
Section 4

ELECTRIC ROLLING STOCK EQUIPMENT POWER

4.1 EQUIPMENT DESIGN AND CONSTRUCTION REQUIREMENTS

The rolling stock equipment to be selected must be designed and built in full accordance with the rules and regulations issued by the Federal Railroad Administration (FRA) and the Recommendations issued by the American Public Transportation Association (APTA). On May 12, 1999, FRA issued comprehensive rules addressing rail vehicle design and construction in accordance with operating speeds. Tier I of the rules apply to "...railroad passenger equipment operating at speeds not exceeding 125 mph..." "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 fact that JPB's equipment: a) operates, or may operate in the future, on the same lines as other freight and passenger trains; and b) that it will likely operate at speeds higher than 79 mph in the future, it is assumed that the electrically powered rolling stock will be required to meet the rules and regulations as written, with no waivers or alternative solutions.

AVAILABLE OPTIONS

Electrically powered rail rolling stock equipment is not commonly used on the United States mainline system due to lack of electrified lines. For instance, there are a few freight services using electrically powered equipment, while passenger services operating on mainlines can only be found in the east (Washington, D.C., New York, Boston) and two lines in the Chicago area. Out of an approximate total of 170,000 miles of mainline rail, less than 3,000 miles are electrified.

Therefore, available options are rather limited, especially when rolling stock equipment operating on mainlines must be in compliance with unique U.S. standards of design and construction.

Railroad electric operation can be accomplished with electric locomotives or self propelled, electrically powered cars (Electric Multiple Units - EMUs). Following is a description of the options currently available in the United States.

Locomotives

The following locomotives are or will soon be in operation in the United States. Only two of these units, not yet in operation, are designed and constructed in accordance with the latest FRA Tier I requirements, namely New Jersey's ALP-46, being built by Adtranz and the new High Horsepower locomotive being built for Amtrak and MTA (MARC, Baltimore) by the Bombardier/Alstom Consortium. In addition, Amtrak still operates a small number of E-60's.

AEM-7 - 55 of these locomotives were purchased by Amtrak in 1978 for use on Metroliner Services. The units were built by then ASEA of Sweden (now Adtranz). These locomotives were assembled in the United States by EMD, using carbodies built by the Budd Co.

- *ALP-44* - 14 of these units were purchased in the 1970s and 1980s by New Jersey Transit, SEPTA and MARC. These units are similar to Amtrak's AEM-7 but were built entirely in Sweden (see Figure 4.1).
- *ALP-46* - Although Adtranz (then ASEA and later ABB) produced the successful AEM-7's and ALP-44 models, the ALP-46 is an entirely new locomotive in the U.S. market. 10 of these units were recently ordered by New Jersey Transit, for delivery by July 2002. The approximate price of each unit is \$4.2 million. This locomotive is designed in accordance with Tier 1 FRA rules and is capable of operating speeds of up to 125 mph.

High Horsepower Electric Locomotives (Amtrak/MARC by Bombardier/Alstom) - Twenty-two of these locomotives were ordered jointly by Amtrak and MARC, as part of the order for high speed Acela trainsets. The first Amtrak units are currently undergoing performance tests. This locomotive is also designed in accordance with Tier 1 FRA rules and is capable of operating speeds of up to 125 mph.

- *Remanufactured Amtrak AEM-7 Locomotives* - These are the same AEM-7 units described on the first bullet, above. Alstom in Hornell, New York is currently remanufacturing thirty locomotives, including new propulsion and traction equipment, utilizing IGBT technology. Amtrak will likely exercise an option for the remaining 20 locomotives, should additional services justify the investment. The first unit is undergoing extensive tests and Amtrak is extremely satisfied with its performance. 3 locomotives have already been delivered to Amtrak and the rest expected to be on hand by mid-2001.

Figure 4.1—NJTransit ALP-44 Locomotive



GE E-60 (Mexico) - In 1981 Ferrocarriles Nacionales de Mexico (FNM) purchased 38 new E-60 electric locomotives for freight use on their newly electrified line between Mexico City and Queretaro. For unknown reasons these locomotives were never used on their intended service. Of the 38 units eleven units remain available today. In addition, Amtrak still operates a small number of E 60's in the Northeast U.S. region.

The E-60 is a six-axle locomotive, weighting 360,000 lbs. and similar to the units used by Amtrak and New Jersey Transit. Some NJ units are still in operation. The Mexican locomotives have been on the market for a long period of time and are available at an approximate price of \$1 million each, although the price may likely be lower through serious negotiations.

All of the above-described electric locomotives are capable of providing commuter rail passenger service on the Caltrain Corridor. With minor modifications, any of these locomotives will also be capable of hauling the current fleet of Gallery cars on push-pull operations. Although performance will vary depending on the model, all will be capable of pulling a trailing load of 1,200,000 lbs. (equal to 7 cars at AW2 load) through a 14-degree curve and 3% grade, from zero speed. This track condition may be found if construction of the access to downtown San Francisco is completed.

4.2.2 EMUs

Given the technical and economic benefits offered by multilevel cars, either Gallery style or full bi-level, it is assumed for the purposes of this assessment, that this type of cars will be required by JPB, should the decision be to replace the current fleet of Gallery cars.

The downside, however, is that there are no Gallery or Bi-level EMUs available in the U.S. market today. There are many modern designs operating in Europe and Japan, but they are not designed to meet the U.S. standards.

A sampling of EMU designs currently operating or will soon operate in the U.S. is as follows:

- *Gallery Metra (ICG) Cars* - These Galley style cars with a capacity of 156 seated passengers, were originally designed and built by the St. Louis Car Co. in the early 70's. The design was later sold to Bombardier who, in the 1970s built 36 additional cars for the same customer.

Metro North M6 Cars (MK) - These are single level cars with a capacity of 118 seated passengers. MK built 48 of these cars in 1994/95. The cars are designed for high-level platform boarding and draw power from a wayside third rail.

- *Long Island M7 cars (Bombardier)* - 226 of these cars were recently ordered from Bombardier, at an average price of approximately \$2,000,000 each. The single level car has a capacity of 87 seated passengers plus two wheelchairs.

NICTD cars (Nippon Sharyo) - 58 of these single level cars were built originally by Nippon-Sharyo, utilizing the same basic carbody shell as for the locomotive hauled single level cars delivered to MARC. Recently NICTD placed an order for additional 8 new cars, at a price of approximately \$2,200,000.

4.3 TECHNICAL AND PERFORMANCE CHARACTERISTICS

The technology data collected was based on critical performance requirements of the PCJPB system. These requirements are shown on Appendix 1.

4.3.1 Locomotives

4.3.1.1 GE E-60 Locomotive (See Appendix 2)

Overview. The GE E-60 is a six axle, six motor freight-based electric locomotive manufactured by General Electric during the seventies and eighties. The locomotive was adapted for Amtrak service in the Northeast Corridor for high-speed passenger trains, as a replacement for the Westinghouse GG1 units. The locomotives were marginally successful; they were generally reliable but only adequate performers in terms of high-speed operation. At speeds up to 85 mph, the ride stability was acceptable. However, at speeds over 85 mph the stability and performance of three-axle truck deteriorated due to the dynamics of weight and speed, and effect on the rails. Given these potential unsafe conditions, Amtrak limited its operating speeds to 70 mph. The locomotives were eventually outclassed by the successful ASEA AEM-7 locomotive, and were relegated to slower and heavier long distance passenger trains operating in and out of the Northeast Corridor.

General Electric produced 38 double-ended freight versions of these locomotives in 1981 for the national Mexican railroad's electrified line. However, the economic and commercial conditions changed and the locomotives were never used. There are eleven units available today. Eight of these units are still owned by GE, with the balance owned by the Mexican railway. These units were never delivered to Mexico and are stored in Brownsville, Texas. Their "as new" condition is such that these locomotives could be made operable with little effort or problems. Many of the problems experienced by Amtrak in the development of the locomotive, such as air compressor overheating, were addressed and corrected. However, since they are freight locomotives, there is no provision for head end power (HEP) generation. Since it is possible to add an HEP package, these locomotives could be considered candidates for the California operation as they could provide acceptable service at a bargain price with immediate availability.

General Description. The locomotives are generally large and heavy. The approximate dimensions are:

Description	Dimension
Length (over pulling faces)	69'3"
Height (to top of lowered pantograph)	16'
Width	9'11"
Weight	360,000 lbs.

The dc electric traction system uses the well-proven and very reliable series wound GE-752 traction motor. The propulsion power design is a basic transformer and power thyristor system that controls traction motor voltage (and therefore traction motor output) in accordance with throttle position. The system has seen many years of service and is a proven, reliable and mature design. The thyristors are standard, air cooled Presspak components. The main transformer is oil cooled and is connected to the 25kV, 60 HZ catenary via pantograph. The propulsion system is rated for 6000 HP, and the locomotive is capable of 117,000-lbs. tractive effort up to 22 mph. The locomotive's top speed is 70 mph with its 83:20 gear ratio and 40 inch wheels.

Advantages. The two main advantages with the E-60 option are cost and availability. The locomotives are surplus and may be purchased for significantly less than the other locomotive options. They also are available for immediate possession, as they have been constructed and now are in storage. Another main advantage is the maintainability of the locomotive. The overall electrical system design is not extremely complicated so that service technicians will not require substantial education and training to diagnose and repair electrical system problems. Locomotive mechanics and electricians in the maintenance staff will be familiar with many of the systems and components, as they are standard GE locomotive design. The traction motors and trucks have been used in GE locomotives for years. Most of the locomotive's replacement parts are readily available through the GE distribution network.

With a simple change in gear ratio, the locomotive's propulsion characteristics would work well in a commuter operation. The problems operating the locomotive over 90 mph would not be as important with the slower speeds normally encountered in commuter service. The commuter locomotive duty cycle is more severe than an intercity passenger locomotive as it spends most of its time accelerating or decelerating the train. The heavy weight of the locomotive also works to its advantage in commuter service. At 160 tons, the locomotive can still develop sufficient tractive effort to maintain schedules in slippery track conditions, even though the maximum adhesion coefficient may dip below 30%. In a lighter locomotive which develops its tractive effort from adhesion levels over 35% using modern and sophisticated wheel slip control systems, performance in slippery rail conditions may not be as good.

Disadvantages. The major disadvantages with the E60 option are the lack of HEP generation and the inefficiencies of the SCR based propulsion system. With regards to HEP generation, it may be difficult to incorporate an HEP system into the existing carbody and frame. In order to adapt the locomotive for the higher traction currents and the more severe environment of slow, heavy-haul freight operation GE modified the traction system. These changes consume the extra space in the locomotive created by the lack of HEP. As a result it is feasible that an HEP inverter system could be installed, but this would require a thorough feasibility study along with extra engineering and manufacturing efforts.

The other main disadvantage with the E60 option is the increased energy consumption from the less efficient SCR dc propulsion system. Most of this consumption is a result of the low power factors of the SCR systems due to low switching frequencies. With their high switching frequencies, the most technologically advanced IGBT propulsion system could consume 25 - 30% less energy per mile operated than the E60 system. Depending upon energy costs and projected duty cycles this extra consumption could result in an overall higher life cycle cost than the modern and slightly more expensive ac propulsion alternatives.

Other disadvantages with the locomotive are more subjective. The locomotive is not a sleek, modern, and technologically advanced machine. It has a dated appearance and uses old analog electronics. From a marketing and public acceptance perspective this may need to be considered.

Conclusion. Provided an HEP system can be installed without major revisions, the E60 option is a low initial cost, low risk means to obtain electric locomotive service for JPB's operation. The locomotive will perform well in the intended service, although its operating cost will be significantly higher than more modern alternatives. The locomotive's limitations and problems are well understood, and many of them have been addressed in the evolution of the design. If Caltrain is willing to accept the increased operating expense and the dated image, it may be worthwhile to investigate the addition of an HEP system to these locomotives.

4.3.1.2 AEM-7 ac (Remanufactured by Alstom) (See Appendix 3)

Overview. The AEM-7 ac locomotive is based on Alstom's remanufactured and repowered AEM-7 design currently in Amtrak's service (see Figure 4.2—Amtrak AEM-7 Locomotive). In a program to elevate the conventional equipment status for the Northeast Corridor to correspond with the new high speed Acela service, Amtrak commissioned Alstom to design a modern, state-of-the-art ac propulsion and HEP system to fit within the existing AEM7 dc locomotive package. In this project, the electrical and control systems of the locomotive have been designed and manufactured in Alstom's Hornell, New York facility and installed in the remanufactured locomotives in Amtrak's Wilmington, Delaware facility. The contract calls for 30 locomotives to be remanufactured under this program, with an option for an additional 22 units.

The AEM-7 was based on the successful RC-4 design for the Swedish State Railway by ASEA, in the mid 1970s and was modified to be suitable for North American operation. In the late 1970s Amtrak purchased 52 locomotives from ASEA. The Budd Co. built the carbodies and the locomotives were assembled by EMD in its LaGrange, Illinois plant. The locomotives have been a solid performer for Amtrak, although they are now starting to show their age and miles. With this new remanufacture and conversion to ac, Amtrak is hoping to extend their life another 20 years, providing reliable service for the conventional Northeast corridor passenger service.

Initial reports from Amtrak have been very favorable, and the combination Amtrak / Alstom program appears to be a success. As of late May 2000, three locomotives have been renovated with a fourth almost completed. Much of the initial testing has been completed and the locomotives are now beginning to operate in revenue service.

General description. The locomotives are generally lightweight and compact. Even though almost all of the original components have been replaced with different equipment, the final weight is basically the same as the original AEM-7. Since the new locomotive's carbody is originally an AEM-7 the original overall dimensions remain the same, as follows:

Description	Dimension
Length (over pulling faces)	53'
Height (to top of lowered pantograph)	14' 10"
Width	10'
Weight	202,000 lbs.

The new ac propulsion system uses water-cooled IGBT technology with five separate inverters across four secondary windings of the main oil-cooled transformer. Four of the inverter systems are each connected to an individual ac traction motor and the fifth inverter is used to power the auxiliary and head end power (HEP) loads. A connection scheme exists where the output of the #2 inverter also can be coupled to the HEP trainline. The ac traction motor was designed such that it mates to the existing AEM-7 axle drive train in place of the original dc traction motor. Although the traction motor is a new design, it is based on existing Alstom technology and has seen over 60,000 miles of service without any failures or problems.

The main transformer is the same as the original AEM-7, and is rated the same as before. However, the power output of the original locomotive was reduced by 20% due to power limitations in the traction

Figure 4.2—Amtrak AEM-7 Locomotive



motors. The new motors do not require these limitations and the locomotive is rated for the full power output of the transformer. The propulsion system is capable of developing 51,700 lbs. of tractive effort during starting and is rated for a maximum 5000 kW at 60 mph with the Amtrak catenary parameters of 12,000 volts at 25 Hz and nominal HEP loads. The HEP system is capable of generating 800 kW under extreme conditions. As is the case with most modern locomotives a full complement of computer display screens, diagnostic networks, and other electronic equipment is used to monitor and troubleshoot the various systems throughout the locomotive.

These locomotives are equipped with regenerative braking capabilities.

Advantages. The primary advantage of this option is the use of an existing, proven, and available truck and axle drivetrain. The AEM-7 truck and drivetrain has been a workhorse for Amtrak, providing millions of miles of revenue service in the North American rail environment. Amtrak is very satisfied with this system and has had very little trouble with it. Any of the problems have long been solved, and the normal surprises associated with adapting overseas systems to North American conditions should be non-existent.

The other main advantages are associated with the use of IGBT's in the propulsion system. Modern ac traction systems either use IGBT's or GTO's to generate a variable voltage, variable frequency waveform from a dc power supply. (In the case of all of these locomotives, the dc supply is provided from the overhead ac catenary power rectified to dc). The primary advantage of the IGBT system over the GTO system is the means in which the device is "turned on" to pass power. The IGBT uses a simpler voltage based system that allows for better control of the waveform and the noise (EMI) within the waveform. With this better control, smaller and fewer filters and snubbers and other devices are required allowing for a simple design. The distortion and noise within the waveform is much better, minimizing interference with the track signaling infrastructure and significantly reducing losses in the traction motors, blowers, and other components. The IGBT's systems are generally less expensive than GTO's as they are easier to package and cool and they require fewer components. The systems are generally smaller and lighter than GTO's.

Disadvantages. The primary disadvantage of this option is the potential lack of available AEM-7 shells for remanufacture. Amtrak may need all the units they have and there are no unserviceable units available as candidates for remanufacture. As a contender for the Caltrain operation, a new locomotive would be required. An entirely new carbody structure would need to be fabricated, creating the possibility for engineering and / or production problems. Fortunately, the truck and axle drive gears are available from other vendors. However, the procurement would need to be very precise regarding these items to ensure the existing equipment is specified. There is also the issue of design rights, as Adtranz basically owns the existing locomotive mechanical design.

Another disadvantage of this option is the lack of service history of IGBT's at these power levels. IGBT technology has been rapidly improving over the past few years. However, the overall population of high power IGBT's is not very large. The application of IGBT's in this locomotive is at the extreme of reliable, production service. There are new classes of IGBT's that are being tested at power ratings exceeding these levels, but these are still only at the end of the developmental phase. Problems relating to the mechanical assembly of the IGBT or the longevity of the device may arise over time.

IGBT inverters have other disadvantages that would need to be addressed in a specification. With the high switching frequencies they will generate higher levels of radiated electro-magnetic interference with other communication and electronic devices in the vicinity of the traction and HEP systems. They will also generate undesirable acoustical noises (buzzing) in the traction motors and other inductive components in

the system. (In a recent commissioning of another ac locomotive, an engineer was able to get the traction motor to play a tune by programming different frequencies at different intervals into the IGBT control microprocessor.)

Conclusion. The Alstom's remanufactured AEM-7 is a viable option for Caltrain. Of all of the alternatives, it is based on the most successful mechanical design for high-speed passenger drive trains in North America. Problems associated with adapting European technologies to United States conditions should be minimal. It uses a modern propulsion technology that is state of the art in precision and control and is simpler and more efficient than the other alternatives. These advantages come with risk, however, in that the power levels are at the extremes for existing IGBT technology and that Alstom will need to source carbodies as well as trucks and drive trains for any significant production run.

4.3.1.3 Adtranz ALP-46 (See Appendix 4)

Overview. Although the Adtranz ALP-44 has been a fairly successful product for Adtranz, the ALP46 (see Figure 4.3) represents a different locomotive. The ALP-44, which is currently operated on New Jersey Transit and other transit authorities in the Northeast, is a dc machine and is an evolution of the basic Swedish ASEA AEM-7 design. The ALP-46 is an ac machine based on a German design. Adtranz recently received an order from New Jersey Transit for twenty-four ALP-46's, and the locomotives are currently in the design and construction phase with an expected delivery of late 2001.

The basic package for the ALP-46 is the German built BR101. There are 145 of these locomotives running in Germany and they were developed for high-speed passenger service. Development of the locomotive was begun in the late 1980s, resulting in an order to Adtranz for the 145 locomotives in 1994. The first locomotives were completed in 1996 and have been fairly successful in operation.

General Description. The ALP-46 locomotive is being developed to be in accordance with the New Jersey Transit procurement. It will be modified from its European base making it operable in North America and compliant with all applicable Tier 1 FRA regulations and requirements. It is a relatively light locomotive. Its overall dimensions are:

Description	Dimension
Length (over pulling faces)	64'
Height (to top of lowered pantograph)	14'8"
Width	9'8"
Weight	214,000 lbs.

It is a powerful locomotive rated at 6000 kW. It is capable of 71,000 lbs of tractive effort at maximum traction motor current and 50,000 lbs of tractive effort up to 45 mph with continuous traction motor current. At 97 tons, Adtranz is expecting an adhesion coefficient of approximately 36%. To develop this power, it uses a GTO-based inverter system and four traction motors.

Advantages. The advantages with the ALP-46 locomotive are mainly associated with the advantages of GTO based inverter systems. The invention of the GTO allowed the development of the ac locomotive. The technology has been in actual service for more than ten years, resulting in a fairly mature, known, and reliable design. This is reinforced by the experience of the propulsion systems in the ALP-46 locomotive; they have been working reliably for more than three years and have been providing revenue service in hundreds of locomotives in Europe. Generally, GTO systems are able to conduct more power more reliably than IGBT systems, at this time.

Figure 4.3—Adtranz ALP-46 Locomotive



Another major advantage is the experience base Adtranz has in the North American environment. One of Adtranz's predecessor companies, ASEA, was the first European company to successfully adapt their electric locomotive technology to North American rail service with the AEM-7. Another predecessor company, Westinghouse, was one of the original American manufacturers of electric locomotives. No other company has the combined knowledge of the manufacture of high-speed passenger electric locomotives in North America than Adtranz.

Disadvantages. Despite the knowledge base of Adtranz, the ALP-46 is still a new comer to the United States. The New Jersey Transit order represents the first application of the locomotive to American conditions. What may work very well in Europe may need some major modifications before it works well in the United States. Given the restructuring of Adtranz it remains to be seen if they will apply their experience assets to developing the ALP-46, or if they will have to relearn all of the hard lessons of the past.

Other disadvantages are associated with the use of the GTO inverter. Although GTO's are more mature, they are also being replaced by IGBT's as the IGBT technology improves. The GTO uses a complex "turn-on" arrangement that has limitations in switching frequency and precision. As a result, the output of GTO systems require more filtering and conditioning than IGBT systems, increasing complexity and cost. It is also much harder to control the output waveform of the GTO, and more problems with conductive electro-magnetic interference result. Finally, in almost every new application of GTO propulsion systems, even if it is an adaptation of an existing system into a new package, the builder has some sort of problems getting the "turn on" systems to work reliably. In all cases, though, they have been able to sort out the problems and make the systems work properly and reliably.

Conclusion. The Adtranz ALP-46 locomotive is a viable option for Caltrain. It is based on a successful German design and is manufactured by a builder with a history of North American experience. Most of the problems associated with operation in the United States should be sorted out with the New Jersey Transit order. It uses an older propulsion technology that is becoming outdated, however, the technology is very mature and will perform well for many years to come. The locomotive represents a solid, efficient, and low risk option for Caltrain.

4.3.1.4 High Horsepower Amtrak/MARC Locomotive (by Bombardier/Alstom) (See Appendix 5)

Overview. As part of Amtrak's Acela Regional Express program, the Bombardier/Alstom consortium has developed a high speed, high horsepower electric locomotive. This locomotive has not received as much publicity as the high profile Acela Express trainset, but it shares much of the heritage and design philosophy of the Acela Express. However the locomotive is designed to Tier 1 FRA Standards (up to 125-mph operation) as opposed to the Acela trainsets, which are designed to Tier 2 Standards (126 to 150 mph operation). Testing has already commenced on the Northeast Corridor.

Amtrak and MARC have ordered 18 and 6 units respectively, at approximately \$6 million each.

General Description. The locomotive is a dual cab, stainless steel carbody, four axle ac locomotive. It is fully compliant with FRA Tier 1 Regulations. Its overall dimensions are:

Description	Dimension
Length (over pulling faces)	67'
Height (to top of lowered pantograph)	14'6"
Width	10'4"
Weight	242,000 lbs.

The locomotive is rated at 6000 kW. It uses a GTO based system with four 1,500 kW traction motors powered by individual inverters. While not much literature is available regarding the locomotive, it is expected to be very similar in performance, weight, and features as the GTO based Adtranz ALP-46. Unlike the ALP-46, which is designed for commuter service as well as high-speed passenger service, the Bombardier/Alstom locomotive may need modifications or adaptations to run in the commuter duty cycle.

The locomotives have regenerative braking capabilities.

4.3.2 Electric Multiple Units (EMUs) (See Appendix 6)

In the United States electrified commuter lines are operated primarily in the Northeast in metropolitan areas served by what was once the Pennsylvania and New Haven railroads. These areas include New York City, New Jersey and Connecticut, Philadelphia, Harrisburg, Baltimore, and Washington, D.C. The Pennsylvania railroad electrified the lines in these congested urban and suburban areas to facilitate commuter and high-speed passenger service with clean, quiet, and energy efficient motive power. Two additional electrified lines operate out of the Chicago area.

Agencies, now operating commuter service in these areas, operate a variety of electric multiple unit trains as well as locomotive hauled trains. The advantages of the EMU are primarily in the flexibility the operator has in train length. If the agency has many smaller branch lines with low ridership, it can economically operate two and three car trains with EMUs. For example, SEPTA's airport train in Philadelphia would be uneconomical to operate as a locomotive hauled consist. Normally, the airport train consists of two or three cars, which are reasonably patronized throughout the day. There is not enough ridership to fill locomotive hauled trains. In addition to EMUs SEPTA does operate Adtranz ALP-44 locomotives with trailing passenger cars. These trains run on the old "main line" suburban routes that are highly patronized during rush hour. SEPTA has found it economical to run these locomotive hauled trains during rush hours only, and these operations are successful for them.

Another variable regarding EMUs versus locomotive hauled trains is the chronology of the procurements for the equipment. In the case of MARC, the Baltimore based commuter rail agency, it runs only locomotive hauled cars. MARC started out as a diesel operation and already had an installed fleet of unpowered trailing cars when the mandate was given for the service expansion. Rather than switch over to EMUs, especially when many of the routes are on the Amtrak Northeast Corridor, MARC ordered electric locomotives to pull their existing fleet of passenger cars.

While NJT's most recent order is for electric locomotives, they have also had several sizable procurements for ac propelled EMUs. Again, they generally try to maximize equipment utilization by operating the EMUs versus the locomotive hauled train in accordance with passenger density. Other factors also exist for NJT in determining equipment type. These include acceleration times, equipment logistics, and catenary power.

As mentioned before, there are no current EMU designs available in the United States, compliant with the latest FRA Rules, nor with PCJPB's assumed needs for multilevel passenger cars. Should the PCJPB decide to replace the existing fleet of Gallery cars with multilevel EMUs, a detailed examination of current European and Japanese designs may need to be undertaken. It must be understood, however, that this examination may only be conducted for the purpose of gathering technical and economic information on major subsystems. Ultimately, a specification for an entirely new vehicle must be developed, addressing the unique and mandatory requirements in place in the United States.

The study should include sufficient analytical work and simulations, reflecting the specific conditions and operating requirements of PCJPB's services and work practices.

4.3.3 Electric Current Demand (See Appendix 7)

The electrical current demand on the overhead catenary is a function of the tractive effort the locomotive is producing. Although tractive effort is directly related to electrical current, the function is complicated due to the nonlinear electrical losses in the transformer, inverters, and traction motors. However, these losses can be conservatively estimated by assuming constant losses at maximum power. With these assumptions, an electrical current demand on the catenary can be projected based on tractive effort performance objectives.

Therefore, in order to predict electrical current requirements, it is necessary to know the planned schedule and the sizes of the train. These figures develop the acceleration requirements and consequently the tractive effort duty cycle for the locomotive. These duty cycles are combined into a total power consumption curve for the entire system, which allows for the system design to be properly "sized".

In order to develop a budgetary estimate of the electrical power system without any detailed schedule data, the current demand of certain operating scenarios were calculated. These figures were based on a locomotive rated for 6000 kW tractive power pulling 10 trailing coaches at 85 tons each with a HEP load of 75 kW each. Typical electrical losses for GTO based inverter systems were included in the calculation to develop power requirements at the catenary. Electrical current figures were then calculated with the 25,000 volts voltage level. These calculations are summarized with the attached table.

4.3.4 Summary

All of the locomotives described above will provide the PCJPB adequate performance. Some of them will provide excellent service but at significantly higher cost. Each of them has advantages and disadvantages that must be evaluated; the best candidate will have the right combination of advantages, disadvantages and cost.

Average and Peak Catenary Line Current Estimates

Scenario	Power (Rail hp)	Energy (kW hrs)	Time (sec)	Average Line Current (amps)	Peak Line Current (amps)
1. acceleration 0 - 90 mph @ full power	7450	287	164	252	292
2. acceleration 0 - 65 mph @ full power	7450	135	89	218	292
3. acceleration 0 - 50 mph @ full power	7450	75	59	183	270
4. acceleration 50 - 90 mph @ full power	7450	209	103	292	292
5. cruising @ 90 mph	1950			97	97
6. cruising @ 65 mph	1058			66	66
7. cruising @ 50 mph	675			53	53

Consist: 1 locomotive at 6000 kW (propulsion inverter output), 105 tons
 71,000 lbs tractive effort max (36% adhesion)
 10 trailing cars at 85 tons each & 75 kW HEP load each
 Assuming linear and constant electrical losses
 25 kV overhead catenary

Note 1: Average line current calculated from energy used to accelerate train (kW hrs) times duration of acceleration (seconds).

Note 2: These figures are based on typical electric locomotive components and include estimates and approximations for transformer, GTO inverter, auxiliary, traction motor, gear and wheel rim losses. They are presented for budgetary purposes only.

ECONOMIC CHARACTERISTICS

Locomotives

The cost of maintaining electric locomotives, especially those equipped with the latest electronic and suspension technologies, should be comparable to the cost of maintaining a diesel-electric locomotive. We have seen that it cost Amtrak \$97,000 per year per unit to maintain an AEM-7 and \$36,000 per year per unit to maintain an F-40 locomotive. This comparison however is not relevant, given the significant differences in duty cycles. On an equal basis, the cost difference should be much less, if any.

With regard to capital costs, we have seen that the price of a new electric locomotive would range from \$4.5 million (NJTC's ALP-46) to \$6 million (High horsepower Bombardier/Alstom units for Amtrak and MARC) each, based on recent procurements. In addition, prices may vary significantly depending on the specific performance requirements of the locomotive.

Another source of capital cost information is the remanufactured AEM-7 Amtrak locomotive, being performed by Alstom. The cost of the rehabilitation work is \$2.7 million per unit, for thirty locomotives. If we assume that the price of the body shell, underframe, trucks and other mechanical equipment is \$750,000, the price of such locomotive would be \$3,450,000. Since existing carbody shells are no longer available, a new design in accordance with FRA Tier 1 requirements will be needed. This will likely increase the price significantly.

EMUs

In general EMU cars are more expensive to operate than electric locomotives and trailer cars. The power available to multiple axles of a train formed by self-propelled cars is greater than that available from a single locomotive. This extra power is used by commuter services with extraordinary high demand, providing greater acceleration and deceleration rates and thereby optimizing trip schedules. This redundancy, estimated by some commuter rail operators to cost up to 60% more than an equivalent locomotive hauled system, also contributes to better utilization of the fleet.

With regard to capital costs, it is estimated that a multilevel electrically propelled car would cost approximately \$3 million in today's market. This price estimate is derived from comparing the cost of a single level locomotive hauled car and a single level EMU. Knowing the price of a locomotive hauled multilevel car at approximately \$1,750,000, the price of a multilevel EMU can be estimated at \$3 million. It is likely however that the ultimate price, under competitive conditions and quantities in the order of 80 to 100 cars, may be lower, at approximately \$2.8 million each.

Cost Estimates and Scenarios

4.4.3.1 Maintenance Costs

Maintenance costs shown in the following Table are provided for reference purposes only, since it is not appropriate to make direct comparisons. This is due to the fact that operating conditions, duty cycles and work practices among other items are very different from one operation to another. For instance, Amtrak's AEM-7 locomotives travel over 155,000 miles per year, while an E-60 locomotive does less than 20,000 miles per year and a SEPTA ALP-44 does a little over 20,000 miles per year.

Maintenance Costs of Electrically Powered Rail Equipment

Operator	Equipment	Cost per Year per Unit ⁽¹⁾
Amtrak	AEM-7 Electric Locomotive	\$96,700
	E-60 Electric Locomotive	\$47,800
	F-40 Diesel-Electric Locom.	\$42,041
SEPTA	ALP-44 Electric Locomotive Silverliner EMUs	
NICTD	EMUs	
NJTC	ALP-44 Electric Locomotive Arrow EMUs	
PCJPB	F-40 Diesel-Electric Locom.	\$119,000
PCJPB	Gallery Coach	\$72,500

⁽¹⁾ Includes overhauls but not remanufacturing, except PCJPB, which includes neither. The cost of remanufacturing an AEM-7 locomotive is \$2.7 million each.

4.4.3.2 Capital Cost Scenarios

With regard to capital costs, two potential scenarios are examined, as follows:

The first is the replacement of locomotives hauling the existing Gallery car fleet;

the second scenario is the replacement of both existing diesel-electric locomotives and Gallery cars with a new fleet of multilevel EMUs.

The cost of implementing the first scenario is estimated to be \$ 82,800,000, assuming the price of a fully compliant electric locomotive of \$5,000,000 each. This assumption is based on the selling price of the ALP-46 locomotive and a budgetary estimate from Alstom. The price of selling the existing fleet of diesel-electric locomotives is assumed to be \$1,400,000, each, thereby generating a credit of \$32.2 million. It is worth noting however that this assumed price may be somewhat optimistic, given that Amtrak has 45 units in storage and available under very attractive leasing programs.

The cost of implementing the second scenario is estimated to be \$98,000,000, assuming the price of a new, fully compliant bilevel EMU at \$2.8 million each. Credits for the locomotives and cars, assuming the selling price of each Gallery car at \$1,400,000 would total \$162,400,000. Amtrak has currently available a fleet of 20 Gallery cars, which they are planning to use for protection of the PCJPB fleet, while being overhauled by Alstom. These cars will later be available in the market, therefore offering some competition to the PCJPB cars. However, Amtrak's is an older fleet from Metra and not as attractive as the PCJPB cars.

These estimated capital costs do not include customer's specification development and QA/QC activities, spare parts, taxes or delivery.

With regard to new equipment, it could be assumed that because of higher operating speeds and therefore better utilization of equipment, the acquisition costs of new electric locomotives could be reduced by five percent and acquisition of EMUs could be reduced by approximately ten percent. These potential savings should be examined and verified during simulation of operations.

Scenario	Capital Cost	Credit	Total
Replace 23 Diesel-Electric Locomotives	\$115,000,000	\$32,200,000	\$82,800,000
Replace 23 Locomotives and 93 Cars	\$260,400,000	\$32,200,000 \$130,200,000	\$98,000,000

Estimated delivery time for a new locomotive would be 2 to 2 and .5 years. For a new EMU would be 3 years.