CHAPTER II

STATE OF THE ART RAIL & VEHICLE TECHNOLOGY

A. Introduction of Transit Vehicle Technologies

As a result of the Phase I of the MIS and further screening prior to entering Phase II, Phase II considers the following technologies:

- Triangle Transit Authority's (TTA) Phase I technology (i.e., as defined in TTA's design criteria, but may not be a Federal Railroad Administration-compliant diesel multiple unit (DMU));
- Busway (i.e., fixed guideway with completely dedicated right-of-way);
- Busway/Mixed Traffic (BMT) (i.e., a hybrid of on-street operation and an exclusive busway); and
- lighter rail technology than TTA Phase I, such as light rail or a lighter DMU.

Within each of these categories lies a range of vehicle, alignment and support systems technologies that are available and have been applied in various locations around the world.

B. Candidate Transit Vehicle Technologies

The following identifies several transit technology "packages" exemplifying the range of High Occupancy Vehicle (HOV) and busway systems offering *rapid bus* services (i.e., vehicles separated from general traffic flows for some or all of their runs), and rail systems providing the kinds of *regional rail* services that would be appropriate given probable levels of passenger demand in the U.S. 15-501 corridor.

- Bus Rapid Transit: Systems using some mix of HOV lanes and/or exclusive busways, perhaps with vehicles that are automatically guided or otherwise innovative.
- Regional Rail: Systems using self-propelled or electrically-propelled rail vehicles, either diesel multiple units (DMUs) or electric light rail transit (LRT).

1. Level Boarding & Low Floor Vehicles

One of the characteristics of rapid transit has been the matching of vehicle entries and boarding platforms to the same, or nearly the same height. On heavy rail systems in larger cities such as in Atlanta and Washington, D.C., this is achieved by using station platforms raised to the height of the car floors, a little over three feet above the rail (for mainline railroads, passenger car floors are typically 4 feet-3 inches above the rail).

In years past, level boarding was not offered on bus, light rail, and most commuter rail systems. Vehicle floors were raised, as on heavy rail cars, and passengers had to climb several steps to board from low station platforms (about curb height, 6-8 inches above the rail or road), and special facilities, lifts or ramps, were needed to accommodate riders unable to use steps. Now, "low floor" vehicles make it possible to offer rapid transit-style level or near-level boarding for all passengers from low platforms raised just a few inches above normal curb height. The result is that stations can be more readily integrated into urban and suburban streetscapes, and in full compliance with the Americans with Disabilities Act (ADA).

Vehicles with kneeling capability, short-rise lifts, and/or bridge plates to close vehicle/platform gaps enhance accessibility for people with disabilities. However, the low floor level makes it impossible to place seats over the front wheel wells. As a result, some seats are lost at the front of buses. This problem is not experienced on low floor rail vehicles.

After 15 years of development, low floor buses, light rail vehicles, and DMU cars have become the norm for transit systems in Europe and elsewhere. Only low floor transit buses can be purchased now in Canada, and they are being ordered increasingly by U.S. transit operators. Now widely used in western Europe, low floor light rail vehicles also are operating in Portland (OR) and northern New Jersey, are being built for San Jose, and will be purchased for Minneapolis and Seattle. Western European railroads, similarly, have embraced low floor DMUs, which also have been ordered for southern New Jersey and will be purchased for the new Oceanside-Escondido line in southern California.

Nearly all of the vehicles discussed in the following sections are low floor buses or rail cars that can offer level boarding from low platform stations. Exceptions are the Curitiba-type bi-articulated bus, some LRT vehicles, and Type I DMU candidates, which achieve level boarding with high platforms like heavy rail systems such as the Washington Metro.

2. *Bus Rapid Transit*

The term, "bus rapid transit" (BRT), has been defined as "operation on an exclusive or reserved right-of-way that permits high speeds. It may include reverse lane operations on limited access roads."[1] The ability of rubber-tired buses to operate on all kinds of paved roads suggests that BRT may be more generally defined as:

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[1] Gray, Benita H. (ed.). *Urban Public Transportation Glossary*. Transportation Research Board, Washington, D.C., 1989.

> ***Bus Rapid Transit (BRT):*** A specialized form of bus transit that incorporates operation on exclusive and/or reserved alignments over a significant portion of its route. Such facilities may include dedicated busways, high occupancy vehicle (HOV) lanes within highways or streets, and/or transit malls. Portions of BRT routes may also use general traffic lanes to provide single-seat pick-up or distribution service. In addition, BRT may involve automatic vehicle guidance.

Thus, a standard bus that begins its run in a city center, then travels relatively freely along an HOV lane before returning to local streets to distribute its riders may be considered as a lower-level form of BRT. At the high end of the BRT spectrum would be routes located entirely, or almost entirely, on exclusive or reserved ways as defined above, and perhaps using guided buses. The following paragraphs provide information on the various BRT vehicle candidates.

a) Standard Bus

Transit bus fleets typically consist of a variety of rigid and, in some places, articulated transit coaches. Most common is the so-called "standard" 40-foot diesel coach (Appendix A, Figure A-1). Smaller 30-foot and 35-foot variants on the basic design also are used for more lightly-patronized lines, but fixed facilities are usually designed around the 40-foot standard. Denver's 16th Street Mall shuttles (Appendix A, Figure A-2) are a specialized 100% low floor variant. Articulated buses (Appendix A, Figures A-3 and A-4) are sometimes appropriate for use on a system's more heavily patronized routes.

b) Guided Bus

At least two European suppliers are offering guided bus systems, and two more have experimental prototype installations under construction. All are based, to varying degrees, on adaptations of electric trolley buses, but two, Bombardier's *Tram on Tires* and the Matra *Civis*, also list diesel-powered versions. (Four of these technologies are illustrated in Appendix A, Figures A-5-A-8.) Primary differences among these candidates are in Table II-I as follows:

Table II-I. Primary Differences Among Guide Bus Packages

Item	**Breda/Neoplan** ***Stream***	**Matra/Irisbus** ***Civis***	**Bombardier** ***Tram on Tires***
Body Types	Std & Articulated	Double Articulated	Double-Articulated
Propulsion	Electric	Electric or Diesel	Electric &/or Diesel
Electric Power Source	Embedded Power Strip	Overhead Wire	Overhead Wire
Guidance System	n/a	Non-Contact Optical	Embedded Rail

Developers of *Civis,* the *Tram on Tires* and another similar product, *Translohr,* each sought to provide a vehicle-guidance-power supply package that would combine some of characteristics of light rail (see below) while retaining the capability to operate on regular paved streets as well as exclusive paved transitways.

- **Stream:** Traction power delivery system being developed by Ansaldo Breda (*Stream* is an acronym, in Italian, for "magnetic pick-up electric transportation system"), and represents an alternative to overhead contact systems. Electric power is transmitted to vehicles from a power strip embedded at surface level in street pavement. Short sections are energized only when a stationary or moving vehicle is above. At all other points, the power strip is not energized, so it poses no hazards to pedestrians or other surface traffic crossing it.
- **Civis:** High-capacity, double-articulated vehicle that can be manually steered or guided via an optical sensor beneath the center-line of the vehicle that reads a path established by two closely-spaced painted lines on the pavement. The vehicle's electric propulsion uses power supplied from an overhead wire and/or an on-board motor-alternator set. For straight electric operation, a second overhead wire is required.
- **Tram on Tires:** Formerly *Guided Light Transit (GLT).* High-capacity, double-articulated vehicle that can be manually steered or guided via small wheel assemblies bearing on an embedded rail placed in the pavement beneath the center-line of the vehicle. Electric propulsion for this vehicle uses power supplied from an overhead wire and/or an on-board diesel-generator set. For straight electric operation, the negative return can be via the guidance rail or a second overhead wire.
- **Translohr:** High-capacity, double- or single-articulated vehicles that can be manually steered or guided via small wheel assemblies bearing on an embedded rail placed in the pavement beneath the center-line of the vehicle. The Translohr's electric propulsion uses power supplied from an overhead wire and/or an on-board diesel-generator set. For straight electric operation, the negative return can be via the guidance rail or a second overhead wire.

  It should be noted that *Stream* is not really a guided bus, as an operator must steer it down the lane with its pick-up shoe properly aligned over the embedded power strip. What *Stream* does is to provide a method for supplying electric power to electric buses without having to build an overhead contact system (OCS) like *Civis*, the *Tram on Tires*, or the conventional trolley buses used in Boston, Philadelphia, Dayton, Seattle and San Francisco.

Key points regarding the BRT options are:

- At grade location of lines and surface operation are feasible;
- Low level platforms compatible with sidewalks and streetscapes are feasible;

- Peak hour, peak direction (PHPD) vehicles needed to carry 1,500 passengers (67% seated):
  - Standard 40-foot buses ≈ 23
  - Articulated buses ≈ 16
- Number of vehicles per run: one (Vehicles cannot be coupled into trains.);
- Average headway (minutes between vehicles): ≈ 2.6 to 3.75 minutes; and
- Emerging technology for guided buses; proprietary vehicles and support systems are just entering or not yet in revenue service, and are available from few suppliers.

3. Light Rail

Modern light rail transit (LRT) represents the highest current level of development of an electric railway technology and has been continually refined for more than a century in countries around the world. As a specialized type of electric railway, LRT has characteristics making it especially well-suited to placement in urban and suburban environments, including highways and streets.

> ***Light Rail Transit (LRT):*** A rail transit technology capable of providing a broad range of passenger capacities. Modern electric rail vehicles operate singly or in short trains. Taking power from an overhead wire, they can run on either exclusive or shared rights-of-way with or without grade crossings, or occasionally in mixed traffic lanes on city streets.

By 1975, only eight U.S. cities retained remnants of what had once been a vast network of city, suburban, and even intercity trolley lines criss-crossing the country. All have been modernized and renovated since then, and 12 completely new LRT systems have been built and placed into revenue service.[2] Virtually all the new systems have been extended or have plans for additional lines. Several more cities are actively pursuing LRT projects.

Locational flexibility is the primary defining attribute separating LRT from other rail modes, and an advantage LRT shares with BRT. Tracks can be laid in any of three generic right-of-way (R/W) categories:

a) Category A - Fully controlled R/W
Grade separated (aerial, fill, cut, tunnel), at- grade with no crossings, or widely-spaced crossings with signal override and gate protection.

b) Category B - Separate R/W
Longitudinally separated (curbs, barriers, grade separation) from other traffic, but with vehicle and pedestrian grade crossings, e.g., curbed medians, side-of-street reservations, private R/W with few-to-frequent grade crossings.

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[2] San Diego (1981), Buffalo (1984), Portland (1986), Sacramento and San Jose (1987), Los Angeles (1990), Baltimore (1992), St. Louis (1993), Denver (1994), Dallas (1996), Salt Lake City (1999), Jersey City (2000).

c) ***Category C - Shared R/W***
Surface streets with tracks in lane(s) that are reserved for transit by paint striping and/or signals, or lanes that are shared with other traffic.

On most new LRT systems, cars are large (80-90 feet long), high capacity (60-75 seats), high performance (50-65 mph), and capable of operation in trains of up to four cars (Appendix A, Figure A-9). Four double-width doors on each side of each car promote fast loading/unloading and, as a result, short station stopping (dwell) times. Smaller cars are used on city streetcar lines throughout Europe (Appendix A, Figures A-10 & A-11). In the past, cars with three steps up to a passenger compartment floor 39" above the rail were typical. Starting in the 1990's, a major change was the introduction of low floor cars (Appendix A, Figures A-12 & A-13). These Light Rail Vehicles (LRV) have passenger compartment floors not quite 14-inches above the rail through at least the center 2/3 of the car body, including all entries, with steps in the aisles leading up to standard-height floors above the normally constructed power trucks at the each end of the car. As long as they are separated from other traffic (except at grade crossings), systems with tracks on surface rights-of-way (R/W) can offer high quality service, sufficiently fast to compete with the automobile when the latter faces some congestion, yet at a fraction of the cost of a fully grade separated transit system.

Key points regarding the LRT option are:

- At-grade location of lines and surface operation are feasible;
- Low level platforms compatible with sidewalks and streetscapes are feasible;
- Peak hour, peak direction (PHPD) vehicles needed to carry 1,500 passengers (67% seated): ≈ 14;
- Number of vehicles per train: generally 2 or 3;
- Average headway (minutes between 2-car or 3-car trains): ≈ 8.6 or 12 minutes; and
- Mature technology; vehicles and support systems available from many suppliers.

4. Regional Rail

"Regional Rail" is a term used to distinguish rail passenger operations that connect cities and suburbs within a metropolitan region, as differentiated from "intercity rail" linking separated metropolitan regions, or "urban rail" systems located within central cities.

> ***Regional Rail:*** A rail transit technology capable of providing a broad range of passenger capacities. Modern diesel-powered rail vehicles operate singly or in trains. They can run on either exclusive or shared rights-of-way with or without grade crossings, or occasionally in reserved lanes on city streets. Operations may or may not be carried out over tracks that are part of the existing freight railroad system in the area.

As defined for the Triangle region, *Regional Rail* differs from traditional *Commuter Rail* in that it is not planned to share tracks with freight railroads. Depending on the forecast level of passenger demand, length of line, and opportunities for locating alignments, regional rail services may be provided by trains of locomotive-hauled or self-propelled railroad cars, or by electric light rail vehicles. Previous work in the U.S. 15-501 corridor suggests that further studies for this corridor should focus on self-propelled cars. In that regard, *Regional Rail* may be very similar to LRT, except in the use of diesel-powered instead of electrically-propelled rail vehicles.

However, it must be kept in mind that a wide range of DMU vehicles exists, in sufficient variety that analysts have agreed on three major classifications, as the vehicles might be applied on U.S. railroad and rail transit lines:

a) Type 1 - DMUs for Mainline Railroads
Such cars should be capable of operating in a mix of freight and other passenger trains, and should meet Federal Railroad Administration (FRA) structural requirements (800,000lb buff, etc.). Nippon-Sharyo and Bombardier have offered self-propelled versions of Electric Multiple Unit (EMU) and/or locomotive-hauled, push-pull cars, the former based on Indiana and Maryland cars, the latter on EMU cars recently delivered in Montreal (Appendix A, Figures A-14 & A-15). Adtranz has developed an FRA-compliant design that has been considered by Pennsylvania and, currently, by Triangle Transit Authority for the Raleigh-Durham corridor. All three designs are "classic" high floor, double-truck vehicles that will result in DMUs configured similarly to Budd Rail Diesel Cars (RDC) (Appendix A, Figure A-16), with end doors and step loading (unless high platforms are provided). Small numbers of the latter may be available for purchase and rebuilding, as was done for the Trinity Railway Express service operating in Dallas since 1996.

a) Type 2 - DMUs for Light Density Railroad Lines
Most of the European designs could be run on little-used lines that would be dedicated primarily to DMU operations (Appendix A, Figures A-17-A-20). Assuming little other railroad traffic on affected lines (e.g., limited local freight service), and the ability to time separate DMU and other trains with a day passenger/night freight pattern, waivers from FRA requirements should be obtainable based on existing and committed LRT lines (San Diego, Baltimore, Salt Lake City), the southern New Jersey DMU project now under construction, and demonstration trains such as Amtrak's *Talgo* trains in the Pacific Northwest. Virtually all manufacturers offer either high and/or low floor cars that could fit this category, for example, LHB *Lint*, Bombardier Eurorail *Talent*, De Dietrich *Eurailbus*, and at least three entries from various predecessors now folded into Adtranz: ABB/Scania *Flexliners*, AEG/Daimler Benz *Regioliner*, and AEG/DWA GTW 2/6 (railroad version).

b) ***Type 3 - DMUs Compatible with Light Rail Alignments***Cars in this category should be capable of operating on LRT street-based alignments, preferably meeting typical LRT standards such as 8.7-foot car width, 82-foot horizontal curve radius, etc., and they should offer low floor loading. Unfortunately, no such cars are known to exist.

Such cars could be straight diesel or dual-mode diesel-electric/electric. They would not meet FRA requirements, since they would be designed for compatibility with LRVs. Operation on railroad lines likely would be limited, such as for the Type 2 cars above, namely, time separation.

One design recently built as a straight electric for Swiss regional lines is intended to become the basis for such a dual-mode car. In fact, a diesel-powered version of this design has been ordered for the new southern New Jersey diesel light rail project (Appendix A, Figure A-21). A transit variant of the Adtranz GTW 2/6, each of the 20 diesel LRVs will consist of two long passenger compartments, cantilevered off a short central body section like the new Portland LRVs, except that the center section houses the propulsion system instead of carrying passengers. Of modular design allowing a variety of lengths and widths, the initial batch are to be 98-foot long and 8.7-foot wide, with a 14.5-inch floor height through 2/3 of the passenger compartment, including all entries. Minimum turning radius is 130 feet, too broad for turns within many city street intersections.

Another possibility is the Siemens *RegioSprinter* (Appendix A, Figure A-22), a mid-1990s design for German branchline railroads, that is on the border between "diesel LRV" and "light railroad DMU." Its three-section, articulated car body is conceptually similar to the GTW 2/6; but the *RegioSprinter* has twin diesel engines and mechanical transmissions, one located under each driver's cab at the ends of the car. Since it was originally designed for light density European branch railroads, its turning ability is even less forgiving than the GTW 2/6. The minimum turning radius for a *RegioSprinter* is 265 feet.

Further refinement is needed to develop a DMU that can turn on the 82-foot curves common on new North American LRT street-running alignments. Short of re-designing the articulation joints and other elements of a less-capable vehicle, the only existing possibility is Bombardier's *Tram Train* (not to be confused with the *Tram on Tires*). Built as a three-section electric LRV for a new system in Saarbrucken, Germany (Appendix A, Figure A- 23), the car has low floor sections at the entries in each of the two end car bodies, with high floors under the driver's cabs and throughout the middle section. Its builder envisions that a diesel-generator set could be mounted under the center car body to power electric traction motors on each of the car's four trucks.

Key points regarding the Regional Rail diesel LRV (*Tram Train* or *GTW 2/6*) option are:

- At grade location of lines and surface operation are feasible;
- Low level platforms compatible with sidewalks and streetscapes are feasible;
- Peak hour, peak direction (PHPD) vehicles needed to carry 1,500 passengers (67% seated): ≈ 10;
- Number of vehicles per train: 1 or 2; and
- Average headway (minutes between 2-car or 3-car trains): ≈ 6 or 12 minutes.

C. Comparison of Vehicle Alternatives

The technology alternatives described in Section B possess a variety of physical, performance and service characteristics. Similarities and differences between technologies are explored in this section.

1. Technology Elements

Physical and operating characteristics of several technologies are presented in Appendix A, Table A-1. The conceptual design vehicles use maximum or minimum values, as appropriate, to accommodate a worst-case or recommended design standard.

Data for standard and articulated buses represent a composite of the 40-foot standard and 60-foot articulated urban transit buses currently in production, typically 70%-80% low floor designs. Exceptions are the “Mall Bus” column, which describes the 100% low floor vehicles used on Denver’s 16th Street Mall, and the high floor “Bi-Articulated” bus, such as used in Curitiba, Brazil, where level boarding is achieved by using the unique raised tube stations to provide platforms at the same height as bus entries.

Information on the *Stream* in-pavement power distribution system, and the three French guided bus systems is taken from materials produced by the firms promoting these proprietary transit technologies. Because it uses standard 40-foot and articulated buses that have been adapted to its unique power system, *Stream* should produce the same capacity and performance results as for regular diesel vehicles. Results vary, however, for the guided buses, which, like the “Mall” and "Bi-Articulated" buses, are designed for in-city urban services.

Similarly, data for the candidate LRT and DMU rail vehicles also is taken from materials produced by supply firms. Unlike the guided buses, there are numerous manufacturers producing many different types of rail vehicles.

2. Consolidation of Vehicle Suppliers

In response to the globalization of the economy and, particularly, the creation of a Europe-wide single market, there has been in progress for several years a distinct pattern of consolidation in the rail car building business. Results of consolidation include:

- Concentration of production at the most efficient plants inherited from predecessor firms, and closure of less efficient facilities.
- Reduction in the number of candidates within each technology type, as the new firms - much like automobile manufacturers - attempt to focus on a few “models”

with “options” to reduce design and manufacturing costs and improve their price competitiveness.

Thus, Adtranz, in the late 1990s, developed new designs combining what were deemed the best features of similar products offered by predecessor firms that had been taken over, for example:

- LRVs for city systems: *Incentro*, based on *GTx-Series*, *Eurotram*, and *Variotram*
- DMUs for regional railroads: *Itino,* based on *Regio-Shuttle, Flexliner,* and *GTW 2/6*

If tooling remains in place and production has continued or only recently ended, or where one or more large orders makes the effort worthwhile, then the “older” vehicles can still be purchased. Marketing, however, is concentrated on the “new” vehicle platforms.

As of this writing, it appears that Adtranz will be merged into Bombardier, making Bombardier the world’s largest rail car builder, ahead of Alstom (a combination of previously separate French and English firms) and Siemens. A similar case is the joining of forces by several European bus builders in France, Italy, Spain, the Czech Republic and Hungary to create a new firm called Irisbus.

3. Operational Fit

The data in Appendix A, Table A-1, address physical and service issues that, taken together, provide the basis for assessing the operational fit of each candidate technology.

a) Dimensions

Alternative vehicles range from standard transit buses (40 feet long by 8.5 feet wide by 10 feet high) to large railroad passenger cars (up to 200 feet long by 10.5 feet wide by 13.1 feet high). The right-of-way, station platform, side and overhead clearances, and other physical facilities required to support operation of this range of vehicles will differ considerably from one option to another. Considering these factors together, it is clear that it will be less difficult to fit alternatives into existing highways and streets and the university campuses using smaller, street-capable vehicles. It will be more difficult to add a facility using railroad vehicles into the same places.

b) Low Floor

Traditional high floor vehicles require rather large, high platform stations to provide level boarding, or inconvenience passengers with slow boarding and alighting by using step entries from low platforms, combined with special lifts or ramps for people unable to climb stairs. Matching low floor vehicles to low platforms raised only a few inches above normal curb height eliminates these drawbacks. Station platforms are more easily integrated into the areas surrounding them, fast step on/step off passenger boarding and alighting is provided, and people using mobility aids are mainstreamed into the general passenger flow. All but two alternatives can be built using low floor vehicles.

c) Accommodations

Passenger capacity and comfort are important issues in designing a transit service. In the Research Triangle area of North Carolina, summer temperatures and humidity cause people to expect public facilities to be air conditioned. Provision of full air conditioning is now the norm for U.S. transit vehicles of all types, but it is not yet universal in Europe. Thus, to provide attractive service in this region, some of the technologies listed in Table II-I would need to be modified to add full air conditioning.

Regarding system capacity, bigger vehicles can carry more passengers, so fewer vehicles can do the same job as a larger number of smaller vehicles. This is not always an advantage. Where demand is light or moderate, use of vehicles that are too large may result in providing too much capacity or, alternatively, too little service. Table II-II compares the number of passengers transported per hour per direction based on the number of runs per hour for the three different vehicles.

Table II-II. Effect of Vehicle Capacity on Service Frequency

Item	Std 40' Bus	GLT	DMU (2-Car Trains)
Riders per Vehicle or Train	65	150	350
Passengers/Hour/Direction if:			
- 2 Runs/Hour (30 min H)	130	300	700
- 4 Runs/Hour (15 min H)	260	600	1,400
- 8 Runs/Hour (7.5 min H)	520	1,200	2,800
- 12 Runs/Hour (5 min H)	780	1,800	4,200

H = Headway = service frequency, the time interval between vehicles.

The table clearly shows why higher capacity transit is limited to a region's primary corridors where their efficiency can be utilized, while standard buses suffice for local distribution, circulation and feeder lines attracting fewer riders. The higher GLT and DMU volumes are consistent with the experience of several LRT and commuter rail lines operating in other U.S. cities.

d) Propulsion Alternatives

Most candidate vehicles can be provided with more than one type of propulsion, though to some extent, the assertions in Appendix A, Table A – 1, depend on how a vehicle is defined. For example, bus options are defined here as diesel-powered; but both 40-foot and articulated electric trolley buses are used in cities around the world. Similarly, LRT is assumed to be electrically propelled using power taken from an overhead contact system (OCS); but LRVs occasionally have small internal combustion engines (e.g., Lausanne) to avoid the expense of OCS in yards and shops. Finally, cars defined herein as Type 1 DMUs are, in fact, based on cars previously built and in operation as electric multiple unit commuter cars. In each case, the choice tends to be one type of propulsion or the other. The exceptions are the three French guided bus systems, whose designs expressly include the flexibility to use diesel or electric propulsion or both.

e) Operating Capability

This category of characteristics covers items that affect the ability of vehicles to operate under varying conditions.

- **Maximum Speed :** Vehicles intended for city and suburban services (U.S. diesel buses) tend to have higher maximum operating speeds compared to vehicles (basically, all the other rubber-tired candidates) targeted for central city services, which are more likely to combine lower speeds, heavier passenger loads, and more closely-spaced stops. As a practical matter, there is a performance trade-off between maximum operating speed and the rate of acceleration, with the choice for a particular service dependent on the relationships of corridor length and station spacing. Short city routes with a stop every block need rapid acceleration more than a high top speed, but long regional corridors with stations spaced miles apart benefit more from high speed than fast starts. Thus, an electric LRV will accelerate at 3 miles per hour per second (mphps), but may attain a speed of 50-60 mph, while an Amtrak train will accelerate at less than 1.0 mphps, but reach in excess of 100 mph. Generally, a diesel-powered vehicle will not accelerate as rapidly as a similar electric vehicle, simply because of the limits on how much diesel engine can be packed physically and economically into the available space, whereas an OCS can supply all the power and electric vehicle can use.
- **Grades and Curves:** Whether rubber-tired or steel-wheeled, vehicles intended for in-street alignments that include turns through intersections must be capable of operating around sharp curves, and on relatively steep grades. These requirements are met by the various steered and guided bus options, and by the LRT alternatives. Among DMUs, however, only one design (a diesel version of Bombardier's *Tram Train* that has not progressed beyond the concept stage) approximates the grade-climbing and turning capabilities of light rail vehicles. Other alternatives are based on the easier grades and broader curves found on railroads.
- **Directionality:** Manually steered rubber-tired vehicles are almost universally set up with one operating cab or position at the front of the vehicle. Steel-wheeled vehicles, which are guided as well as supported by their rails, typically are designed with a cab at each end, and can be run with equal facility in either direction. Some LRT systems use single-ended cars to reduce costs (fewer operating cabs and doors on only one side of the car) and increase seating. The trade-off is the requirement for a loop or other turnaround facility wherever direction is to be reversed, and a reduced ability to respond in

emergencies, because "short turns" cannot be effected easily at any point on the line, as they can be with double-ended cars. It should be possible to operate the guided buses as double-ended vehicles, so long as they are in "guided" mode, but *Translohr* is the only candidate that includes this feature in its design package.

- **FRA Structure:** Passenger-carrying cars operating on the tracks of the general railroad system of the U.S. must be built to the standards imposed by the Federal Railroad Administration (FRA). These regulations encompass many areas of design, but the standards covering car body strength have the most impact on light rail transit vehicles and the lighter DMUs, because such cars are designed to meet the less stringent standards of European railway and/or European and U.S. rail transit regulations. Commuter rail lines operating on tracks also used by freight and/or intercity passenger trains have acquired cars that meet the FRA's standards.

  Most of the newer LRT systems have kept their tracks separate from those of the general railroad system, in part to ensure that they will remain under Federal Transit Administration (FTA) rules and not FRA. Three systems - San Diego, Baltimore, and Salt Lake City - operate non-compliant light rail vehicles on tracks owned by the transit authorities, but that also carry freight trains. FRA has granted waivers to these systems, and to the similar southern New Jersey DMU line now under construction, on the basis that transit and freight trains will be positively separated in time, i.e., transit passenger services during day and evening hours, and freight trains on the line only in the late night hours when the transit service is not running. This limitation on freight operation is feasible on branches where local freight trains serve shippers along the line, but would be onerous for a freight railroad trying to run numerous through and local freight trains on a heavily-used main line. Under such conditions, FRA-compliant passenger equipment must be used, unless separate tracks can be built for the transit passenger operation. Even in the latter case, however, the center lines of adjacent transit and railroad tracks must be separated by at least 25 feet to avoid FRA regulation of items such as flagging for track workers on the other line.

  In its TTA Phase I planning, the Triangle region has chosen a Durham-North Raleigh route that is based on sharing existing railroad rights-of-way, and the vehicle choice appears to be leaning toward a FRA-compliant DMU, even though separate trackage is contemplated for the rail transit service. For the MIS Phase II route from Durham to Chapel Hill, however, both highway-based and new alignments are under consideration. As a result, design issues related to grades, curves and "urban fit" seem likely to be divergent between the TTA Phase I and MIS Phase II routes. Laying out alignments that accommodate railroad grades and curves, and that result in a comfortable blending of railroad rolling stock into built environments such as the university campuses is likely to pose challenges greater than laying out alignments for options using LRVs, guided buses, or standard buses.

4. Costs

There are two kinds of cost that must be considered: the initial capital investment to design and build fixed facilities, and to specify, procure and install vehicles and support systems, and the operating and maintenance expenses that will continue over the useful life of the project.

a) Capital Investments

The individual elements of capital investment can be classified as occurring in nine major categories:

- Guideway Elements: Roadbeds, structures, track or paving;
- Stations: Platforms, shelters and associated furnishings, transfer facilities, park-ride lots;
- Yards and Shops: Vehicle storage yards, maintenance buildings, tools & equipment;
- System Elements: Electrification, signals, communications, fare collection;
- Vehicles: Revenue (passenger) and non-revenue (maintenance & supervisory);
- Special Conditions: Utility relocation, demolitions, roadway changes, environmental issues;
- Right-of-Way: Land acquisition, relocation; and
- Project Soft Costs: Engineering & design, construction management, overall project management, finance charges, training/start-up/testing.

Not all capital cost elements would be incurred for every candidate transit vehicle technology. The following table lists technologies and the related cost elements to add a new service to an existing transit system that already has some bus service and facilities in place.

Table II-III. Correlation of Capital Cost Categories and Vehicle Technologies

Cost Category	Street Bus	Bus Rapid	Guided Bus	LRT	DMU-New	DMU-RR
Guideways:						
- Roadbeds	No	Some	Some	Yes	Yes	Some
- Structures	No	Some	Some	Yes	Yes	Some
- Paving	No	Some	Yes	Some	No	No
- Track	No	No	Steering	Yes	Yes	Some
Stations:						
- Platforms	Some	Yes	Yes	Yes	Yes	Yes
- Transfer facilities	Some	Yes	Yes	Yes	Yes	Yes
- Park-ride lots	Some	Yes	Yes	Yes	Yes	Yes
Yards & Shops:						
- Storage yard	Expand	Expand	Expand	Yes	Yes	Yes
- Maint. Building	&/or	%/or	&/or	Yes	Yes	Yes
- Tools & equipment	modify	modify	modify	Yes	Yes	Yes
Systems Elements:						
- Electrification	No	No	Maybe	Yes	No	No
- Signals	No	Ltd [a]	Ltd [a]	Yes	Yes	Yes
- Communications	Radio	Radio	Radio	Yes	Yes	Yes
- Fare Collection	On board	Maybe	Maybe	Yes	Yes	Yes
Vehicles:						
- Revenue	Yes	Yes	Yes	Yes	Yes	Yes
- Non-revenue	Maybe	Probably	Probably	Yes	Yes	Yes
Special Conditions:						
- Utility relocation	No	Some	Some	Yes	No	No
- Demolitions	Ltd	Some	Ltd	Some	Some	Ltd
- Roadway changes	Ltd	Some	Some	Some	Ltd (Xings)	Ltd (Xings)
- Environmental	Few	Some	Ltd	Yes	Yes	Ltd
- Railroad agreements	No	Ltd [b]	No	Ltd [b]	Ltd [b]	Yes
Project Soft Costs:						
- Eng. & design	Ltd	Yes	Yes	Yes	Yes	Yes
- Construction mgt	Ltd	Yes	Yes	Yes	Yes	Yes
- Project mgt	Yes	Yes	Yes	Yes	Yes	Yes
- Finance charges	Ltd	Probably	Probably	Probably	Probably	Probably
- Train/start-up/test	Ltd	Yes	Yes	Yes	Yes	Yes

[a] Traffic light prioritization. [b] Only portions of facility place within a railroad r/w.

The qualitative analysis in the above table suggests that for a given corridor, LRT is likely to be more costly to put in place than a DMU service. Furthermore, LRT is likely to cost more than guided bus or bus rapid transit, for which some segments can be placed in existing streets without major reconstruction, and/or new facilities built at intermittent locations instead of throughout the entire corridor.

b) *Operations & Maintenance*

It is usually most convenient to think of operating and maintenance (O&M) costs in terms of five large categories:

- Transportation: Costs of revenue vehicle operation;
- Maintenance of Equipment: Costs of servicing and repairing revenue vehicles;
- Maintenance of Way: Costs of servicing and repairing all other fixed facilities and systems elements;

- Claims: Costs of injuries and damages; and
- General and Administrative: Costs of managing the transit system.

The experience of U.S. transit systems operating more than one mode has been that rail, when properly used on the system's most heavily patronized line(s), usually costs less in O&M per passenger mile than the bus networks serving all the other lines, but that the overall effect is to produce a more cost-efficient system than if only buses were being operated.

There is the higher labor efficiency of larger vehicles running in trains. In Sacramento, for example, four-car trains of LRVs, each with only one operator, run on 15-minute headways to carry about 1,800 peak hour, peak direction riders. That level of demand would require about 30 standard buses, each with its own driver. The increase in operating labor utilization is so great that it more than offsets the increased expense of LRT fixed facility and systems maintenance personnel that an all-bus system would not experience. This high labor efficiency must be achieved for rail transit, whether LRT or DMU, to become a beneficial addition to a region's transit system.

D. Summary

Ordinary street bus routes provide an adequate level of service on most of the local transit routes in U.S. cities and suburbs. As metropolitan areas grow, road congestion associated with the increase in trip-making leads to opportunities to introduce higher-capacity transit in one or a few main travel corridors.

The attractiveness of such services increases with the extent to which they can be separated from the general traffic flows. Bus priority schemes are a first step, using traffic light prioritization, queue-jumper bus lanes through intersections, and later adding more extensive high occupancy vehicle (HOV) lanes.

When it appears some portion of transit passenger flows can be concentrated on one or more primary trunk lines, larger-capacity vehicles such as articulated buses, LRVs and DMUs can be considered. Each has its own advantages and drawbacks, as noted in the foregoing pages, and highlighted below.

- Can intermittent facility improvements built in increments over time lead to faster trips? If so, a bus rapid transit program may be in order.
- Is the desired technology proven in revenue service and available from multiple suppliers, or is it developmental and proprietary to a single manufacturer? If the latter, does it offer enough advantages to make the risk of being a "pioneer" application worth taking?
- Will peak ridership support the operation of trains of two or more cars? When this occurs, improvements in operating efficiency may favor using vehicles that can be

coupled into trains, i.e., a rail system, even though a corridor-length investment in facilities is needed initially.

- Is there a railroad line with capacity for traffic growth? A shared-track rail service may become feasible.
- Is there an alignment opportunity through some significant portion of the corridor, but not throughout? A technology that can run on reserved and exclusive alignments, and also in streets may be appropriate, either bus rapid transit (manually steered or guided) or LRT.

In a growing metropolitan region, the choice of appropriate transit technologies - vehicle and support systems - must be considered in terms of present, near-term future and long-term future needs and expectations.