New Jersey Light Rail Transit Standardization Issues

John P. Aurelius, *New Jersey Transit*

Transit projects are in planning or preliminary engineering in three diverse New Jersey corridors. At least two will use light rail technology. How can they be standardized? The Hudson–Bergen Light Rail Transit (LRT) System is a 22-mi route, generally running north–south near the west bank of the Hudson River and operating on former railroad rights-of-way, on boulevards, and on city streets. The Newark City Subway, an existing 4.2-mi light rail line on private right-of-way, will be modernized. Extensions in planning range up to 10 mi using various operating environments. The Burlington-Gloucester Transit Study is planning major improvements on two corridors radiating from Camden; technologies being considered include light rail. Standardization begins with choosing a technology, and light rail implies electric vehicles running on rails singly or in short trains. An overhead contact system supplies direct current power at 750 V. Most track is at surface level with varying degrees of separation from automotive traffic. There are several fundamental choices for vehicle design. The car can be optimized for street service or for high speed. It is possible to use lifts, mini high-level platforms, full high platforms, or cars with partial or full low-floor design to make the system accessible to persons in wheelchairs. Car length generally ranges from about 45 to 90 ft, with zero to two articulations, although other variations exist. New Jersey (NJ) Transit has selected an articulated partial low-floor car design, double ended and about 90 ft long by 8.8 ft wide, with about 70 percent of the car floor 14 in. above rail. This configuration permits installation of four doors on each side, all in the low-floor section. The top speed is to be 55 mph; minimum curve radius will be either 60 or 80 ft. Light rail lines will use proof-of-payment fare collection. Cab signals will be installed except where operation is on or adjacent to streets and drivers follow traffic rules. Wayside signals will be used only at interlockings, which will be driver-actuated using a system like VTAG. The Newark City Subway will be converted in stages to proof-of-payment, 750-V power for pantograph-equipped cars, and minimum curve radii that match the vehicle capability. Stops will have remote-controlled public address systems with a visual display of messages. Call-for-aid telephones will be provided at each platform, in elevator cabs, and at each elevator landing. The telephones will be monitored by slow-scan television. Elevators will be equipped for remote locking and unlocking. These systems and the ticket machines will be derived from existing designs now used on the commuter rail lines and the Newark City Subway.

Transit improvements are in planning or preliminary engineering in three diverse New Jersey corridors: along the Hudson River waterfront, in the Newark-Elizabeth area, and in South Jersey between Camden and suburban areas to the north and to the southeast. Light rail is an existing mode in Newark, has been selected for the Hudson waterfront, and is one option in South Jersey. Each project has its own characteristics. How can they be standardized?

Three Projects

Hudson-Bergen LRT System

This line (Figure 1) has a defined 22-mi route and is in preliminary engineering. The northern end is at a park and ride lot on the New Jersey Turnpike near the Bergen County border. It will run south on former railroad rights-of-way and cross eastward under the Palisades in an existing tunnel. A deep underground station will serve Bergenline Avenue in Union City. The line emerges on the river front in Weehawken and continues south. In Hoboken it runs alongside a street east of Stevens Technical Institute and on street to Hoboken Terminal, a hub for commuter rail, bus, Port Authority Trans-Hudson (PATH) rapid transit, and ferry services.

The light rail line will turn west to Marin Boulevard, then south under the rail yard in a street underpass and continue south and east on right of way into Jersey City. A stop at Pavonia Street will serve the Newport development and PATH trains to midtown New York. At Exchange Place there is more development and PATH trains to the World Trade Center in lower Manhattan. Then the line will go south on Hudson Street and west on Essex Street. Entering a presently undeveloped area, it will turn south and pass west of the Morris Canal

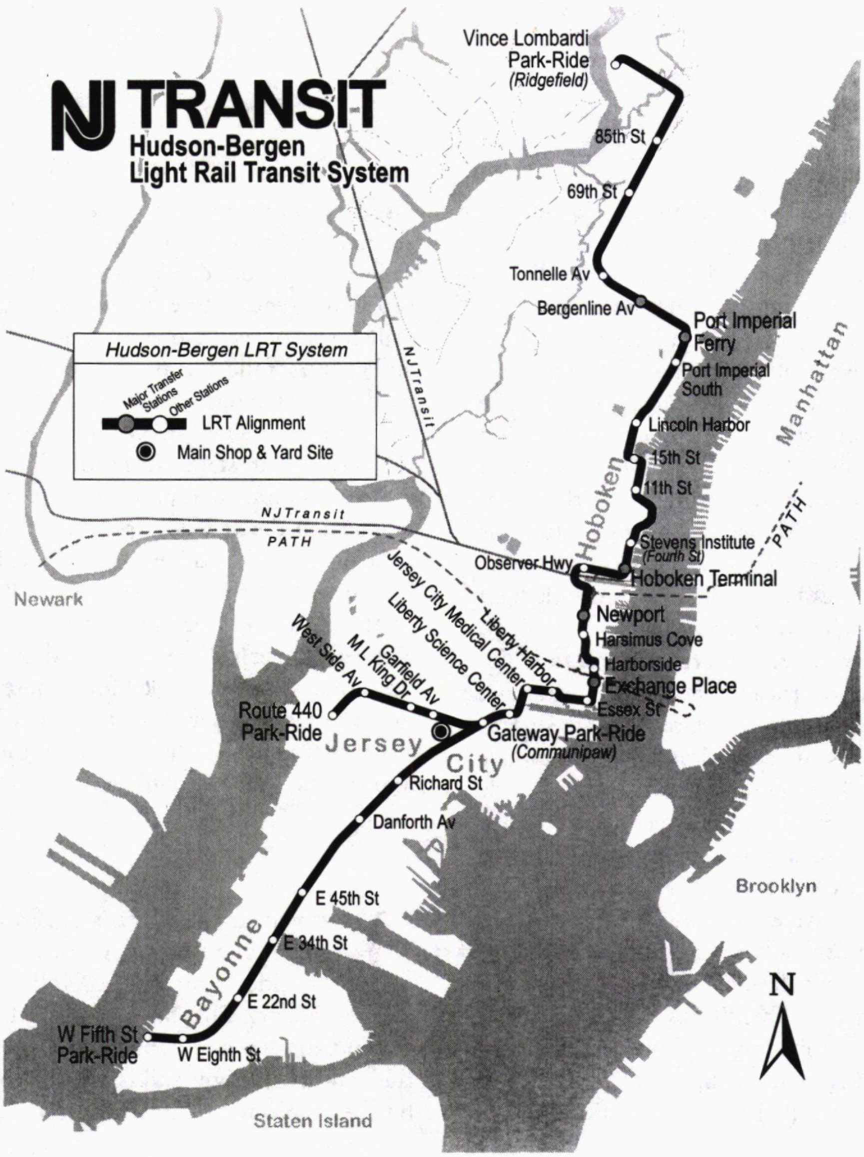

FIGURE 1 Hudson-Bergen Light Rail Transit System.

Big Basin and Liberty State Park, which is at the site of the former Jersey Central Railroad Terminal.

A park and ride station, a junction, and the operating/maintenance depot will be located here. One branch continues south on railroad right-of-way to southern Bayonne. Three stops will have park and ride lots and three others will not. Near the southern end of the route, a mile of single track will support late-night Consolidated Rail Corporation (Conrail) freight operations. The other branch will go west across Jersey City on a former railroad line. The final two stops will be near a major highway with park and ride lots.

This is a very demanding route, combining high passenger volume, fast running on railroad rights-of-way, operation on streets, and compatibility with railroad freight that will use some of its track. Some stops will be located in the street environment, where the length of trains cannot exceed the distance between cross streets. Two such stops, at Hoboken and Exchange Place, will handle large passenger volumes.

Newark City Subway

The Newark City Subway (Figure 2) is a 4.2-mi light rail line, the only remnant of the once-extensive Public Service streetcar system. Built in the 1930s on the bed of the Morris Canal, it runs from the Newark-Belleville border, south toward downtown Newark alongside Branch Brook Park. After it crosses over the Morris & Essex commuter rail line there is one at-grade street crossing. The line then curves to the west and enters a mile-long subway on its approach to center city. A long 4 percent grade in the tunnel was once the site of an inclined plane on the canal. The final stop is under Newark Penn Station, where the maintenance depot is located. A fleet of 24 President's Conference Committee (PCC) streetcars built between 1946 and 1949, acquired second-hand in 1953, is still in service.

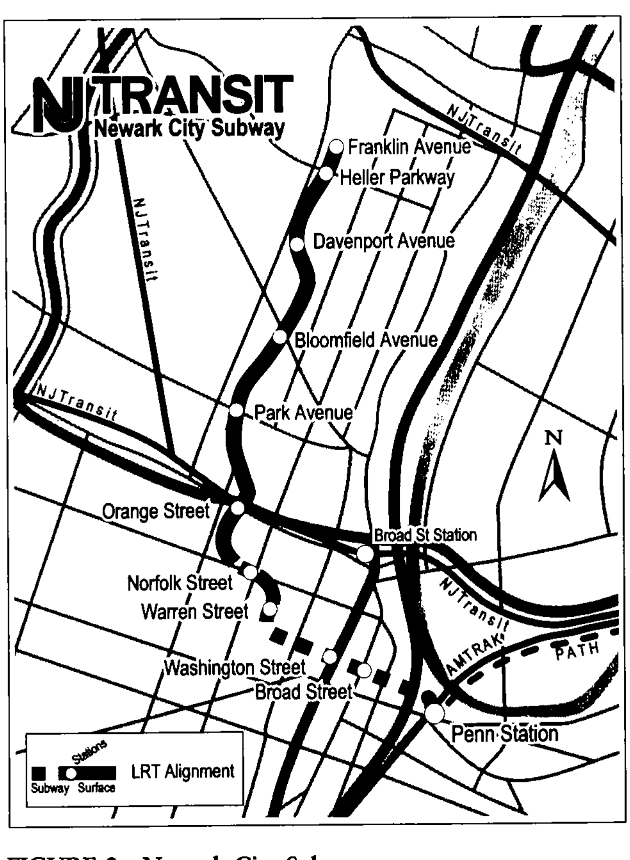

FIGURE 2 Newark City Subway.

Present plans are to replace the cars with modern light rail vehicles (LRVs), build a new operations and maintenance facility on a short extension to the northwest, upgrade the electric substations, and renew the overhead contact system. Studies have been conducted on an extension southward to connect Newark's two railroad stations, provide improved access to Newark Airport, and encourage development in Newark and Elizabeth. Passenger volume on this route is somewhat less than expected on the Hudson-Bergen project. The proposed extension through Newark to Elizabeth would have a significant amount of operation on streets, but its shorter trains present fewer problems in station design.

Burlington-Gloucester

Historically, New Jersey suburbs east of Philadelphia were served by commuter rail from a ferry terminal on the Delaware River in Camden. Railroad operations in Camden were replaced in 1969 by the Port Authority Transit Corporation (PATCO) rapid transit line (Figure 3), using an existing Southeastern Pennsylvania Transportation Authority (SEPTA) rail line over the Ben Franklin Bridge and continuing for 12 mi on the railroad right-of-way to Lindenwold. Commuter trains were operated until late 1980 between Lindenwold and Atlantic City, with a branch to Cape May. The railroad to Atlantic City was rebuilt in 1987 and NJ Transit commuter trains (Figure 4) operate between Atlantic City and 30th St., Philadelphia, via Conrail's Delair Bridge, also connecting with PATCO at Lindenwold.

The Burlington-Gloucester Transit Study has identified two corridors, north and southeast from Camden, for improved transportation service. The southeast corridor to Glassboro would follow a railroad right-of-way. The northern corridor to Burlington has two alternates, either on a railroad line or in the median of Interstate 295. Technologies under study include

- Rapid rail extensions to PATCO;
- Modified rapid rail extensions with grade crossings and overhead current collection;

FIGURE 3 Lindenwold park-and-ride station, PATCO line. The 22-km (14-mi) route from Center City Philadelphia ends here.

- Light rail, passengers transferring to PATCO in Camden; and
- Busways, with service into Philadelphia via the Ben Franklin Bridge.

What is Standard?

Standardization begins with choosing the technology: *light rail* implies electric vehicles running on rails as single cars or short trains. Many light rail systems share the following characteristics. Power is supplied from overhead wires as direct current at 750 V. Vehicle width is compatible with street traffic, on the order of 2650 mm (8.5 ft). Track gage is standard 1435 mm (56.5 in.). Most track is at surface level, streets may be crossed at grade, and some operation may be in the street. Signal systems are provided except in streets, and car operators select routes at track switches. Stops have dedicated platforms, low level or high level. Shelters are provided. Fare collection is barrier free, using proof-of-payment rules.

FIGURE 4 NJ Transit operates commuter rail service between Atlantic City and 30th Street, Philadelphia. Absecon station is shown here.

Variations on these norms are frequent. For example, in North America there is full underground subway construction on portions of light rail lines in Boston, Newark, Philadelphia, Pittsburgh, Cleveland, San Francisco, Guadalajara, and Edmonton. Turnstiles are used for fare collection in some of these underground stations. Proof-of-payment fare rules generally apply in new systems but not on older U.S. systems upgraded from streetcar days. The fully elevated Monterrey and Manila systems are considered to be light rail. SEPTA's Norristown line has third-rail electrification.

Light rail is sufficiently standardized that it is sometimes possible to take cars from one system and use them on another. The Newark PCC cars were purchased used from Minneapolis. New Orleans recently acquired some used PCCs from Philadelphia; although purchased for parts, one car was taken for a test trip on the St. Charles line. Calgary and Edmonton have exchanged cars; the cars are the same but wheels had to be changed. Contrast light rail with "people mover" technologies, which are generally proprietary.

Design of the Cars

Strassenbahn versus Stadtbahn

The street railway, or Strassenbahn, is alive and developing in Germany along with light rail, or Stadtbahn, systems. Distinct cars are used for each. Streetcars are optimized for ability to negotiate sharp curves and for easy boarding from railhead level; light rail cars are optimized for speed and comfort. German streetcars typically are 1 m narrow gage, and have 2300 mm (7.5 ft) bodies; most new streetcars there have 100 percent low-floor construction with unconventional running gear. Light rail cars more often are standard gage and have a 2650 mm (8.5 ft) body. Recent examples are articulated partial low-floor designs with conventional powered trucks at the ends and an unpowered center truck that has individual wheels. The floor is at about 300 mm (12 in.), except over the powered trucks.

The PCC car (Figure 5) is a streetcar, able to negotiate curves of about 12 m (40 ft) radius, with 660 mm

FIGURE 5 The PCC streetcar was developed by a committee of presidents of transit operating companies. Standardized cars of this type were manufactured by two builders between 1937 and 1952.

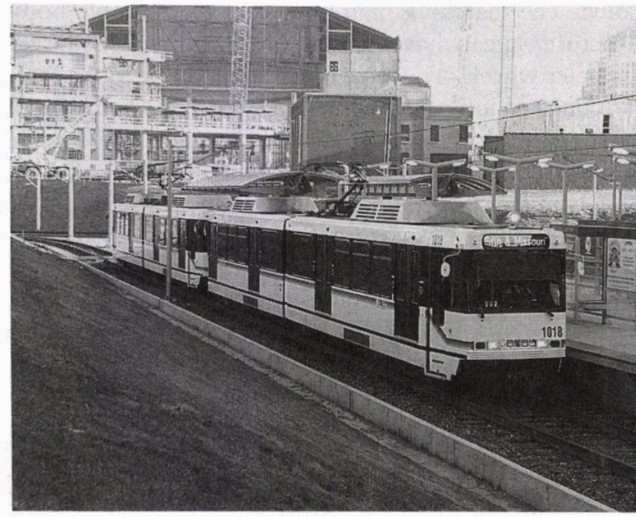

FIGURE 6 The high-floor articulated Model U-2 car by Siemens-Duewag operates on several North American light rail lines, including St. Louis.

(26 in.) wheels and a floor 813 mm (32 in.) above rail. The trucks swivel to a wide angle, as do the couplers, if provided. Top speed is about 70 km/hr (44 mph). PCC cars were generally 8.5 ft wide, but those on the Newark City Subway are 9 ft wide. A more recent streetcar is the Boston Type 7 car, which is articulated and can negotiate sharp street-type curves. In Newark and Boston, the route is light rail but the cars are streetcars. The 26 in. wheels appeared in the United States before World War I and were standard (not universal) for city cars built in the 1920s and 1930s.

New light rail systems typically are designed with 18 or 25 m (60 or 80 ft) minimum radius curves. The larger radius eases car design requirements for extreme angles on truck swivel, coupler angle, and articulation performance. The car floor often is higher, 1 m (39 in.) above rail, so larger wheels and larger diameter motors can be used. This makes it easier to design for high speed. The Siemens-Duewag U-2 type car (Figure 6), operating on several properties in North America, has a single large motor, or monomotor, on each powered truck. It sits longitudinally between the wheels, and each end of the armature shaft drives one axle. Top speed is about 80 km/hr (50 mph).

Boarding the Car

New projects have to comply with the Americans with Disabilities Act and be accessible to patrons who use wheelchairs. Light rail lines recently built in the U.S. generally use cars with a 39-in. floor height. Boarding and exiting at street level is a chore even for the able-bodied, as the cars are too narrow for ideal steps, and do not have the easy boarding of the PCC streetcar with its 32-in. floor. Those unable to climb stairs need another route to the floor level: on-board lifts in San Diego, station lifts in Portland (presently) and San Jose, or mini high-level platforms (high-blocks) in Sacramento, Baltimore, and on the Buffalo transit mall.

An excellent solution from an engineering perspective is the high-level platform as used in Los Angeles-Long Beach (Figure 7), Calgary, Edmonton, and St.

FIGURE 7 High-level platforms provide level entry to high-floor cars. Integrating such platforms into the city scene can be done attractively, as in Long Beach, California.

Louis. The matching high-floor car has a simple body structure. It can have conventional trucks with large-diameter wheels. This type of car should afford the lowest construction and maintenance cost. It is the ideal solution for a line that operates entirely on a former railroad or other private right-of-way.

For on-street operation, vehicles with a floor height of about 330 mm (13 in.) provide easy access. Level boarding is afforded from a curb-height platform (Figure 8). If it is necessary to board from the street, it is only a single step up to floor level. A ramp can be deployed for riders who use wheelchairs and are boarding from the street. Streetcars with full low floors are popular in Europe, but most are complex and unconventional in design. Like the PCC, the top speed is usually about 40 mph.

What about a route that has enough private right-of-way to allow high-speed operation, but must operate in the street part of the time? Will the city fathers permit block-long high-level platforms in the streets? Should a complex low-floor car be chosen? Partial low-floor cars, as used in several European cities, including Paris (Figure 9), offer a compromise. As with most compromises there are disadvantages. A typical 70 percent low-floor car has steps or ramps to the higher floor at the ends. The steps, leading to an isolated high area, are seen as a major disadvantage to this design. A ramp can replace the steps if low-profile powered trucks are supplied. With this layout it is more difficult to place a door near the driver so that he or she can inspect tickets of boarding passengers.

Vehicle Standardization at NJ Transit

An early decision is that the Hudson-Bergen Light Rail System and the Newark City Subway will be light rail

FIGURE 8 Low-level platforms are not as intrusive on a city street as are high-level platforms. This stop is in Paris.

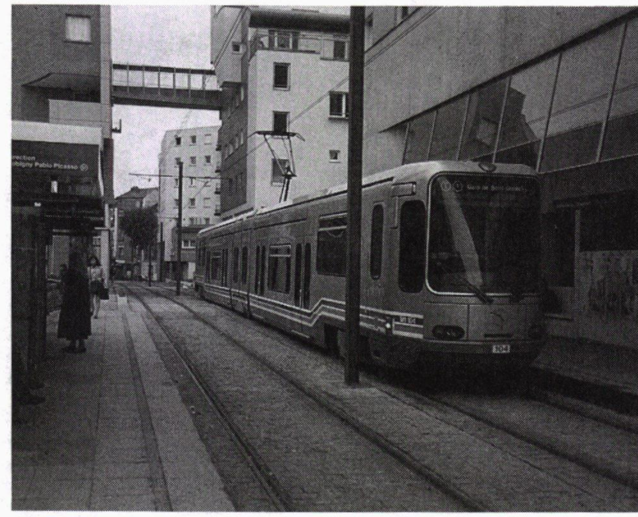

FIGURE 9 All passenger entry doors in a partial low-floor car are the low-platform level, typically about 330 mm (13.5 in.). This example is operating in Paris.

lines, not commuter rail or rapid (heavy) rail. From this beginning, there are several choices to make.

Length and Width

The PCC cars on the City Subway route are 46 ft long, and during the peak hour a 2-min headway is required to attain the needed capacity. The Hudson-Bergen line expects a maximum one-way per-hr demand of 8,000 riders. On a 3-min headway, this amounts to 400 riders per train. The South Jersey routes will have peak loadings that make large cars appropriate.

Single-body cars are in the minority today in North America (Buffalo, Philadelphia, Toronto). Articulated vehicles are used in Baltimore, Boston, Calgary, Edmonton, Pittsburgh, Sacramento, San Diego, San Francisco, San Jose, St. Louis, and Toronto (uses both types). Most cars are about 2650 mm (8.5 ft) wide, with Baltimore an exception at 9.5 ft.

Standardization differs from optimization. The Hudson-Bergen line will need 28-m (90-ft) articulated cars, operated in two-car trains, to achieve its planned capacity with a practical minimum headway of 3 min through congested intersections. During peak hours, the City Subway can make use of these large cars operated singly with headways increased from 2 to perhaps 4 min. However, many City Subway patrons use the line for trips under 1 mi. If service is not frequent some will just walk and save the fare.

Minimum Curve Radius

The Hudson-Bergen line is being built with curves of 25 m (80 ft) radius or greater. On the City Subway the approximate radius of the loop at Franklin Avenue is 12 m (40 ft), and one at Newark Penn Station is 18 m (60 ft). We can choose the minimum radius for the cars:

- 12 m, raising the cost of the cars and constraining interior design;
- 18 m, having less impact on the car design but the existing outer loop at Franklin cannot be used; or
- 25 m, requiring reconfiguration for double-ended operation without loops.

Ends and Sides

The Newark PCC car is single-ended and single-sided. Loops now exist at each end of the line, and all stations have side platforms. Most light rail cars today are double-ended and have doors on both sides.

Floor

The structure of the car is seriously affected by the floor arrangement. A high floor allows for a simple structure, with strong elements under the doors. A 100 percent low floor is more complex, requiring projections into the passenger space for wheels, suspension elements, and perhaps drive components. The partial low-floor design requires main body elements at two different levels. Each design has its collision protection challenges.

Propulsion and Speed

The new standard of a 750 VDC power source offers an advantage over the U.S. streetcar standard of 600 V or less, especially when trains of heavy articulated cars are to be operated. New light rail lines are generally built for top speed of about 90 km/hr (55 mph). Three-phase asynchronous AC motors are smaller than the DC equivalent and commutator maintenance is eliminated. However, the electronic inverter for the AC motor is larger and more complex than a chopper for DC motors. The propulsion system must be correctly sized to handle the grades encountered on the route.

Choosing the Characteristics

Turnkey Contract

Although the engineers make recommendations, the choices ultimately are made by management. One such decision is that the Hudson-Bergen line will be built by a design-build-operate-maintain or "turnkey," contractor who will also prepare final designs and order the fleet. The current schedule calls for this contractor to receive a Notice to Proceed in mid-1996. With preliminary engineering complete before that time, an order for cars should be placed by the end of 1996.

Vehicle Fleet

The initial operating segment of the Hudson-Bergen line would require about 35 cars. The Newark City Subway has 24 PCCs and would need 12 to 15 large cars. It will use the same cars as the Hudson-Bergen line. Follow-on orders for later phases of Hudson-Bergen and possible City Subway extensions would call for a similar car, leading to a total fleet of perhaps 100 to 120 cars. As this is written it is too early to make firm predictions for the South Jersey project, which may not choose light rail technology.

Low-Floor Car

Management has also decided that high-level platforms are too intrusive for street deployment in Jersey City and Hoboken. Level entry from a platform 13 in. above rail height is desired, which could be achieved by a partial low-floor vehicle. A baseline design has been developed (Figure 10), resembling the new Portland partial low-floor vehicles.

1. Double-ended articulated car, standard gage, length 26.7 m (90 ft), width 2680 mm (8.8 ft).
2. 70 percent low floor at 350 mm (14 in.), 30 percent high floor (at ends) 720 mm (28 in.) desired, 990 mm (39 in.) acceptable. Level change by ramp desired, steps acceptable. Four double stream doors on each side of the car at low-floor level, 1320 mm (52 in.) opening, plus two drivers' doors.
3. A small center body mounted to the unpowered "axle-less" middle truck, providing 1162-mm (46-in.) width at low-floor height as aisle/leg space for longitudinal seating.
4. 72 seats and standing space for 120 at 4 passengers/m^2.
5. Maximum grade on routes designed is 6 percent. One car should be able to push one dead car up any grade on the system. The 6 percent grade now identified is under 100 m long, but a 4 percent grade in the City Subway is about 1000 m long.
6. Top speed 88 km/hr (55 mph). Propulsion system to use four asynchronous 3-phase motors fed from nominal 750 VDC source, and controlled regeneration is desired. The car must be capable of operating on 600

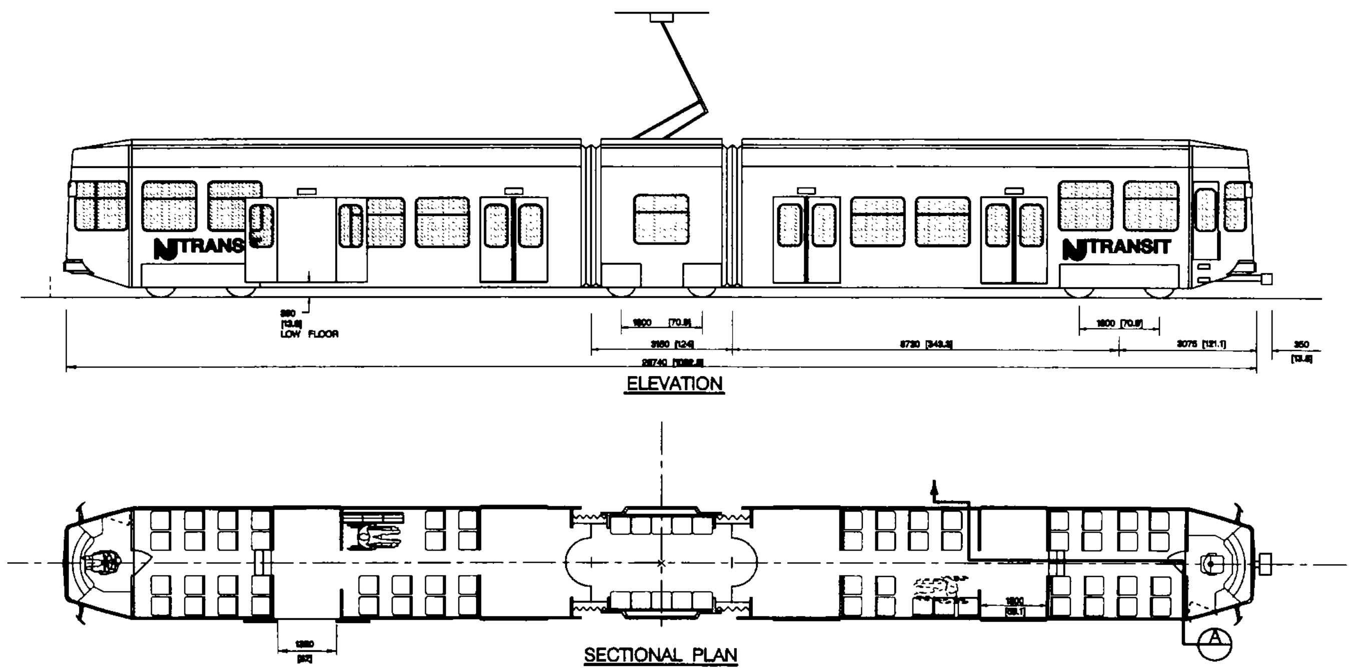

FIGURE 10 Partial low-floor concept car developed for NJ Transit by Parsons-Brinckerhoff.

VDC in the City Subway until the PCC cars are all retired and new substations have been constructed. During this period, somewhat reduced acceleration and top speed would be acceptable.

7. A low-profile powered truck is preferred, with wheels 590 mm (23 in.) in diameter used on both the powered and nonpowered truck. Should this not be practical, a conventional powered truck with wheels 711 mm (28 in.) in diameter will be accepted, and the nonpowered truck would have smaller wheels, that is, 660 mm (26 in.).

Presentations from two potential car builders have focused on their 100 percent low-floor car designs. The presenters assert that these vehicles can meet NJ Transit's performance requirements. The baseline 70 percent low-floor design is not a hard requirement, and it is possible that, in the end, a full low-floor vehicle will be selected.

System Standards at NJ Transit

Fare Collection

A proof-of-payment fare system has been selected for light rail lines at NJ Transit. An implementation study is under way for the Newark City Subway, and preliminary design for Hudson-Bergen is based on this concept. With on-street stations, a barrier system for the latter line would not be practical. The partial low-floor car with raised ends is not well suited to farebox collection at the driver's location, and a second employee in the rear car of a train is not economical. NJ Transit intends to adopt the design of ticket machine now in use at bus terminals and on the commuter rail lines. These machines will be standard across transit modes and can sell one-way tickets, multiride tickets, passes, and magnetic encoded PATH multiride tickets. Cash and credit or debit cards are accepted.

Electrification

Catenary energized at 750 VDC will be used on the Hudson-Bergen route, except in the street environment where simple trolley wire or a low-profile catenary will be specified. The Newark City Subway has a typical streetcar electrification, with simple trolley wire energized at 600 volts. Wire support structures and wire frogs are designed for trolley poles and shoes, not pantographs. NJ Transit intends to accomplish a staged conversion to an overhead contact system that is compatible with light rail cars equipped with pantographs and operating at 750 volts. In the early stages of conversion modifications will be made to allow both PCC and LRV operation. Later, the electrification can be modified for optimal performance of the LRVs.

Signals

A signal system was chosen for the Hudson-Bergen LRT that will have cab signals and automatic train protection. Wayside signals will be placed only at interlockings. The signal system will not be carried into slow-speed operating areas in or adjacent to streets; at these locations traffic rules will apply. When not under cab signals the maximum vehicle speed will be reduced. Operators will select routes at track switches, using an electronic control system such as VTAG. Signaling standards are not yet firmed up for Newark City Subway and its possible extensions. Route selection today uses streetcar technology, which measures current draw as the car passes a trolley wire contactor.

Communications

Radio communications on light rail routes are and will continue to be governed by the standards of the existing bus system. Modern bus radio systems allow fleets of vehicles to be defined, with each fleet talking (relatively) privately among its members and its controllers. NJ Transit police use a VHF radio system that is compatible with the railroad, and its coverage will be enhanced for use on the light rail lines.

A remote-controlled public address system will be used to advise patrons at stops about service irregularities and the like. It will be patterned generally on standards developed for commuter rail. Routine message phrases are prerecorded in computer memory and concatenated into complete sentences for transmission to one or more stops. A text version is also transmitted for display on signs at stops. This system allows the operator to set up a series of messages that will be customized, both in content and timing, for each stop.

Passenger security will be enhanced by installation of call-for-aid speaker telephones (without handset) on each platform, each in view of a closed circuit TV camera. When a patron activates the phone, the camera is also activated to send still pictures to the control center. Where elevators are provided, there will be phones (with camera) at all landings and in the cabs. Access to elevators will be under remote control. When and where vandalism is likely to occur, a remote operator can speak to and observe the patron before granting access and also can observe the patron using and departing from the elevator. Standards for public address and security systems are derived from those on the commuter rail services and the City Subway. Dispatchers will use radio and bus-type Automatic Vehicle Locator systems to control vehicles on the road.

Conclusion

Even within one agency, standardization does not come easily. Each of the projects has its own characteristics, and it is easiest and (in the narrow view) cheapest to optimize the fleet and fixed systems to the project. With a single car for all, it will be necessary for each route to make some adaptations and live with characteristics that are less than ideal. Standardization will, however, pay off in the long run. Three small, distinct, and incompatible fleets would be expensive to buy, difficult to commission, and a challenge to maintain. As time goes on, it would become harder and harder to keep personnel up-to-date on repair skills and to obtain the large variety of parts. Furthermore, if the same car is used on the three route systems, it will be possible to adjust service to demand by moving cars from one route to another.

Standards for infrastructure should follow industry norms as much as possible to keep costs moderate and avoid "inventing" technologies. Customers should perceive transit services as a system, with a logical fare system allowing easy use of bus, light rail, commuter rail, and PATH.