner, and helping to reduce dwell times at stations.

Following is a more detailed description of the most relevant bi-level EMUs:

5.2 TER 2N

This is the newest order for 72 bilevel EMU trainsets in Europe, placed by SNCF in France in November, 2000. The price of the initial order is 420 million Euros (US$ 385.5 million or US$ 5.345 million per unit or married-pair) and SNCF would award an option for additional 426 vehicles. These prices should not be compared to those encountered in the U.S. market, since there are usually a variety of other conditions, such as warranties, spare parts and contractual terms and conditions, affecting the price of each car.

The cars are being built by a joint venture formed by Bombardier and Alstom.

This is the fourth generation of electric traction equipment for bilevel vehicles for SNCF. It has been developed for regional transportation (local or express trains) for distances ranging from 100 to 200 km. It features a modular design, which allows the formation of trainsets of 2 to 5 units, while maintaining traction/braking performance. Each unit is a married pair of 2 cars. Passenger capacity according to SNCF's seating arrangement specifications is 210 for a single married pair, including 19 in first class, 175 in second class and 16 on flip-up seats. The total capacity is 388, including seated and standing passengers.

A similar model called the MI 2N is more specifically adapted to higher capacity requirements for services around Paris. Each train consist is formed by 5 cars and each car has 3 doors per side, for greater and faster flow of passengers.

Following a typical arrangement for SNCF, the propulsion equipment is installed in one of the married pairs, while the second is a trailer. Both cars are equipped with control cabs. Each car has two 51.2" wide doors per side. The entrance is at approximately 28 to 30" above top of rail (TOR). Only the trailer is equipped with accommodations for the handicapped, including a toilet and seating space.

Each Married Pair is 172' long, 14' high and 9.2' wide. The total weight for the Married Pair is 274,000 lbs.; the power car weight is 159,000 lbs. and the trailer 115,000 lbs.

The electrical equipment is designed to work under systems supplying 1500 Vdc and 25 kV, 50 Hz ac. There is also the possibility of working under 3000 Vdc or 15 Kv 16 2/3Hz ac. Maximum speed is 90 mph, the acceleration rate is 0.9m/s2 and the brake rate is also 0.9 m/s2.

5.3 TRENO AD ALTA FREQUENTAZIONE (TAF) EMU

TrenItalia, the operating company created in June 2000 by the Italian State Railways, is also procuring a fleet of 104 modern bilevel EMUs. The Italian contractors Ansaldo-Breda and Firema are supplying the trains. Adtranz supplies the electrical equipment. The first of these trains was introduced two years ago in commuter service in Rome.

A typical train consist is formed by four cars, including a power car, two trailers and a power car. Both power cars are equipped with control cabs at one end. Overall dimensions are:

- Length: 85'
- Width: 9.2'
- Height: 14.1'

- Weight: 136,400 lbs.

With clearances more restrictive than in the United States, the side walls/windows at the upper level taper-in quickly, reducing the interior space.

The four car consist has total passenger capacity of 841, with 469 seated and 372 standing. The seating arrangement is typically European, of 2+2, face-to-face. Each car has two large 70" wide bi-parting entrance doors per side, at 25.5 inches from top-of-rail. Each power car is equipped with one toilet room and each trailer car is equipped with one accessible toilet.

The interior of the car is very attractive, offering modern amenities and passenger comfort.

The vehicles are designed to operate at a maximum speed of 90 mph at an operating voltage range of 2000 to 4000 Vcc. The peak traction effort is 214 kN and the continuous traction effort is 147 kN. One truck per power car is equipped with traction motors, all other trucks are unpowered.

The static power system uses GTO impressed voltage inverters to feed the traction motors (two per truck). The traction drive semiconductors are cooled by a water based system which is environmentally friendly. The microprocessor control system provides redundant common vehicle functions and provides support for resident diagnostics. The low voltage command and control circuits are fed at the nominal battery voltage of 24V. A low voltage trainline provides power car battery charger redundancy.

The brake system incorporates regenerative, rheostatic, electro-dynamic braking and automatic electro-pneumatic braking.

5.4 SIEMENS

Siemens has extensive experience in the development and supply of electric traction equipment and power conditioning systems throughout the world. Siemens has not built an integrated bi-level EMU, however it has built non-powered bi-level cars for commuter services in the city of Vienna, Austria, as well as numerous single-level EMU's. Siemens has assembly plants in the United States (Sacramento, Long Beach, Ca.) and has delivered several orders of electrically propelled LRV and Metro type cars. Siemens is therefore, very familiar with FRA Rules and Regulations and related Recommended Industry Practices.

Siemens also has extensive experience in turn-key type projects, including vehicles, maintenance services and power supply and distribution systems. Siemens should be considered a serious competitor in the PCJPB Electrification project.

5.5 ADTRANZ

In cooperation with Alusuisse of Switzerland, Adtranz built the IC2000 bi-level electrically powered trains for use in commuter and intercity passenger services in Switzerland. The trains are typically formed by power and trailer cars, with the power equipment installed at one end of the car, over the trucks and immediately behind the control cab.

As with Siemens, Adtranz has extensive experience in the development and supply of electric propulsion and traction equipment for both locomotives and passenger cars. Adtranz also supplies rolling stock equipment and provide maintenance services. Adtranz has facilities in the U.S. and should be considered a serious competitor.

6 U.S. TECHNOLOGY

The only multi-level EMU ever built in the United States was the Gallery style car for the Illinois Central Gulf Railroad (ICG), whose commuter passenger rail services are now under the control of METRA. The first order was built by St. Louis Car in 1972 and the second by Bombardier in 1979, utilizing the same design. Both contractors built a total of 165 cars. The cars operate on 1500 Vdc supplied by overhead wires and the power control is through a motor driven cam. All cars and all axles are powered.

Given the latest developments in electronics and related systems, the propulsion technology used in the mid-to-late seventies can be considered obsolete.

There are however several transit authorities utilizing single level EMUs, where more modern technologies are being applied. The more recent procurements include the Bombardier M-7 cars for the Long Island Railroad, currently under construction; the Nippon-Sharyo cars built for the Northern Indiana Transportation District (NICTD), the Morrison-Knudsen M-6 cars for Metro North, and the Bombardier built Deux-Montagne cars for Montreal, among others. In addition, modern propulsion and traction technologies were also applied to cars remanufactured by Adtranz for New Jersey Transit.

In any case, it is important to note that all propulsion technology being employed in the U.S. market is of foreign origin. Mitsubishi for instance, is supplying the electrical equipment to Bombardier for the Long Island cars and Toshiba is supplying the equipment to Nippon-Sharyo. Other suppliers of electrical equipment in the United States are Alstom, Adtranz and Siemens, among the most active in the market.

6.1 M-7 LONG ISLAND RAILROAD CARS

Following is a description of the single level EMUs being constructed by Bombardier for the Long Island Railroad.

6.1.1 TRAIN DESCRIPTION

The train cars are configured for normal operation as two-car units (married pairs). Each married pair consists of two cars of different types, designated A Cars and B Cars. Train consist length under normal operating conditions can include as many as 14 cars and may be operated in consists up to 28 cars in length, but at reduced speed and performance.

The LIRR M-7 car propulsion system provides the performance required under all conditions on the electrified portions of the present Long Island Railroad and future service to Grand Central Terminal (GCT) and the Hudson and Harlem Lines of the Metro-North Railroad.

The cars are to provide commuter service up to 80 mph. In addition, each car is capable of operating in commuter service at sustained speeds of up to 100 mph.

6.1.2 CAR PROPULSION SYSTEM CONFIGURATION

The A and B cars each have four powered axles. There are two independent inverters on each car.

The propulsion system truck mounted products consist of the following:

- Traction Motors with speed sensor
- Gear Unit with ground brush

The carbody-mounted products consist of the following:

- Inverter Box
- Circuit Protection Box
- Brake Resistor

A schematic representation of two truck sets of propulsion equipment is shown in Figure 1.

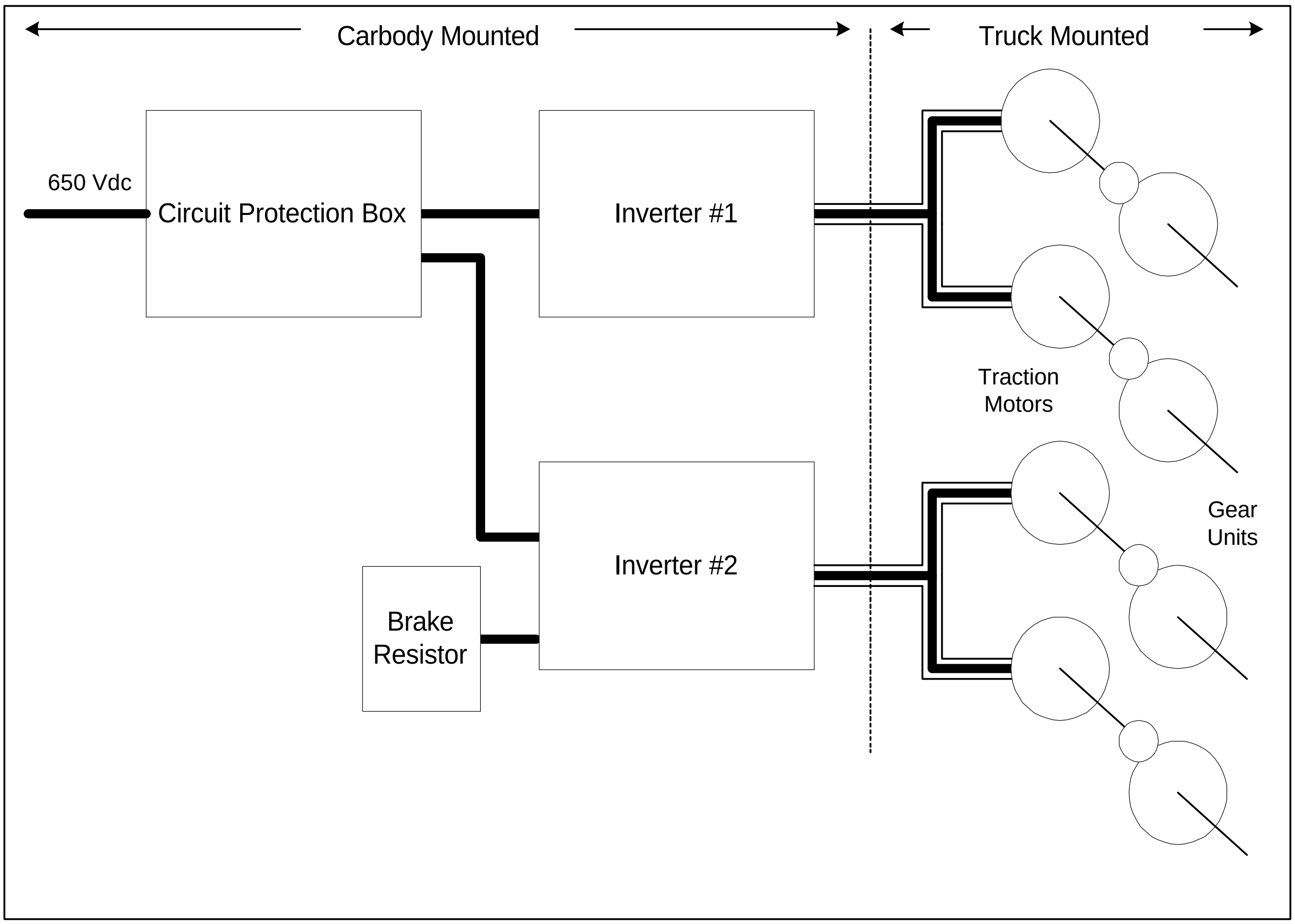

FIGURE 2: CAR PROPULSION SYSTEM EQUIPMENT

The major propulsion system components are described in the following sections.

6.1.3 INVERTER

Each inverter controls and powers two motors on a truck and has a separate and independent propulsion controller. The inverter power section consists of IGBTs. The inverter is characterized by the following ratings.

Input: 650 Vdc

Output Voltage: Variable 0 to 480 Vac, 3-phase, line voltage

Output Current: 320 amps

Rated Frequency: 70 Hz

Load: Traction Motors, two parallel connected, each approximately 260 hp(shaft)

Each inverter equipment box includes the following items of equipment:

- Inverter Module
- Line Contactor
- Charging Contactor
- Filter Inductor
- Filter Capacitor
- Propulsion Controller

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6.1.4 PROPULSION CONTROLLER

The Propulsion Controller provides the logic and control functions required to operate the inverter. It transforms the trainline signals for accelerating, cruising, coasting and braking modes from the Master Controller to the necessary frequency and voltage output from the inverter.

The Propulsion Controller is the repository for the fault and operational data collected by and for the propulsion system. It also interfaces with the Central Diagnostic System and the Portable Interface Unit to provide operational, fault and maintenance information to the train or operations or maintenance staff.

6.1.5 TRACTION MOTOR

Each car will be electrically propelled by alternating current (ac) propulsion technology. The motors are three-phase, ac induction motors with squirrel cage rotors. They are powered by a variable-voltage, variable-frequency (VVVF) supply that is created by the inverter from the 650 Vdc third rail supply. By means of the VVVF supply, the torque and speed of the traction motors are independently controllable for all operation conditions of input voltage, car loading and gradients.

The configuration is one traction motor per axle, and one inverter and an associated Propulsion Controller for each truck.

Table 6 - LIRR ac traction motor ratings and characteristics.

Type	3 phase squirrel cage rotor induction motor, self-ventilated 4 poles
Rating Category	Continuous
Output	260 hp (approx.)
Voltage	480 V
Current	320 A
Max Revolution	Approx. 6500 r/min
Frequency	70 Hz
Insulation class	Class 200

6.1.6 GEAR UNIT

The gear unit that transmits the tractive effort from the motor to the axle of the car is a parallel, single reduction type with helical type gears.

The Gear unit also comprises a flexible coupling that connects the gearbox to the output shaft of the traction motor. This is a double, internal and external, self-aligning type of coupling.

6.1.7 CIRCUIT PROTECTION BOX

The purpose of the Circuit Protection Box is to connect and isolate the propulsion system from the third rail supply and to monitor the current drawn and voltage supplied. The Circuit Protection Box includes a High Speed Circuit Breaker.

6.1.8 BRAKE RESISTOR

Electric braking is provided in which power generated by traction motors, when configured as generators, is dissipated as heat by dynamic brake resistor grids and/or is supplied to power the auxiliary loads on the train.

6.1.9 PASSENGER ACCOMODATIONS AND AMENITIES

The M-7 car is a high capacity single level car, accommodating 93 seated passengers on the typical 2+3 Northeast seating arrangement and there are two wheelchair locations. The cars have two 50" sliding doors per side with boarding from high level platforms. No steps are required. Half of the fleet (113 cars) is equipped with toilets accessible to the handicapped.

No dedicated space for bicycles is provided.

The customer and the contractor claim that the interior of the car was designed with input from passengers and employees, and offer cellular phone connections and other amenities.

The fabricated trucks and coil/pneumatic suspension system is designed to provide high quality ride to the passengers.

6.2 NICTD PROPULSION SYSTEM

The new NICTD car propulsion system incorporates state-of-the-art technology in its major systems components, which consist of four traction motors, four gear units, one inverter, one input circuit protection and one brake resistor box. The propulsion system configuration is shown in Figure 4. The minimum train formation is 3M1T (M-M-T-M).

The inverter utilizes a configuration of IGBT power semiconductors to achieve a variable-voltage variable-frequency output. The precise control over the motoring and braking thrust is achieved using the vector control method to generate a pattern of IGBT gate signals in response to a thrust command signal. Vector control is an algorithm that controls the motor torque by the independent control of two derived or equivalent currents, namely the torque current component and the magnetic flux current component.

The vector control is part of the propulsion controller that provides the logic and control functions required to operate the inverter. The propulsion controller also translates the trainline signals for accelerating, cruising, coasting and braking modes from the Master Controller to request the necessary frequency and voltage output from the inverter.

The cars are propelled by alternating current (ac) technology. The traction motors are three-phase, ac induction motors with squirrel cage rotors. Utilization of high temperature insulation, quality magnetic materials and optimal design techniques result in low weights and volumes for the traction motors.

The single reduction gear unit includes a flexible coupling that connects the gearbox to the output shaft of the traction motor

Input circuit protection and isolation is accomplished with a high-speed circuit breaker. Monitoring of the current drawn and the supply voltage is also provided.

General characteristics of the propulsion system are presented in Table 1.

TABLE 6: NICTD PROPULSION SYSTEM GENERAL CHARACTERISTICS

1.	Inverter	VVVF with vector field control, IGBT, 1100 kVA, 0 to 1100 V, 0 to 130 Hz, natural convection cooling
2.	Traction Motor	Three-phase, squirrel cage induction motor, 150 kW, 1100 V, 102 A, 1755 rpm, 4 poles
3.	Motor speed, maximum safe	Typically 6000 rpm
4.	Motor cooling	Forced air
5.	Dynamic brake resistor design	Edge wound, ribbon steel element
6.	Resistor cooling type	Natural convection
7.	Gear Box	Single reduction gear, approx. 4:1

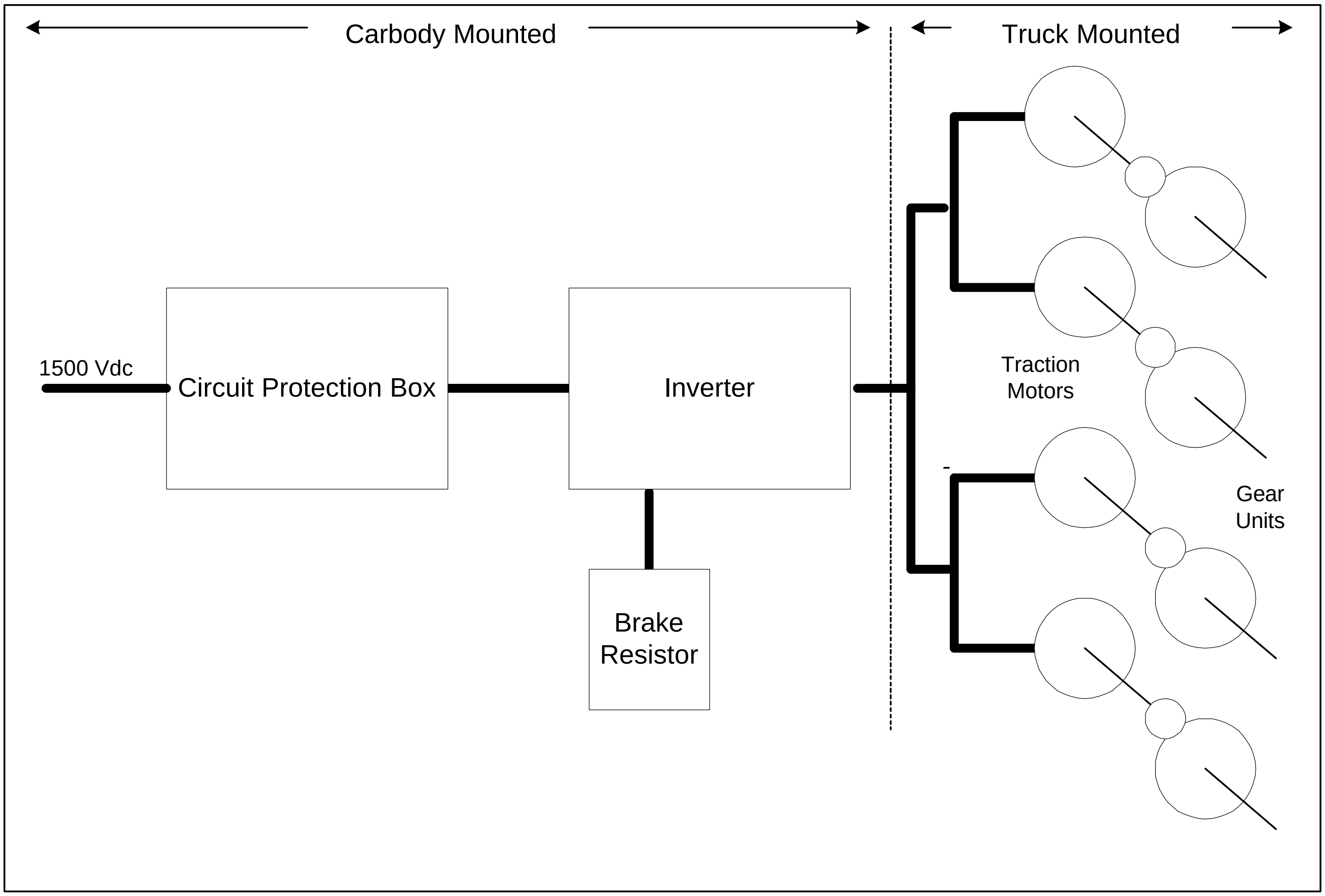

FIGURE 4: NICTD PROPULSION SYSTEM EQUIPMENT

With regard to passenger accommodations and amenities, this single level, stainless steel car offers the typical U.S. commuter vehicle arrangement, as follows: two 36” entrance doors per side at the end vestibules, with steps for boarding from low level platform; 2+3 seating arrangements to accommodate 94 seated passengers and 2 wheelchairs. There is no space allocated for bicycles.

7 U.S MANDATORY REQUIREMENTS AND INDUSTRY STANDARDS

On May 12, 1999, the Federal Railroad Administration (FRA) issued comprehensive Rules addressing the design, construction and maintenance of rail passenger cars, CFR 49 Parts 238 and 239. Tier I of the Rules apply to "…railroad passenger equipment operating at speeds not exceeding 125 mph…". Further, the Rules establish the effectivity of the requirements as follows: "Unless otherwise specified, these requirements only apply to passenger equipment ordered on or after September 8, 2000 or placed in service for the first time on or after September 9, 2002.

The Rule also states that: "The structural standards of this subpart…do not apply to passenger equipment if used exclusively on a rail line:

(i) with no public highway-rail grade crossings;

(ii) on which no freight operations occur at any time;

(iii) on which only passenger equipment of compatible design is utilized;

(iv) on which trains operate at speeds not exceeding 79 mph.

The Rule provides for alternative compliance by demonstrating "…at least an equivalent of safety in such environment with respect to the protection of its occupants from serious injury in the case of a derailment or collision"

Given the likelihood that JPB's equipment:

a) will or could operate in the future on the same lines as other freight and passenger trains; and…

b) that it will likely operate at speeds higher that 79 mph in the foreseeable future,

it is therefore reasonable to assume that any new rolling stock equipment, electrically powered or not, will be subject to the FRA Rules, Part 238, as currently written. The likelihood of obtaining any waivers or offering alternative solutions is very low.

In addition to mandatory requirements (FRA Rules and Regulations) the commuter rail industry is also guided by Recommended Industry Standards and Practices developed by the American Public Transportation Association (APTA) under full participation and consensus of commuter rail operators and agencies. These Recommendations are a modern version of the old Association of American Railroads (AAR) Recommended Practices for the design and construction of rail passenger cars. The Recommendations are consistent with the FRA Rules and although do not have the mandatory force of the Rules, commuter rail operators are committed to comply with

With regard to electrical equipment, more specifically propulsion inverters, traction motors, and auxiliary electric systems of European and Japanese origin, state-of-the-art technologies have already been implemented in the U.S., adapted to meet all industry practices and standards.

Appendix C provides further detail on the typical requirements and standards that would have to be met by a propulsion system. The following requirements have been addressed:

- Noise, Vibration, Ride Quality
- Electromagnetic Interference and Compatibility
- Reliability
- System Safety Program
- AC Power Supply
- Low Voltage Power System
- Equipment Ventilation
- System Components
- Component Qualification Tests
- System Conformance Tests

Typical standards associated with the requirements are also included in Appendix C.

Foreign manufacturers have experience with IEEE and NEMA motor standards. Also many IEC standards are used in NA for the detailed specification of traction equipment. As a result only minor changes in design would be required to meet U.S. requirements.

The electromagnetic compatibility issues expressed in the U.S. Standards are more specific to our operating environment and practices, therefore some equipment design changes would be required.

Only minor design changes would be required for the converter/inverter equipment. Most of those would be associated with the input supply voltage and frequency, and the inverter output voltage and frequency.

All standards requirements are manageable and achievable through the design process.

8 CONCLUSIONS AND RECOMMENDATIONS

With the development of electrical and electronic technologies, propulsion and traction equipment in Europe and Japan have made a dramatic advance over the past 5 to 7 years. These developments have resulted in more reliable and powerful packages, easier to maintain and to operate. It also has allowed assembling the equipment in a more efficient package, especially when applied to bi-level passenger rail cars.

Both European and Japanese electrical propulsion technologies can be easily adapted to the particular demands and requirements of the North American railroad environment.

With regard to the mechanical components of the car, especially car body structures and size, it will need to be adapted or designed in compliance with the Rules and Regulations currently in effect in the United States. While the PCJPB will be able to learn from a variety of modern interior arrangements and amenities, door location and size and floor and stairway layouts, and adopt the layout most suitable to the specific levels of safety and comfort to the passengers, the final design of the vehicle must be in compliance with mandatory rules and regulations in force in the United States. As discussed before, it is highly unlikely that foreign car body designs will be allowed to operate as is.

With specific regard to the electrical characteristics of the double deck EMU units that are in revenue service in Japan, the Japan Railway Companies have standardized on the use of a VVVF inverter system with an induction motor drive as a means of achieving high levels of torque and low weight. In addition, the VVVF system gives them the advantage of lower maintenance costs over the life of the car.

The characteristics of supply and power levels mentioned in the particular example of the Series E4 Shinkansen are different and much larger respectively than would be needed for this particular application in California. Nevertheless, it is stressed that the technology is both transferable and scalable. Therefore the characteristics found in the inverter induction motor system for Shinkansens are readily applicable to EMUs and subway cars. The front end section, whether it is a transformer/rectifier or converter, will have to be selected on the basis of the type of power supply that is available. Since it is anticipated that the power will be 25 kV 60 Hz ac, the existing propulsion equipment for the E4 and similar Shinkansens can be readily adapted to the particular requirements for the US bi-level EMU.

The propulsion and auxiliary power systems used by the various Japan railway companies represent the state of the art with proven revenue service.

With regard to European technologies for rail passenger services, the industry has made significant progress over the last few years. Given the increasing demand, bi-level cars have now been adopted in most European countries, and because of the fact that most of those railroads are electrified, the rolling stock is powered by electricity. The arrangement of the power equipment is typically found in one or two cars in the train consist, formed by one or more trailer cars.

With regard to the location and power of the propulsion equipment and the formation of each unit (consisting of one or more cars, powered or trailer), the modularity of the components, a concept truly optimized by European and Japanese manufacturers, permits a variety of options. The arrangement and size will depend on the physical characteristics of the infrastructure (vertical and horizontal geometries), the number of stops along the route, the capacity of the trains (length and trailing loads) and the trip time requirements (acceleration and deceleration rates, maximum speed).

The strategic arrangement and size of the power equipment will also permit the formation of different size consists, addressing peak and non-peak or regular/express services in an efficient manner.

It is not prudent at this time to attempt to determine the type of unit and train formation most appropriate for the Caltrain services. The power arrangement should be determined through simulation of a variety of reasonable options, once all elements and requirements of the service and the corresponding duty cycle of the equipment are properly and correctly defined. At this time one can only assume that certain power arrangement would be better than the other, based on the experience of the European and Japanese users. But this would be speculative and non productive.

A critical part in reaching an intelligent solution is, for instance, energy consumption. Through simulations one can adopt optimum acceleration and deceleration rates, consistent with the geometries of the infrastructure, or perhaps delay the trip 2 or 3 minutes, and obtain significant benefits on consumption of energy and cost.

Alstom, Siemens, Adtranz and Ansaldo-Breda have all developed state-of-the-art propulsion and traction equipment. Bombardier and CAF, among others have ample experience in integrating electrical equipment to mechanical components, including bi-level passenger cars.

In summary, both European and Japanese manufacturers are highly capable and qualified to produce rolling stock equipment adapted to the U.S. technical and regulatory railroad environment.

It is important however to express a cautionary note at this time. If the decision is made to adopt EMU rolling stock for the Caltrain electrified system, the eventual bi-level EMU suitable for the services will likely be a new vehicle, formed by certain major existing components described in this report. Under this scenario, the process of integrating all major systems and components will be a critical aspect of the project. The ultimate long-term performance of the vehicles will depend heavily on how well this process is approached and managed.

Unfortunately, history is not on our side in the United States. The most recent example of attempting to match certain foreign rolling stock technologies with the U.S. rail infrastructure, namely the Acela high-speed trains for the Amtrak Northeast Corridor service, is finding severe difficulties. Ultimately, there is no doubt that most if not all technical problems will be solved, as demonstrated by European and Japanese operators, but proper time for development, testing and commissioning must be allowed. While European and Japanese manufacturers have indeed demonstrated their capabilities in their own countries, it must be remembered that they work closely with the railways during the development of specifications and development of the vehicles. In the United States the environment is different, where a variety of technical and legal factors contribute, right or wrong, to a more distant relationship between the customer and the contractor.

It should also be remembered that carbuilders are good engineers but have little experience on operations, and only recently are getting involved in maintenance contracts. The lack of solid operating experience contributes to designs that do not perform as efficiently during revenue services. The best approach to address these problems is to enter into a contractual relationship that is truly a partnership. If one wins, the partner wins as well. If one looses, the other one looses as well. This is not a common approach in the United States.

Procurement of the equipment is also a related issue affecting the results. European manufacturers have gained experience in offering supply, maintenance and even operation of the services in some cases. This procurement approach has advantages and disadvantages, depending on the structure and mandate of the customer, labor issues, how the project is funded and the strings attached to the funding.

Once those issues have been resolved and clarified, then the specification of the equipment can be undertaken. This is extremely important because the scope of the procurement will drive the type of specification to be prepared. For instance, if the procurement involves both supply and maintenance of equipment, then the customer can enhance and enforce performance guarantees by the contractor, including penalties and incentive payments. Under this scenario the specification can and should be written by defining performance requirements only. If on the other hand the scope of the procurement involves only the supply of the equipment and it is limited to a low-bid process, then the specification should define design issues with more clarity.

As discussed before, procurement laws and policies affecting the PCJPB would drive the process.

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Based on the technical evaluation of locomotives and EMU type rolling stock equipment, the decision to use either should be based on financial considerations and economic results. The economic decision should be based on life cycle cost analysis, determining the overall initial and operating cost of the equipment over the life of it. However, while this may be the most appropriate approach, the available data or assumptions may not permit an accurate assessment and determination. This is due to the availability of true maintenance and operating costs reflecting the conditions in the United States, therefore data from foreign sources will need to be modified and mixed with local assumptions.

A more reasonable alternative is to prepare Performance Specifications and allow the bidders to offer either locomotive hauled train sets or EMU's. This process must be carefully laid out and properly managed in order to ensure optimum selection.

With regard to car interior arrangements, amenities, colors and materials, the Europeans have generally done a better job in addressing passenger needs and comfort.. We must therefore learn from that experience and use it in the best interest of Caltrain users. This can be achieved through the Performance Specification process, clearly establishing the performance parameters. Other critical aspects of this process are as follows:

- clear definition of the evaluation process and selection criteria of the bids;
- clear definition of the terms and conditions of the contract;
- realistic development and testing schedules, to avoid false expectations and unreliable services;
- serious consideration of vehicle prices, as affected by volume. For instance, METRA in Chicago recently awarded a contract to Nippon-Sharyo for 300 Gallery style cars at a price of $ 1,329 million average, each. The last purchase of 20 Gallery cars by PCJPB resulted on a unit price of $ 1.6 million for trailers and $ 1,734 million each for a cab car.

RVB+A

January 2001

APPENDIX A: COMPARISON OF JAPANESE DOUBLE DECK CAR EMUS

	Model	Double Deck Electric Railcar Series 215	Shinkansen EMU Series 100	Shinkansen Double Deck EMU Series E1	Shinkansen Double Deck EMU Series E4
Electric System		1.5 kVdc	25 kVac, 60 Hz	25 kVac 50 Hz	
Train set	Consist	12 motored cars and 4 trailers	4 motored cars and 6 trailers	6 motored cars and 6 trailers	4 motored cars and 4 trailers
	Seating capacity	1319	1010	1235	819
	Tare Weight (tons)	851	368.5	692.5	428
Performance	Maximum service speed	230 km/h 142.9 mi/h	120 km/h 74.5 mi/h	240 km/h 150 mi/h	
	Acceleration at starting	1.6 km/h/s		1.6 km/h/s	1.65 km/h/s
	Rated traction motor output	185 kW		410 kW	420 kW
Car body	Structure	Steel, with under floor suspended equipment	Stainless steel, except for leading car and part of under frame	Steel with airtight design	Aluminum alloy
	Length (mm)	M – 25,800 T – 24,500	M - 20,000 T - 20,500	M -26,050 T -25,000	M - 25,700 T - 25,000
	Width (mm)	3380	2,900	3430	3,380
	Height with pantograph raised (mm)		4070		
	Height with pantograph folded	M - 4,000 T - 4,490	3980	Car 1 & 12: 4485 Cars 2 – 11: 4493	4485
	Distance between bogie centers (mm)	17,500	M - 14,000 T - 14,150	17,500	
Bogie	Structure	Air suspension type 2-axle bogie with gear coupling device	Bolster less		
	Rigid wheel base (mm)	2,500	2,100	2,500	
	Wheel Diameter (mm)	910	860	910	

Model		Double Deck Electric Railcar Series 215	Shinkansen EMU Series 100	Shinkansen Double Deck EMU Series E1	Shinkansen Double Deck EMU Series E4
Gear Ratio		16:83 = 1:5.19	27:65 = 1:2.41	69:19 = 3.63:1	94:26 = 3.62:1
Principle Equipment	Pantograph	6 pantographs with slightly movable contact strips 3 pantographs when a bus is installed between 2 pantographs	PS21	2 per consist	
	Main Transformer	2,510 kVA 6 sets per consist	Not Applicable	3,700 kVA 3 sets per consist	4,105 kVA 2 sets per consist
	Main Rectifier		Not Applicable	Converter controls one inverter 6 per consist	Converter (Gifts) controls one inverter 4 per consist
	Traction Motor	230 kW 3 per car	Series dc motor	3-phase asynchronous motor 410 kW	3-phase squirrel cage asynchronous motor, continuous rating 420 kW, forced air ventilation
	Power Source	Phase controlled rectifier	Cam controller	Inverter (controls 4 motors)	Inverter (Gifts)
	Air Conditioner	Semi-concentrated heat pump 2 units per car	2 units/car, 20,000 kcal/h, sheathed resistance heater	Roof mounted centralized air-conditioning equipment 37,500 kcal/h x 2, heater 30 kW x2	Integrated air conditioner cooling system: 37,500 kcal/h, heating capacity: 30 kW

	Model	Double Deck Electric Railcar Series 215	Shinkansen EMU Series 100	Shinkansen Double Deck EMU Series E1	Shinkansen Double Deck EMU Series E4
Control	Powering	Continuous phase control by thrusters	Series/parallel switching with resistance	VVVF vector field control Parallel Card an drive system	
	Braking	Electric command dynamic brake, eddy current brake and disc brake	Electric command air brake with regenerative braking, straight air reserve braking, holding braking, preventative snow braking	Electric command airbrake with regenerative brake	
	Auxiliary Power Supply System	Static inverter	3-phase, 440 V, 190 kVA static inverter	Static inverter 12 kVA: Type 1 - dc/constant voltage ac, 100V, 50 Hz Type 2 – unregulated ac 100 V, 50 Hz 3 units per consist	Static inverter 16 kVA Type 1 - dc/constant voltage ac, 100V, 50 Hz Type 2 – unregulated ac 100 V, 50 Hz 2 units per consist

APPENDIX B: COMPARISON OF JAPANESE ELECTRIC PROPULSION SYSTEMS

	Model	Double Deck Electric Railcar Series 215	Shinkansen EMU Series 100	Shinkansen Double Deck EMU Series E1	Shinkansen Double Deck EMU Series E4
Propulsion System					
Supply	Voltage	25 kV	1.5 V	25 kV	
	Frequency	60 Hz	Dc	50 Hz	
	Current Collector Configuration	Pantograph			
Protection	High Speed Circuit Breaker	Vacuum		Vacuum	
Inverter	Continuous Power Rating		N/A		
	Power Semiconductor Type	Thruster	N/A	IGBT	
	Traction Motors Per Inverter		N/A	4	2
	# Of Inverters Per Car			1	2
Traction Motor	Type		MT61 Dc motor	3-phase squirrel cage asynchronous motor	
	Number of Poles			4	
	Output Continuous Power Rating			410 kW	420 kW
	Voltage (max)		1,500 V	1850 V	
	Current (max)			166 A	
	Frequency (max)		N/A	130 Hz	
	Cooling System			Forced ventilation	
	Traction Motors per Car		4	4	
Drive Method	Description			Parallel Cardan drive with gear coupling	Parallel Cardan drive with flexible gear coupling
	Gear Ratio	1:2.41	1:5.19	1:3.63	1:3.62

	Model	Double Deck Electric Railcar Series 215	Shinkansen EMU Series 100	Shinkansen Double Deck EMU Series E1	Shinkansen Double Deck EMU Series E4
Propulsion System					
Braking System	Description	Electric command dynamic brake, eddy current brake and disc brake	Electric command air brake with regenerative braking, straight air reserve braking, holding braking, preventative snow braking	Electric command airbrake with regenerative brake	
Control System	Type	Continuous phase control by thyristor	Series parallel connection rheostatic control, superposed field excitation control (with regenerative braking and constant speed control)	VVVF inverter system 3-step PWM control Vector field control	

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APPENDIX C: TYPICAL US REQUIREMENTS AND STANDARDS

Requirement	Equipment Affected	Standard
Noise, Vibration, Ride Quality		
Equipment Noise Prior to Installation on Vehicle	Traction motors	IEC 349-2
Vibration and Impact Loads	All vehicle equipment	IEC 61373
Electromagnetic Interference and Compatibility		
Radiated Emission Limits	All vehicle equipment	FTA-MA-06-0153-85-11, MIL-STD-461A, and SAE Recommended Practice ARP 1393, 5/3/76
Conductive Emission Limits	All vehicle equipment	FTA-MA-06-0153-85-6, Method RT/CE02A
Inductive Emission Limits	All vehicle equipment	FTA-MA-06-0153-85-8, method RT/IEO1A
Reliability		
Reliability and Failure Analyses	System hardware and software design	MIL-HDBK-217 or certified field failure data
System Safety Program		
General	All vehicle equipment	MIL-STD-882C
Applicability of MIL-STD-882C	All vehicle equipment	MIL-STD-882C
AC Power Supply		
General Requirements	Inverters	IEEE 11
	AC power supplies	IEEE P1476
Low Voltage Power System		
General	LVPS and battery	IEEE P1476
Storage Battery		
Emergency Battery Cut-Out Switch	Battery Circuit	NFPA 130 Chapter 5-3.9
Equipment Ventilation		
Ventilation Blowers	Equipment and traction motor ventilation blowers	IEEE 11
		NEMA MG-12.06
		IEEE 11
System Components		

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Requirement	Equipment Affected	Standard
Traction Motors	Traction Motor	IEC 349-2
		IEEE 11
		ANSI/AFBMA
		NFPA 130
Gear Drive	Gear Units	ANSI/AFBMA
Dynamic Brake Resistors	Brake Resistors	NFPA 130
Component Qualification Tests		
Motors		
AC Traction Motors	Traction Motor	IEEE 11 & IEEE 112
		IEC 349
AC Auxiliary Motors	AC Auxiliary Motors	IEC Publication 349 or IEEE Standard 112
DC Auxiliary Motors	DC Auxiliary Motors	IEEE Standard 11 or IEC Publication 349
System Conformance Tests		
Motors	All Motors	IEC Publication 349, IEEE Standard 11, or IEEE 112, NEMA MG 1-12.06

PASSENGER ACCOMMODATIONS IN THE DOUBLE DECK SHINKANSEN EMU E4

CAR TYPE	**Tc**	**M1**	**M2**	**T**	**1.**	**Mp**	**Ms**	**Tpsc**	**M – motor car** **T – trailer car**
CAPACITY	817 passengers for 8 car consist; 1634 for 16 car consist								
2ND floor	40	64	64	55	55	55	36	18	
Flat		14		14		12			
1st floor	35	55	55	55	55	55	55	25	
Total	**75**	**133**	**119**	**124**	**110**	**122**	**91**	**43**	
EMPTY WEIGHT	53.3	52.3	56.9	50.3	51.2	52.9	56.9	54.2	428 (t)
LENGTH (ft' ins'')	84' 4''	82' .25''						84' 4''	
WIDTH	11' 1''								
HEIGHT	14' 8''								
CLASS	2	2	2	2	2	2	1	2	
DOORS	4	4	4	4	4	4	4	4	
FACILITIES	T; Vending m/c.	Ph	Ph	Vending m/c	Ph; WhC T	Ph; WhC		Wh C lift; Wh C T	T – toilet; Ph phone; WhC wheel chair
EXT CAR INFO	Car No.; Destination, train name; reserved seats								
INT CAR INFO	Car No.; Departure/arrival times; station stops; facilities info; announcements; news								

ALL CARS ARE AIR-CONDITIONED

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PASSENGER ACCOMMODATIONS IN THE DOUBLE DECK SHINKANSEN EMU E1

CAR TYPE	**Tc1**	**M1**	**M2**	**T1**	**T2**	**M1**	**M2**	**Tpk**	**Tps**	**M1s**	**M2s**	**Tc2**
CAR NO.	1	2	3	4	5	6	7	8	9	10	11	12
CAPACITY	86	121	121	135	124	110	110	91	75	91	91	80
EMPTY WEIGHT	56.2	59.2	61.2	53.7	53.6	59.2	61.7	55.2	54.6	59.4	62	56.5
LENGTH	85’ 6’’	82’ .25’’										85’ 6’’
WIDTH	11’ 3’’											
HEIGHT	14’ 9’’											
CLASS	2	2	2	2	2	2	1&2	2	1&2	1&2	1&2	2
DOORS	4	4	4	4	4	4	4	4	4	4	4	4
FACILITIES	T;	Vending m/c	Ph	T: V m/c	T; Ph;	Vending m/c		Res. T; Wh C lift; Wh C-T	T; WhC	V m/c		T
EXT CAR INFO	Car No.; Destination, train name; reserved seats											
INT CAR INFO	Car No.; Departure/arrival times; station stops; facilities info; announcements; news											

All cars are air-conditioned

SEATING CAPACITY 1235 FOR A 12 CAR CONSIST

DRAFT

PASSENGER FACILITIES IN THE DOUBLE DECK EMU 215

CAR TYPE	Mc1	M'1	T	T'	T'	Ts	T's	T	M'	Mc
CAR NO.	1	2	3	4	5	6	7	8	9	10
CAPACITY	64	120	111	120	120	90	90	111	120	64
Empty weight	56.2	59.2	61.2	53.7	53.6	59.2	61.7	55.2	54.6	59.4
Length	M cars 65' 7''; T cars 67' 3''									
Width	9' 6''									
Height	13' 4''									
DOORS	4	4	4	4	4	4	4	4	4	4
FACILITIES		Ph	T			T	Ph	T	Ph	
INT CAR INFO	station stops; facilities info; announcements; emergency instructions									

All cars are air-conditioned

Seating capacity 1010 for a 10 car consist; 1522 for a 15 car consist

APPENDIX D: PHOTOGRAPHS

FIGURE 3: SHINKANSEN DOUBLE DECK SERIES E1

FIGURE 4: SHINKANSEN DOUBLE DECK EMU SERIES E4

APPENDIX E: COMPARISON OF DOUBLE-DECK CAR EMUS

	Model	Double-deck EMU TER 2N	Double-deck EMU M12N (SNCF)	Double-deck EMU BR 445
Electric System		25 kV, 50 Hz AC	25 kV, 50 Hz	15 kV, 16 2/3 Hz
Trainset	Consist (minimum or basic unit)	1 motored car 1 trailer car	5 car consist	1 motored car (MC1) 1 center coach (CC) 1 motored car (MC2)
	Seating capacity	338	Total consist - 550	320/car
	Tare Weight (tons)	M – 72.3 T – 52.2	Total consist - 305.34	Total consist - 197.3
Performance	Maximum service speed	230 km/h (142.9 mi/h)	140 km/h (87 mi/h)	140 km/h (87 mi/h)
	Acceleration at starting	0.9 m/s^2		1.0 m/s^2 (3.3 ft/s^2)
	Rated traction motor output		3,500 kW	1,800 kW
Carbody	Structure			Light-weight aluminum
	Length – m (ft.in.)	52.5 (172’ 3”)	112 m (367’ 5”)	82.27 (269’ 11”)
	Width – m (ft.in.)	2.82	2.9 (9’ 6”)	2.77 (9’ 1.25”)
	Height with pantograph raised			
	Height with pantograph folded – m (ft.in.)	4.32		600
	Distance between bogie centers (mm)	17,500		
Bogie	Structure			
	Rigid wheel base (mm)			
	Wheel Diameter (mm)			
Gear Ratio				
Principle Equipment	Pantograph	1 pantograph per consist		1 pantograph per consist
	Main Transformer			
	Main Rectifier			
	Traction Motor			
	Power Source			
	Air Conditioner			
Control	Powering			
	Braking			
	Auxiliary Power Supply System			

APPENDIX F: TYPICAL US REQUIREMENTS AND STANDARDS

Requirement	Equipment Affected	Standard
Noise, Vibration, Ride Quality		
Equipment Noise Prior to Installation on Vehicle	Traction motors	IEC 349-2
Vibration and Impact Loads	All vehicle equipment	IEC 61373
Electromagnetic Interference and Compatibility		
Radiated Emission Limits	All vehicle equipment	UMTA-MA-06-0153-85-11, MIL-STD-461A, and SAE Recommended Practice ARP 1393, 5/3/76
Conductive Emission Limits	All vehicle equipment	UMTA-MA-06-0153-85-6, Method RT/CE02A
Inductive Emission Limits	All vehicle equipment	UMTA-MA-06-0153-85-8, method RT/IEO1A
Reliability		
Reliability and Failure Analyses	System hardware and software design	MIL-HDBK-217 or certified field failure data
System Safety Program		
General	All vehicle equipment	MIL-STD-882C
Applicability of MIL-STD-882C	All vehicle equipment	MIL-STD-882C
AC Power Supply		
General Requirements	Inverters	IEEE 11
	AC power supplies	IEEE P1476
Low Voltage Power System		
General	LVPS and battery	IEEE P1476
Storage Battery		
Emergency Battery Cut-Out Switch	Battery Circuit	NFPA 130 Chapter 5-3.9
Equipment Ventilation		
Ventilation Blowers	Equipment and traction motor ventilation blowers	IEEE 11
		NEMA MG-12.06
		IEEE 11
System Components		

Requirement	Equipment Affected	Standard
Traction Motors	Traction Motor	IEC 349-2
		IEEE 11
		ANSI/AFBMA
		NFPA 130
Gear Drive	Gear Units	ANSI/AFBMA
Dynamic Brake Resistors	Brake Resistors	NFPA 130
Component Qualification Tests		
Motors		
AC Traction Motors	Traction Motor	IEEE 11 & IEEE 112
		IEC 349
AC Auxiliary Motors	AC Auxiliary Motors	IEC Publication 349 or IEEE Standard 112
DC Auxiliary Motors	DC Auxiliary Motors	IEEE Standard 11 or IEC Publication 349
System Conformance Tests		
Motors	All Motors	IEC Publication 349, IEEE Standard 11, or IEEE 112, NEMA MG 1-12.06

APPENDIX G: TER 2N DOUBLE-DECK EMU

APPENDIX H: SUPPLIER OVERVIEW

1. Bombardier Transportation

Bombardier Transportation is a world leader in the manufacturing of passenger rail cars, is responsible for all of Bombardier's operations in the field of rail transportation equipment. With a workforce of over 16,000 employees, Bombardier Transportation operates 24 manufacturing facilities in Austria, Belgium, Canada, China, Czech Republic, France, Germany, Mexico, Russia, Switzerland, United Kingdom and United States.

Bombardier Transportation offers a complete range of urban, suburban and intercity/high-speed vehicles, as well as integrated transit systems for turnkey projects; locomotives for passenger trains; bogies; components; and freight wagons. Bombardier also provides services such as operations and maintenance of rolling stock and refurbishment.

Bombardier is well established in the U.S. Market and with its access to European technologies, the company is a serious and competitive candidate.

2. Alstom Transport

Alstom Transport is a manufacturer of trams, metros, light rail vehicles and regional and intercity trainsets for all types of passenger transport.

In addition, Alstom manufacturers diesel, electric and diesel-electric locomotives for applications ranging from TGV power cars to freight or shunting locomotives, and provides a full rail transport network signaling systems, sub-systems and equipment components.

Over 550 of Alstom's Very High Speed TGV type trainsets are in operation in seven countries. In addition, they have more than 1,600 Light Rail Vehicles, 30,000 electric and diesel-electric locomotives, 26,000 EMUs and DMUs and 4,500 double-deck trainsets in operation worldwide.

With the acquisition of Morrison-Knudsen, Alstom has now a more visible presence in the United States, although the company has a long history of supplying the market. Alstom is currently supplying bi-level cars to Amtrak is rehabilitating electric cars and locomotives for WMATA, in Washington, D.C. and Amtrak respectively. Alstom is thoroughly familiar with all U.S. Rules, Regulations and industry practices.

3. Siemens

Siemens is a large supplier of rolling stock equipment and electrical components. Siemens produces people-movers, LRVs, Metros and mainline cars and locomotives. Siemens is also a large supplier of power supply systems for railroads and is involved in several turnkey type projects. In addition, it provides equipment and systems maintenance and operations.

Siemens has two plants assembling rolling stock equipment in the United States. As with Alstom, Siemens is very familiar with U.S. Rules and Regulations and industry practices, therefore it will likely be a strong competitor on the JPB electrification project.

4. Adtranz

As with Siemens and Alstom, Adtranz is also a worldwide supplier of rolling stock equipment, railroad electrification systems and equipment and maintenance and operation services. Adtranz has plants in the United States, however it has disposed of an assembly plant in Elmira, NY.

Adtranz has supplied electrically powered rolling stock equipment to the U.S. market, including passenger cars and locomotives. Adtranz is currently filling an order for 10 electric locomotives for New Jersey transit Corp.

The effects of a recent announcement by Bombardier to acquire Adtranz can not be fully measured at this time. If the acquisition is approved by the European authorities, Bombardier will then be the beneficiary of all the technologies available to Adtranz.

5. Ansaldo-Breda

Ansaldo-Breda is the result of the recent merging of two of the Italian firms developing and manufacturing rail rolling stock and electrical systems. While Breda continues to be an active participant in the U.S. rail vehicle market, Ansaldo has dedicated its resources to the supply of electrical power equipment and signaling and train control systems. The combination makes it a strong competitor in the U.S. market. The new firm has state-of-the-art technologies to offer to the rail industry.

Ansaldo-Breda does not have rolling stock assembly facilities in the United States.

6. Hitachi Limited

Hitachi, Ltd. was founded in 1910. The company is a leading electronic/electrical equipment manufacturer with a global network.

Hitachi is a developer and manufacturer of mass transit rapid and railway systems for the international rail transportation industry, including high-speed Shinkansen electric cars, straddle-type monorails and linear motor-driven railcars for subway applications. The company has also developed its own IGBT Inverter product for rail propulsion.

7. Kawasaki Heavy Industries, Inc.

Over the years, Kawasaki Heavy Industries, Inc. (KHI) has expanded from its origins in shipbuilding to become a global leader in building rolling stock. It also builds aircraft, machinery, plants and equipment, bridges, motorcycles and more.

KHI manufactures rolling stock including electric and diesel locomotives, electric cars, passenger coaches, diesel rail cars (DMU's), automated guideway transit systems, monorail cars, light rail vehicles, freight cars and tank cars at their Hyogo Works, near Tokyo. KHI's *subsidiary* company, Kawasaki Rail Car, has a plant in Yonkers, New York.

8. Kinki Sharyo Co., Ltd.

Kinki Sharyo Co., Ltd. was established as Tanaka Sharyo in 1920. The company is one of the leading manufacturers of rolling stock in Japan. It also makes metal doors and sashes for buildings and various types of industrial equipment. Manufacture of rolling stock and its parts and maintenance services accounted for 57% of fiscal 1999 revenues. The company has one consolidated subsidiary in the United States. The company is a subsidiary of Kinki Nippon Railway Co., Ltd., which holds 50.17% of issued stock.

9. Mitsubishi Electric Corporation

Mitsubishi Electric Corporation (MELCO) was established in 1921 with the separation of the electrical machinery division from Mitsubishi Shipbuilding's Kobe shipyard. The company develops, manufactures and market a broad range of electrical equipment in fields as diverse as home appliances and space electronics.

Propulsion equipment for railways and transit systems is included with industrial products and automation equipment, which constitutes 16% of its total revenue.

10. Nippon Sharyo Ltd.

For over 90 years, Nippon Sharyo Ltd. has been manufacturing railroad vehicles. The company has three main segments; its largest manufactures trains, including cars for the Shinkansen, the world-famous Japanese high-speed bullet trains. Nippon Sharyo also manufactures other transportation equipment such as railway cars and subway trains. More than 90% of the company's sales occur within Japan.

11. Toshiba Corporation

Toshiba Corporation was founded in 1875. It is engaged in research and development, manufacture, and sale of a range of electrical products for railways and transit systems.

The power and industrial systems which has 10% of Toshiba's total revenues, designs and manufactures rail products. The Fuchu complex near Tokyo and the Houston plant are the centers for propulsion systems.

12. Tokyu Car Corporation

Tokyu Car Corporation was established in 1946. The company manufactures railway rolling stock for Tokyu Corporation, Japan Railway and other railway operators. Tokyu Car Corporation also manufactures special-duty vehicles including trailers, tank lorries and dump trucks. Rolling stock generates 38% of its total sales revenue.

13. Toyo Denki

Toyo Denki Seizo K.K. was established in 1918 to manufacture electrical equipment including generators and control equipment for railway operations. The company now manufactures electrical switchboards and controls, generators and motors for general industrial use; electrical equipment for rolling stock, railway ticket vending machines and other equipment for railway use. Electrical equipment for railway operations accounted for 60% of fiscal 1999 unconsolidated revenues. The company has eight consolidated subsidiaries that are engaged in the manufacture, maintenance services, repairs and supplies of electrical equipment and rolling stock in Japan.