LIGHT RAIL TRANSIT CONSTRUCTION COSTS

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Light rail transit has attractive service characteristics that can be secured in most cities for modest investments. The relatively low construction costs of light rail transit are due primarily to avoiding large civil works by relying instead on reserved rights-of-way at grade. Many options are available for alignments at grade, and costs for way reservation can vary widely. This paper describes the construction costs for modern light rail transit; it takes into consideration way reservation and the more predictable costs for stations, street crossings, track, cars, electrification, signals, communications, and other requirements. The costs presented are estimates, based on the experience of the author in recent evaluations of light rail transit for several U.S. cities. Few new light rail facilities have been built in the United States in recent years; therefore, little opportunity exists for relating estimates of this type to actual construction. Figures discussed here range from high to low where convenient, and single estimates presented are conservative representations of the largest values likely to be experienced in most cities.

Light rail transit does not cost much to build compared with available alternatives. Urban highways now cost between 4 million and 6 million dollars/mile (2.5 million and 3.7 million dollars/km). Underground rapid transit lines require much larger expenditures that range from 30 million to 45 million dollars/mile (18.6 million to 30 million dollars/km).

Light rail transit can be built for between 2.5 million and 5 million dollars/mile (1.6 million and 3.1 million dollars/km), including all costs for way facilities, stations, shops, yards, and cars. Light rail transit service is not as attractive as full-scale rapid transit, but its construction costs are much lower. The low costs of light rail transit are attributable primarily to the avoidance of requirements for major civil works. Light rail transit service can be secured with lines built entirely at grade where appropriate arrangements for reserved rights-of-way can be made.

WAY RESERVATION

There are many alternatives for securing reserved rights-of-way. Light rail lines can be built in the median strips of boulevards and major highways, thus eliminating costs for land acquisition or isolating the line from automotive traffic. Light rail lines also can be built on city streets where curbs or planting can be used to isolate the line from street traffic. These elements can add up to 170,000 dollars/track mile (105,000 dollars/track kilometer) to track construction costs.

Light rail lines can be integrated effectively into pedestrian malls and shopping centers in either downtown or suburban settings. The lines can be built in intimate relationship with the commercial establishments served, and costs for construction and other facilities will be only a small part of the total investment.

Railroad branch lines also can be converted to light rail service. In many cities

where little-used freight lines exist, this last alternative can appear very attractive because it frequently allows development of a completely reserved right-of-way for the light rail trains and no significant interference with automotive traffic.

Costs for way reservation for railroad lines can vary widely depending on the extent of track revisions needed to facilitate continued railroad freight service at levels that would be acceptable to shippers. In some cases, the use of railroad rights-of-way may invite consideration of possibilities for the local transit authority to operate local freight service. This could provide an opportunity to preserve railroad freight service that otherwise would be abandoned.

STATIONS

Light rail transit stations need not be elaborate. In most cases, a low-level platform with good lighting and a simple shelter to protect waiting passengers from the elements will suffice. Costs for an arrangement such as this for a station that could handle 4-car trains would be approximately 75,000 dollars/station. In downtown areas, island platforms in streets or at curbside may cost slightly more, but separate lighting often is not necessary in these locations.

High-level platforms may be desirable to reduce dwell times at downtown stations that experience heavy peak volumes, but they often are not necessary even in these circumstances. High-level platforms can be provided for an additional cost of approximately 36,000 dollars/4-car-train station.

Fare collection at stations is an important question involving a requirement to balance investment costs against the continuing costs of operation and maintenance.

One alternative is to use cashier booths. These are easy to provide, but they require that the station area be secured. Fences and turnstile gates at the booths can be used in underground or elevated stations downtown where access to the station platforms can be controlled easily. Suitable arrangements generally cannot be provided in outlying areas where the light rail trains would run at grade. In any case, the need to staff the cashier booths can introduce significant operating costs.

Cashiers can be omitted, and automated fare collection systems can be introduced. Automatic equipment for sale of tickets and ticket-activated turnstiles can be provided for an investment cost of approximately 120,000 dollars for a typical station requiring 2 entrance points. Without the presence of a cashier, security arrangements may need to be tightened, and some means of continuous or periodic surveillance is required. Television surveillance can require an additional investment of 50,000 dollars/station. Automatic equipment introduces a need for continuing maintenance costs. Because most modern equipment relies heavily on electronics, skilled labor, which is expensive, is required for maintenance. Additional staff to provide surveillance and maintain television surveillance systems may be needed also.

A simpler system that has been used effectively in other countries relies on passenger validation of tickets. In this arrangement, automatic vending equipment is installed at stations, allowing passengers to purchase tickets themselves without a cashier. The passengers then validate tickets after boarding the vehicles by using simple marking machines inside the cars. A random patrol force rides the trains and provides periodic checks. This simple system can be installed for an investment cost of approximately 30,000 dollars/station and 1,200 dollars/car. Its advantages are that it does not require any fencing, turnstiles, or surveillance equipment. Also it does not require continuing costs for cashiers or sophisticated maintenance.

Stations, especially those in outlying suburban areas, frequently must incorporate parking and feeder transfer facilities. These items can be provided easily at grade. Costs for parking in suburban territories now are approximately 1,400 dollars/parking space. A loading dock for buses that has a covered waiting area for passengers typically costs approximately 20,000 dollars/bus space.

GRADE CROSSINGS

One of the best advantages of light rail transit is that it usually can be installed without grade separations. Trains are small enough and headways are long enough that operation at grade is acceptable. Cross streets need to be closed to permit the passage of trains, but the crossing movements generally pose no greater interference with automotive traffic than that incurred at ordinary signalized intersections.

In addition, arrangements can be made for light rail trains to preempt signals at street crossings to allow them to negotiate the crossings without stopping. This scheme minimizes delay for the largest number of travelers seeking access to the crossing and has been proved to be very effective in other countries.

Costs for suitable safety protection at crossings are modest. Gates and flashing lights that close streets when trains approach can be installed for approximately 25,000 dollars/crossing. Integrating the crossing protection with the light rail signal system to provide preemptive capability can require an additional cost of approximately 12,000 dollars/intersection.

When overhead electrification is used, pedestrian crossings at grade are safe and completely acceptable.

Although full grade separation of an entire line would never be necessary, the need may exist for individual grade separation structures at particularly difficult crossings. Costs for grade separation improvements will vary greatly depending on local site conditions.

Generally, an investment of approximately 2 million dollars would be needed to carry a 4-lane arterial street over a 2-track light rail line. To carry the light rail line over the same arterial would require approximately 2.5 million dollars. Both of these figures would be higher if railroad freight service were to share use of the light rail transit track. The larger underclearance required for railroad operations would add approximately 500,000 dollars where the rail line would be carried beneath the arterial. If the rail line were carried over the arterial, the heavier railroad axle loads would require an additional 250,000 dollars.

OTHER CIVIL WORKS

Major civil works may be required for light rail lines where negotiation of river crossings or other obstacles imposed by terrain or existing land use is necessary. Often, however, low-cost solutions can be obtained by relying on existing facilities. Reservation of a single traffic lane through an existing tunnel or over an existing bridge often can be satisfactory even where it might require a short stretch of single-track operation for light rail service.

The possibilities and requirements for major civil works depend entirely on local planning and development preferences, however. Many cities find it desirable to place new light rail lines in tunnels or on elevated structure over short distances through the heart of downtown business areas. Where downtown distances are short in relation to total route length, construction costs for the tunnels or elevated structures need not inflate total project costs to unacceptable levels.

Wherever tunnels or elevated structures are used, they should represent the first installment in the development of full rapid transit. Construction of such facilities in downtown business areas represents a relatively painless way to get started in the development of a rapid transit system. It goes without saying that, where tunnels or elevated structures are deemed necessary, they should be designed and built at standards that would be acceptable for full-scale rapid transit.

Costs for tunnels vary widely with respect to prevailing local geology and soils, underground utilities, and urban development in general. Typical costs for tunnels that can be bored without excavation at the street surface are approximately 18 million dollars/route mile (11.2 million dollars/km). Where cut-and-cover techniques must be used, costs would range between 18 million and 35 million dollars/route mile (11.2 million and 22 million dollars/km). Elevated structures would cost between 10 million

and 15 million dollars/route mile (6.2 million and 9.3 million dollars/km). Where tunnel construction would require that underground stations be built, each station would cost between 5 million and 15 million dollars. Elevated stations would cost approximately 5 million dollars each.

TRACK

Generally, light rail transit lines require the installation of new track structure even where they are being developed on existing railroad rights-of-way. This is necessary to provide acceptable ride quality.

The number of tracks required depends on the passenger volumes expected and the distances to be traveled. The figures presented here relate to construction of single track. The figures can be doubled where 2 tracks are needed; double crossovers between a pair of tracks would add approximately 320,000 dollars each; this would include all track specials, switch machines, and interlocked signaling.

Light rail lines have no special geometric requirements. Existing grades and curves for streets, highways, railroads, or canals would be acceptable for light rail development. New grading of the roadbed is seldom necessary except to dress and shape it for the receipt of new track.

Occasionally the restoration of drainage channels and the installation of improved drainage facilities may be necessary. Revision of existing utilities is seldom needed. Typically an allowance of approximately 40,000 dollars/route mile (25,000 dollars/km) would be sufficient to cover these requirements.

The new track structure should include entirely new ballast, ties, rail, and fittings. Welded rail should be used wherever possible to ensure a high-quality ride. Costs for the new track structure would be approximately 270,000 dollars/mile (169,000 dollars/km) of single track, for nearly all applications.

Where only the light rail trains are to use the track, a rail section of only 100 lb/yd (50 kg/m) would be sufficient. Even lighter sections would work, but they would not generally be available from U.S. rolling mills without extra charges above the base price. Where railroad freight trains are to operate over the light rail line, a heavier section of up to 119 pounds per yard (60 kg/m) would be desirable. Because the running rails are used for the return leg of traction circuits, conductivity requirements may sometimes influence the selection of a rail section, but the electrical requirements are seldom controlling criteria.

The variations of track construction cost with respect to the weight of rail used are relatively small; they are typically less than the variance reflecting local site conditions.

CARS

Cars represent the largest single component of light rail transit system construction costs in most applications. If a light rail system is being developed with all or nearly all of the track at grade, 50 percent or more of the total investment requirement will reflect costs for cars.

The cars are important because of the effect they have on the perceived quality of light rail service. For most passengers, the majority of the time consumed in a trip is spent in the cars. Interior design, seating, lighting, heating, and air conditioning are important elements of comfort that will affect rider choices. The appearance of the exteriors of the cars is also a major influence on public impressions of the attractiveness of light rail transit service. The performance capabilities of the cars can critically affect service speeds for the station spacings most typically encountered in light rail development.

Speed, comfort, and convenience are the service characteristics most needed to attract riders from automobiles in U.S. cities. Therefore, the cars represent a critical factor in the development of a light rail service that can be expected to compete

successfully with automobiles.

The actual configuration of the cars is not critical. Articulation sometimes has an advantage for tight turns in city streets or to improve driver productivity where existing work practices will not allow operation of cars in trains with only 1 operator on board. Except for circumstances such as these, however, articulation usually is not necessary.

Car sizes can vary. A typical 50-ft (15.24-m) car can provide space for 55 seats and standing room for approximately 100 additional persons.

Whether the cars are single units or are articulated, they should be capable of operating in trains. This frequently is desirable from an operating standpoint even when work practices do not allow work force savings.

Economies in car design and construction are possible. Modular design of structural components that would allow size variations is practicable and deserves further attention. It would allow wide latitude in tailoring car dimensions to fit local requirements without extra costs (as was possible with the Presidents' Conference Committee car years ago).

Possibilities for standardization of electrical and mechanical components are even more realistic. Standardization can permit substitution of propulsion components, climate control apparatus, and door mechanisms to satisfy local preferences and needs. The important thing is to preserve the capability to respond to local requirements in ways that can provide performance and comfort advantages to allow the light rail service to compete effectively with the automobile.

The full value of standardization of components probably cannot be realized unless all suppliers in the market can share in the engineering cost savings that would follow from it. Without sharing the savings, the current weakness caused by too few builders in the market probably will be perpetuated. Today's small number of active car builders reflects primarily the uncertainty in recent years regarding the prospective size and durability of the market for light rail cars. It also reflects cost inflation risks in car construction contracts, which have been severe in recent experience.

The present cost of a light rail transit car produced in the United States that would be attractive to riders in most urban transport markets would be approximately 450,000 dollars/unit when at least 200 cars are ordered. This cost nearly equals that of a modern rapid transit car, which the contemporary light rail vehicle closely resembles. Future standardization would reduce real costs but to what degree is now uncertain. Certainly broader market participation over the longer term also would reduce real costs.

ELECTRIFICATION

Electrification system requirements depend directly on car characteristics. Supply voltages can vary, but most light rail installations are developed for service with direct-current power supply at 600 V.

High-performance and commercial speeds of approximately 30 mph (48 km/h) are necessary in most U.S. urban areas; cars designed for this level of service will draw large amounts of current. The current requirements together with the train densities on the line needed to carry expected volumes generally will determine the size of substations.

Light rail transit generally requires that substations be durable; they must be capable of sustaining heavy overloads during short intervals when trains are accelerating. A substation for a system requiring 4-car-train operation at 5-min peak headways generally costs 210,000 dollars today.

Although variations can occur, the substations typically are spaced at the same interval as the passenger stations served. An exception to this rule would be in downtown areas where a separate substation for each of a number of closely spaced stops would be neither necessary nor desirable.

Distribution of power along the light rail line should be by overhead trolley wire. Suitable arrangements for overhead supply are easy to design and build. They also

pose little danger to the public and obviate fencing the right-of-way.

The required overhead conductor sizes depend on train traffic density and substation spacings. It may be necessary, especially with high-performance cars, to include feeder cables as a supplement to the trolley-wire conductor. These usually can be strung separate from the trolley wire, however, and elaborate catenary structure to support the trolley wire is rarely needed.

The trolley wire can be suspended from simple pole supports that can be spaced at distances of 100 to 200 ft (30.5 to 61 m). A bracket can be used to suspend the wire from the poles, or a transverse span wire between the poles can be employed. Fittings and insulators are available and can be installed without difficulty. Arrangements for constant tension on the trolley wire also are possible.

The return leg of the traction circuits generally is on the running rails, and rail joints therefore must be bonded. Reliance on the running rails can introduce the possibility that electrolytic corrosion would be imposed on nearby utilities or conduits buried in the ground. This is seldom a major problem, however.

The cost for electrification on a typical line with pole supports spaced 120 ft (36.6 m) apart would be approximately 140,000 dollars/mile (86,000 dollars/km) of single track. If substations were spaced at approximately 1-mile (1.6-km) intervals, total costs for the electrification system would be approximately 490,000 dollars/route mile (304,000 dollars/km).

SIGNALS AND COMMUNICATIONS

Simple signal and communications systems are desirable in light rail applications. Requirements and costs for grade-crossing protection already have been discussed. At other points along light rail lines, traffic densities usually are not large enough to require signals, but better speeds and performance usually can be obtained with them. In addition, sight lines can be a problem, and protection for them often is most effectively achieved by providing signals over the entire line.

Either wayside indicators or cab signals can be used. Cab signals are usually easier to install in urban environments and have the advantage of providing a continual indication of conditions ahead for train operators. Typical costs for cab signals are approximately 95,000 dollars/mile (59,000 dollars/km) including all requirements for track circuits, car-borne equipment, signal power supply, and track impedance bonds.

For efficient operations, simple communications systems also are advantageous. Radio contact with train operators from a central control point can be provided for a cost of approximately 5,600 dollars/car. Telephone connections for information and assistance to riders at stations would cost approximately 21,000 dollars/station. With open and well-lighted stations and a simplified fare collection system, television surveillance usually is not necessary.

OTHER COSTS

Yards and shops, land acquisition, and special facilities for physically handicapped riders may add costs for light rail transit development.

Requirements for maintenance and storage of light rail cars are not extraordinary. The design characteristics of shops, shop equipment, and yards have been established by years of experience. In most new systems, costs for these facilities would average approximately 60,000 dollars/vehicle.

Land acquisition requirements arise primarily in relation to car storage yards and parking at stations. Costs vary widely depending on location and existing improvements on the land to be acquired.

Acquisition of land for assembly of a right-of-way generally is not needed. Where light rail lines can be developed in existing streets and highways, there may be no right-of-way costs. Where light rail transit service is to be developed in existing railroad corridors, arrangements for occupancy of the railroad right-of-way may vary,

and costs for use of the railroad property would depend on the effect that the light rail service would have on railroad freight operations.

With regard to facilities for physically handicapped riders, the simplicity of light rail stations is advantageous. With a simplified fare collection system and no fencing or gates, movement to and from train boarding areas for handicapped persons would be the same as they currently experience in pedestrian traffic. Simple ramps and platforms for boarding trains can be arranged at minimal cost (approximately 10,000 dollars/station); floor space and entrances on the cars are more than adequate.

CONCLUSIONS

A brief acknowledgment and word of caution may be appropriate in conclusion.

All the figures discussed here represent estimates based on my recent experience in evaluations of light rail transit proposals for several U.S. cities. They have been developed on the assumption that construction of new light rail facilities would be performed by contractors working under competitive bid procurement procedures, and they reflect current price and cost experience in the construction industry.

There is always some risk in an effort such as this in which estimated costs are developed and presented without reference to particular site conditions in some given location. The risk is acknowledged here by emphasizing the major elements required to build a light rail transit line and by providing estimates of costs for each of them. The estimates represent the largest costs that might reasonably be encountered in most cities, except in unusual local circumstances.

The total cost for construction of any given system would depend on how these building blocks would be put together to satisfy local requirements. When the total estimates are assembled, however, total cost for light rail transit construction should fall between 2.5 million and 5 million dollars/mile (1.6 million and 3.1 million dollars/km).

If, during preliminary planning for a line, total estimates begin to exceed this range, it would be wise to stop and reconsider basic objectives. Generally, higher costs would mean that elements representing full-scale rail rapid transit are being mixed in with an outwardly light rail transit solution, and it may be desirable to consider whether full-scale rapid transit development would represent a more effective response to local requirements than would reliance on the light rail alternative.