PART II

SYSTEMS AND TECHNOLOGIES

Chapter 4

URBAN PASSENGER TRANSPORTATION MODES

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This chapter presents a systematic classification of concepts and definitions of terms in urban public transport, focusing mainly on transit. Features of the basic mode characteristics, such as guided versus steered technologies and small versus large vehicles, are also presented and then applied to a comparison of different transit modes.

TRANSIT CLASSIFICATIONS AND DEFINITIONS

Modes and concepts can be classified on several different bases. Some of the classifications are interdependent. For example, mode, often identified only with system technology, actually also incorporates characteristics of rights-of-way and operations. All major classifications are given here, from the basic classification of all urban travel to the definitions of physical system components and performance concepts.

CLASSIFICATION BY TYPE OF USAGE

There are three basic categories of transportation by type of operation and usage: private, for-hire, and public or common carrier. The main characteristics, typical modes, and optimal operating domains of these categories are given in Table 4-1.

TABLE 4-1
Classification of Urban Passenger Transportation by Type of Usage

Characteristic	Usage Type: Private		For-hire		Public or Common Carrier	
Common designation	Private transportation		Paratransit		Transit	
Service availability	Owner		Public		Public	
Service supplier	User		Carrier		Carrier	
Route determination	User (flexible)		User	User (carrier)		Carrier (fixed)
Time-schedule determination	User (flexible)		User	User (carrier)		Carrier (fixed)
Cost-Price	User absorbs		Fixed rate			Fixed fare
Carrier type	Individual				Group	
Modes	Automobile	Carpools		Taxi	Dial-a-ride	Stree transit (bus, trolleybus, streetcar)
	Motorcyle	Vanpools		Rented car	Jitney	Semirapid transit (semirapid bus, light rail transit)
	Bicycle				Charter bus	Rapid transit (rail, rubber-tired, regiolal rail)
	Walking				Special and proposed modes	
Optimum (but not exclusive) domain of operation:						
Area density	Low-medium	Origin: low Destination: high		Low	High-medium	
Routing	Dispersed	Radial		Dispersed		Concentrated (radial)
Time	Off-peak	Peak only		All times		Peak
Trip purposes	Recreation, shopping, business	Work only		Cusiness		Work, school, business

Private transportation consists of privately owned vehicles operated by owners for their own use, usually on publicly provided and operated streets. Private auto is the most common mode, but motorcycle, bicycle, and, of course, walking also belong in this category.

For-hire urban passenger transportation is commonly designated as paratransit. It is transportation service provided by an operator and available to all parties who meet the conditions of a contract for carriage [that is, pay prescribed prices (rates)], but which is adjustable in various degrees to individual users' desires. Most paratransit modes do not have fixed routes and schedules. Taxi, dial-a-bus, and jitney are major modes.

Common-carrier urban passenger transportation is known as transit, mass transit, or mass transportation. These are transportation systems with fixed routes and schedules, available for use by all persons who pay the established fare. Most common representatives are bus, light rail, and rapid transit, but there exist a number of other modes.

Paratransit modes with routes and schedules that change with the desires of individual users are referred to as demand responsive; when the difference is pointed out, transit is described as fixed-route, fixed-schedule service.

Urban public transportation, strictly defined, includes both transit and paratransit categories, since both are available for public use. However, since public transportation is frequently identifieD with transit only, inclusion of paratransit is often specifically emphasized.

A secondary classification of travel categorizes transportation as individual or group. *Individual transportation* refers to systems in which each vehicle serves a separate party (person or organized group); group transportation carries unrelated persons in the same vehicles. As Table 4-1 shows, the former is predominantly private transportation and the latter is transit, while paratransit encompasses modes from both categories.

TRANSIT MODES

A transit mode is defined by three characteristics:

• Right-of-way (ROW) category.

• Technology.

• Type oF service.

Modes vary with each of these characteristics. Contrary to the common belief that technologies mostly determine modal characteristics, the ROW category has the strongest influence on both performance and costs of modes. For example, streetcar service is more similar to surface bus than to rail rapid transit service.

Right-of-Way

Transit ROW is the strip of land on which the transit vehicles operate. There are three basic ROW categories, distinguished by the degree of their separation from other traffic.

1. Category C represents surface streets with mixed traffic. Transit may have preferential treatment, such as reserved lanes separated by lines or special signals, or may be mixed with other traffic.

2. Category B includes ROW types that are longitudinally physically separated by curbs, barriers, grade separation, and the like from other traffic, but with grade crossings for vehicles and pedestrians, including regular street intersections. High-occupancy vehicle (HOV) lanes or roadways represent a lower-quaIity ROW category B: they provide better traffic flow than other lanes, but they do not separate public from private vehicles, the most important element for giving transit the favored role on the basis of its type of service and higher efficiency than private transportation.

3. Category A is a fully controlled ROW without grade crossings or any legal access by other vehicles or persons. It is also referred to as "grade-separated" or "exclusive" ROW. In exceptional cases the ROW may have widely spaced grade crossings with signal override and gate protection of the tracks, and yet be considered as category A, since such crossings have little effect on line performance, although they may adversely affect safety.

Technology

Technology of transit modes refers to the mechanical features of their vehicles and ways. The four most important features are defined here.

1. Support is the vertical contact between vehicle and riding surface that transfers the vehicle weight. The most common types are rubber tire on concrete, asphalt, or other surface and steel wheel on steel rail. Other types of support are vehicle body on water (boats and hydrofoils), air cushion (hovercraft), and magnetic levitation. Technologies with support under the vehicle body are supported; those with the body around the guideway are straddled; those with support above the vehicle body are suspended. The supported type is by far the most common.

2. Guidance refers to the means of lateral vehicle guidance. Highway vehicles are steered (by the driver) and their lateral stability is provided by wheel/support adhesion. Rail vehicles are guided by flanges and the conical form of the wheel surfaces. A distinct feature of rail technology is that its wheel/rail assembly combines both support and guidance. Externally guided rubber-tired vehicles in all forms must have additional horizontal wheels and vertical surfaces for guidance.

3. Propulsion refers to the type of propulsion unit and method of transferring acceleration/deceleration forces. Its major components are:

a. Type of propulsion unit — the most common are the diesel internal combustion engine (ICE), used on buses and some regional rail, and electric motors, used on trolleybuses and most rail modes. Gasoline ICEs dominate small highway vehicles, while the gas turbine, steam engine, and others are still under development. Several rail systems built in the 1980s are propelled by linear induction motors (LIM).

b. Methods of transferring tractive force include friction/adhesion (dominant), magnetic, cable, and propeller, among others.

4. Control is the means of regulating travel of one or all vehicles in a system. The most important control is for longitudinal spacing of the vehicles, which may be manual/visual, manual/signal, fully automatic, or various combinations of these.

Conventionally, transit technologies were defined only by the techniques of support and guidance. Such definitions are not precise enough to distinguish bus from trolleybus or light rail from rapid transit. With support, guidance, propulsion, and control, all technologies can be defined to any desired degree of precision.

Type of Service

There are many different types of transit services. They can be classified into groups by three characteristics. The first classification is by the types of routes and trips served:

• Short-haul transit is defined as low-speed service within small areas with high travel density, such as central business districts (CBDs), campuses, airports, and exhibition grounds.

• City transit, the most common type, includes transit routes serving the entire city. They may operate on any ROW category (A, B, or C).

• Regional transit consists of long, high-speed routes with few stops, serving long trips within the metropolitan region. Regional rail and some express bus routes exemplify this category.

The second classification is by stopping schedule:

• Local service is with all vehicles stopping at all stops (or as required by passengers).
• Accelerated service is when successive vehicles skip different sets of stations on a predetermined schedule (for example, skip-stop and zonal service).
• Express service is with all vehicles on a route stopping only at widely spaced stops. These routes often parallel local service but serve fewer stops/stations, making express/Iocal service.

The third classification is by time of operation:

• All-day service is transit operated during most daily hours. This is the basic transit service, and it includes a great majority of transit lines.

• Peak-hour service or commuter transit refers to routes operated during peak hours only. They are usually radial from suburbs, focusing on the CBD, and designed mostly to serve work trips (for example, buses on the Shirley HOV Express Roadway in the Washington, D.C., area). Commuter transit service is a supplement to, but not a substitute for, all-day regular transit.

• Irregular service is transit operated only during special events, such as sport events, exhibitions, or public celebrations.

Generic Classes of Transit Modes

There is no rigorous definition of what differences in ROW category, technology, or service make a separate mode, but it is common to consider systems as different modes if they differ substantially in one or more of the three characteristics. Thus, bus and trolleybus operating the same type of service on the same ROW are different modes because of their substantial technological and performance differences; but standard and articulated buses operating under the same conditions would not be considered different modes. An express bus line is a different mode than a shopper shuttle, even if the vehicles are identical, because of the drastically different services; but skip-stop transit service during peak hours is not considered a different mode than the same line operating locally at other times because the two services are quite similar.

The best known classification of transit modes is into three generic classes, based mostly, but not entirely, on ROW category. They are defined here.

1. Street transit (also known as surface transit) designates modes operated on streets with mixed traffic (ROW category C); its reliability is often low because of various interferences, and its speed is lower than the speed of traffic flow, owing to the time lost at passenger stops: buses, trolleybuses, and streetcars are in this class.

2. Semirapid transit consists of modes utilizing mostly ROW category B, but C or A may also be used for some sections. This class includes a wide range of modes, from those with B and C categories, such as buses and light rail transit (LRT) operating on separated ROW and streets on the low side, to largely grade separated LRT (B and A) on the high side. The performance of these modes depends greatly on the degree and locations of ROW separation; it is particularly important that transit be separated from other vehicular traffic in central, congested urban areas. Another factor is technology, rail modes can operate in short trains and have higher safety through automatic signalization than buses. Higher types of semirapid transit (with little or no C category ROW) can match or exceed the speed and reliability of auto travel.

3. Rapid transit modes operate exclusively on category A ROW and have high speed, capacity, reliability, and safety. All existing rapid transit systems utilize guided technologies (rail or rubber tire), which permit the operation of trains (high capacity) and automatic signal control (high safety). Strictly, "bus rapid transit" does not exist since a bus line operating entirely on ROW category A would have much lower capacity, higher operating costs (single vehicles), and lower safety (steering instead of guidance, no automatic signals) than rail modes.

Most transit modes belong to one of the three generic classes. The exceptions are such modes as ferryboats, aerial tramways, and inclines. The latter two do have exclusive ROW, but they have no other features of rapid transit. These modes are therefore classified as special transit.

A matrix of mode classification by ROW category and major technological features (mainly support and guidance) is given in Table 4-2. Other technological and some service variations are given in individual matrix boxes. In addition to all street transit modes, category C contains also water- and airborne modes. Semirapid transit modes are in category B, while all rapid transit modes belong, by definition, in category A. This category also includes, however, all guided nonrail modes, since they cannot tolerate grade crossings. Inclines and aerials are also included. Thus, the three generic classes correspond closely, but not exactly, to the three ROW categories. An overview of the preceding mode definitions, classifications, and characteristics is presented in Fig. 4-1.

TRANSIT SYSTEM COMPONENTS

The physical components of the transit systems are generally classified into the following items:

Vehicles or cars are referred to collectively as fleet for buses and rolling stock for rail vehicles. A transit unit (TU) is a set of vehicles traveling together; it may be a single vehicle unit or a train with several vehicles.

Ways, travel ways, or rights-of-way may be common streets and highways, reserved lanes (designated only), exclusive lanes (physically separated), transit streets, busways (grade-separated roadways for buses only), tracks in roadways, on partially or fully controlled ROW at grade, above grade (embankments and aerials), or below grade (cuts and tunnels).

Locations and facilities at which vehicles stop to pick up and drop off passengers can be of several types. Stops are locations along streets with simple facilities (signs, shelters, and so on); stations are usually buildings below, on, or above ground with facilities for passengers and system operation. Terminals are end stations of major transit lines. Transfer stations serve more than one line and provide for passenger interchange among them. *Multimodal transfer stations* are served by several modes. Interface is another term for a transfer station.

TABLE 4-2
Classification of Urban Public Transportation Modesa

ROW Category	Technology: Highway—Driver-Steered	Rubber-Tired—Guided, Partially Guided	Rail	Special
C	Paratransit Shuttle bus Regular bus Express buss (on streets)	Trolleybus	Streetcar Cable car	Ferryboat Hydrofoil Helicopter
B	Semirapid bus	O-Bahn	Light rail transit	
A	Bus on busway only*	Rubber-tired RT Rubber-tired monorails Automated guided transit GRT PRT*	Light rapid tranist Schwebebahn Rail rapid transit Regional rail Commuter rail	Incline Aerial tramway Continuous short-haul systems

aModes extensively used are in italic type. Modes that are not operational are designated by asterisks.

Determinant Factors	Categories /Types	Basic Characteristics	Individual Modes*	Generic Classes
Separation	C	Right-of-way		
from other	B	Categories		
traffic	A		(Paratransit modes)	
			Shuttle	
			Regular bus	
			Express bus/street	Street
			Trolleybus	transit
			Streetcar	
			Cable car	
			Semirapid bus	Siemrapid
Support	Highway—driver-		O- Bahn	transit
Guidance	steered		Light rail transit	
Propulsion	Rubber-tired—guided,			
-Motor/Engine	semiguided	Technology	Schwebebahn	
-Traction	Rail		Rubber-tired monorails	Rapid
Control	Special		Light rail rapid transit	transit
			RT (rail and rubber-tired)	
			Regional rail	
			Automated guided transit	
			(rubber-tired, rail, magnetic)	Special
Line length	Short-haul	Local	Ferryboat	transit
Type of operation	Regular	Accelerated	Type of	Helicopter
Trips served	Regional	Express	Service	Inclines
				Belt systems

*The list is not exhaustive.

Figure 4-1 An overview of transit made definition, classification, and characteristics

Bus garages or depots and rail yards are buildings or areas for vehicle storage. Shops are facilities for vehicle maintenance and repair.

Control systems include vehicle detection, communication and signal equipment, as well as any central control facility. Power supply systems on electrically powered modes consist of substations, distribution wiring, catenary or third-rail structures, and related equipment. Except for the vehicles, all these items constitute fixed facilities of transit systems, or their infrastructure.

Transit route or transit line is a designated set of streets or separated rights-of-way that transit vehicles regularly traverse. The term route is commonly used for buses and line for rail modes and for sections on which several routes overlap, but the two terms are sometimes used interchangeably. The collection of all routes/lines in a city is its transit network.

TRANSIT SYSTEM OPERATIONS, SERVICE, AND CHARACTERISTICS

Transit operations include such activities as scheduling, crew rostering, running and supervision of TUs, fare collection, and system maintenance. Together they produce transportation that is offered to potential users.

Transit service is the transit system operation as seen by its actual and potential users.

Transit system characteristics are classified in four categories.

1. System performance refers to the entire set of performance elements, the most mportant ones being:

a. Service frequency (f), number of TU departures per hour.

b. Operating speed (Vo), speed of travel on the line that passengers experience.

c. Reliablity, expressed as a percentage of TU arrivals with less than a fixed time deviation from schedule (for example, 4 min).

d. Safety, measured by the number of fatalities, injuries, and property damage per 100 million passenger-km (passenger-mi), or a similar unit.

e. Line capacity (C), the maximum number of spaces (offered capacity) or persons (utilized capacity) transit vehicles can carry past a point along the line during 1 hour.

f. Productive capacity (Pc), the product of operating speed and line capacity (VO x C). As a composite indicator incorporating one basic element affecting passengers (speed) and one affecting operator (capacity), productive capacity is a very convenient performance indicator for mode comparisons.

g. Productivity, the quantity of output per unit of resource [for example, vehicle-km, space-km, or person-km per unit of labor, operating cost, fuel, ROW width, and so on].

h. Utilization, also the ratio of output to input, but of the same or similar units, for example, person-mi/space-mi (person-km/space-km) offered.
2. Level of service (LOS) is the overall measure of all service characteristics that affect users. LOS is a basic element in attracting potential users to the system. Major factors comprising LOS can be divided into three groups:

a. Performance elements that affect users, such as operating speed, reliability, and safety.

b. Service quality (SQ), consisting of qualitative elements of service, such as convenience and simplicity of using the system, riding comfort, aesthetics, cleanliness, and behavior of passengers.

c. Price the user must pay for the service (that is, its fare or rate).

3. Impacts are the effects transit service has on its surroundings and the entire area it serves. They may be positive or negative. Short-term impacts include reduced street congestion, changes in air pollution, noise, and aesthetics along a new line. Long-term impacts consist of changes in land values, economic activities, physical form, and the social/human environment of the city.

4. Costs are usually divided into two major categories: investment costs (or capital costs) are those required to construct or later make permanent changes in the physical plant of the transit system. Operating costs are those costs incurred by regular operation of the system.

The evaluation and comparative analysis of transit systems must include all four categories: performance, LOS, impacts, and costs of each system. The preferred mode is usually not the one with the highest performance or lowest costs, but the one with the most advantageous "package" or combination of the four.

THE FAMILY OF TRANSIT MODES: DEFINITIONS AND COMPARISONS

Transit modes can be ordered into a family, ranging from taxis to regional rail systems. Brief definitions and characteristics of the commonly used modes are presented here. Several pairs of modes "adjacent" to each other in the family of modes are compared. Detailed methodology for their comparison is presented in Chap. 10.

LOW-CAPACITY MODES: PARATRANSIT

Taxis are automobiles operated by a driver and hired by users for individual trips. The service they offer is tailored entirely to the user's desire. Users may find a taxi at a number of locations in the city; they may hail it on the street; or they may telephone a central dispatching office. The use of a taxi may involve longer waiting than with a private car, but there is no parking problem. The user avoids the financial responsibility of owning a car, but the out-of-pocket cost of taxi travel is the highest of all modes. Since most of the cost covers the driver's time, a high price is inherent in this mode.

Dial-a-ride or dial-a-bus consists of minibuses or vans directed from a central dispatching office. Passengers call the office and give their origin, destination, and desired time of travel. The office plans the bus routings so that as many passengers as possible are served on a single trip.

Dial-a-bus usually operates within geographically delineated low-density areas. It serves trips that have one common end ("one-to-many" or "many-to-one") or both ends dispersed ("many-to-many"). Thus, this mode provides a service between those of taxi and regular bus.

Compared with taxi, dial-a-ride offers:
+ Lower-cost service.
+ More comfortable ride (larger vehicles).
— Slower, less direct travel.
— Less personalized service.
— Service within a limited area only.

Experience has shown that in most cases dial-a-rides have low average vehicle occupancies, which result in high cost per passenger. Where moderate fares are required to attract a substantial number of riders dial-a-ride may require considerably higher public assistance per rider than conventional transit services.

Jitneys are privately owned large passenger cars or vans (6- to 15-seat vehicles) that operate on a fixed route (in some cases with minor deviations), without fixed schedules. They pick up and drop off passengers along their route by request at designated stops or, in some cities, practically anywhere, contributing to traffic congestion. Because of their small capacity, jitneys operate in large numbers and offer high-frequency service on major routes; on lightly traveled routes their service is often unreliable. Since each individual jitney stops less frequently than a bus. jitneys' travel speeds are higher than those of buses on the same facilities.

Consequently, jitneys typically offer more frequent and faster service, but with lower reliability, safety, and comfort than regular transit. They are used extensively in many developing countries with very low labor wages, particularly in cities with inadequate transit services.

MEDIUM-CAPACITY MODES: STREET TRANSIT

Regular bus (RB) service consists of buses operating along fixed routes on fixed schedules. Buses comprise by far the most widely used transit mode. With vehicles varying in capacity from minibuses (20 to 35 spaces) to articulated buses (up to 130 spaces) and the ability to operate on nearly all streets, arterials, and freeways, buses provide services covering a wide range of LOS, performance, costs, and impacts.

At the lower end of their application range, regular buses serve low-volume suburban routes, overlapping somewhat with the domain of dial-a-ride applications. In marginal cases it is possible to operate regular buses as dial-a-bus service during hours of low demand. The more the travel demand is concentrated along corridors, the more advantageous the regular bus becomes.

Compared with dial-a-ride, the regular bus offers:
+ Higher reliability (fixed schedule, predictable waiting times).
+ Lower cost per passenger (lower fares and/or lower public assistance).
— Less personalized service (not door-to-door).
— Less frequent (not by request) service.

The most typical bus services are street transit routes, which may represent the entire transit network (small and most medium-size cities) or supplementary and feeder services to rail networks. At the upper end of their application range, regular buses overlap with the LRT domain: they can serve lines with 3000 to 5000 pr/h, exceptionally with even higher volumes. Their largest overlap, however, is with the domains of trolleybuses and streetcars.

Express bus service is provided by fast, comfortable buses on long routes with widely spaced stops. It is characterized by higher speed and more comfortable travel, but serves fewer points. It sometimes has a higher fare than regular buses. Its reliability of service is dependent on traffic conditions along the route.

Trolleybuses (TB) are the same vehicles as buses except that they are propelled by an electric motor and obtain power from two overhead wires along their route. The trolleybus can basically be used for the same services as the regular bus. It involves a higher investment cost and more complex operations, which some operators do not like. The advantages the trolleybus offers include higher riding quality (smooth vehicle motion), ability to operate on steep grades, and excellent environmental features (extremely low noise and no exhaust). Since these factors are not directly reflected in the operator's revenues, financial problems of transit agencies have often led to substitution of buses for trolleybuses, even where this change was not in the interest of either transit users or the general public.

Streetcars (SCR), also known as tramways or trolleys, are electrically powered rail transit vehicles operating in 1- to 3-car TUs, mostly on streets. Their tracks and distinct vehicles give streetcar service a strong identity. Spacious vehicles and comfortable ride are also popular with passengers. Operation on the streets with congested traffic, however, causes considerable friction with other vehicles, impeding both the streetcars and the auto traffic.

A number of street design and regulatory traffic engineering techniques exist that can alleviate these problems and even provide a better flow for streetcars than for buses. But without such measures, buses usually offer superior speed and reliability street operation. For this and several other reasons, streetcars, which used to be the basic transit mode, have been either replaced by buses or gradually upgraded into higher-performance rail modes in most cities.

Streetcars compared with buses have:
+ More comfortable ride.
+ Quieter, pollution-free operation.
+ Better vehicle performance.
+ Higher labor productivity (larger vehicles).
— Higher line capacity.
— Higher investment cost.
— Less reliable street operation unless transit enjoys priority treatment.
— Less flexible operation (detours, use for charters, and so on).
— Higher maintenance of way and power supply system costs.
— Greater impedance of other traffic.

HIGH-PERFORMANCE MODES: SEMIRAPID TRANSIT AND RAPID TRANSIT

Transit modes in the upper range of the "mode family' are better characterized by high overall performance than specifically by high capacity. They all offer high speed and reliability, but their capacity and productivity vary greatly between the two extremes, semirapid buses and rail rapid transit. Semirapid transit includes only semirapid bus and light rail transit. Rapid transit includes light rail rapid transit, rubber-tired rapid transit, rail rapid transit, regional raid and, in a broader sense, automated guided transit.

Semirapid Transit

Semirapid buses (SRB) are regular or high-performance buses operating on routes that include substantial sections of ROW categories B or A. The performance of such systems depends greatly on the following factors:

1. Proportion and locations of separated ROW sections: their provision in congested areas is more important than in suburban, low-density areas.

2. ROW types: HOV- or bus-only lanes, streets, or roadways.

3. Types of operation: routings, transfers, stop spacings, speed, frequency, safety, and reliability of service.

The concept of buses on busway was exemplified by the initial operation of Shirley Busway in the Washington, D.C., area. In spite of its successful operation, this and most other busways in the United States have been converted under pressures of highway interests into HOV facilities. This conversion represents a degradation (decreased reliability, diminished identity) of transit services and upgrading of their competition, certain classes of private vehicles, which often "steal" transit passengers. This results in further decrease in the level of transit services.

In either case, busway or HOV roadway, this mode consists of a facility usually in a freeway median that is utilized by a great number of bus routes converging during the commuting hours from suburban areas. Buses travel on the high-speed facility with few or without any stops to the CBD, where they use streets for distribution. Routes are usually radial, terminating in the CBD, and have few coordinated transfers with other routes. During the afternoon peak the same operation occurs in reverse. The exclusive facility may be used for travel in one or both directions.

In most cases these services exist only during peaks; sometimes a few routes operate throughout the day. Thus, buses on busways or HOV roadways typically represent commuter rather than regular transit. They are an efficient mode for peak hour travel, but offer a lower type of service, if any, in the off-peak hours. The main reason for this deficiency is that, since they follow freeway alignments, busways are not optimally located with respect to transit demand. Moreover, they provide high-speed travel in outlying, low-density areas, but the service drastically deteriorates in slow distribution and frequent congestion in the CBD.

Oriented to CBD commuters, the SRB mode does not serve the increasing volumes of "reverse commuters" (from central city into suburbs) as well as many rapid transit or regional rail systems do with their much more frequent and regular services.

These deficiencies of buses are not necessarily inherent in the SRB mode. If properly designed, SRB can utilize different types of reserved or exclusive ROW, including busways that follow alignments of major passenger travel. Its routes can be simpler (similar to rail lines), have stop spacings of 400 to 800 m (1250 to 2500 ft), have transfers with other routes, and operate with reasonable frequencies throughout the day. This type of system exists in Ottawa, Canada, where extensive facilities in suburbs and the CBD are provided strictly for transit buses, and the entire network is operated as an all-day, regular transit system serving many suburban and center-city stops with satisfactory frequency.

Adelaide, Australia, has a semirapid bus system utilizing O-Bahn (that is, guided buses on a radial facility, which technically precludes all other vehicles and thus guarantees bus exclusivity). By concept, however — a long busway with very few stations and street operation in the CBC — this system is similar to its counterparts in several U.S. cities and inferior to the much more extensive Ottawa SRB network with its many stations.

Because of the separated ROW, the SRB mode requires a considerably higher investment than regular buses for its infrastructure, but it offers a higher LOS and system performance.

Light rail transit (LRT) is a mode utilizing predominantly reserved, but not necessarily grade-separated ROW. Its electrically propelled rail vehicles operate singly or in trains. LRT provides a wide range of LOS and performance characteristics.

LRT takes advantage of a feature of rail technology that is unique among guided systems: the ability to operate not only on ROW category A, but also on B and C. Unlike virtually all other guided technologies, rail technology can have crossings of its tracks and crossings of tracks with streets, as well as running along streets. This gives LRT the ability to utilize all types of ROW on the same line, and yet offer the advantages of guided technology: high capacity, high labor productivity (train operation), very high riding comfort, and so on. Street running is least desirable because of the disadvantages described before for streetcar operation; fully controlled ROW is the most desirable, but the most capital-intensive type of facility.

Consequently, a typical LRT network, such as those found in Cologne and Stuttgart, Germany, or San Francisco may have tunnels under the most congested central area, while its degree of separation decreases toward outlying areas where congestion is not a problem. LRT can also operate in pedestrian malls (as in Zurich, Switzerland, Mannheim, Germany, and San Diego). The lower noise, absence of exhaust fumes, and better safety record make LRT more compatible with pedestrian environments than buses. Because of the limited speed, however, mall running can be used only on short sections, usually up to 1 to 2 km (one mile).

LRT is a higher-investment, higher-performance mode than streetcars. Its relationship with regular buses is similar to that with streetcars: their comparison would show that LRT is superior in nearly all LOS and performance items, but that it requires a much higher investment and, therefore, has a more limited network. Consequently, it has a smaller area coverage for walking access, but a much stronger ability than buses to attract park-and-ride users from large areas. Hence, the most important comparison is between LRT and SRB: both utilize similar ROW categories and require similar investments, but have different technologies.

This comparison shows that, as the extent of B and A ROW on a transit line increases, LRT becomes more advantageous than SRB. Since most of the infrastructure construction costs depend on ROW type, investments required for bus or rail on the same alignment are rather similar. The relatively small additional investment for LRT as compared to buses brings the very significant advantages of rail mode over buses in LOS, performance, operating costs, and impacts.

Another factor to consider in comparing bus and rail modes is the type of network. Buses have the greatest ability to operate on interconnected and overlapping routes; raid rapid transit (metro) is least capable of that. Metro networks typically consist of independent lines that may have a few (usually two) branches. They rely on easy transfers or even simultaneous passenger exchange across platforms among frequent services on different lines. Thus the trade-off is between fewer transfers in overlapping bus networks and higher frequency and greater simplicity and reliability of service in rail networks. The selection of either type of service and mode depends on local conditions. In some cases no-transfer service, which buses offer, prevails; in others, regimes on branches and trunk lines are so different that the use of different modes (bus feeder with rail on trunk) or different vehicles (minibus feeders and regular or articulated buses on the trunk) offers a much more reliable and economical network service. LRT is between these two modes and it often represents a good compromise of these features: LRT can have more branches than metro, and it offers considerably more reliable and comfortable service than buses. Due to their higher LOS and stronger image, rail modes attract considerably greater ridership than buses under comparable conditions.

Light rail transit compared with semirapid buses on the corresponding alignments is characterized by:
+ Easier securing of B or A ROW (less pressure to mix with other traffic).
+ Stronger image and identity of lines (rail technology).
+ More spacious, comfortable vehicles.
+ Higher passenger attraction (result of the preceding two).
+ Lower noise, no exhausts.
+ Better vehicle performance due to electric traction.
+ Higher system performance (capacity, productivity, reliability, etc.).
+ Lower operating cost per space-km.
+ Ability to operate in tunnels.
+ Ability to upgrade into rapid transit.
— Lower service frequency for a given demand due to larger vehicles.
— Somewhat higher investment for the same alignment.
— For new applications, a need to introduce new facilities for a different technology.
— Lower ability to branch out, requiring more transfers.
— A longer implementation period.

The LRT mode was developed in an evolutionary manner from streetcars in several European countries, particularly West Germany, since the late 1950s. A number of systems with LRT characteristics that had existed in U.S. cities several decades earlier had disappeared with the serious neglect of transit on this continent. With the revival of transit during the late 1960s and 1970s, LRT finally became a recognized transit mode. It has had a significant development worldwide since that time.

Since the late 1970s, new LRT systems have been built in a number of U.S. cities (four in California alone), in Canada (Edmonton and Calgary), and Mexico (Guadalajara). Many cities in other developed counties (France, Great Britain, the Netherlands, and Switzerland) have been joined by some cities in developing countries (Tunisia, Brazil, Hong Kong, and the Philippines) in building new LRT systems.

Rapid Transit (RT)

Light rail rapid transit (LRRT) or light rapid transit represents small-scale rapid transit: it consists of light rail vehicles (LRVs) operating only on ROW category A. There are very few conventional systems of this mode in operation (the Norristown line in Philadelphia and line 8 in Goteborg, Sweden, are the best known). The significance of this mode is increasing rapidly with the recent introduction of fully automated rail transit lines. During the 1980s, Vancouver, British Columbia, and London, England, opened automated LRT lines, and a number of cities began to plan constructing such systems.

Rubber-tired rapid transit (RTRT) consists of moderately large vehicles (gross floor areas between 36 and 53 m2 or 380 and 570 ft2) supported and guided by rubber tires, running on wooden, concrete, or steel surfaces in trains of 5 to 9 cars. The cars also have steel wheels for switching and for support in the case of a tire failure.

Rail rapid transit (RRT), increasingly known in most countries as metro, typically consists of large four-axle rail vehicles (area up to 70 m2 or 750 ft2) that operate in trains of 2 to 10 cars on fully controlled category A ROW, which allows high speed, high reliability, high capacity, rapid boarding, and fail-safe operation (in the case of driver's error or disability, the train is stopped automatically). Some RRT systems are further characterized by a high degree of automated operation.

Although the main representatives of semirapid transit (LRT) and of rapid transit (RRT or metro) are extremely similar in their technologies and can have compatible operations, the full ROW control gives RRT several significant distinctions, as the following summary comparison of the two modes shows.

Rail rapid transit compared with light rail transit has:

+ Higher LOS (speed, reliability, comfort, and so on).

+ Higher system performance (canacity due to long trains, productivity, efficiency).

+ Higher safety (signalized, fail-safe). Stronger image (separate ROW and rail technology).

+ Higher passenger attraction and land-use impact (result of the above).
— Higher investment.
— Lower ability to fit into urban environment.
— Less conducive to stage construction.
— Longer implementation.

Rail rapid transit represents the ultimate mode for line-haul transportation (that is, for serving a number of points along a line). Trains of spacious vehicles with several doors on each side board passengers from high-level platforms without fare collection delays at rates of up to 40 persons/sec, many times higher than any other mode; with train capacities, where required, often exceeding 2000 spaces and up to 40 trains/h passing a point, the capacity of RRT greatly exceeds that of any other transportation mode; full ROW control allows the most reliable and safe travel at the maximum speeds that station spacings and passenger comfort permit. In all these features there is no physical way that a major further improvement in performance can be achieved for line-haul service. This highest performance is achieved, however, at an investment cost higher than for any other mode; provision of its major item, a fully controlled ROW (A) through urban areas, requires a considerably higher cost than any other ROW type.

Regional rail (RGR) is a transit mode usually operated by railroad companies. It has high standards of alignment geometry and utilizes the largest vehicles of all rail transit systems (up to 80 m2 or 860 ft2, or more in bilevel cars) that operate in trains of 1-12 cars, on longer routes, with fewer stations, at higher speeds than typical for RRT. Thus, RGR functionally represents a "large-scale RRT" which serves most efficiently regional and longer urban trips.

Electric rail transit represents the oldest group of mechanically powered transit modes. Yet, the development of the technology and operation of these modes continues to be very dynamic. Since 1970, the diversity of rail modes has increased significantly. In addition to numerous technical inventions, a number of systems have been built that represent combinations of features of two or more different modes. For example, many cities have lines that represent a transition between streetcars and LRT; Rotterdam, the Netherlands, has a line that is a combination between LRT and metro; the BART system in San Francisco and the Washington, D.C., Metro represent systems between metro and regional rail modes, while Manchester, England, has developed a set of regional rail lines served by light rail vehicles, so that they have been extended through the center city and operate there as typical LRT lines.

Consequently, the family of rail transit modes now represents a nearly continuous spectrum of characteristics; yet, systems typical of the four rail transit modes (SCR, LRT, RT, and RGR) have distinctly different features, as the above discussion and their comparisons show.

Automated guided transit (AGT) is the group of modes that operates in a fully automated manner (their TUs have no crews). "Automated guideway transit," although often used, is conceptually incorrect: systems are automated, not guideways. During the period of development of many new concepts for transit systems (1960 through the 1970s), AGT modes, also known as people-mover systems (PMS), referred to rubber-tired guided systems with vehicles of small to medium size. It should be noted that the term people-mover system has been used liberally for all short-haul modes except conventional bus and rail. AGTs were originally classified into the following two categories.

(See Chap. 24 for a more detailed discussion of AGT classifications and operating systems.)

Personal rapid transit (PRT) systems consist of small (3-6 seat) vehicles operating automatically on a complex network of guideways and serving only individuals or parties traveling together. This theoretical system concept is infeasible for applications because it combines an investment-intensive system (extensive infrastructure and sophisticated automation) with the very low transporting capacity of small vehicles. This low capacity is physically incompatible with high-density urban development. Consequently, in spite of numerous theoretical papers, no PRT has been built for real-world application.

Group rapid transit (GRT) systems consist of medium-capacity (15 to 100 spaces) vehicles operating singly or in short trains on exclusive guideways without crews. Following a number of applications of these systems as shuttle and short-line services in airports, campuses, and amusement parks, they have now been developed and built as regular transit lines in various cities, including Kobe and Osaka, Japan; Lille, France; Miami; Detroit (see also Chap. 5); and several others. The team downtown people mover (DPM) is identified with GRT modes used for local service within city centers.

In recent years, several developments with automated transit systems have occurred. First, while the PRT mode has remained without any applications, automated systems that have been built are larger in size than initial concepts indicated; these systems matured into actual transit applications. Present automated transit systems, which are, strictly, GRT by initial definition, have become better known under the term AGT.

An additional development has been the introduction of fully automated conventional rail systems (LRRT) in several cities (Vancouver, London), so AGT modes are no longer limited to unconventional, rubber-tired systems. AGT is therefore defined as medium-capacity guided transit modes operating on category A ROW in a fully automated manner. Line capacities of AGTs are typically in the range from 8000 to 15,000 sp/h, although some systems (primarily rail) can have capacities considerably above this range. For example, the Vancouver Advanced Light Rail Transit (ALRT) has been designed for some 28,000 sp/h (see also Chap. 5).

Table 4-3 classifies guided modes by guidance and support technology and vehicle size. It encompasses all guided transit modes except special ones, such as funiculars and aerial tramways.

Fully automated operation (driverless TUs) is technically feasible for all guided modes on category A ROW. For some AGT systems, however, such operation is a sine qua non for their economic feasibility, since the small size of their TUs would make labor costs prohibitively high; for metro systems, full automation is desirable but not crucial, because of their inherently high labor productivity.

Referring to Table 4-3, it can be seen that the large-vehicle modes (third column) are by far the most common. Applications of medium-vehicle modes. Will inease further as automation inproves and becomes more common. Small-vehicle modes are entirely experimental, and there are no realistic prospects that they will become technically and economically feasible in the near future.

TABLE 4-3

Classification oY Guided Modes w~th ROW Category
A **by Vehicle Size and Guidance Technologya**

Guidance Technology \ Vehicle Size	Small	Medium	Large
Rubber-tired	Rubber-tired PRT* (Aramis, CVS, Kabinentam, Monocab)	GRT or people mover systems (Skybus, Air trans, VAL, Trans urban*)	Monorails (Alweg, Safege *) *Rubber-tired RT* (Paris, Montreal, Mexico City)
Rail	Rail PRT* (Palomino, Mini tram)	ALRT (Vancouver) Light rail rapid transit	*Rail rapid transit* *Regional rail*
	Automated guided Transit		Rapid transit

aModes extensively used are in italic type. Modes that are not operational are designated by asterfsks.

REVIEW OF THE FAMILY OF REGULAR TRANSIT MODES

A systematic overview of the categories and types of characteristics for all major modes defined here is presented in Table 4-4. The characteristics of the factors determining modes (see Classification by Type of Usage and Fig. 4-1) are ordered in the sequence of increasing performance; modes are also ordered ascending from the lowest performance up; the correlation between the two shows in the table as the diagonal set of x marks. The two frames designate the lowest and the highest performance sets in the family of modes. It is emphasized, however, that performance refers to absolute values of system capacity, productivity, and efficiency and does not imply evaluation of modes; the lowest and highest performance modes are by no means "the worst" and "the best" in the family; they are only best suited to the minimum and maximum demand conditions, respectively.

Several other comparisons of modes and their generic classes are given in the next six tables and figures. The ranges given encompass all existing systems, with the exception of some extreme values found in very special cases. Since individual systems seldom have several extreme values (for example, maximum TU capacity and maximum frequency), the maximum values of derived performance measures (capacity and productive capacity) are less than the products of the maximum values of their components. Thus, the boundaries of modal characteristics depicted in the diagrams are neither absolute nor precise limits, but the ranges of values derived from existing systems.

Table 4-5 gives the ranges of the basic technical, operational, and system characteristics of the most important modes, classified into the three generic classes: street transit, semirapid, and rapid transit. Private auto is included for comparison.

Several modes that are similar in the given characteristics to the selected ones are not included (for example, taxi is similar to auto, trolleybus to bus, RTRT to RRT, and commuter to regional rail).

Table 4-6 summarizes the values from Table 4-5 by generic classes and presents several numerical examples of systems typical for each class. This table is the basis for Figs. 4-2, 4-3, and 4-4, which graphically show such basic characteristics as capacity, speed, cost, and productive capacity. Both representative systems and ranges of values for each class are plotted. Other important aspects, including LOS and impacts, cannot be shown graphically. They are discussed in Chap. 10.

Figure 4-2 shows the relationship between TU capacity, maximum line frequency, and line capacity (as area) for different modes. The diagram shows that, starting from the auto (taxi) toward higher-performance modes, maximum frequencies decrease while TU capacities increase. The most common values form a hyperbolic set of points (dashed lines) with rapidly increasing line capacities.

Since a comparison of capacities is incomplete without consideration of speed, Fig. 4-3 shows mode capacities, speeds, and productive capacities (as areas). The diagram clearly shows the large differences in all these performance elements among the classes; street transit has far lower capacity and operating speed than semirapid and rapid transit. This last mode has by far the best performance and the broadest range of performance values.

The most important factor for mode evaluation, relationship of performance and investment costs, is presented in Fig. 4-4. Productive capacity is plotted as the best representative of performance: it is the product of speed, affecting primarily passengers, and capacity, important for the operator. Similar to Fig. 4-3, the differences among classes of modes are major. There is a jump in investment cost between street and semirapid transit, and then a continuous investment range through rapid transit, with a rapid increase in productive capacity. Maximum productive capacity increases from street to semirapid transit by a factor of 4, and to rapid transit by about 13. The low performance of the auto/highway mode is conspicuous.

Figure 4-4 shows that although RRT can be designed for 70,000 sp/h, 50 km/h, and involve an investment cost of $50 x 106/km, it can also have much lower values of all these items. Its particularly broad range stretches from high-performance systems such as San Francisco's BART (by its yet to be achieved design specifications it would have 2.16 x 106 space-km/h2, at the upper boundary) to low-performance systems such as some lines on the Chicago rapid transit, which overlap with high-performance LRTs (for example, Boston's Green Line).

Another important modal characteristic is passenger attraction, which is a function of LOS. Since LOS is generally strongly correlated with system performance, the passenger attraction of transit modes increases significantly from street to rapid transit, as the conceptual dashed lines in Fig. 4-4 indicate. Street transit, always inferior in LOS to that of auto, mostly serves captive riders. Rapid transit, usually superior to auto in the same corridor, attracts most of the trips and generates additional travel.

TABLE 4-4
Review of Basic Features of Urban Public Transit Modes

Categories-Types	Determinant Factors	Paratransit	Regular bus RB	Trolleybus TB	Streetcar SCR	Semirapid bus SRB	Light rail transit LRT	Rubber-tired RT RTR	Rail rapid transit RRT	Region rail RGR
Streets (C)	R/W category	X	X	X	X					
Rubber tires	Support	X	X	X		X		X		
Steered	Guidance	X	X	X		X				
ICE	Propulsion	X	X			X				(X) [a]
Manual	Control	X	X	X	X	X	X			
Small vehicle (<30 pers.)	Transit unit	X								
Medium vehicle (30-100 pers.)	Transit unit		X	X		X				
Part. control (B)	R/W category					X	X			
Large vehicle (>100 pers.)	Transit unit		(X)	(X)	X	(X)	X	X	X	X
Electric	Propulsion			X	X		X	X	X	X
Guided	Guidance				X		X	X	X	X
Steel wheels	Support				X		X	(X)	X	X
Short trains (1-3 cars)	Transit unit				(X)		X			
Semiautomatic	Control						X	X	X	X
Full control (A)	R/W category							X	X	X
Long trains (>3 cars)	Transit unit							X	X	X
Fully automatic	Control							(X)	(X)	(X)

Minimum performance: Paratransit (boxed).

Maximum performance: Rubber-tired RT RTR, Rail rapid transit RRT, Region rail RGR (boxed).

[a] (X) indicates less common applications.

TABLE 4-5
Technical, Operational, and System Characteristics
Of Urban Transportation Modesa

Generic Class Private Street transit Semirapid Transit Rapid Transit
Characteristic Mod Auto on Auto on
Unit Street Freeway RB SCR SRB LRT RRT RGR

1. Vehicle capacity,Cvsp/vh 4-6 total,1.2-2.0 usable40-120100-18040-120110-250140-280 140-210
2. Vehicles/transit unit Veh/TU 1 1 1 1-3 1 1-4 1-10 1-10
3. Transit unit capacity sp/TU 4-6 total, 1.2-2.0 usable 40-120 100-300 41-120 110-600b
140-2400 140-1800
4. Miximum technical km/h 40-80 80-90 40-80 60-70 70-90 60-100 80-100 80-130
speed,V
5. Maximum frequency, 600-800 1500-2200 60-180 60-120 60-90 40-90 20-40 10-30
fmaxc
6. Line capacity,C sp/h 720-1050b,d 1800-2600d 2400-12,000 4000-20,000 4000-
12,000 6000-20,000 10,000-72,000 8000-60,000
7. Normal operating km/h 20-50 60-120 15-25 12-20 20-40 20-45 25-60 40-70
speed,Vo
8. Operating speed at km/h 10-30 20-60 6-15 5-13 15-30 15-40 24-55 38-65
capacity,V0C
9. Productive capacity, (sp-km/h2) 10-25b 50-120 20-90 30-150 75-200 120-260 400-1800
500-2000
Pc x10-3
10. Lane width(one-way) m 3.00-3.65 3.65-3.75 3.00-3.65 3.00-3.50 3.65-3.75
3.40-3.75 3.70-4.30 4.00-4.75
11. Vehicle contorle — Man./vis. Man./vis. Man./vis. Man./vis.
Man./vis. Man./vis. Man.- Man.-
sig. aut./sig. aut./sig.
12. Reliability
– Low-med. Med.-high Low-med. Low-med. High High Very high
Very high
13. Safety — Low Low=med. Med. Med. High High Very high Very high
14. Station spacing m — — 200-500 250-500 350-800 350-800 500-2000 1200-4500
15. Investment cost per ($/km) 0.4-4.0 5.0-40.0 0.2-0.8 2.0-4.0 5.0-15.0 5.0-120.0 15.0-50.0
10.0-60.0
pair of lanes x10-6

aMetric conversion: 1 km = 0.62 mi. Abbreviations: sp, spaces; veh, vehicles; TU, transit unit.
bValues for C and Pc are not necessarily products of the extreme values of their components because these seldom coincide.
cFor auto, lane capacity; for transit, line (station) capacity; single lane, but 2-lane stops for busses; single track for rail.
dFor private auto, capacity is product of average occupancy (1.2-1.3) and fmax since all spaces cannot be utilized.
eAbbreviations are for: manual, visual, signal, and automatic.

TABLE 4-6
Performance Values for Generic Classes of Modes (Based on Table 4-5) and for Serveral Typical Systemsa

Generic class

Characteristic	Unitb	Private auto on									
		Street	Freeway	Street transit		Semirapid transit		Rapid transit			
1. Transit unit capacity		sp/TU	1.2-	2.0c	40-300	40-600	140-2200				
2. Maximum frequency,fmax			TU/h	600-800	1500-2200		60-180	40-90	10-40		
3. Line capacity,C		sp/h	720-1050		1800-2600		2400-20,000		4000-20,000		10,000-
72,000											
4. Operating speed,Vo		(km/h)	20-50	60-120	5-20	15-45	24-70				
5. Productive capacity,Pc		(sp-km/h2) x 10-3			10-25	50-120	20-150	75-600	400-2000		
6. Investment cost per pair of lanes			($/km) x 10-6		0.4-4.0	0.5-40.0	0.2-4.0	3.0-20.0	15.0-60.0		

		System	System									
Typical systemsd “s”		“f”	RB-1	RB-2	SCR	SRB	LRT-1	LRT-2	RRT-1	RRT-2	RGR	
1. Transit unit capacity		sp/Tu	1.3	1.3	65	75	140	100e	180	430	800	
1100	1000											
2. Maximum frequency,fmax			TU/h	700	1800	120	90	90	100	90	40	30
35	28											
3. Line capacity,C		sp/h	910	2340	7800	6750	12,600	10,000	16,200	17,200	24,000	
38,500	28,000											
4. Normal operating speed,V			km/h	35	80	20	18	16	26	30	33	38
36	50											
5. Operating speed at capacity,VoC			km/h	20	40	10	12	11	18	23	25	38
34	48											
6. Productive capacity,Pc		(sp-km/h2) x 10-3			18.2	93.6	78	81	138.6	180	372.6	
430	912	1309	1394									
7. Investment cost per pair of lanes			($/km) x 10-6		0.6	8.0	0.2	0.3	1.6	7.0	8.0	
9.0	12.0	20.0	18.0									

aThe systems shown are assumed to be heavily loaded, but somewhat below capacity of respective mode.
bMetric conversion: 1km = 0.62 mi.
cMaximum number of spaces that can be utilized.
dDesignation used in Figs. 4-2, 4-3, and 4-4.
eArticulated buses.

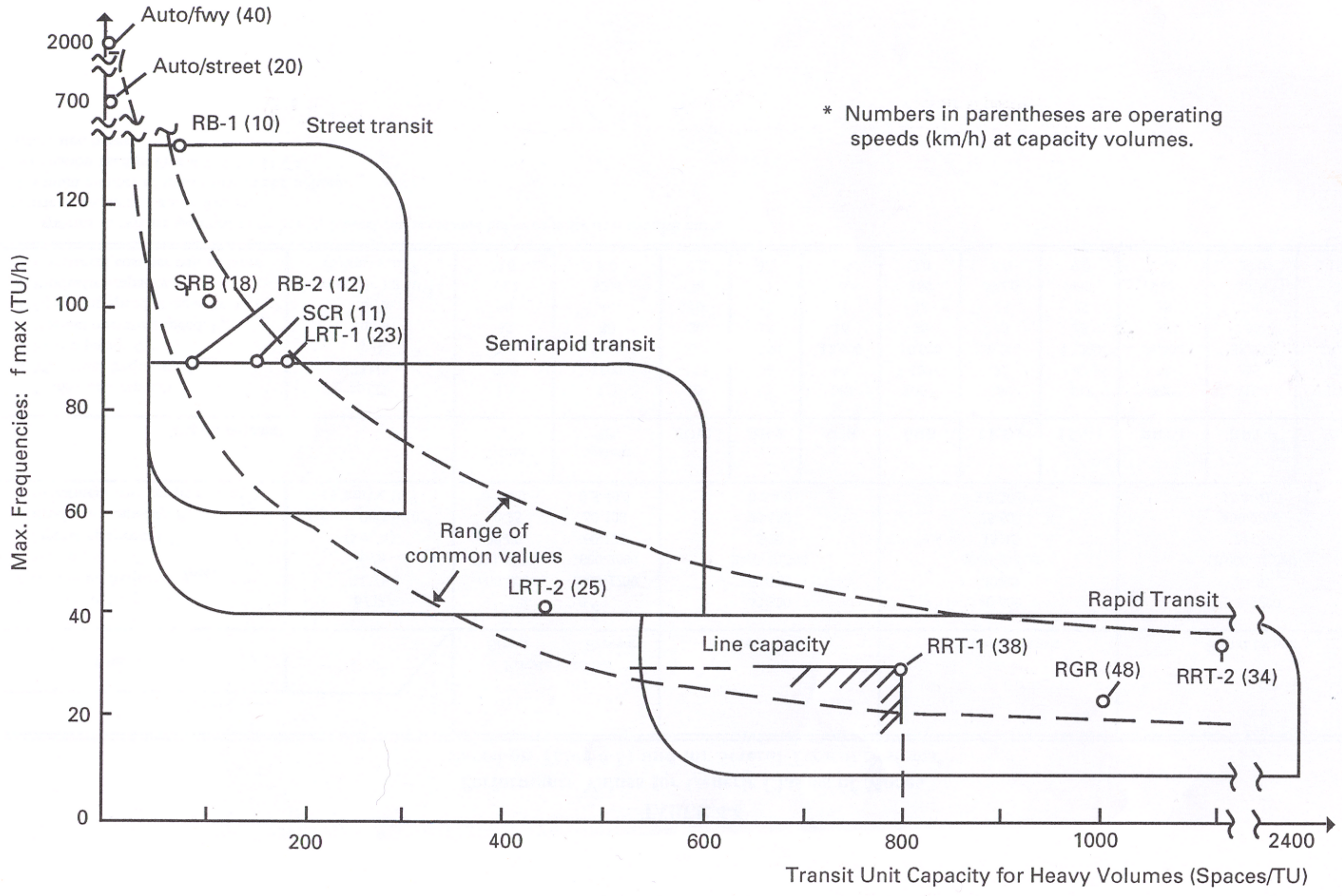


Figure 4-2 *Vehicle capacities, maximum frequencies, and line capacities of different modes.*

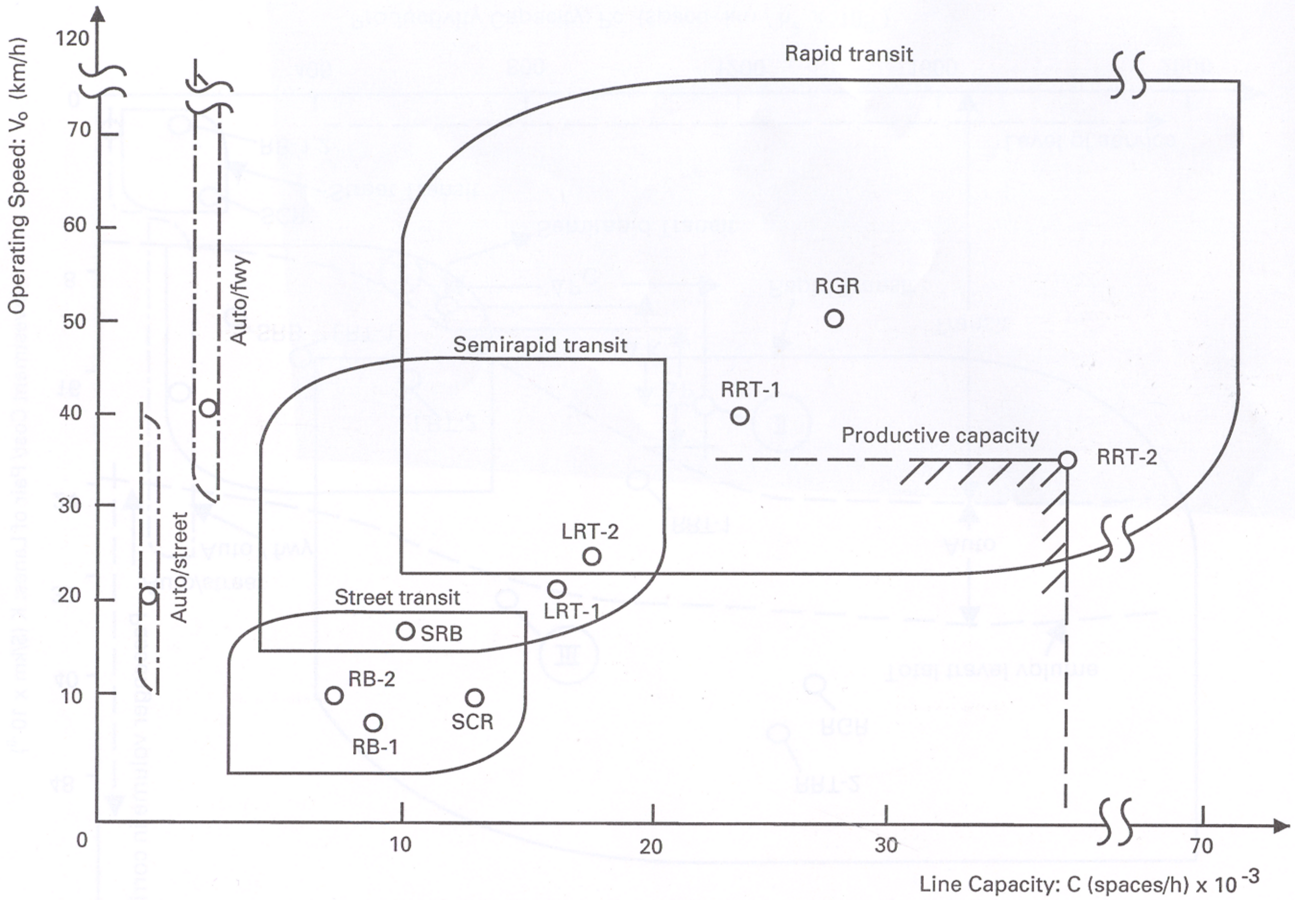


Figure 4-3 *Line capacities, operating speeds, and productive capacities of different modes.*

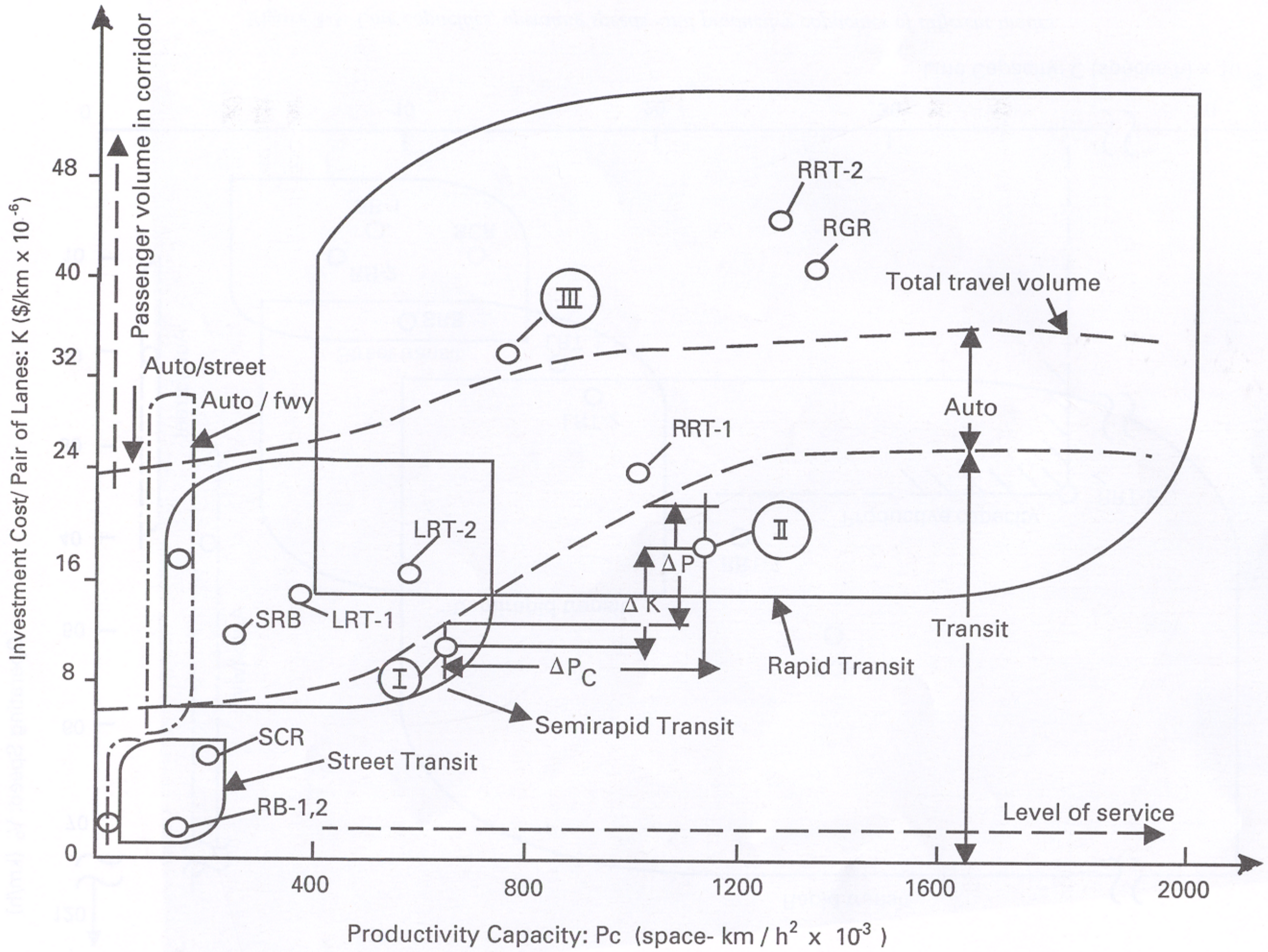


Figure 4-4 *Relationship between productive capacity, investment cost, and passenger attraction of different generic classes of transit modes.*

It is clear from Fig. 4-4 that comparisons of modes based on costs only can be highly deceptive; they compare ordinates of modes, disregarding their abscissa values. For modes with similar performance, the error caused by disregarding abscissa values may not be great, but for modes as diverse as street and rapid transit, the error is always very large.

Although the mode comparison must include many different factors, one basic relationship of performance/cost characteristics of different modes is illustrated in Fig. 4-4 by hypothetical systems I, II, and III. System III can be easily eliminated as inferior to system II: it has a higher cost, has much lower productivity, and attracts fewer passengers. A comparison between I and II must evaluate the trade-off between the higher productive capacity (APc) and passenger attraction (AP) of system II against the lower cost (?AK) of system I.

Observing modal characteristics in the three diagrams (Figs. 4-2, 4-3, and 4-4), it is interesting to note that the relative positions of the 11 plotted systems vary considerably; LRT-1 and LRT-2 are remote in the first, but close in the second and third diagrams. However, they all fall in the ranges plotted for their generic classes. The overlaps between classes also vary among the diagrams, but in all three they clearly show the same sequence from low to high performance. Most modes fall in the central zone of the class areas (for example, the dashed lines in Fig. 4-2), forming a nearly continuous family of transit modes. The extreme corners have been rounded off on the diagrams since they represent either extremes impractical to operate (for example, smallest transit unit and lowest maximum frequency) or a nonoptimal combination (highest investment and lowest performance).

Another way of illustrating differences in modal capacities is by a sketch of the facilities required for transporting 15,000 pr/h by different modes, shown in Fig. 4-5. This volume is found in many cities since even facilities carrying only 5000 to 7000 pr/h obtain rates of flow of 15,000 to 20,000 pr/h for a 15- to 20-min period, making the latter the design volume. Line capacity reserves are also given since they influence LOS (comfort). Terminal areas are quoted as a significant component of the space efficiency of modes. The figure clearly shows the superiority of high-capacity modes in serving high-density areas, particularly when their much lower terminal area requirements are also taken into account.

In conclusion, this review of the family of modes shows that all major transit modes have optimal domains of application; adjacent modes overlap their domains to some extent (dial-a-ride and RB, or LRT and RRT), but modes as remote from each other as taxi and bus or bus and RRT should never be competitive, but complementary. For example, there is no way in which it can be more efficient and economical to transport 40 persons from point A to point B at one time in 20 taxis than in one bus, or 750 people in 15 buses than in one train, unless the lower-capacity mode is operated by underpaid drivers, has low comfort and safety standards, and is indirectly subsidized, while the higher-capacity mode is excessively luxurious, inefficiently operated, and driven by overpaid drivers. Similarly, it can never be more efficient to transport a single passenger from one suburb to another by a bus than by a taxi. As a matter of fact, when such remote modes are competitive, it is a clear sign that the

Mode	Schematic of R/W	Line Capacity Reserve	Terminal Area Requirements
Private autos on street (Persons/vehicle: 1.3; maximum freq.: 700)	17 Lanes x 3.50 m 119 m	None	Parking: 23 m^2/person For 15,000 people, 34.5 ha (85 acres)
Private autos on freeway (1.3 : 1800)	7 Lanes x 3.65 m 51 m	None	Same as above, plus interchanges
Regular buses (R/W C) (75 : 100)	4 Lanes x 3.50 m 14 m	None (station and way capacities reached)	Each station 20 x 80 m on the surface
Semirapid buses (artic., R/W B) (100 : 90)	2 Lanes x 3.65 m + shoulders 7.3 m	None (station capacity reached, way capacity not)	Each station from 25 x 100 m
Light rail transit (400 : 50)	2 Tracks or: 7.5 m or:	33%	Each station from 12 x 50 m on the surface to 20 x 90 m grade separated
Rail rapid transit (1000 : 25 RGR; 1000 : 40 RRT)	2 Tracks 8 m	67–167%	Each station from 20 x 100 to 25 x 210 m grade separated. No surface occupancy.

Figure 4-5 *Areas required for transporting 15,000 persons per hour by different modes.*

conditions (policies, financing, planning, regulation, design, and the like) are greatly distorted against the mode that should be optimal in that application. This is clearly the case in cities where auto travel into the CBD during peak hours is not only competitive, but superior to bus or even to rail services.

This analysis also shows that there can never be a single optimal mode for all urban transportation. Conditions and requirements for urban travel vary so much that *in most cities,* except very small ones, *the optimal (sometimes referred to as balanced) transportation system should consist of several complementary modes coordinated into a single integrated multimodal system.*

COMMUTER TRANSIT

In addition to the regular public transportation services operated by the modes previously defined, some cities have separate commuter services that use standard transit technologies as well as other modes. In medium-size cities, commuter transit may represent the dominant share of public transportation; many bus routes operate during the peaks only. As city size increases, the relative role of these services decreases. In large cities, if regular transit provides adequate services throughout the city at all times of the day, commuter transit should only be a minor supplement to these services. The great attention given to commuter transit in U.S. cities is a consequence of the unsatisfactory condition of regular transit and highway congestion in most cities.

The following modes are used for commuter transit:

Carpooling is travel of different parties (two to six persons) together in a private car on a regular basis. Since carpooling is private transportation, it cannot be organized, scheduled, or regulated by an agency, but its use can be encouraged by such measures as assistance in establishing contacts among potential users, reduced or eliminated toll and parking charges, provision of: special lanes, and so on.

Carpools are socially more desirable than individual travel by car because they take less space and cause fewer negative side effects per person-km of travel. Their use is limited, however, to commuting because they require that travel of the participants in each pool coincides in origin, destination, time of departure, and time of return. Moreover, carpooling is often a greater deprivation of privacy than transit travel; it involves precise travel coordination, cost sharing, and joint ride in private cars of persons who may have nothing else in common but travel pattern.

Vanpools are privately or publicly provided vans (S to 18 seats) transporting groups of persons to and from work on a regular basis. Owing to their lower unit transportation cost and space occupancy, vanpools are even more socially desirable than carpools. They require, however, a more formal organization for vehicle purchase, maintenance, driving, insurance, and so on.

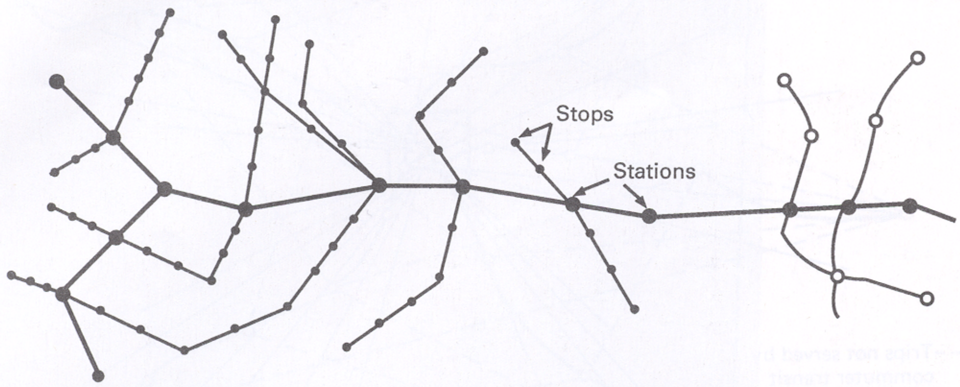
Subscription bus is bus service provided for persons who subscribe for a time period (week or month) to travel every working day at the same time on the same route (commuting).

Express commuter bus, express bus service operated during peak hours only, is a common mode of commuter transit. Usually, express commuter bus routes operate locally in suburbs and then use arterials and freeways for fast travel into the CBD.

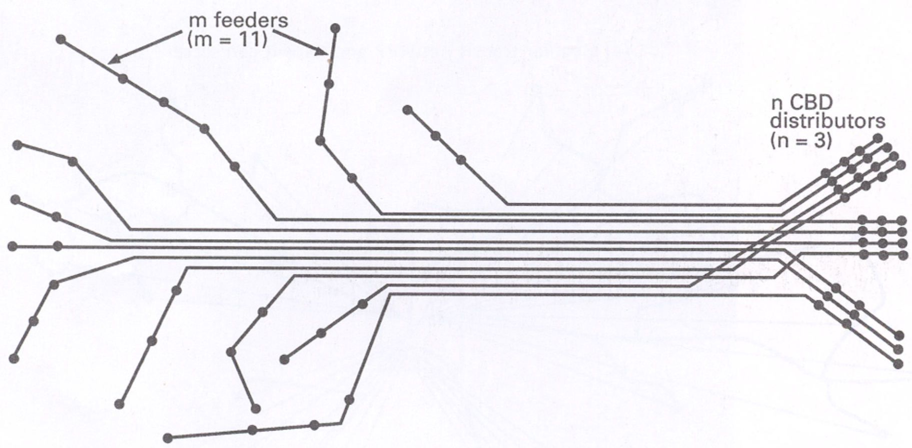
Commuter rail is regional rail operating during peak hours only. This term is often incorrectly used for all regional rail systems.

Commuter buses that utilize busways and commuter rail have fixed facilities used for transit during peak hours only. This represents a poor utilization of facilities, which can often be greatly improved by the introduction of properly marketed and efficiently operated regular transit services.

Figure 4-6 shows schematically corridor service by regular transit and by commuter bus transit and lists their characteristics. The figure shows that regular transit offers service between any two stops on feeder routes or stations on the trunk line, while commuter bus transit serves only the trips between the suburban collection area and CBD, the many-to-one travel pattern. Moreover, each of the m collector routes offers service to only one of the n CBD distributors. Transfer to the other distributors can be organized if all routes use the same freeway exit, but this is seldom the case. Direct, no- transfer connections among all feeders and all distributors would require m x n routes (33 in the example), resulting in much lower frequencies on each of them than on regular transit lines. A schematic of the network in Fig. 4-7 shows that commuter transit serves an even smaller fraction of all urban trips than corridor trips: it cannot serve any suburb- to-suburb trips. Consequently, the more decentralized the city is, the more important is the role of regular transit relative to commuter transit. Equally important is the advantage that regular transit operates at all hours, whereas commuter transit operates only during the peaks.

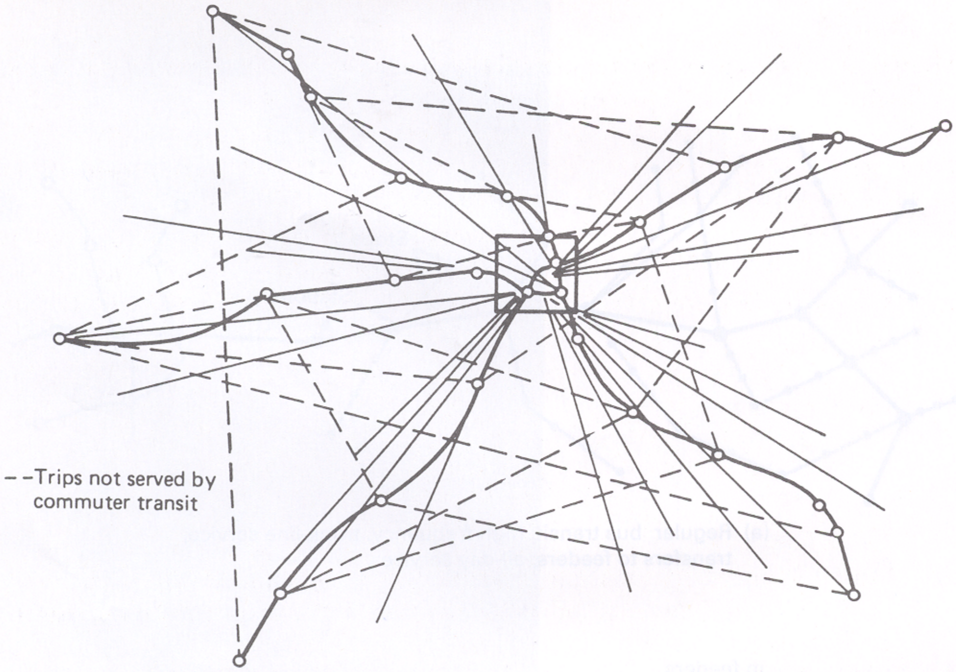


(a) Regular bus transit: high-frequency, trunk-line service, transfers to feeders; all-day service

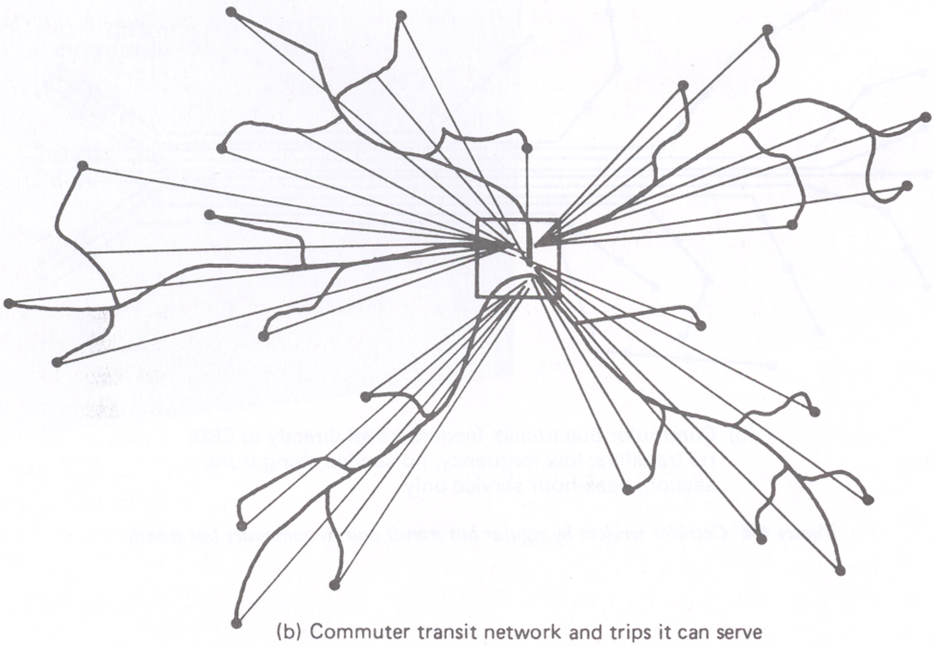


(b) Commuter bus transit: feeders travel directly to CBD: no transfers; low frequency, no service along trunk section; peak-hour service only

Figure 4-6 *Corridor services by regular bus transit and by commuter bus transit.*



(a) Regular transit network and trips it can serve



(b) Commuter transit network and trips it can serve

Figure 4-7 *Urban trips served by regular transit and by commuter transit.*

FURTHER READING

INSTITUTE OF TRANSPORTATION ENGINEERS, *Transportation and Traffic Engineering Handbook* (2nd ed.), ed.

Wolfgang S. Homburger. Englewood Cliffs, N.J.: Prentice-Hall, Inc., 1982.

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PUSHKAREV, BOR[S S., AND JEFFREY M. ZUPAN, *Public Transportation and Land Use Policy,* a Regional Plan Association Book. Bloomington, Ind.: Indiana University Press, 1977.

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VUCHIC, VUKAN R., *Urban, Public Transportation Systems and Technology.* Englewood Cliffs, N.J.: PrenticeHall, Inc., 1981.

EXERCISES

4-1 Which characteristics of a transportation system determine whether it is private or public? If a private bus operator operates a transit line, is that private or public transportation?

4-2 Which basic characteristics make the following systems different modes: dial-a-ride and regular bus; bus and streetcar; light rail transit and metro?

4-3 What are the basic differences between steered and guided technology systems with respect to their investment costs, operating costs, and performance?

4-4 If passenger volume on a transit line steadily increases, how should vehicle size, method of guidance, ROW category, and degree of automation change?

Give definitions, dimensions, and common units in troth the ST and
English

system for service frequency, offered capacity, utilized capacity, and operating speed.

Which modes frequently use two or all three ROW categories, even along the same line?

4-7 In a corridor that needs improved transit service, the main alternative systems are semirapid bus (SRB) with exclusive busways, rather than HOV lanes, on trunk sections and light rail transit (LRT). Explain how the following factors would influence the mode choice (i.e., which of the following conditions or changes would favor SRB, which LRT?): the outlying network has many branches and the common trunk section is rather short; street congestion is so bad that a tunnel has to be built in the CBD; labor wages are very high; in several suburban areas, operation ROW C (street running) is unavoidable; there is considerable potential for future development in the corridor.

4-8 Define productive capacity and explain for what purposes it can be used in evaluating and comparing transit systems or modes.

4-9 What are the differences between commuter transit and regular transit?