Key Issues in Light Rail Transit Station Planning and Design

JEROME M. LUTIN AND GREGORY P. BENZ

Planning for light rail transit (LRT) systems often focuses on the development of alignment alternatives to maximize use of available rights-of-way. The selection of station locations sometimes seems to follow almost as an afterthought. Ideally, station sites should be planned first, and the alignments should be developed to connect the stations. In practice, however, LRT planning involves a balance between locating alignments and locating stations. Some of the major issues planners must address in locating and designing stations include station spacing, station location, mix of land uses served, pedestrian access to stations, station layout and its relation to operations, and implementation. How LRT planners can address each issue to maximize ridership and reduce costs is illustrated by examples from recently constructed LRT systems and systems still in planning.

Transit systems, including light rail transit (LRT) systems, exist to move people safely, conveniently, and efficiently. Along with the transit vehicles, a transit system's primary interface and exposure to the passenger is through its stations. Station location and design have a major effect on the ability of passengers to access and use a transit system.

To gain the support of citizens and elected officials for a new LRT system, planners must demonstrate that the system effectively serves the community. The system must take people where they want to go, be convenient to use, and offer a transportation service that is better than the available alternatives. Ideally in planning and designing stations every decision should be tested against these criteria.

The following principles should guide station planning:

- Station sites should be planned before alignments.
- Travel speeds needed to attract riders should be considered in determining station spacing.
- Alignments in residential areas are preferred over industrial corridors.
- Pedestrian access to stations should be considered early in the planning process.
- Land use plans for new developments, such as suburban office parks, should emphasize the clustering of buildings around station stops to reduce walking distance.

Because the LRT planning process is ultimately exposed to public scrutiny, planning ideals such as these will inevitably be challenged by politics, NIMBY (not-in-my-back-yard) sentiments, and the pragmatic consideration of costs. Trade-offs and compromise will be needed.

The importance of stations, their location, and design are often not fully recognized and reflected in the implementation of rail transit projects. Rail alignment design criteria, right-of-way, and land availability may dictate the locations of stations rather than allowing stations to be where they can best serve the riders. Trade-offs are necessary to make a project affordable and implementable, but too often station planning and design issues that could easily be addressed well in the conceptual planning stages are given low priority as detailed design, construction, land acquisition, and implementation issues are addressed in later phases. LRT technology has several special characteristics that make it possible to locate stations where they can serve the riders.

PLANNING OBJECTIVES, STATION TYPES, AND LRT TECHNOLOGY

Station planning and design should achieve a number of objectives. The primary issues relate to providing a means for passengers to use the transit system safely, conveniently, and comfortably. Safety includes minimization of accidents, falls, and crush load conditions as well as security considerations and provisions for emergencies (including evacuation of the station and train occupants). Convenience is reflected by the ease of use, relatively short and direct travel paths, minimal queuing (delay), and reduction of congestion and crowding. Comfort addresses issues of amenities, architectural and environmental (lighting, air, noise) treatments, and aesthetics.

Many other objectives for station planning and design exist, such as encouragement of land development and community cohesion. The focus here, however, is on objectives related to passenger service and train operations issues.

Depending on the nature, extent, and location of the transit system and methods of fare collection and other operating procedures, stations may accommodate a number of passenger activities, including

- Interchange with the transit system(s) and access to and from the station,
- Transfer between transit services or modes,
- Fare transactions and collection,
- Information regarding use of system, and
- Waiting, including seating and weather protection.

Although these activities are generally common to all transit technologies and even most other transportation modes, LRT

J. M. Lutin, New Jersey Transit, 2 Journal Square Plaza, Jersey City, N.J. 07306. G. P. Benz, Parsons Brinckerhoff Quade & Douglas, Inc., One Penn Plaza, 5th Floor, New York, N.Y. 10119.

stations may provide for them in a wide range of ways. For instance, stations may be as simple as stops with on-board exact-change fare collection (like a bus system) or as elaborate as multilevel stations with fare gates defining a "paid" zone similar to most rapid rail transit systems.

Station Functional Types

Stations can be categorized into three functional types reflecting the role they serve for passengers. One, the line-haul collector function, is typical of a suburban station that serves as a focus of passengers coming from residential origins. Provisions should include park-and-ride, kiss-and-ride, feeder and shuttle buses, walk-in, and bicycles. This type of station is primarily subjected to boarding flows in the morning, with the need for ample inbound platforms, and evening alighting flows, with the need to accommodate exit surge volumes of automobiles and buses after passengers leave outbound trains.

Another type, the line-haul distributor function, is typical of stations at a major development concentration such as a central business district (CBD) or a major activity center in a CBD fringe or suburban area. Provisions must be made for pedestrian access as well as distributor bus services, and taxis and shuttle vans. These stations primarily have alighting morning flows, and therefore need ample inbound platform egress capacity, and boarding flows in the evening principally headed for the outbound platform.

The third type is the transfer stations. Although all stations involve some interchange of travel modes, this type of station involves the interface with another line-haul or major distributor transit service. This could be another line of the same mode or a different technology. Stations must contend with the particular transfer volumes and patterns at different periods of the day, accommodate the particular fare control and informational needs of each system, and accommodate the passenger needs in the event of service disruptions on one or more of the intersecting services. Convenient passenger transfers are a primary objective. This type of station may also have one of the other functions as well, particularly in a CBD setting where line-haul services often intersect and the station must play the line-haul distributor role as well.

Terminal stations at the end of the line, stations where lines branch, and those serving special trip generators such as an arena or airport have special needs and considerations peculiar to the situation.

LRT Technology

LRT is characterized by steel-wheeled vehicles running along paired steel rails with power supplied via an overhead wire. The size, configuration, capacity, performance, and other features vary. Trains can be a single vehicle or multicar consists. The characteristics of LRT as a technology that enable LRT stations to be advantageously located are its flexibility, adaptability, and potential range and combinations of system feature choices. In particular an LRT alignment has the ability to have relatively tight turning radii (as low as 100 ft), relatively steep grades (as much as 8 percent), and to operate with single-track sections and in a variety of environments—in street, semiexclusive, exclusive, or a combination. A light rail vehicle's (LRV's) floor height is typically 39 in. (1 m) above the top of the rail. Platforms can be high level—at the same height as the vehicle floor—or low level—passengers use on-vehicle stairs to access the vehicle. A low-floor LRV—approximately 12 in. (0.3 m) above the top of the rail—allows level boarding from "low" platforms.

Similarly, as will be discussed later, LRT stations can have a range of features and be adapted to the specific site conditions, service needs, and system operational requirements. LRT's flexibility, adaptability, and range of choices give this technology an ability to reduce cost or avoid major cost or community and environmental problems. Even when taking advantage of these LRT features, site-specific conditions can sometimes require a compromise with travel speeds (such as in mixed traffic environments or around a tight curve) or schedule reliability (because of grade crossings or single-track segments.) More than most other transit options, LRT provides the opportunity to trade off and optimize operating objectives with station placement, costs, and effects.

STATION PLANNING AND DESIGN PRINCIPLES

These station objectives, activities, and functions can be addressed by LRT station design by exploiting the special characteristics inherent in LRT technology.

Station Spacing

Modern LRT systems function in a competitive environment, and station spacing has a direct bearing on the competitiveness of an LRT line. Almost every household in America has an automobile available and many have more than one. To be successful an LRT line must draw as many automobile users out of their cars as possible. LRT service must therefore be competitive with automobile travel in terms of travel time and convenience.

Patrons want both a short walk to and from the station and high-speed travel between stations. Yet, these two desires, short walking distance to the line and high speed travel, present conflicting goals for the LRT system planner. Trade-offs must be made to achieve a satisfactory balance.

A number of factors are included in the mathematical equation used to determine average speed on an LRT system:

- Station dwell time,
- Vehicle acceleration rate,
- Vehicle deceleration rate,
- Jerk (rate of change of acceleration or deceleration),
- Vehicle top speed, and
- Distance between stations (*1*).

Station dwell time is a function of the number of people boarding and alighting, time needed to collect fares on entering or exiting the vehicle, and the number and width of the doors available. Vehicle acceleration, deceleration, and jerk rates are generally governed by comfort levels. All three parameters must be kept in a range that allows standing passengers to maintain their balance easily when the vehicle starts or stops. Top speed is a function of vehicle motor capacity and gearing but more frequently is governed by horizontal and vertical curvature and superelevation of the tracks.

Distance between stations, as it affects LRT line speeds, differs from the factors just mentioned. Whereas all the other factors are determined largely by the laws of physics, station spacing is almost entirely a judgment call, left to the planners' discretion.

To illustrate the relationship between average line speed and station spacing, an "average" North American LRV was assumed based on published vehicle performance data for nine North American systems (*2*). Figure 1 shows the average speed attained on a typical line segment between two stations as a function of station spacing with an assumed dwell time of 20 sec. The example shown assumes that the vehicle accelerates to its maximum cruise speed (Vmax) and decelerates to a stop. Where the line segment is too short for the vehicle to reach Vmax, the vehicle is assumed to accelerate to the point at which it must begin braking for the next stop. From this example one can see that 0.25-mi (0.4-km) station spacing yields an average speed of 15 mph (24 km/hr), 0.5-mi (0.8-km) spacing yields 23 mph (37 km/hr), 1-mi (1.6 km) spacing yields 32 mph (51.5 km/hr), and 2-mi (3.2-km) spacing yields 40 mph (64.4-km/hr).

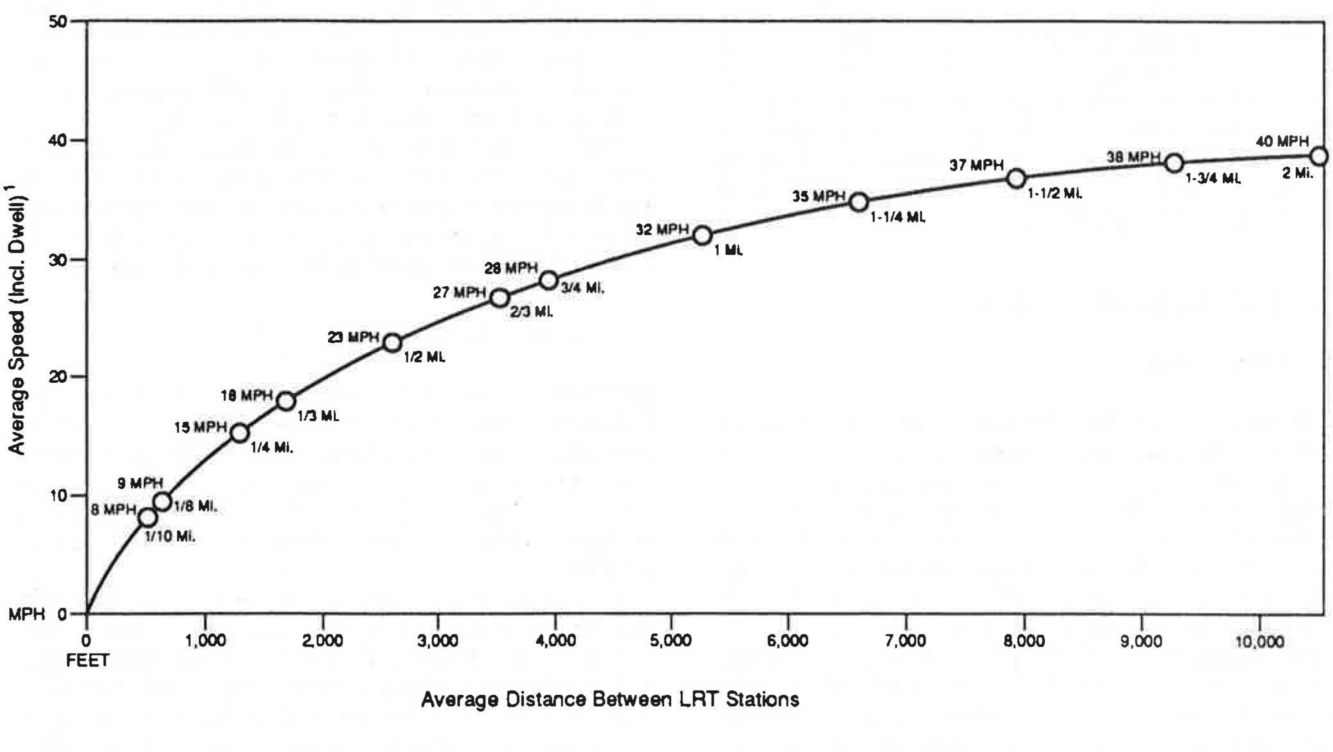
This example clearly indicates that the LRT planner must consider the implications of station spacing on meeting the travel time goals and objectives established for the prospective system. If, for example, a major goal is to improve service for existing transit riders using a local bus system averaging 12 mph (19.3 km/hr) on local streets, then stations spaced as close as 0.25 mi (0.4 km) may be used. If, however, a major goal of the planned system is to attract drivers from a parallel freeway on which they average 25 mph (40.2 km/hr) in the peaks, then average station spacing must be kept to 1 mi (1.6 km) or more to maintain a speed average.

In most corridors it is possible to adjust station spacing to accommodate local access conditions. In CBDs where most riders walk to and from stations, closely spaced stations are most appropriate. In the suburbs where the line is intended to serve either dispersed office concentrations or park-and-ride users drawn from residential areas, more distant station spacings can be used.

In the early sketch planning phases, however, planners should calculate the average station spacing over the entire line and check to see if it will allow the line to achieve the desired travel speed needed to attract the potential riders the line is intended to serve.

Station Location and Trip Purposes

People make trips because they have needs that can be met only at a location other than the one at which they happen to be. This simple fact means that given the way our cities are laid out, the heaviest travel demands lie between areas with differing land uses. If a new LRT line is to be successful,



[1] Assumes V_{MAX} = 53.3 MPH, Jerk = 3.05 MPH/Sec^3, Accel = 1.64 MPH/Sec^2, Decel = 3.06 MPH/Sec^2, Dwell = 20 Sec.

FIGURE 1 LRT station spacing—average speed relationship.

it must provide connections among the land use types and activity centers that correspond with the reasons people make trips. Consequently station locations must be planned with regard to existing trip-making patterns in a corridor or provide opportunities to create new trip patterns among diverse land uses.

Rail transit's traditional role has been to serve work trips linking residences (preferably high-density) with jobs (also preferably concentrated in high-density locations). Historically the home-work-home trip has constituted the majority of all trips made on transit. Today, however, new trip patterns are developing in response to changes in lifestyle and family composition. Examples of changed lifestyles that affect travel are more dual-worker households and more single-parent households.

Dual-worker households often result in home-drop spouse-work-pick up-spouse-home trip patterns in which one spouse drives to work and the other takes transit. This pattern will increase the need for convenient kiss-and-ride access to stations, which lends importance to locating stations with easy access to arterial streets that run between residential areas and employment concentrations. It also requires convenient drop-off points and kiss-and-ride circulation at stations as well as adequate space for cars to queue for evening pickups.

Dual-worker households also have less time available for shopping and personal business. Consequently the evening trip from work to home often becomes a work-shop-home or work-day-care-eat meal-home trip. More riders may be attracted to stations at the residence end if they are located close to shops and restaurants.

Single-parent households often have unique trip needs, requiring home-day care-work-day-care-home or home-school-work-baby sitter-home daily trip patterns. Locating a park-and-ride station close to a school or day care center may provide a way to attract single-parent users who otherwise might find transit too inconvenient given their hectic schedules.

The essence of these examples is that station locations in a proposed LRT corridor should be planned to link sensible destinations that correspond with contemporary travel needs of the expected user population.

Land Use Environment for Stations

Rail Rights-of-Way

In laying out prospective LRT lines, planners often concentrate on finding continuous alignments, because the issue of continuity is critical and most problematic. In many instances planners strive to find an at-grade alignment to avoid the expense of subway tunneling or aerial structures. The search for available corridors often focuses on existing rail freight rights-of-way, either active or abandoned, and leads to LRT alignments that pass through industrial corridors.

Although an old freight line satisfies the need for a continuous corridor, the adjacent land uses typically include industry, warehousing, and often abandoned industrial buildings and vacant land. These land uses are poor trip generators today, and prospects for future development may not be great either. Such properties may be contaminated with hazardous waste, have poor automobile access (as well as security concerns about leaving a car in a lot or using the station late at night), or appear sufficiently unattractive to discourage developers from investing in the area.

The pattern of industrial corridors radiating out along rail rights-of-way is typical of many urban areas, and residential corridors tend to lie between the industrial corridors like alternating spokes of a wheel. In essence the radial pattern of residential corridors is "out-of-phase" with the pattern of existing rail corridors most readily available for rail transit.

Another implication of this pattern for LRT planners is that the residential population may be fairly distant from the rail corridor, and pedestrian access routes to stations may traverse inhospitable tracts of industrial or vacant land. In these instances the LRT planner should examine the relationship between residential areas and station sites at a micro level. Although using an industrial corridor is very appealing, other alignments may be needed that pass closer to the residential areas to be served if the maximum benefit to riders is to be obtained.

Suburban Office Parks

In some urban areas new growth has taken place in suburban office parks and light rail service is often seen as a way of serving reverse commute trips and reducing the highway congestion that accompanies such development. Yet suburban office centers are often planned with buildings in a campus setting, set far back from the main road, with large parking lots and landscape buffers. This layout creates long, exposed, walking distances between places of employment and possible station sites. In such areas the LRT station should be located to minimize walking distances. Where this is not possible shuttle bus service should be planned with full consideration of the likely impact of shuttle operating costs on the annual operating budget and the impact of shuttle frequency, travel time, and transfer penalties on system ridership.

If LRT service is planned to suburban office parks still under development, the planners should strive to have site development master plans revised to cluster future buildings around LRT station sites and create short, direct pedestrian links to the stations, avoiding the need for shuttle buses.

Park-and-Ride Stations

Most new LRT lines expect to draw a significant share of their CBD-bound riders from park-and-ride access, especially in low-density suburban residential areas. To minimize regional automobile vehicle miles of travel and gain maximum transit passenger miles of travel, park-and-ride lots should be located to capture riders as close to suburban residential areas as possible.

In many areas the LRT line will not be competitive with automobile travel time on suburban portions of radial, CBD-bound freeways. Closer to the CBD, however, traffic congestion worsens and LRT can be faster than automobiles for the downtown portion of the trip. Park-and-ride lots should be conveniently located to take advantage of travel time differences that favor transit. Consequently "intercept" lots should be located with access to major commuter roads at points just before traffic congestion begins to build in the morning peak.

In considering the environmental effects of prospective LRT lines, it is usually assumed that LRT will reduce automobile use and improve air quality. At large park-and-ride sites, however, the reverse may be true. Park-and-ride lots may have very sharp peak hour usage, as large numbers of riders take advantage of travel time savings by leaving home closer to the time they must arrive at work. In the evening peak train arrivals bring several hundred passengers at a time, creating surges of vehicles departing the station parking lot.

To reduce the potential environmental consequences of park-and-ride lots, the lots should be planned in locations away from areas with land uses likely to have peak traffic flows that coincide with the transit system peaks. As a practical matter prospective park-and-ride sites should also be planned with ample vacant space for expansion.

Pedestrian Access

Pedestrian access is crucial to the success of any light rail line in terms of patronage. At least one end of a transit trip involves a walk between the station and the point of origin or destination. Over 90 percent of local transit riders walk less than 1,500 ft (457 m) or about 6 min. Fifty percent walk less than 3 min. LRT planners can assume that virtually all origins or destinations served by pedestrian access from the system lie within 0.25 mi (0.4 km) of a station.

The pedestrian access area is defined by the pedestrian network serving the station, usually the street grid. In the typical rectangular street grid network, the pattern of all points lying within 0.25 mi walking distance of a station is described by a square rotated 45 degrees from the axes of the street grid, with sides approximately 1,870 ft long (549 m), covering a total area of 80 acres (32.4 ha). See Figure 2. Using a circle with a radius of 0.25 mi to represent the area served by a station in a street grid can overstate the area served within a 5-min maximum walk by almost 60 percent.

Land use and pedestrian access within the immediate vicinity of the station require close attention if the station is to be located to draw the highest possible ridership. Planners should avoid locating stations in places where they cannot draw riders from all sides, such as along a river bank or other barrier. Placing stations adjacent to a freeway or park, which can act as barriers to pedestrians, adds to the average walking distance for most riders. Placing an LRT station in the median of an expressway with frontage roads is also to be avoided from an access perspective. Such locations can add significantly to the station access walking time. The roadway system itself can consume up to 17 percent of the land available within a 5-min walking time, reducing the area available to generate transit trips.

Because of the critical importance of pedestrian access to LRT line ridership, walk-in safety and security are paramount. Pedestrian routes to stations must be well-lighted, active, and visible. Avoid mixing walk-on's with park-and-ride and kiss-and-ride vehicle flows. To access stations pedestrians should not be routed through parking lots. They should be provided with direct, wide, well-drained sidewalks buffered from adjacent traffic flows.

Because so many issues must be considered in early planning for an LRT line, the micro level issues just discussed are often dismissed with statements such as,"We can deal with that in the final design stage." It is necessary, however, to consider pedestrian access issues early in the planning. In the alternatives analysis/draft environmental impact statement (AA/DEIS) stage, the ridership forecasting methodology should incorporate a realistic estimate of pedestrian access. UMTA's *Procedures and Technical Methods for Transit Project Planning* devotes several pages to a discussion of transit access modeling. In addition the planners should conduct some "reality checks" by spending time walking the areas around each station site and questioning assumptions about future conditions.

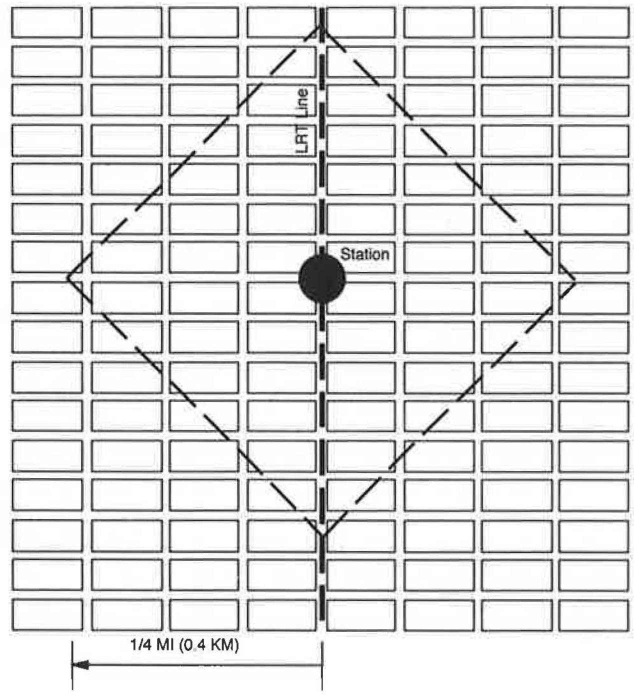


FIGURE 2 Area within a nominal 5-min walk.

In the preliminary engineering (PE) phase, station siting studies should be conducted to a refined level of detail, and pedestrian access conditions should be fully investigated. If station access and ridership forecasts are based on assumptions about future site development or redevelopment, then agreements should be negotiated with local developers, and amendments to zoning and master plan ordinances or regulations should be enacted to ensure that the assumptions are realizable. By the end of the PE phase of the project, all major station siting issues should be resolved, and access assumptions should be verified.

Station Layout and its Relation to Operations

With any public transportation technology, the physical layout of the station must be integrated with the vehicle and its operation to create a "system." For most rail systems, a single set of standards for stations, vehicles, and operations must be established and followed throughout the entire system. LRT, perhaps more than any other mode, provides flexibility and variety to these relationships, allowing many possible combinations that can vary within a specific system or line. Some of the primary issues affecting station configurations and the relationships to vehicle configurations and operation need to be explored.

LRT trains can operate as single cars and multicar consists, which largely determines the necessary platform length. Maximum train lengths are often governed by constraints along at-grade segments, particularly city block length (distance between intersecting streets) in a CBD or other developed area. If the train length exceeds the length of a block, a stopped train can block the cross streets and interfere with crossing vehicular and pedestrian traffic.

A feature of most LRVs is that passengers cannot move between cars because of full-width operator cabs at the ends of the cars. Therefore LRT platforms should be able to handle the maximum length train. (Commuter rail platforms, on the other hand, can be shorter than the maximum train length, if necessary, because passengers can move through the train to access the platform.) Some compromise in platform length can be achieved by making multiple stops at a station, which slows down operations but may be doable for low-volume "flag stops"-type stations.

Platform Configuration

Platforms can have a number of configurations: side, center, side/center, single, or split (see Figure 3).

Side With the side configuration, a platform is located on each side of the tracks. The distance between the track centerlines can remain constant through the station so that the right-of-way requirements expand beyond the track needs only at the station. Usually passengers must cross the tracks to reach a platform (over, under, or at grade) for either the initial or return portion of the trip.

Center With the center arrangement a single platform is placed between the two tracks. The track centerlines must widen to allow for the platform, which requires a track transition zone with a spiral or S-curve several hundred feet long. The right-of-way requirements for the tracks must similarly widen. This can be a design issue where an existing rail right-of-way is being used. However, when center catenary support is used, the amount of widening is reduced. Because it must handle two-directional loading, allow two safety boundaries along the edges, and accommodate possible vertical circulation, a center platform is generally wider than a one-side platform but is narrower than the sum of two side platforms.

Combined Side/Center In certain conditions it may be advantageous to have both a center and two (or one) side platforms. At high-volume stations, especially with heavy simultaneous boarding and alighting movements in the same direction, boarding passengers can use one platform and

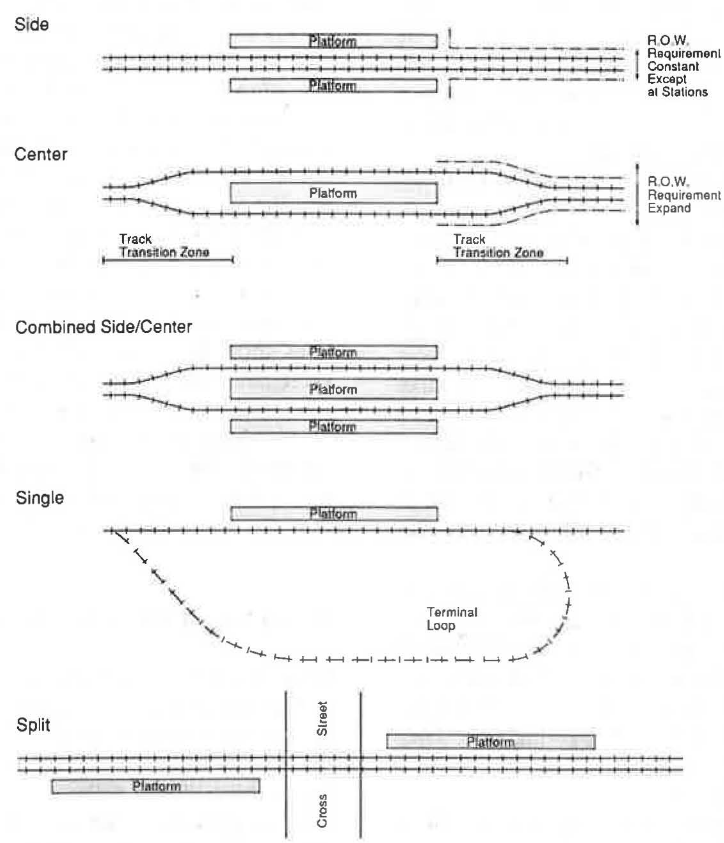


FIGURE 3 LRT platform configurations.

alighting passengers can use the platform on the other side of the car. This reduces dwell time. Also, this arrangement provides extra platform capacity at a station subject to heavy surge loads such as one near a stadium or arena. It can also be used where certain types of system interlining or branching occurs.

Single Where there is a single-track loop or a single-track segment (because of cost reduction or other constraints), a single-sided platform can serve both directions of travel. The end of the line is a potential location for this configuration. Two side platforms could be used as well, but the second platform is usually not needed. The Franklin Avenue terminal loop of the Newark City Subway has a single platform although it often discharges people at the front end and then pulls farther up the platform to pick up passengers. The New Orleans waterfront line has a single side platform station on a two-track segment where passengers in one direction board from the track area of the other direction. The trolley operating environment of this system makes this feature possible. Wheelchair patrons at this station board from the one platform only and can travel the other direction by going to end of the line (the next station) and get on the next return train.

Split In the split configuration, the two platforms are separated longitudinally. This often occurs in restricted right-of-way conditions where insufficient width is available for paired side or a center platform as is often the case in CBD-street environment. The platforms are frequently split on either side of an intersecting street with the platform located on the near side of the intersection so the train dwell time at the station and any intersection signal delay time can overlap.

Access to the platform depends on site-specific conditions. Platforms can be end-loaded (accessed from the ends) or center- or side-loaded. In the vertical dimension, access can be from above or below the platform or at grade across the tracks. With the use of the overhead power pickup for LRT, passengers can cross the tracks with designated crossing areas and other design features and operating policies to ensure safety. Because LRT allows at-grade access to the platform, costly overhead or underground facilities and elevators for wheelchair access required with grade-separated access are reduced.

Selecting the appropriate platform arrangement depends on a number of factors, particularly site constraints. LRT offers a variety of options that can be used to meet the particular needs and conditions.

Fare Collection

Platform height and placement can be strongly influenced by two systemwide features—fare collection and elderly and disabled access. Fare collection and control have a wide range of characteristics that influence station layout.

Self-Service Fare Collection With self-service fare collection the passenger pays a fare and receives a proof-of-payment or purchases and validates a ticket for a given trip. Once in the LRV the passenger must show the validated ticket or proof-of-payment to an inspector on demand. This fare collection system is common on most new LRT systems in North America and lends itself to being highly automated. No in-station fare collectors are generally required. Space is needed for ticket vending, fare payment, or ticket validating equipment, and perhaps change-making machines. Other than instructions and information on fare structure and fare zone maps, no other equipment or station facilities are required.

On-Board Fare Collection With on-board fare collection a passenger pays the fare either when entering or exiting by dropping a token or cash into a fare box usually in view of the driver or attendant, or by validating a ticket using a machine on board the vehicle. This system is common on older trolley systems. Little if any in-station equipment is required, although ticket or token purchasing or change-making equipment or attended booths can be provided along with information and instruction signs.

In-Station or Barrier-Type Fare Collection The in-station or barrier-type fare collection type of system is common in rapid rail transit systems. It involves a barrier separating a "free" or unpaid area from a "paid" area. Turnstiles or fare gates form the barrier and require deposit of cash, token, or fare card to gain entry to the paid area. In more sophisticated applications with zone or trip length-based fare structures, fare cards with a machine-readable magnetic strip passed through a fare card reader allow entry into the paid zone. The card may also be required to allow exit from the paid area to the free area at the destination station. This type of system has the greatest requirements for station layout in that a secured "paid" zone that includes the platform must be defined and the necessary architectural features provided to define the paid zone and allow for the barrier. Access to the platforms is restricted except through fare control barriers. At platforms access from the trackway must be controlled, which in exclusive guideway environments is not particularly difficult. In nonexclusive alignments, especially with at grade sections, preventing unauthorized access to the platform can be challenging. High platforms, where the platform is the same height as the LRV floor, are a solution. Because high platforms require the vehicle to have a different type of door configuration on the vehicles, mixing high- and low-platform stations within the system, although possible with LRT systems, does add to design and operating complexity. Barrier systems also require fare vending equipment and can involve attended booths.

High-level platforms offer the potential for shorter station dwell time than low-platforms. Passengers can board and alight faster because no steps on the vehicle have to be negotiated. As discussed earlier, high-level platforms aid in barrier-type fare collection systems. However, high-level platforms require that the vehicles have a floor that meets the platform within a few inches of the platform edge and that the doors either open clear of the platform or retract within the vehicle walls. Systems can mix high and low platforms such as in San Francisco where retractable floors cover stairwells at the high-platform stations. In Pittsburgh, the new LRVs are essentially designed for the high-level platforms in the new CBD section but also have a second door near the operator with steps to serve the low-level platforms on the rest of the system. Because President's Conference Committee (PCC) cars still operate on the line, the new high-platform stations have a low-level area at the end of the platform.

The nature of the fare collection method, discussed previously, can affect station layout and train operations. Collecting fares in the station or using a self-service method, particularly at high-volume stations, reduces dwell times by allowing all doors of the LRVs at the platform to be used. However, more in-station facilities are needed than for on-board collection. Capital and operating costs of providing in-station facilities must be compared against the cost and operating efficiency, schedule, reliability, travel time, and fare evasion rates under the various options. Fare collection systems, of course, can be mixed in LRT system. The Newark City Subway, for instance, employs barrier-type fare collection in some of its underground downtown stations and on-board collection at its other stations.

Wheelchair Access

Probably the most significant factor influencing platform configuration is the Americans with Disabilities Act (ADA), particularly the provisions for wheelchair access. ADA, like its antecedent, the 504 Regulations, requires wheelchair access between the station and LRV. The most direct method to achieve wheelchair access is high-level platforms such as those used on the Los Angeles–Long Beach line or the low-floor LRVs being used in Grenoble, France, and proposed for Boston's Green Line.

Several methods are possible at low-level platforms including use of wheelchair lifts in the LRV, use of platform lifts as on the Portland MAX, use of mini-high or "high-block" platforms at the end of the low platform as used on the Sacramento and Baltimore lines. The mini-high platform employs a short high-level platform at the front (operator) end of the station platform that is accessible via a ramp or some sort of lift. When a wheelchair passenger needs to board or alight, the operator aligns the front door of the first car with the mini-high-level platform which is next to the operator. The operator manually lowers a plate that covers the stairwell and unfolds a second plate that covers the gap between the platform edge and the vehicle floor. This arrangement requires all wheelchair patrons to use only the first car. This can introduce limitations on split-train operations for branch lines. The use of platform lifts or on-vehicle lifts imposes fewer special design and operational considerations other than defining a designated loading location. Use of a mini-high platform can create constraints on end-load platforms, especially center platforms, by restricting passenger circulation from the low-level portion of the platform.

Providing wheelchair access throughout the rest of the station poses some special design considerations as do other features of the ADA requirements, including those dealing with visual, auditory, and mobility impairments other than those rectified by wheelchairs. However, when incorporated into the design of the station from the outset, many of the accessibility-oriented design features can benefit a large portion of the patron population.

IMPLEMENTATION ISSUES

As discussed in the previous section, LRT can have a number of station layout, vehicle/system, and operational characteristics. Lines can be located in mixed-traffic environments, semiexclusive, or exclusive alignments. Tracks could be single or double (or more). Platforms can be high, low, or mixed and located in a variety of arrangements. Any number of fare collection methods can be used. These features can be mixed and combined within a given system, especially as they affect stations. This flexibility enables the design of an LRT station to adapt to its application and environment, avoid certain types of costs and problems, and better serve the needs at particular sites.

The flexibility in LRT station design is particularly beneficial in implementation phasing, especially when financial or construction schedule constraints exist. Systems can be constructed very "lean" initially with segments of single-track and single-sided platform stations. The San Diego and Sacramento systems are good examples of how this can be done. Stations can be constructed initially with low platforms and upgraded to high platforms later as required. This has been done in many European "pre-metro" systems. At-grade alignment segments can be built initially with very simple, low-cost "stops" and upgraded to grade-separated segments with very little lost capital in the "stations" on the initial alignment. LRT stations along with the rest of the system can be implemented, operated, and later upgraded in phases as conditions allow.

CONCLUSION

Passenger stations (and transit vehicles) are the primary interfaces for passengers with a transit system. Therefore sound station planning and design are essential to successfully maximizing the potential benefits of a transit system. LRT's particular flexibility and adaptability provide station locations and layouts that can serve the riders well while avoiding to some degree cost and problems. Several station planning and design principals exploit the inherent advantages available with LRT systems.

REFERENCES

1. T. McGean. *Urban Transportation Technology*. Lexington Books, D.C. Health and Company, Lexington, Mass., 1976.
2. *International Transit Compendium Light Rail Transit*, Vol. IV, No. 2. N.D. Lea Transportation Research Corporation, Washington, D.C., 1986.