Chapter 13

SYSTEM AND SERVICE PLANNING

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The planning of urban transit systems and services should reflect the history, geography, and economy of the particular area. Past practice and precedents, the city's physical setting and features, the patterns of population and employment, the attitudes and perceptions of residents, and the prospects for growth and change influence the form of the city, the importance and use of public transportation, and the role of the various transportation modes.

Factors such as population and employment density, per capita income and car ownership, and transportation cost by public and private conveyance are among the key quantifiable factors for transit planning and service decisions.

This chapter presents the parameters and principles that underlie system and service planning. It describes the relationship between transportation (public transportation in particular) and urban development, sets forth general approaches to transportation system planning, gives guidelines for rail transit system and operations planning, and contains service planning methods for bus transit.

TRANSPORTATION AND DEVELOPMENT

Transportation technology has been closely linked with the density of human settlement and with the uses of urban land. It has continually influenced the location, form, and economy of urban areas throughout the world. Mechanized transportation (both public and private) has enabled cities to intensify at their centers and expand at their parameters; it has made the modern urban region a reality. The specific impacts have varied, depending upon the degree of economic development, extent of urbanization, social and cultural patterns, antecedents, and public policy.

Cities were first built to a pedestrian scale. Travel distances were short, development was compact, and densities were high. As urban transportation became mechanized, the scale of the city expanded. Each transportation mode—streetcar, rail transit line, and motor vehicle—expanded the area of urban development, and each contributed to the employment concentration at the city center and population dispersion on the periphery. Between 1875 and 1900, the steel-frame skyscraper, vertical elevator, and electric railway changed the scale of the city and its center. The "electric railway city" replaced the "pedestrian city" as the radius of development increased from 3 to over 10 mi. This trend reached its peak prior to the Great Depression of the 1930s.

As the automobile, the bus, and other motorized vehicles became more reliable and popular, areas that had not been reached before by rail became accessible. This filling in of outward expansion between transit corridors continued and accentuated the decentralization process already started by street railway, rapid transit, and commuter rail lines. Although these changes began about 1925, the trend toward decentralization was constrained by depression and war for almost a quarter-century. Between 1950 and 1970 the "automobile city" became a reality, and the "urban region" blurred the differences between city and country.

The pertinent characteristics of the pedestrian, electric railway, and automobile city and their density implications are shown in Table 13-1.

TABLE 13-1
Transportation Mode and Urban Form

	Type of City		
Item	Pedestrian(Rapid Transit)	Electric Railway (Railway Transit)	Automobile
Population	3,000,000	3,000,000	3,000,000
Area (mi2)	30	200	1000+
Density (pers./mi2)	100,000	15,000	5000
Jobs in city center	200,000	300,000	150,000
Development pattern	Compact	Major corridors	Dispersed
Example	paris,1900	Chicago, 1920	Houston,1980

Todays major transit improvements in American cities are superimposed on an auto-oriented environment. In location, lines are fitted to major thoroughfares, freeways, topography, and open areas—not directly to density patterns. Therefore, theydo not provide the dramatic improvements in overall access that was common before1930. These systems by themselves do not have strong impacts on residential developments unless they are complemented by many other factors. Also needed are the availability of attractive sites for development, strong zoning incentives, and a vigorous demand for residential and commercial space in the system's service area. Even then, for the North American city, the primary function of new transit lines is to serve and reinforce the core area rather than to create the opportunity for high-density residential development along corridors.

INTERACTIONS

The effects of public transportation investment on urban development vary widely from city to city and within each city. The impacts depend on the changes in accessibility resulting from improved transport, the conditions of the land (whether vacant or built up and whether right or wrong location), the demand for housing and commercial development, and the presence or absence of government policies. (See Fig. 13-1.)

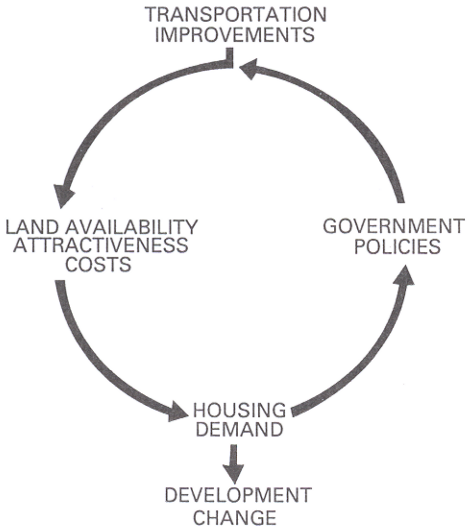


Figure 13-1 *Land development factors.*

Thus, transportation improvements have important *differential* impacts on urban land.[1] The extent of these impacts depends upon the relative changes in accessibility introduced into the overall transportation system in relation to other development factors—anticipated future growth, availability of developable land, utilities, topographic constraints, and inducements. Impacts are most pronounced in developing areas, since it is relatively difficult to change the use and intensity of existing built-up land. Impacts are greatest in rapidly growing high-income areas and least in established medium- or low-income areas.

These phenomena suggest the following theory of urban development. Where transportation improvements increase accessibility in high-income, low-density areas, they may bring about multifamily dwellings, offices, or mixed-use developments. Initial occupants of the land are replaced by a second group. The second group eventually may be displaced by a third lower-income group of families at a higher density. In contrast, many areas built initially for lower-income groups do not change appreciably as new transportation facilities are introduced. There is usually little short-term change in already built-up areas.

This cyclical theory of urban change assumes that the urban area has a high level of dynamism. It also assumes that urban growth patterns will not be unduly impacted by social and demographic changes. These interactions have important implications for the planning of rail transit systems. A key planning decision is the extent to which new lines should (1) serve existing demands from already built-up areas or (2) serve future demands that might result from or be enhanced by building along the line. Ideally, system design should capture both markets and preserve rights-of-way for future expansion.

DENSITY AND TRANSIT RIDERSHIP

Transit works best where travel is concentrated in space and time. It is well suited to serving areas with high population and employment densities. It is effective where street travel is slow and parking costs are high. (Parking costs usually correlate with employment density.) Low levels of car ownership also reinforce transit ridership.

The effects of population and employment densities (and car ownership) on urban travel patterns and public transportation ridership are well documented. Many origin—destination and travel demand surveys have shown how these densities influence the number and type of trip and the modes of travel used.2

As population density rises, there is an increase in the total number of person trips, including pedestrian trips, and a corresponding decrease in the number of trips in vehicles. This is because many shopping, social, and school trips, and some work trips, are made on foot in high-density environments. Also, a greater proportion of the nonwalking trips are made by public transportation in these areas. Moreover, in high-density areas, income and car ownership—the two important explanatory factors that influence trip rates and mode choice—are normally less. As densities decline, travel becomes more dispersed and transit becomes less effective in serving travelers.

In almost every city, overall person-trip rates (in vehicles) decrease and transit-trip rates increase as cities or neighborhoods become more dense. This is apparent from the relationships between person trips and residential densities shown in Fig. 13-2 for six U.S. urban areas.

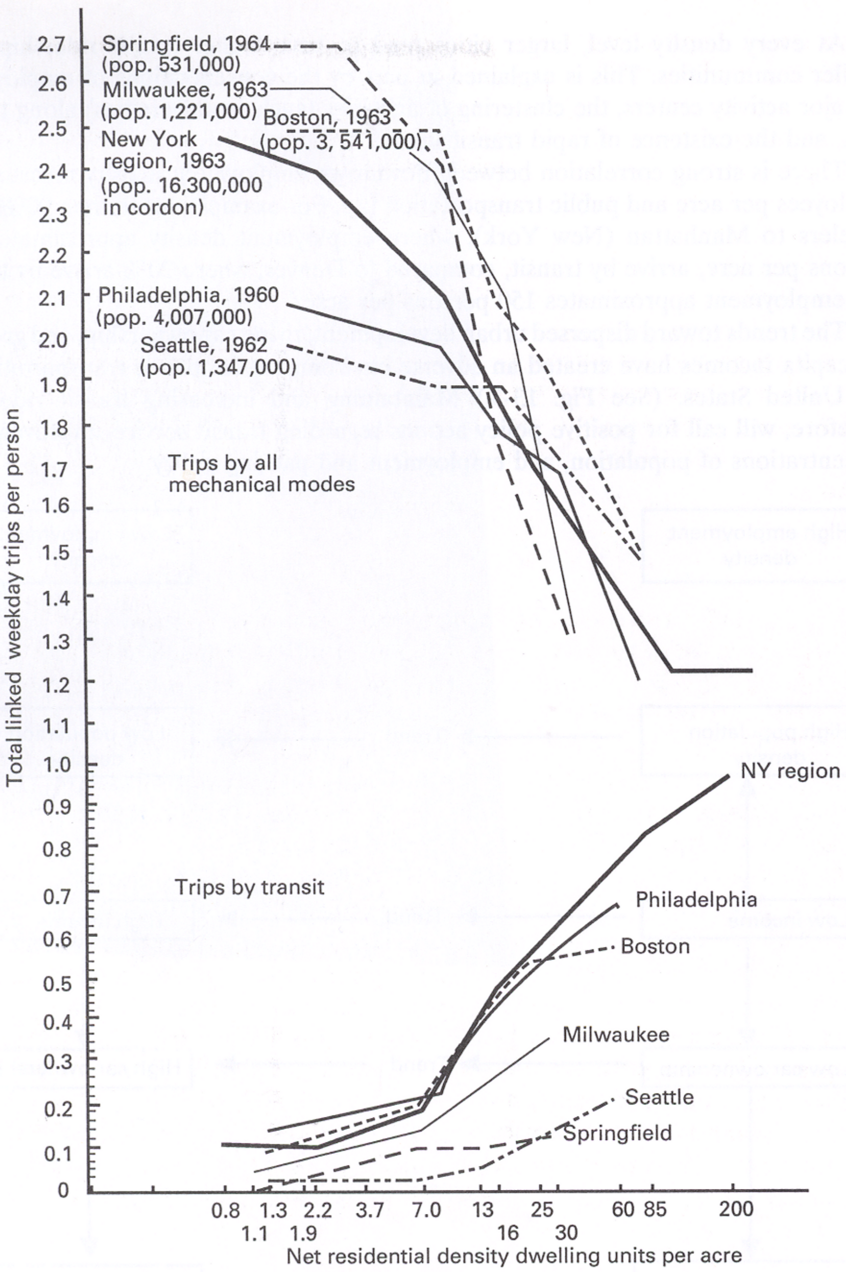


Figure 13-2 *Total trips per person by mode related to residential density in six urban areas. [Source: Boris S. Pushkarev and Jeffrey M. Zupan,* Public Transportation and Land Use Policy, *a Regional Planning Association Book (Bloomington, Ind.: Indiana University Press, 1977), p. 31.]*

At every density level, larger cities tend to have higher transit ridership than smaller communities. This is explained in part by the concentrations of employment in major activity centers, the clustering of activities (such as universities) along transit lines, and the existence of rapid transit lines.

There is strong correlation between downtown employment density measured in employees per acre and public transportation use. For example, more than 90% of all travelers to Manhattan (New York), where employment density approximates 800 persons per acre, arrive by transit, compared to Denver, where 20% arrive by transit and employment approximates 150 persons per acre.[3]

The trends toward dispersed urban development, rising car ownership, and growing per capita incomes have created an adverse environment for public transportation in the United States. (See Fig. 13-3.) Maintaining and increasing transit ridership, therefore, will call for positive policy actions regarding transit service improvements, concentrations of population, and employment and parking policy.

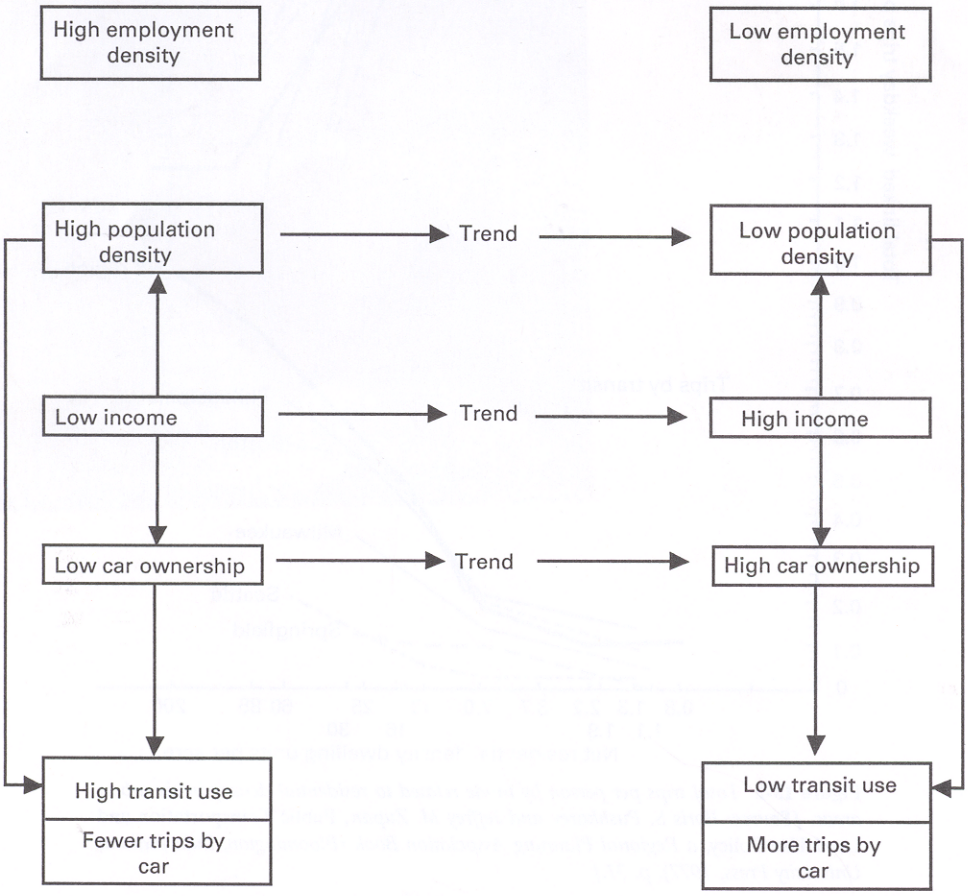


Figure 13-3 *Modal use factors.*

GUIDELINES FOR TRANSIT MODES

Each transit mode has an important role depending upon urban area size, population density, structure, and CBD activity. The guidelines in Table 13-2 are useful in system and service planning. They show minimum residential densities suggested for each transit mode. The corresponding minimum CBD floor-space guidelines are:

Mode	Millions of Square Feet
Commuter reil and rail transit	75
Light rail transit	35
Express bus	20-50
Local bus	
10-min service	18
30-min service	5-7

Chapter 11 discusses another set of conditions that are conducive to rail and bus rapid transit development in the U. S. based upon past experience: an urban area population of at least 2 million persons, 50 million ft2 of CBD floor space, and a CBD employment of at least 100,000. Lesser conditions are indicated for light rail transit (LRT) and busway development. (See Table 11-1, p. 299.)

Many other factors influence the feasibility, type, and extent of rapid transit development, including the size and shape of the city—for example, the angle or length of arc subtended by the city center; topographic barriers, notably the presence of water bodies or mountains; the type of downtown street system and its suitability for on street transit distribution; and the availability of suitable rights-of-way. Equally important are the operating speeds of the existing bus system, both in the city center and throughout the region. The rates of regional and CBD growth also must be considered, as well as the extent and adequacy of the existing freeway system.

The number of riders needed to justify a major transit investment depends upon the cost to build the system and the expected time savings to passengers. Table 13-3 gives daily ridership threshold volumes suggested for various types of construction and fixed-guideway transit. Values are shown in terms of passenger miles per mile of line. The required passenger volumes can be estimated as follows:

$$V = \frac{pM}{r} \tag{13-1}$$

where V = passenger-volumes on line
M = length of line in mi
r = average length of ride
p = passenger-mi/mi of line

The key point is that the threshold volumes increase with the cost and complexity of construction.

TABLE 13-2
Transit Modes Related to Residential Density

Mode	Service	Minimum Neccssary Residential Density (dwelling units/acre)	Remarks
Dial-a-bus	Many origins to many Destimations	6	Only if labor costs are not more than twice Those of taxis
	Fixed destinations or Subscription service	3.5 to 5	Lower figure if labor costs are twice those Thrice those of taxis
Local bus	Minimum, ½-mi Route spacing, 20 Buses/day	4	
	Intermediate, ½-mi Route spacing, 40 Buses/day	7	Average, varies as a function of downtown size and distance from Residential area to Downtown
	Frequent,1/2-mi route Spacing, 120 buses/day	15	
Express bus Reached on Foot	5 buses during 2-h peak period	15 (average density over 2 mi ^{2} tributary area)	from 10 to 15 mi away to largest down-towns only
Reached by Auto	5 to 10 buses during 2-h peak period	3 (average density over 20 mi2 tributary area)	from 10 to 20 mi away to downtowns larger than 20 million ft2 of nonresidential floor space
Light rail	5-min headways or Better during peak Hour	9 (average density for a corridor of 25 to 100 Mi2)	to downtown of 2- to 50 million ft2 of non-residential floor space
Rapid transit	5-min headways or Better during peak Hour	12 (average density for a corridor of 100to 150 Mi2)	to downtown of larger than 50 million ft3 of nonresidential floor space
Commuter rail	20 trains a day	1 to 2	Only to largest down-Towns, if rail line exists

Source: Boris S. Pushkarev and Jeffrey M. Zupan, *Public Transportation and Land Use Policy,* a Regional Plan Association Book (Bloomington, Ind.: Indiana University Press, 1977).

TABLE 13-3

Threshold Volumes for Rapid Transit Development
(keyed to type of structure)
(minimum service frequency, 8 min)

Mode	Type of Construction	Daily Pass.-Mi/Mi of Route
Rail rapid	Above ground	14,000
	One-third tunnel	17,000-24,000a
	All tunnel	24,000-42,000a
LRT	Low capital	4000
	Considerable grade separation	7000
	One-fifth in tunnel	13,500
	All tunne1	40,000
Downtown people mover	Above ground	12,000
	All tunnel	30,000

aRange reflects varying criteria for cost/weekday passenger-mi of travel

Source: Adapted from Boris Pushkarev, with Jeffrey M. Zupan and Robert S. Cumella, *Urban Rail in America: An Exploration of Criteria for Fixed-Guideway Transit* (Bloomington, Ind.: Indiana University Press, 1982), p. 116.

THE TRANSIT PLANNING PROCESS

Transit planning takes many forms. It includes *strategic planning,* which takes a broad global look at how an agency might function in its surrounding environment; *long-range system planning,* which generally relates to major facility development (and in the United States, UMTA's alternatives analyses process if federal funding is expected); *short-range planning,* which traditionally produces a transit development plan; and *service or operations planning,* which looks at service changes on a continuing basis.

The appropriate type of planning depends upon specific circumstances. *Strategic planning is* appropriate when a transit agency wants to reassess its role, mission, and organization. *Long-range system planning is* needed wherever a community wants to expand its existing rail transit or busway systems or develop new capital-intensive facilities. High rates of population and employment growth normally underlie these efforts. Procedures are similar to those used in traditional comprehensive, cooperative, continuing transportation studies (the federal 3C process). *Short-range planning* (usually for a 5-year period) is desirable where administrative, funding, and service charges are contemplated. *Service or operations planning is* an ongoing activity—often on a route or corridor basis—to improve service efficiency and effectiveness as well as to respond to immediate community concerns.

Transit planning studies should assess existing problems and how they are likely to change, identify improvement options, and suggest directions. They should provide essential information for a community's decision makers relative to ridership, costs, performance, and environmental and economic impacts. They should produce transit plans that are compatible with an area's needs, goals, and resources. These studies are necessary wherever major fixed-guideway systems (rail or bus) are implemented. See Chap. 11 for a detailed discussion of this process.

TRANSIT PLANNING AND PUBLIC POLICY

Transit is an important asset to metropolitan areas, especially their city centers. It is logical, therefore, that transit planning be complemented by appropriate public policies to reinforce transit ridership. It does not make good public investment sense to spend a billion dollars on a new fixed-guideway system (rail or bus) and then to undercut its ridership by expanding radial freeway capacity or doubling the downtown parking supply. Furthermore, it does not make sense to let the city's bus system languish while the guideway is being built.

URBAN DEVELOPMENT AND TRANSIT

Urban development and transit decisions should be coordinated to the maximum extent possible. Expanding development in the city center and clustering commercial and residential activities around transit stations will provide both environmental and transportation benefits over the long run. Opportunities for transit-friendly environments also should be realized in newly developing parts of the urban region.

Zoning policies and tax incentives should encourage integrated development corridors in which the transportation facility and its adjacent development are viewed as a total environmental system. This concept has been successfully applied in places like Singapore and Stockholm where new-town developments are keyed to rail transit lines. Conversely, where high-density developments exist, appropriate investments in transit should be encouraged.

Improving the transit orientation of suburban areas is a desired long-range objective. Transitways, and attractive bus terminals where transitways are not practical, are desirable at major activity complexes. (Obviously, many new suburban streets are needed to cope with traffic congestion.)

Residential subdivisions should be transit friendly. Street continuity should be sufficient to allow bus service through larger residential clusters, and adequate pedestrian access to bus stops should be provided (see Fig. 6-10). Clustering of activities in new developments is conducive to good bus service. Ideally, each new subdivision or major commercial development should be checked for its transit service as well as its traffic adequacy. Zoning should be conditional on the provision of suitable transit services. (See also Chap. 6.)

FREEWAYS AND TRANSIT

Radial freeway design and location should be coordinated with public transportation services. In larger cities, this may involve joint multimodal transportation corridors or development in separate corridors. In some settings (such as the penetration of high-density areas), effective rail or bus transitways may reduce the need for freeway development.

Bus priority schemes (for example, ramp metering, reserved bus lanes, special bus ramps) can improve line-haul transit. These are best accomplished by integrally incorporating them into the basic freeway design. Median strips along radial freeways could be reserved for future bus or fixed-guideway rail transit, particularly in urban areas that exceed 1 million persons. Figure 13-4 illustrates the evolutionary development of such a multimodal transportation corridor. (See also Chap. 12.)

PARKING AND TRANSIT

Urban parking policy should complement transit planning decisions. This can be done in two basic ways: (1) provision of extensive park-and-ride facilities along express bus and rail transit lines and (2) managing downtown parking supply and price.

Zoning ordinances in large cities should either prohibit additional off-street parking in the city center or limit the amount of off-street parking for offices. (Boston, Chicago, New York, Portland, San Francisco, and Seattle are among the U.S. cities where such policies have been established.)

In cities with a high dependence on transit, maximum and minimum parking requirements should be established for various parts of the city based upon land-use intensity and proximity to transit. The standards should be realistic, however, and should not inhibit continued development.

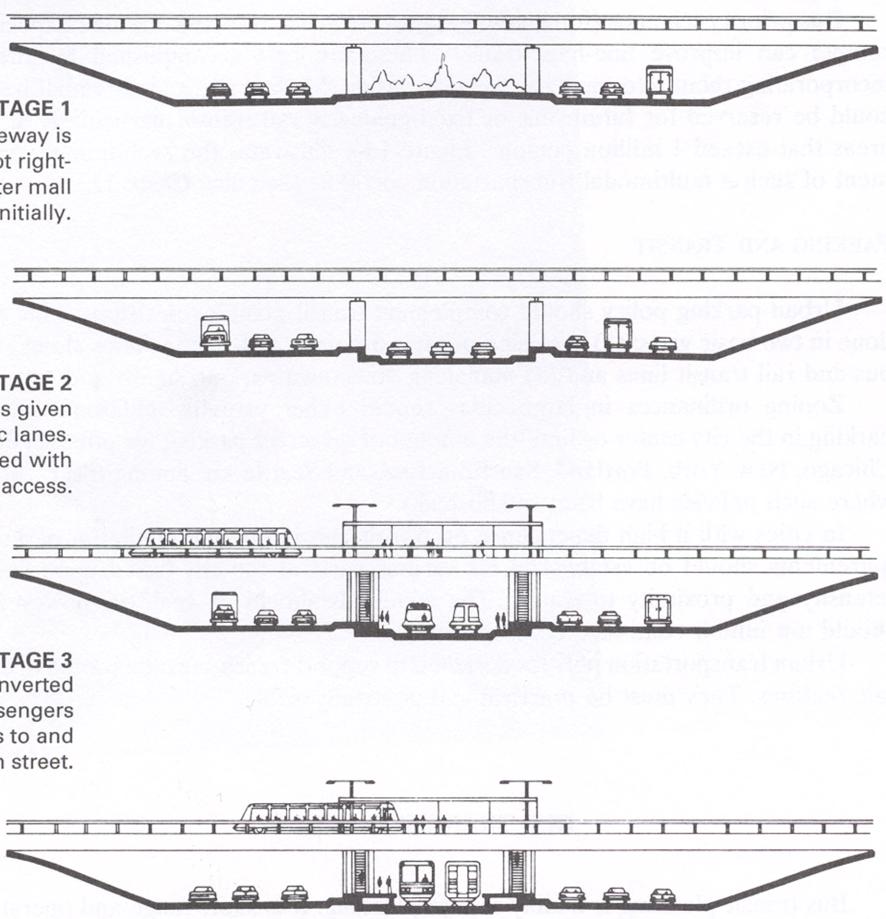
Urban transportation policies designed to support transit must be rooted in economic realities. They must be practical and politically viable.

BUS TRANSIT PLANNING

Bus transit planning is mainly service planning. It is short-range and operational, rather than long-range and capital intensive. It involves changes in where, when, and how services run in response to changing land use, travel patterns, and resources.

Most changes in service patterns reflect small-scale, fine-grained adjustments that reflect ridership changes caused by population growth or decline; service to new employment centers, schools, hospitals, shopping centers, and residential areas; service via new streets and expressways; and restructured or reduced service to bring costs and revenues into better balance. In almost every case, the amount of financial support beyond farebox revenues influences the amount and type of service.

STAGE CONSTRUCTION OF FREEWAY-TRANSIT CORRIDOR



STAGE 1
Six-lane freeway is built on 300-foot right-of-way. Center mall undeveloped initially.

STAGE 2
Center mall is given reversible traffic lanes. Freeway metered with preferential bus access.

STAGE 3
Center mall converted into busway. Passengers use escalators to and from stations on street.

STAGE 4
Bus lanes converted to rail transit service when passenger loads exceed busway capacity.

Figure 13-4 *Evolutionary development of transportation corridor. [Source: Wilbur Smith and Associates,* The Potential for Bus Rapid Transit *(Detroit, Mich.: Automobile Manufacturers Association, 1970), p. 98.]*

Major changes in routes and services come about when (1) urban and regional services are integrated into one system, (2) the service area is expanded to cover surrounding communities, or (3) rail transit, bus way, or HOV-lane development allows reorienting of routes.

RELEVANT FACTORS

Bus transit service planning should reflect the specific needs and operating requirements of each urban area. Relevant planning factors include past operating practices and procedures; the current operating authority and system extent; farebox cost-recovery requirements; land use, population density, and employment features; street patterns; and the availability of off-street rail transit. These factors, singly and in combination, influence the pattern of bus services and the opportunities for change and expansion.

Street Patterns

Service planning should recognize the type of city and its basic physical and economic structure; the strength and character of the city center; and the locations of residences, shops, schools, and employment areas. These factors, coupled with the ease or difficulty of driving and parking, influence riding habits and the locations and amount of service. High development densities, concentrated travel corridors, topographic barriers, a growing economy, and strong central areas make for a good transit city. Conversely, low densities, dispersed development, and weak central areas limit ridership.

Street patterns influence service in several ways. First, the presence or absence of suitable streets limits where buses can travel. The lack of suitable streets in many suburban areas makes it difficult to provide effective bus service. Cities with radially developed street patterns have radial bus service with no or limited crosstown routes. Even the large Boston metropolitan area has relatively few crosstown (circumferential) routes because of the restricted street patterns. Conversely, systems with grid street patterns, such as Chicago, Toronto, Los Angeles, and Milwaukee, develop many crosstown bus routes, and passenger transfer becomes an important part of the bus system. Second, the old, established transit routes are often the locations of apartments and retail areas, which are developed in a ribbon along these streets. Moreover, traffic engineering improvements are usually concentrated along arterial streets, making these streets better suited for bus operations.

Rail Transit

The availability of rail transit lines operating on exclusive (or semiexclusive rights-of-way also influences bus service patterns. The presence of rail transit tends to limit the number of radial bus lines and, in some cases, the amount of express bus service. The rail lines should provide the line-haul part of the trip to the city centers, and the bus routes should feed the rail lines as much as possible. This arrangement can provide faster rides for CBD-based travelers, reduce service duplication, maintain schedule reliability, and minimize operating costs. Cities without rail transit must provide radial line-haul local and express buses. This usually leads to a radial bus pattern, even with a grid street system.

Ridership

Ridership demands also influence route structure and service frequency. Family income, car ownership, and residential and employment density have important bearing on line and system patronage—socioeconomic and land-use variables that are normally outside of the control of the transit operator. Fare structure, system speed and reliability, and the actual service provided, which also affect ridership, can be influenced by operating policy and service planning. In most cities, about two-thirds to three-quarters of all bus trips are made by people without driver's licenses. The proportion of "choice" and "captive" (transit-dependent) riders, however, varies widely by city, route, service type, and time of day.

It is necessary, therefore, to know the types of riders along any route or group of routes. This means identifying the mix of riders by trip purpose (work, shop, school, medical, and so on), time of day (peak, off-peak), and age group (young, school children, adult, elderly). Special travel pattern surveys (such as home interviews) usually are needed for new systems or major route changes. Schedule, ridership, and transfer data can be augmented by on-vehicle rider surveys for existing bus lines.

SERVICE GOALS AND GUIDELINES

Goals and policy guidelines enable transit agencies to plan services and allocate available resources in a consistent, rational, and systematic manner. Guidelines also provide a context for developing detailed service standards and planning criteria and for establishing performance measures. When service policies conflict with economic limitations, funding resources should be administered in the most cost-effective manner.

Goals

Typical underlying community goals are:

- To establish and maintain a network of high-quality urban transit services for residents and visitors.
- To provide access to places of residence, work, school, personal business, shopping, and recreation with the amount and type of service appropriate to each. This goal implies a minimum level of service on routes where minimum acceptable levels of ridership and revenues cannot be realized.
- To decrease auto use by attracting new customers (that is, choice riders),

thereby helping to reduce traffic congestion, air pollution, and energy consumption.
• To provide and ensure reasonable service for elderly, handicapped, young, and low- income people.
• To operate buses in a safe, clean, and comfortable manner.

Corollary goals may include (1) meeting a specified farebox cost-recovery ratio, (2) achieving a specified increase in annual ridership with no increase in employees, (3) maximizing benefits to the regional economy, and (4) contributing to an improved environment.

Service Objectives

The bus system should provide the best possible service to the greatest number of people within the governing economic constraints. Planning must balance the amount and type of services provided with the net cost of service.

Conventional fixed-route bus service should meet the travel needs of most residents in the service area. System design should emphasize bus service to vital activities such as employment, shopping, medical, and education.

A well designed service should have:

1. An up-to-date route system consistent with current demands and understandable to riders.
2. Convenient schedules.
3. Reliable services.
4. Coordinated transfer opportunities.
5. Effective integration with rapid transit systems and other public transportation services and/or systems when they exist.
6. Amenities at bus stops.
7. Reasonable fares.
8. Park-and-ride facilities where appropriate.

Guidelines

The goals and objectives are generally translated into service guidelines and standards. These guidelines give each transit agency a systematic basis for making changes in routes, hours of service, or service frequency. Representative guidelines are summarized in *Bus Route and Schedule Planning Guidelines.4*

ROUTES AND SERVICE

Providing the best possible bus service to the greatest number of people calls for carefully relating service to existing and potential markets. Bus services should be concentrated in heavy travel corridors, with the greatest service frequency and route coverage usually provided on approaches to the city center. Route structure should be clear and understandable, and service duplication should be avoided. Changes in bus service must be coordinated with planning and traffic agencies to expedite bus flow and to assure that streets in nearby developing suburban areas are able to accommodate buses. These changes in service should minimize the disruption of existing riding patterns.

Service Area and Route Coverage

Bus service coverage and frequency should reflect the density of the population and the density of the street system. United States and Canadian experience suggests that bus service should be provided where population density exceeds $2000/mi^2$ and ridership exceeds 20 to 25 passengers/bus-h on weekdays, 15 on Saturdays, and 10 on Sundays. Route continuity and transfer requirements may lower these factors.

The actual service area is usually defined by legislation. Within this area, the delineation of areas served or "covered" provides a measure of transit accessibility and a method by which to judge duplicate service. Area coverage expresses the extent of population within a reasonable walking distance. The area within a 5-min walking distance from bus stops is traditionally considered the primary service area, and areas between 5 and 10 min are considered secondary service areas. For park-and-ride facilities, where passengers come by car, longer distances are acceptable. The following general guidelines are suggested:

- 90% of the residences should be within 0.25 mi of a bus stop where population density exceeds 4000 persons/mi^2 or three dwellings per acre.
- 50 to 75% of the population should be within 0.5 mi of a bus stop where population density ranges from 2000 to 4000 persons/mi^2.

These criteria translate into parallel bus routes every 0.5 mi in urban areas and every mile in suburban areas.

The desired spacings of bus routes are not always possible because of the configuration of the street system, the interposition of physical barriers, and the occasional need to reach closer points of heavy passenger travel demand. Thus, the spacing standards for any given transit system are subject to modification where physical barriers (such as unbridged rivers, severe differences in elevation, or lack of cross streets) prevent access to the route and impel a closer spacing. Where the blockage of access is due to lack of cross streets, efforts should be made to have the necessary streets or pedestrian ways opened, because the transit system should not have to bear the cost of adapting to an inadequate street design.

The effect of grades should be considered in evaluating route coverage. A 5-min walk on a level grade, based on 3 mi/h, results in a 0.25 mi walking distance. This distance drops to 1200 ft for an 8% grade and 900 ft for a 14% grade.

Route Structure

Transit routes in smaller communities normally include a few radial lines that meet in the city center. As the size of the service area and system increases, there is a corresponding increase in the number and complexity of the route structure. Large bus systems, in particular, include a combination of radial, circumferential, and grid route structures. Sometimes, as in Pittsburgh, complex or irregular systems emerge due to topographic barriers or irregular street networks. In all cases, the route structure should rationally relate activity centers to residential areas over the available street network. See Chap. 6 for a discussion of the different types of bus route networks.

In general, a few lines with frequent service are preferable to many lines with infrequent service. Operation of similar lines parallel to each other at short distances is a duplication of service and lowers the quality of service. In areas of very low demand, however, it is preferable to reduce the frequency rather than increase separation of lines farther than 1 mi (to avoid poor area coverage). Moreover, if service is infrequent, riders must rely on schedules.

Bus routes in the city center that are concentrated on key streets will give riders a sense of transit identity and a clear idea of the service. Such routes will result in enough use to make a priority treatment feasible. Accordingly, depending on the size of the business district, as many routes as possible should operate on the same street or the same few streets. Unless prevented by a one-way street pattern or by looping requirements, buses should operate in both directions on the same street to simplify routes, improve passenger understanding, and minimize excess bus travel. These factors underscore the desirability of downtown bus malls.

Dispersed routing patterns may be necessary in larger city centers because of dispersed employment areas or capacity limitations on the curb bus lanes. Los Angeles, Washington, D.C., and Manhattan are obvious examples; however, similar conditions exist on a smaller scale in other city centers.

Bus routes entering the city center should be spaced to traverse the center of the area within three city blocks (900 to 1200 ft). The goal is to bring major downtown employment and shopping concentrations to within 600 to 800 ft of a bus stop. Routes generally should cross the entire central area to provide convenient passenger delivery to all points and to minimize bus turns on congested downtown streets. Through routing is often desirable, but buses that must terminate and lay over downtown should pass through the CBD so that their curb layovers are located in less congested areas.

Passengers leaving major CBD activities should be able to board and alight from buses without having to cross major traffic flows.

Express Bus Service

Although most cities of more than 25,000 people can sustain some sort of local bus service, express service generally requires a population of more than 250,000. Express service has greatest potential in metropolitan areas larger than 1 milion, where it may account for 25 to 30% of the total route mileage. Where local routes go beyond 3 mi.

of the CBD and passenger volumes are great enough (especially for longer trips), express or limited-stop service may complement local service. In addition, the following should be considered:

• The CBD is generally the primary area that can be served successfully by express buses. CBD employment should exceed 30,000. Occasionally a major airport or outlying commercial center can be served, as can special events at stadiums or sports arenas.
• The journeys to and from work usually represent the greatest proportion of express trips, and the system should be designed to meet these demands.
• In cities with rail transit, express buses should not serve the same corridors as the rail lines.
° It is usually easier to draw patronage for a new express bus service from local buses than to get people to shift from automobiles. Where service is competitive with automobile travel, however, some diversion of motorists can be expected.
• Residential population densities must be high enough to generate a full or nearly full bus load with as few local service stops as possible. Unless a strong CBD orientation has been fostered by using express bus (or rail) service in promoting an area's development, a gross density of about 7000 to 10,000 people/mi is usually necessary to support direct express bus service. This density is common in older, small-lot, single-family developments and is found in recent garden apartment and town-house developments. At least 30 potential peak-hour CBD passengers per mile of route appear necessary for direct express bus service to a residential area.
• Park-and-ride lots, needed in suburban areas where densities are too low to generate walk-on traffic, enable express buses to attract riders who might otherwise drive. These lots should be located where off-peak service is provided so that patrons can reach their cars, for example, in case of emergency.
• Buses should operate at or near free-flow traffic conditions for all or most of their trip. The best routes are along busways, freeways, or other roadways where buses can travel quickly without congestion once satisfactory passenger loads are achieved. Express bus service along arterial streets may be desirable where employment and population are clustered at major intersections and there is no freeway in the corridor.
• Express bus service on freeways should be offered in peak periods only, except in very large cities or under unusual circumstances. Express bus service on arterials can be provided during both base and peak periods, although base (midday) service will depend on traffic density.
° Service may operate nonstop in the express zone (typical freeway "closed-door" operations) or limited stop (typical "open door" arterial operations). Where limited-stop service is provided, buses should stop at major transfer points and cross streets but not more often than about every 0.5 mi.
• An attempt should be made to give every passenger a seat, even during the

peak 20-min periods. This is especially important where long (more than 5-mi) nonstop runs operate at relatively high speeds.

- Express and local bus service may be mixed effectively in high-volume corridors (Archer Avenue, Chicago, is one such example; Geary Street, San Francisco, is another). Where the two services operate on the same street or in the same corridor, the express service should provide a means of obtaining better overall passenger distribution and load control in the corridor.
- Express service at spacings closer than 0.5- to 1.0-mi intervals should be discouraged to minimize service duplication.
- Express buses should save at least 5 min over local bus travel. This calls for a minimum 3-mi express bus run from the CBD. The time saved by express buses compared to local buses operating on the same streets is usually 1 to 2 min/mi. Where buses enter the downtown area, every effort should be made to give them preferential treatment to reduce delays and improve service dependability.

The extent to which express runs can draw substantial patronage depends on (1) the size and compactness of the group of transit patrons or potential transit patrons with CBD destinations to be served; (2) the availability of a busway, freeway, other type of limited access highway, or multilane arterial street; (3) a reasonably free flow of traffic on that highway during weekday rush hours; (4) extensive congestion in the area to be bypassed, which makes it rewarding to avoid the surface streets; and (5) the practicality of bypassing a 3-mi annular ring around the CBD without creating demand for uneconomical duplication of bus services and without eroding existing local bus patronage.

Service Coordination

Service coordination implies (1) the ability to transfer freely and conveniently between modes, (2) distinct service areas for each mode, thereby minimizing duplication, (3) adjustments and interrelationships of schedules (especially during midday and evening hours), and (4) joint fare structures. Coordination may take place between urban and suburban carriers, rail and bus transit, and bus and car. It may involve coordination of routes and schedules within a single bus system or between bus and paratransit services. It implies adequate park-and-ride lots at express transit stations and the use of express bus or rail for long line-haul trips.

Convenient and easy transfer between routes and services is the key to effective coordination. The experience of cities with effective transfer facilities (including Atlanta, Boston, Chicago, Cleveland, and Philadelphia in the United States and Edmonton, Vancouver, and Toronto, Canada) indicate that:

- A network of routes can operate much more economically and offer higher frequency of service if transfers are given than if attempts are made to avoid them at all costs.

- Transfer stations can be very efficiently integrated with such facilities as long-distance terminals, shopping centers, and administrative complexes.

- When transfers are well designed and operated, passenger objections to transferring are diminished. Timed transfers are increasingly popular.
- Transfers simplify service patterns, especially in a grid system.

SERVICE LEVELS

Bus service levels reflect past practices, ridership requirements, and economic constraints. Peak-hour service frequencies generally reflect ridership levels and capacity needs, whereas base-period and evening services often reflect policy headways.

Service Periods

Twenty-four hour service, 7 days per week is normally limited to major systems such as New York, Chicago, Philadelphia, Pittsburgh, San Francisco, and Washington, although many large cities do not provide overnight service. Medium-size cities provide service 7 days a week, usually about 18 hours per day.

In most cities, regular weekday service should be provided from about 6 a.m. to 11 p.m. on weekdays on principal routes. Suburban feeder service should operate from 6 a.m. to 7 p.m., and in some cases only during peak periods. Saturday and Sunday service should be provided on principal routes, although Sunday service may be optional in smaller communities. (See Chap. 6 for a discussion of scheduling.)

Loading Standards

Loading standards should reflect the type of service and time of day. Seats should be available for passengers at all times on freeway express bus service and on local routes during midday and evening periods. Desirable loading standards for local bus service are: peak 30 min, 125 to 160% of seats; peak 60 min, 100 to 140%; transition periods, 100 to 120%.

New Routes and Service Changes

Service changes are initiated in response to requests from the community, metropolitan planning organization (MPO), or transit agency board; as a result of on- going system evaluation by the transit property; or to reflect major changes in the system's financial requirements. Changes should be evaluated by the transit management, including appropriate boards of the transit agency. The flexibility of bus operations makes it easy for transit systems to experiment with service changes without major capital cost expenditures.

Service experiments should be tried for a sufficiently long time to allow ridership patterns to develop and to give riders a sense of route permanence. Trial periods should be at least 6 months long.
Because of funding constraints, bus service extensions and changes in the United

States normally follow development. This contrasts with some Canadian and European experience, where bus service often precedes development. When bus transit comes first, it has the opportunity to help shape the development and establish the riding habit. In some recent major developments, the community has required that the developer bear the cost of providing timely bus service.

Service Planning Process

Bus service planning is a short-range process that is usually done on a route-by-route basis. Therefore, many of the procedures developed for analysis of major transit investments usually do not apply.

Planning service changes involves estimates of costs, revenues, and community benefits associated with new, expanded, or restructured bus routes. The key steps include (1) reviewing characteristics of the service area—including the physical feasibility of the proposed bus routes, (2) estimating ridership, (3) estimating revenues, (4) simulating bus travel times, (5) estimating service requirements and costs, and (6) assessing economic performance. These steps are outlined in Fig. 13-5.

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Review characteristics
of service area,
inlcuding existing routes

Estimate ridership
(for example, compare
area to similar areas)

Estimate revenues

Simulate travel times
by car,
considering bus
running requirements

Prepare schedules
(by Schedule Department)

Estimate costs

Assess
economic
performance

Figure 13-5 Generalized procedure for planning new bus routes. [Source: Transportation Research Board, Bus Route and Schedule Planning Guidelines, NCHRP Synthesis of Highway Practice 69 (Washington, D.C.: Transportation Research Board, May 1980).]

The analysis of the territory to be served should consider (1) the density and distribution of income and age structure of the population; (2) the nature of the terrain and the available street pattern, with particular regard to the suitability of the bus service; and (3) locations of employment, retail and recreational areas, hospitals and medical centers, churches, and schools. Aerial surveys provide a useful tool for quick analysis. After examining the existing route structure, service concepts for the proposed change should be prepared. These concepts should be checked in the field for their practicality. Consideration should be given to (1) how the route serves the areas of passenger generation, (2) potential interchange points with other bus and rail lines, (3) adequacy of the street system, (4) ability to turn buses back at the end of the line, (5) opportunities to provide terminal facilities for drivers, and (6) adequacy of bus stops. Bus running times should be simulated in the field.

Ridership Estimates

Potential new patrons are perhaps the most important criterion for deciding to make a route or service change. A variety of ridership estimation techniques has been developed to assess the effects of various road and transit system changes. Most of these techniques explicitly or implicitly use such factors as car ownership (or income and residential population density), employment density, and relative travel times and costs by bus and car. But they vary widely in ease of application, treatment of parameters, precision afforded, and responsiveness to fine-grained service changes. From the perspective of most transit operations, the best available estimating techniques are as much art as science, but they can be effectively applied by an experienced transit planner.

Long-range transportation planning studies derive relations based on modal choice models that relate *disutilities* (car—bus travel times and costs) to choice and dependent users. The current state-of-the-art involves logit modal choice curves, which can be applied on a network basis to person-travel between zones. These techniques apply to large-scale, long-range changes in system capabilities, but they are not suited to short-range, small-scale service changes.

Elasticity relations have been used to estimate the effects of fare and service frequency changes on ridership of existing routes. *Fare elasticity* (change in ridership per unit change in fares) has ranged from -0.1 to more than -0.5, depending on market segment and trip purpose. Fare elasticities of about -0.15 to -0.20 have been found in recent years for several medium-size bus systems. Headway elasticities have been found to range from -0.3 to -0.8, which implies that a 100% increase in headways would result in a 30 to 80% drop in patronage.

Transit agencies have traditionally estimated ridership by analogy methods that compare a route under consideration with ridership on a similar route in terms of service, land-use, and demographic characteristics.

Ridership estimation includes the following steps for each route under consideration:

1. Estimate the dwelling units and population within the coverage area, preferably by block. This may include use of census data, mail drops by zip code area, or analysis of aerial photographs.
2. Estimate the nature of the area. This includes median family income, type and

age of dwelling units, and car ownership.
3. Conduct telephone surveys as needed to identify market and travel attitudes and patterns.
4. Apply the *riding habit* (daily or annual rides per capita) to the population base to obtain ridership potentials for residential areas served.
5. Identify schools, shopping centers, offices, and industries within the service area. Obtain estimates of enrollment, employment, places of residence, and probable travel modes. Estimate the ridership potential of these activities and add it to the residential ridership identified in step 4.

IMPROVING BUS MOVEMENT

System and service planning should encourage high bus speeds, since an increase in speeds benefits both the transit passenger and operator. Higher speeds give the passenger a more attractive ride and, in some cases, may attract new riders. They benefit the transit agency by increasing driver and vehicle productivity, reducing fleet size, and cutting costs.

High bus speeds may be attained by (1) reducing the number of stops, (2) reducing the dwell times at stops, (3) improving traffic conditions along the route, and (4) giving buses priority over other traffic.

Reducing Time at Stops

Bus dwell times can be reduced by providing multiple-berth stops, fare prepayment at major boarding points, use of exact fares (preferably single-coin fares), auxiliary fare collection personnel that board passengers through the rear door, and use of honor fare systems. Wider, double-channel entrance and exit doors can expedite passenger loading. To expedite CBD bus boarding, several systems (for example, Pittsburgh and Seattle) use a pay-as-you-enter system for inbound trips and a pay-as-you-leave system for outbound trips.

Reducing Traffic Delays

Effective traffic engineering along bus routes will benefit overall bus movement. At many locations, turn controls, parking restrictions, especially during peak hours, widened radii, and intersection channelization will allow buses to operate more effectively. Enforcement of parking restrictions with prompt towing of illegally parked vehicles is especially desirable.

Giving Buses Priority

Bus priority measures have proved successful in rationalizing street use and reducing bus travel times. Most priority measures involve normal-flow curb bus lanes on city streets. A growing number of cities, however, have provided reserved bus lanes on freeways, often for use by carpools as well. Houston, for example, has instituted an extensive series of such transitways, complete with large park-and-ride lots from which express buses run nonstop to the city center.

Busways in Ottawa, Canada, Los Angeles, and Pittsburgh provide stations and, in many respects, operate similarly to light rail lines. Buses operate in mixed traffic in residential areas and then run local or express on the busway to the city center, which they traverse via reserved bus lanes. Seattle has a CBD bus tunnel, which connects directly to bus lanes along I-5. Because the guideway sections form only over part of the overall bus route, the investment cost is less than would be needed for rail transit.

Busways, transitways, and priority lanes properly applied can produce major time savings. Their successful implementation requires a reasonable concentration of bus services, a high degree of bus and car congestion, community willingness to enforce the lanes, and overall support of public transportation services. Planning calls for a realistic assessment of demands, costs, benefits, and impacts.

RAIL TRANSIT PLANNING

Many types of rail transit operate in cities throughout the world. Their arrangements, designs, and operations reflect when they were built and the environment in which they operate. The more common systems include commuter rail, rail rapid transit, and light rail transit (discussed in Chap. 5) and automated guideway transit (discussed in Chap. 24).

The differences among these systems mainly reflect degree of access control, amount of automation, method of operation (including fare collection, train consist length, station frequency), and vehicle design. The fully automated systems must be completely grade separated, while the other technologies may permit grade crossings, or in some cases, running in mixed traffic.

REASONS FOR RAIL TRANSIT

The main reasons for building a new urban rail transit line or other fixed-guideway system are to improve the movement of people in a densely developed area in an environmentally attractive manner, to increase the CBD orientation of residential areas, to provide transportation capacity for future growth, and to strengthen the city center. (Many of these reasons also apply to bus rapid transit systems that provide similar alignment and performance.)

Rail transit services operating mainly or completely on exclusive rights-of-way can provide fast, dependable service, especially during peak periods. They can help structure urban development to permit more intensive development in the city center, and they provide radial transportation capacities that cannot be achieved by highways and surface transit. These benefits often offset the long lead times and high development costs.

Rail transit is especially important where public transportation delivers a large number of peak-hour trips to the city center. It enables the CBD to be built upward rather than outward without unnecessary street and parking requirements. Rapid transit and commuter railroads are the main means of traveling to or from the downtown areas in most large cities. They account for more than half of all peak-hour entrants into downtown New York, Chicago, Philadelphia, and Boston.

Rail transit complements (or supplements) freeways in major travel corridors. It can penetrate areas where freeway construction is difficult, impractical, or impossible. It can provide high peak-hour capacities in the radial corridors that lead to the city center without extensive land-taking for streets and parking. Thus, in some cases, it can reduce radial freeway capacity requirements and the extent of freeway construction.

Rail transit reduces travel times to the city center. Operating speeds range from 20 to 35 mi/h on most rapid transit systems, as compared with 10 to 20 mi/h by surface mixed-traffic transit. This time saving serves to increase the downtown orientation of outlying parts of metropolitan areas located near transit stops.

Rail transit is sometimes perceived as symbolic of a modern metropolis. More significantly, the permanence of the right-of-way provides a basis for investment along the line. The extent of this investment depends upon market forces and incentives provided by the community.

PLANNING NEW SYSTEMS

The geography of each urban area should help determine the type, location, extent, and design of rail transit. The goals should be to (1) maximize ridership, (2) facilitate efficient operations, (3) maximize development impacts, and (4) minimize construction costs.

The various lines should serve the corridors that produce the maximum patronage. Frequently, but not always, these are the corridors of existing transit ridership. Availability and costs of right-of-way, however, may require modifications in optimum alignment to cut costs and build an affordable system. Use of freeway medians and rail rights-of-way and minimizing underground construction may be desirable to cut costs.

System Extent

There is no simple formula for determining how far a proposed rail line should extend. Political, market, and physical factors and operating conditions influence the location and length of line. The following guidelines emerge from the differing perspectives on the desired length of line.

1. It should be as short as possible to provide the desired service and attract the needed ridership. Once the line is opened and its ridership is established, it can be extended.
2 It should be long enough to provide a "few good stations" at its outer end that will develop the desired ridership.

3. It should extend out far enough so that sufficient park-an-ride facilities can be provided at outer stations.
4. It should serve existing markets, and it should capture new markets as well.

It is important to determine the extent that a new line should serve existing demands versus capturing new markets. Ideally, both the coverage of the system and the spacing of stations should capture *both* markets. At minimum, new lines should extend beyond the limit of existing urban development, and right-of-way should be preserved for subsequent extensions as land is developed. Experience with rail transit developments in U.S. and Canadian cities indicates that many of today's most successful lines and markets did *not* exist when the lines were built.

Typically, rail lines in North American cities should extend about 12 to 20 mi distance from the city center. Because speed is essential, corresponding travel times should not exceed 30 to 40 min. Rail transit speeds should compare favorably with freeway automobile speeds; otherwise, both passenger attraction and the long-term value of the service will be limited.

For maximum development impact, lines should extend beyond the built-up area. This is apparent from the evolving population density profiles shown in Fig. 13-6. Residential densities in New York, Chicago, Philadelphia, and Boston clearly reflect the result of rail transit development during the first half of the twentieth century. In all these cities, the patterns were similar. Rail transit lines had their greatest impact around station areas located *farthest* from the city center, which were previously undeveloped and unserved by public transport. Settlement generally was as close to stations as land availability allowed; impacts were much less in already built-up areas.

Neighborhoods change along rail lines over time. When transit serves built-up areas, there is a slight growth that is often followed by a decline. The peak ridership at a particular station usually occurs about 5 to 10 years after the line is opened. In contrast, when an unbuilt area is served, ridership may grow dramatically for a 10- to 15-year period before the neighborhood and ridership stabilize. (See Fig. 13-7.)

System Configuration and Design

Desirable (and undesirable) aspects of rapid transit system configuration and design are shown in Fig. 13-8. They reflect the following guidelines:

1. *Radial character.* Rail transit lines should radiate outward from the city center. Crosstown or circumferential lines should be avoided. United States and Canadian experience indicates that about 75% of all rapid transit riders begin or end their trips in the CBD (or travel through the city center).
2. *Market penetration.* Rail transit lines should penetrate, rather than skirt, major market areas such as high-density residential neighborhoods, schools, medical centers, and outlying business areas. This makes it possible to augment the home-to-CBD work-trip ridership base.

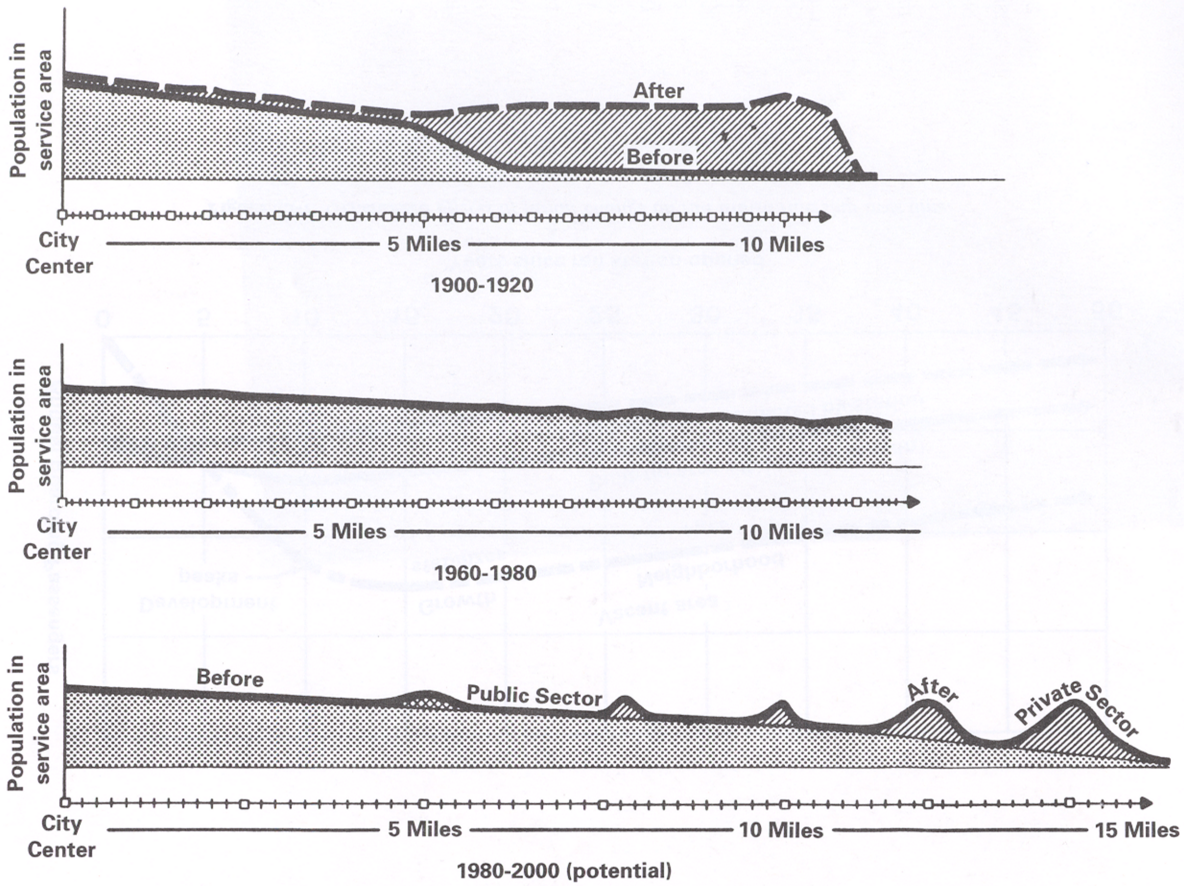


Figure 13-6 *Residential density profiles along rail transit line.*

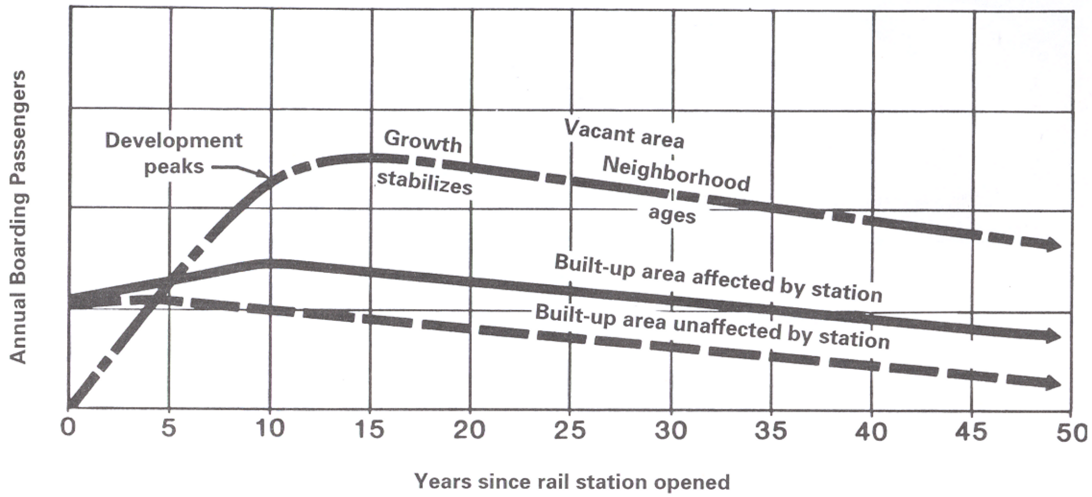
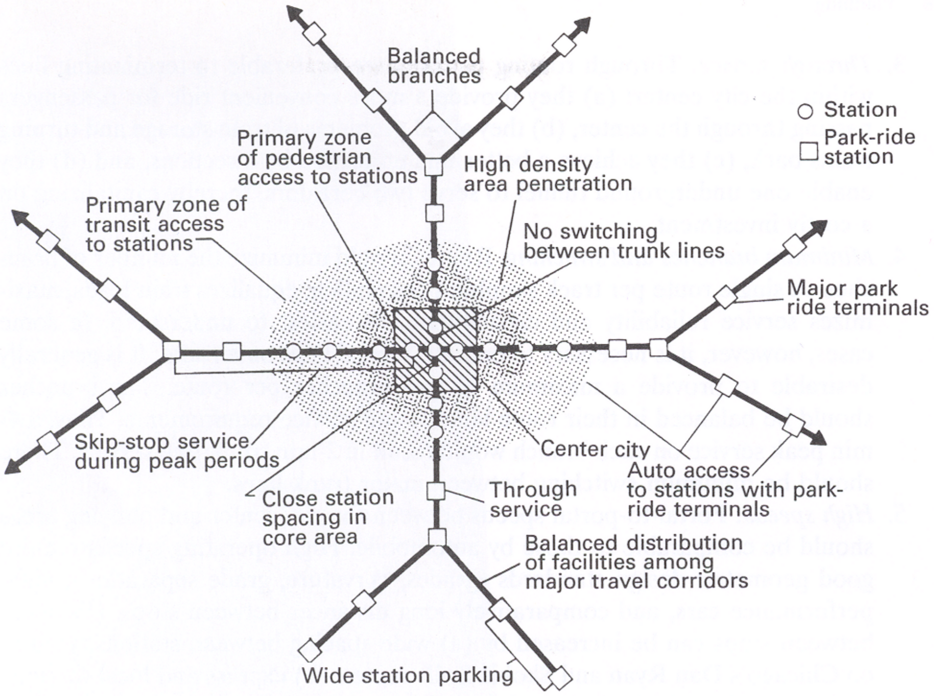
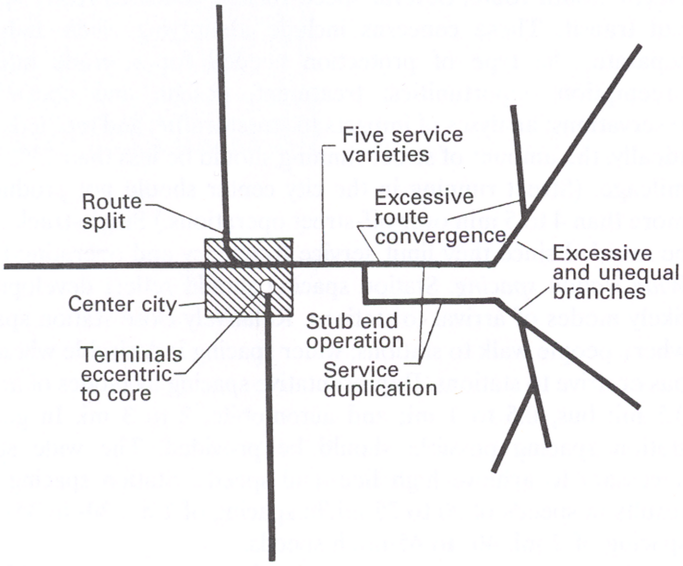


Figure 13-7 *Generalized effects of urban change on rail transit ridership over time.*



(A) Desirable



(B) Undesirable

Figure 13-8 *Rapid transit route configuration concepts.*

3. *Through service.* Through routing patterns are preferable to terminating lines within the city center: (a) they provide a more convenient ride for passengers passing through the center, (b) they avoid problems of train storage and turning trains back, (c) they achieve a better line utilization by directions, and (d) they enable one underground tunnel to serve two corridors, thereby capitalizing on a costly investment.

4. *Minimum branches and switching.* Routes should minimize the number of branches. A single route per track simplifies scheduling, equalizes train loads, maximizes service reliability and capacity, and is easiest to understand. In some cases, however, it is necessary to operate several lines on a route. It is generally desirable to provide a maximum of two branches per route. The branches should be balanced in their route lengths and service requirements. Thus, a 4-min peak service on each branch would result in 2-min trunk-line service. There should be minimum switching between major trunk lines.

5. *High speeds.* Portal-to-portal speeds between the city center and outlying areas should be comparable to those by automobile. High operating speeds require good geometric design standards (grades, curvature, grade separation), high-performance cars, and comparatively long distances between stops. Distances between stops can be increased by (a) wide spacing between stations, such as on Chicago's Dan Ryan and Skokie Swift routes; (b) express and local services, such as on New York City's major trunk routes; and (c) alternate or skip-stop services, such as on Philadelphia's Market—Frankford line and Chicago's North—South route. Several speed-related concerns relate specifically to light rail transit. These concerns include identifying when and where to grade separate; the type of protection needed for at-grade intersections, signal preemption opportunities; treatment, design, and operation in on-street reservations; analyses of impacts to street traffic; and methods of signal control. Ideally, the amount of street running should be less than *25%* of the total route mileage. (Street running in the city center should not produce a time loss of more than 4 to *5* min over off-street operations.) Single-track operations should be avoided since they limit service frequency and operating flexibility.

6. *Wide station spacing.* Station spacing should reflect development density and likely modes of arrival to stations. Relatively close station spacing is desirable where people walk to stations; wider spacing is desirable when people arrive by bus or drive to stations. Representative spacing by modes of arrival are walking, 0.5 mi; bus, 0.5 to 1 mi; and automobile, 2 to 3 mi. In general, the widest station spacing possible should be provided. The wide station spacing is necessary to achieve high line-haul speeds. Station spacing of 0.5 to 0.7 mi results in speeds of 20 to 25 mi/h; spacing of 1 mi, 30- to 35-mi/h speeds; and spacing of 2 mi, 40- to 45-mi/h speeds.

7. *Ample station access.* Attractive pedestrian access should be provided to stations, especially within medium- and high-density areas. Convenient bus—rail interchange is necessary where bus lines serve stations. Facilities may range from a simple bus stop adjacent to a station entrance, to an elaborate bus terminal (for example, Jefferson Park, Chicago). The Toronto Transit Commission designs its major rail—bus interchange facilities to permit barrier-free transfer between bus and rail lines.

Park-and-ride facilities are essential along rail lines in suburban areas. Experience with existing park-and-ride lots and garages indicates that occupancies often exceed capacity; in these cases, transit ridership is inhibited by the lack of parking.

Facilities range in size from small lots along Cleveland's Shaker Heights rapid transit lines to the 2500-car parking garages located along the Massachusetts Bay Transportation Authority Red Line in Braintree and Quincy. When more than 2000 spaces are required, garages should be provided to keep walking distances less than 1000 feet.

8. Maximum operational efficiency. System layout and design should permit maximum operational efficiency. Yards and shops should be placed at strategic locations (the end of line). Frequent crossovers and turn-back opportunities should be provided. Automation should be used to the maximum extent possible in train operation, service monitoring, fare collection, and train control.

The downtown end of the rail transit trip offers an excellent opportunity for time savings over automobile travel. It is essential, therefore, to maximize service convenience by placing routes through areas of heavy demand, providing frequent stations, and interconnecting stations and mezzanines with major pedestrian movement corridors. To the maximum extent possible, facilities should serve as their own distributors, thereby minimizing transfers to other transit vehicles or changes in travel mode.

OPERATIONS PLANNING

Rail transit operations are affected by the system layout and ridership patterns and by work rules. Operations are also influenced by past practices and the institutional setting: is the rail system run as an independent entity or is it coordinated with the bus system?

Service Periods

Systems may operate around the clock, from early morning to late evening, or just during peak hours. The choice depends upon precedent, local policy, and system design. When systems are shut down overnight, provisions must be made for securing stations.

Fare Collection

Most of the older rapid transit and LRT systems utilize a flat fare, payable at stations or on vehicles upon entering. Fares are paid to station attendants, turnstiles, or directly to fareboxes on vehicles. Zone fares are limited to a few long trips on special services. Commuter rail lines, in contrast, utilize a zone fare system, with peak-period schedules often keyed to the zones to facilitate ticket collection; traditionally, tickets are purchased from station attendants and collected on trains.

The newer rapid transit systems utilize automatic farecards, which are keyed to zone fares. New LRT lines (Los Angeles, Portland, Sacramento, Santa Clara, San Diego) also utilize zone fares. Tickets are obtained from fare vending machines, and there is no on-vehicle fare collection; an honor system is used, with random on-board inspection for compliance.

Service Patterns

A single service per route is the preferred service pattern. A single service simplifies schedules, assures uniform intervals between trains, equalizes train loads, and is the easiest for riders to understand. Many lines have branches, however, and require more than one service per track. For rail rapid transit systems, there generally should not be more than two services per trunk-line route. This restriction can be relaxed for LRT and commuter rail services.

LRT lines generally have all trains make all stops. Many commuter rail lines operate zone express service, especially during peak periods, because headways are relatively long. Sometimes different services are scheduled on the same track.

Most North American rapid transit lines have all trains stop at each station along a route. New York City, Chicago, and Philadelphia, however, utilize zone express service on three and four-track lines and skip-stop service on two-track lines. The skip-stop operation lets alternate trains serve lightly used stations; all trains serve major stops. This operation speeds service for most riders and equalizes train loads. (See Table 13-4.)

TABLE 13-4
Comparison of Skip-Stop and Zone Express Service

Mode	Advantages/Disadvantages
Skip-stop	Balances passenger loads on trains.
	May pose problems of speed difference with short headways
Zone express	Needs multiple tracks in same directions (except where headways are long).
	Facilitates ticket collection on trains.
	Increases transfer between services.

Train Length

The length of train consists can remain the same throughout the entire period of operation, with intervals between trains varied to reflect variations in ridership. This policy (used by the New York City Transit Authority, the Toronto Transit Commission, and BART) works well where ridership is high; it also avoids the need to couple and uncouple trains.

Where rail ridership is light, however, it is desirable to maintain frequent service. This may call for tailoring the train consist length to the ridership demand. (Examples of systems changing train length throughout the day include Boston, Chicago, Cleveland, and Philadelphia.)

FLEET AND CAPACITY REQUIREMENTS

Most transit agencies are concerned with (1) the number of rail cars or buses needed to serve passengers on a given transit line at the maximum load point or section and (2) the ability to accommodate these cars at major passenger boarding points or interlocking points. Capacity standards and computational approaches vary among properties.

FLEET REQUIREMENTS

The number of rail cars or buses that are required depends upon (1) the peak passenger demand, (2) the car or bus size and seating arrangement, (3) the passenger loading standard per vehicle, (4) the number of cars per train, and (5) the round-trip travel time. Computational steps are as follows:

1. Apply passenger loading standards. Each transit agency has its own standard for vehicle loading. This standard reflects the size of vehicle, number of seats, area available for standees, and allowable space per standee. Commuter rail lines generally base car requirements on seated loads. Subway and LRT services normally allow standees and base service requirements on *schedule design loads*—approximately 2 passengers/ft of car length. *Crush capacity*—about 3 passengers/ft of car length—should *not* be used for scheduling or planning purposes. Because it is not possible to load all cars of a train equally, under schedule design loads, some cars will operate at crush capacities. Examples of rail loading standards are as follows:

° The Metropolitan Atlanta Rapid Transit Authority, Georgia, uses 4.25 ft2/passenger as a basis for estimating the number of cars needed.

° Pushkarev, in *Urban Rail in American,5* suggests 5.4 ft2/passenger.

° The *1985 Highway Capacity Manual6* suggests 5.0 ft2/passenger for level of service D, and 3.3 to 3.0 ft2/passenger for the maximum scheduled load.

° Fruin (Chap. 8) states that 2.3 ft2/passenger is the absolute value used for scheduling services by the New York Transit Authority.

2. Compute minimum headways. The peak-hour, peak-direction passenger demand at the maximum load point or section, related to the specified loading standard, determines the number of rail cars needed. The *number of* cars per train is dependent on length of platforms and is established by the transit agency, based upon operating policy for the number of trains per hour. (Commuter rail trains may range up to fourteen 85-ft cars; rail transit trains range from six to ten cars, with 400 to 600 ft as a typical train length; LRT trains may range up to four cars).

Given the peak rate of passenger flow and the passenger capacity of individual transit vehicles, the required headway can be determined as follows:

$$\mathbf{h} = \frac{60nc}{p\,\mathrm{max}} \qquad \mathbf{(13\text{-}2)}$$

where c = passenger capacity of individual cars (persons/car)

n = the number of vehicles or cars per transit unit (n is 1 for a single unit)

p max = peak flow rate (persons/h)

h = headway between individual trains (min)

It is important to assure that this headway can be maintained at critical points along the line. United States and Canadian experience indicates that up to 30 rapid transit trains per track per hour can be accommodated assuming block signal control. (When trains become overloaded and dwell times increase, this figure may drop to about 26 to 28). A maximum of 20 commuter rail trains per track per hour can be accommodated. Current experience suggests that 60 to 90 LRT cars per track per hour can be accommodated. The precise number of LRT trains depends upon train length, method of CBD distribution (on- versus off-street), and traffic and/or block signal controls. CBD bus lanes can carry 80 to 100 buses/h.

3. Estimate fleet size. Once the headways have been computed, estimating fleet size is straightforward. It can be done by tracing individual vehicles on a time-space or "string" diagram or computed by formula. It also can be estimated from the relationship shown in Eq. (13-3). The values derived by this formula should be increased by the number of trains waiting in the terminal and by about 10% for spare cars.

$$N = \frac{n(2L)(60)}{Vh} \qquad (13\text{-}3)$$

where N = number of rail cars or buses needed

n = cars/train (n = 1 for buses)
V = average speed (mi/h)
L = length of line (mi) h = headway (min)

CAPACITY ESTIMATES

The passenger capacity of a rail or bus line is the product of the *vehicle flow rate* (the number of vehicles per hour past the busiest stop or other point of constriction) and the *load factor* (the number of passengers per vehicle that could be carried). Capacity is influenced by (1) passenger capacity of individual vehicles at the designated loading standard, (2) minimum possible headway or time spacing between successive trains, and (3) the number of tracks and station platforms.

The minimum possible headway is influenced by the signal control system, the passenger service times at the busiest CBD and terminal stations or stops, and the constraints posed by junctions and interlocking points. For light rail systems with street running and buses, street traffic and traffic signal controls should be considered.

Equation (13-4) is a general formula for estimating the capacity of a transit line.

$$c_p = \frac{(g.c)(3600)nSR}{(g/c)D + t_c} \qquad (13\text{-}4)$$

where cp = people/h/track (or lane)
tc = clearance between successive trains (or buses)
D = dwell time at major stops
S = passengers/car
n = cars/train (for buses use *nb* = number of effective berths/stop)
R = reductive factor to account for variations in dwell times and arrival variations (0.833 for on-street; 0.90 to 0.95 for off-street operation)
g/c = green/signal cycle (1.00 for off-street operations)
h = headway between successive trains (or buses) = (g/c)D + *tc*

This formula shows how important it is to maximize the number of passengers accommodated per unit and to minimize the dwell times at stops. Each of these factors has important bearing on vehicle design and operation. (See references *6* and 7 for further details on estimating transit capacities.)

SUMMARY

This chapter contains guidelines for transportation system and service planning. It indicates how transit can service and shape urban development and how factors such as population and employment density, car ownership, and parking costs influence the demand and role of public transportation in today's metropolis.

Public transportation works best where travel is concentrated in space and time. Thus, CBD employment levels and residential population densities define the roles of the various types of transit. Equally important is the need for public policy decisions that reinforce transit ridership, especially where major new systems are planned.

Bus service planning should reflect the specific needs, operating requirements, and financial constraints of each urban area. The underlying goal is to provide the best possible service to the greatest number of people at least total cost and least adverse impact.

The chapter shows when, where, and how rail transit systems should be developed. It stresses the importance of high-speed radial routes and services that can compete favorably with the automobile in terms of speed and reliability. Finally, it sets forth procedures for estimating fleet requirements and transit capacities.

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EXERCISES

13-1 Discuss the desirability of developing a rail transit system in Phoenix, Arizona, based upon the guidelines set forth in this chapter and Chap 11. CBD employment is estimated at 35,000, and 1980 population, area, and density characteristics were as follows:

	City	Urbanized Area
Population	789,704	1,409,279
Land area (mi2)	324	641
Density (persons/mi2)	2437	2199

13-2 Transportation planning studies for a proposed LRT line that will have considerable grade separation, but with no tunnels, showed a volume of 15,000 riders per day. The line would be 15 mi long, and the average trip length would be 7.5 mi. Comment on the desirability of this line based upon the criteria set forth in Table 13-3.

13-3 The fare elasticity for local bus service has declined from about -0.30 in 1950 to about -0.20 in 1990. Cite the reasons for this decline.

13-4 An urban bus line carries 10,000 riders per day. The fare charge is $1.00. If the fare is increased to $1.25, what would be the change in daily ridership and revenues?

13-5 Estimate the number of LRT cars needed to carry a peak load of 7500 passengers/h in 2-car trains. Assume that each car can carry a maximum of 150 people and that 15% spare cars should be provided.

13-6 A bus lane on a CBD street provides the equivalent of two effective berths at each major stop. Assuming 60 passengers/bus, a g/c ratio of 0.6, a dwell time of 60 s, and 15 s clearance between buses, how many people/h can the bus lane accommodate?

13-7 Conduct a speed-and-delay study of a bus line. Estimate the amount of time spent moving, in traffic delays, and at bus stops. What actions should be taken to improve speeds?

13-8 Develop a service pattern and schedule for the line profile shown in the following table. Assume 43-passenger buses and an acceptable load factor of 1.4.

P.M. Peak-Hour Line Profile for a Hypothetical Bus Route
(passengers/hour)

Section	Distance (mi)	On	Off	On bus
A (CBD)	0.0		600	0
A – B	1.0	0	100	500
B – C	2.0	50	150	400
C – D	3.0	30	200	230
D – E	4.0	20	50	200
E – F	5.0	25	50	170
F – G	6.0	30	100	100
G – H	7.0	0	100	0