CHAPTER 14

TRANSIT CONCEPTS

CONTENTS

EXHIBITS

I. INTRODUCTION

For more information on transit, see the TRB Transit Capacity and Quality of Service Manual

This chapter introduces capacity and level-of-service (LOS) concepts for transit modes—bus, streetcar, and light rail—that operate on public streets and interact with other users of streets and highways. Transit modes that operate only on exclusive rights-of-way—such as rapid transit, commuter rail, and automated guideway transit—are not discussed here. All transit modes are addressed in more detail in the *Transit Capacity and Quality of Service Manual* (*1*).

This chapter may be used in conjunction with Chapter 27 and Part IV of the HCM. Chapter 27 provides analytical procedures and applications for determining transit capacity and LOS for transit stops and route segments. Part IV of this manual integrates the application of transit system capacity and quality-of-service concepts into multimodal corridor and areawide analyses.

ROLE OF TRANSIT

Transit plays two major roles in North America. First, it accommodates choice riders—those who choose transit for their trip-making even though they have other means of travel, such as a motor vehicle. Many commuters choose transit because they are unwilling to deal with traffic congestion during peak periods. Choice riders dominate transit during the peak periods for work trips. In this way, transit increases the number of people who can be carried by urban transportation systems and reduces—or at least constrains—the growth of more than 4.36 billion person-hours (*2*) lost to urban traffic congestion annually in the United States. Transit is essential for mobility in the central business districts (CBD) of some major cities, which could not survive without it. Accommodating choice riders is especially critical in cities with high CBD densities and costly and limited parking.

The other major role of transit is providing basic mobility for segments of the population that are too young, too old, or otherwise unable to drive due to physical, mental, or financial situations. About 35 percent of the adult population in the United States and Canada do not have a driver's license (*2*) and must depend on others to transport them in autos, on transit, or on other modes, including walking, cycling, and taxis. This is the principal role of transit services provided specifically for people with disabilities and it is the dominant role of many smaller transit systems. These transit users have been called captive riders.

Rail service offers higher capacities than buses

Rail service offers higher capacities than buses for heavily traveled corridors, and its use of fixed routes makes it more visible and attractive in densely populated areas. Light rail is characterized by a versatility of operation—it can operate separated from other traffic below grade, at grade, or on an elevated structure, as well as at grade in mixed traffic.

Exhibit 14-1 provides examples of peak-hour trips to the CBD by transit in selected North American cities. The variations in transit use reflect differences in population, CBD employment, extent of bus and rail transit services, and geographic characteristics.

TRANSIT CHARACTERISTICS

Unlike the auto mode, transit availability is an important consideration

Several characteristics differentiate transit from the automobile in terms of availability and capacity. Although the automobile has widespread access to roadway facilities, transit service is available only in certain locations during certain times. Roadway capacity is available 24 h/day once constructed, but transit capacity is limited by the number of transit vehicles operated at a given time.

EXHIBIT 14-1. PEAK-HOUR NORTH AMERICAN CBD TRANSIT TRIPS

City	Year	Percent of Peak-Hour Trips by Transit
New York City	1988	87
Chicago	1983	77
Toronto	1994	64
Ottawa	1997	60
Montreal	1994	49
Philadelphia	1997	42
Vancouver	1997	40
Seattle	1997	40
Los Angeles	1980	39
Calgary	1997	39
Edmonton	1994	32
San Diego	1997	15

Sources: *Transit Capacity and Quality of Service Manual* (*1*), Levinson and St. Jacques (*3*), and Morrall and Bolger (*4*).

Transit passengers are typically pedestrians, bicyclists, or motorists for parts of their trips

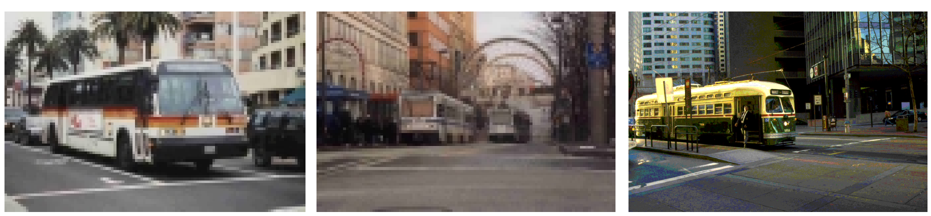
Transit passengers frequently rely on other modes to gain access to transit. Transit use is greatest where population densities are highest and pedestrian access is good. A typical transit user does not have transit service available at the door and must walk, bike, or drive to a transit stop and then must walk or bike from the transit discharge point to the destination. In contrast, suburban areas are mainly automobile-oriented, with employment and residents dispersed, often without sidewalks, and without direct access to many transit lines. If potential passengers cannot have access to transit from both their trip origin and destination, transit is not an option.

Transit goals are to move large numbers of people, rather than large numbers of vehicles

Finally, transit is about moving people rather than vehicles. Transit operations at their most efficient involve relatively few vehicles, each potentially carrying a relatively large number of passengers. In contrast, roadway analysis traditionally involves relatively large numbers of vehicles, each usually carrying only one occupant. When evaluating transit priority measures for transit and automobile users, it is the number of people affected that should be compared, rather than the number of vehicles.

All transit modes are addressed in the Transit Capacity and Quality of Service Manual

This manual addresses only those major transit modes (in terms of passengers carried) that operate on streets and interact with other users of streets and highways. These modes include buses, streetcars, and light rail (see Illustration 14-1).



Bus (Los Angeles) Light Rail (Baltimore) Streetcar (San Francisco)

ILLUSTRATION 14-1. Transit modes covered in the *Highway Capacity Manual*.

Bus services can be provided by several vehicle types, ranging from minibuses to articulated and double-deck buses. Standard 12-m buses with more than 35 seats are the dominant type of bus in U.S. transit systems and comprise more than 80 percent of the national bus fleet. Articulated buses 18 m in length have been adopted by a few agencies, but their use is increasing as agencies seek to improve capacity and comfort with only small increases in operating costs. Double-deck buses have had tryouts but have not found widespread use in either Canada or the United States. A few transit agencies operate trolleybuses (both standard and articulated), powered from overhead electrical lines.

During the first half of the 20th century, streetcars were common in most larger North American cities but nearly disappeared in the 1950s as automobile use increased and the spreading suburbs could not be served efficiently by rail. The modern equivalents of the streetcar are the light-rail systems that have started up since 1978. The two modes are similar; however, light rail provides higher speeds and somewhat higher capacity than streetcars. Also, in North America, light-rail tracks usually are separated from general traffic, even when operating on the same street as other traffic, but streetcars sometimes share a lane with other traffic.

Streetcars can share a lane with other traffic; light rail trains are almost always separated from other traffic, even when running on-street

GENERAL TRANSIT CAPACITY CONCEPTS

Transit capacity is different from highway capacity. It deals with the movement of both people and vehicles; it depends on the size of the transit vehicles and how often they operate; and it reflects the interaction of passenger traffic and vehicle flow. Transit capacity depends on the operating policy of the transit agency, which specifies service frequencies and allowable passenger loadings. Accordingly, the traditional concepts applied to highway capacity must be adapted and broadened.

Definitions

Capacity, vehicle capacity, and person capacity

Throughout this chapter and Chapter 27, a distinction is made between vehicle and person capacity. Vehicle capacity reflects the number of transit units (buses or trains) that can be served by a loading area, transit stop, guideway, or route during a specified period of time. Person capacity reflects the number of people that can be carried past a given location during a given time period under specified operating conditions, without unreasonable delay, hazard, or restriction, and with reasonable certainty. In this chapter and Chapter 27, the term capacity applies both to persons and vehicles.

Exhibit 14-2 illustrates the two-dimensional nature of on-street urban transit capacity, using buses. It is possible to operate many buses, each carrying only a few passengers. Whether the buses are full or empty, a larger number of buses can have a negative impact on LOS in terms of highway capacity. Alternatively, a few vehicles could operate, each overcrowded. This represents a poor quality of service from the passenger perspective, and long waiting times would detract from user convenience.

Vehicle Capacity

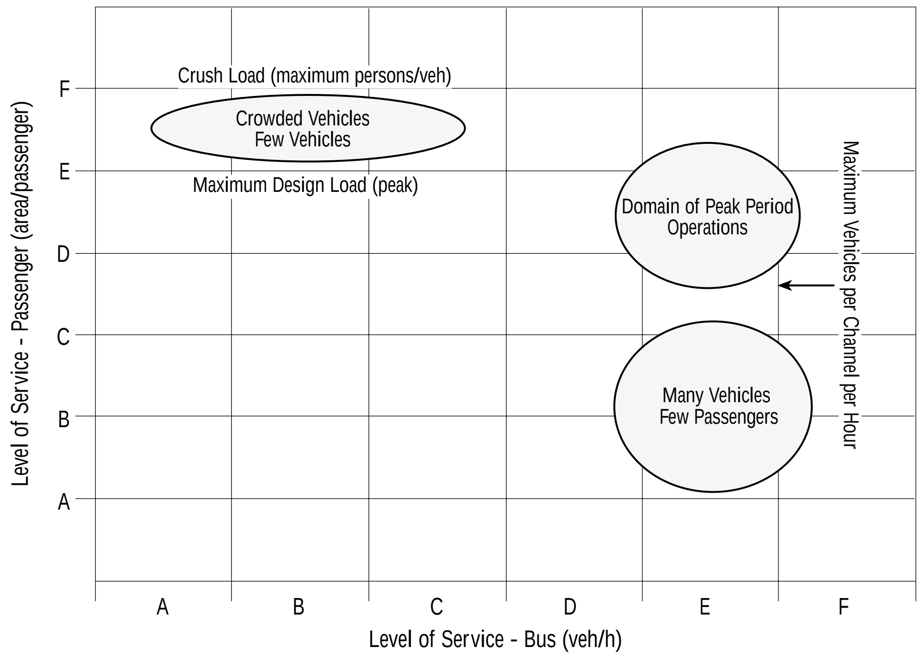
Transit vehicle capacity is commonly determined for three locations: loading areas or berths; transit stops and stations; and bus lanes and transit routes. Each location directly influences the next. The vehicle capacity of a bus stop or rail station is controlled by the vehicle capacities of the loading areas, and the vehicle capacity of a bus lane or transit route is controlled by the vehicle capacity of the critical stops along the lane or route.

Dwell times and g/C ratios have the greatest influence on loading area vehicle capacity

The two greatest influences on loading area vehicle capacity are the dwell time and the ratio of the green time to the cycle length (g/C ratio) for the street on which the transit operates. Dwell time and the g/C ratio also have major influences on the vehicle capacity of transit stops and routes. However, dwell time—the time required to serve passengers at the busiest door plus the time required to open and close the doors—has the greater influence on loading-area vehicle capacity.

The amount of green time provided to a street controls the number of transit vehicles that theoretically can arrive at a loading area during an hour. In addition, the length of red in relation to a vehicle's dwell time also affects vehicle capacity: if passenger movements have finished, but the vehicle must wait for a traffic signal to turn green, vehicle capacity will be less than if the vehicle can leave immediately, so that another vehicle can use the loading area.

EXHIBIT 14-2. RELATIONSHIP BETWEEN PERSON AND VEHICLE CAPACITY



Person Capacity

Person capacity typically is calculated for transit stops and stations and for the maximum load point of a transit route or bus lane; it is calculated for three locations:

- Transit stops and stations,
- Transit routes at their maximum load points, and
- Bus lanes at their maximum load points.

Exhibit 14-3 shows the factors that control person capacity.

Operator Policy

Increasing the maximum allowed passenger load increases person capacity but decreases quality of service

A transit operator directly controls the maximum passenger loads allowed on transit vehicles and the service frequency. An operator with a policy requiring all passengers to be seated will have a lower potential person capacity for a given number of vehicles than an operator with a policy allowing standees. However, passengers experience a higher quality of service with the first operator. The service frequency determines how many passengers actually can be carried, even though a transit stop, transit route, or bus lane can serve more vehicles than actually are scheduled.

Passenger Demand Characteristics

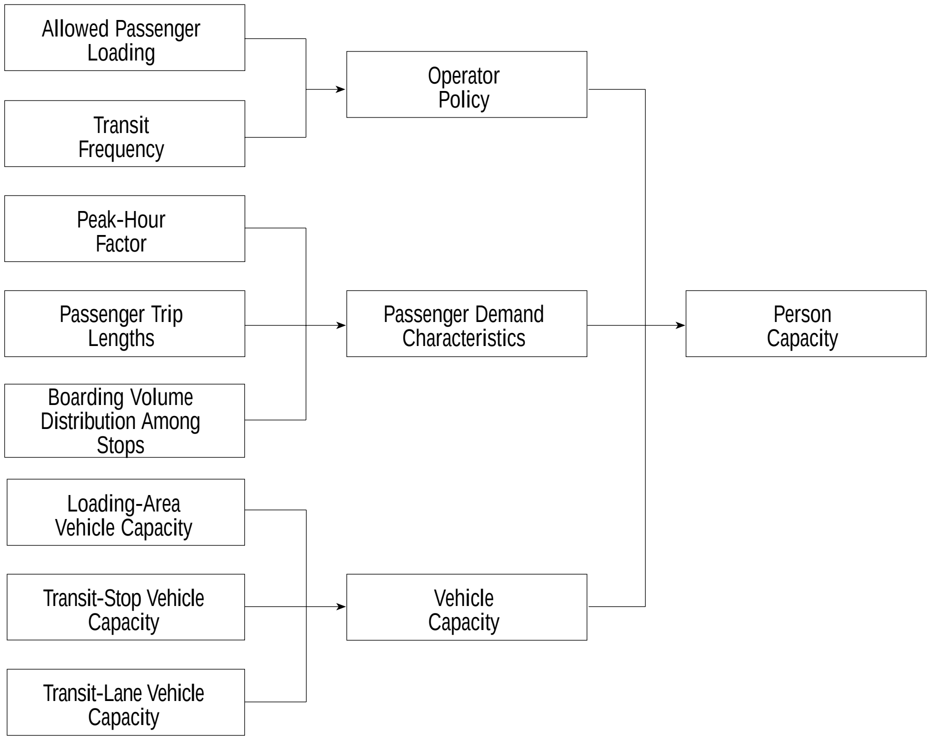
Person capacity is typically stated for the maximum load point

How passenger demand is distributed spatially along a route and how it is distributed over time during the analysis period affects the number of boarding passengers that can be carried. Because of the spatial aspect of passenger demand, person capacity must be stated for a location (typically the maximum load point), not for a route or a street as a whole.

Peak-hour factors reflect fluctuations in passenger demand

Passenger demand fluctuates during the peak hour. The peak-hour factor (PHF) reflects peak demand volumes typically over a 15-min period during the hour. A transit system should provide sufficient capacity to accommodate peak passenger demand. However, since peak demand is not sustained over the entire hour, and since every transit vehicle will not experience the same peak loadings, actual person capacity during the hour will be less than the peak 15-min demand volumes.

EXHIBIT 14-3. INFLUENCES ON TRANSIT PERSON CAPACITY



Passenger trip length

The average passenger trip length affects how many passengers can board a transit vehicle as it travels its route. If trips tend to be long with passengers boarding near the start of the route and alighting near the end, vehicles will not board as many passengers as when passengers board and alight at many locations. However, the total number of passengers onboard at the maximum load points may be similar for each route.

Passenger distribution among transit stops

The distribution of boarding passengers among transit stops affects the dwell time of vehicles at each stop. If passenger boardings are concentrated at one stop, the vehicle capacity of a transit route or bus lane will be lower, since the dwell time at that stop will control the vehicle capacity (and, in turn, the person capacity) of the entire route or lane. Vehicle capacity (and person capacity at the maximum load point) is greater when passenger boarding volumes (and dwell times) are evenly distributed among stops.

Vehicle Capacity

Person capacity is constrained by vehicle capacity

The vehicle capacity of various transit facilities—loading areas, stops and stations, and bus lanes—sets an upper limit to the number of passengers that may use a transit stop or that may be carried past the maximum load point. The relationship between the vehicle capacity of transit facilities and the elements of person capacity is illustrated in Exhibit 14-4.

Dwell Time

Just as dwell times are key to determining capacity, passenger demand volumes and passenger service times are key to determining dwell times. Dwell times may be governed by boarding demand, alighting demand, or total interchanging passenger demand (i.e., at a major transfer point). In all cases, dwell time is proportionate to the boarding and alighting volumes times the service time per passenger. Dwell time also can influence a transit operator’s service costs: if average vehicle speeds can increase by reducing dwell time, and if the cumulative change exceeds the route headway, then fewer vehicles may be required to provide the same service frequency.

EXHIBIT 14-4. CALCULATING TRANSIT PERSON CAPACITY

Transit-Lane Vehicle Capacity	x	Allowed Passenger Loading	x	Peak-Hour Factor	=	Transit-Lane Person Capacity at Maximum Load Point
Route Frequency	x	Allowed Passenger Loading	x	Peak-Hour Factor	=	Transit-Route Person Capacity at Maximum Load Point
Stop/Station Vehicle Capacity	x	Peak 15-min Passenger Interchange Volume per Vehicle	x	Peak-Hour Factor	=	Transit-Stop Person Capacity

Influences on dwell time

There are six main influences on dwell time. Two relate to passenger demand; the others relate to passenger service time:

- Passenger demand and loading. The number of people boarding and alighting through the highest-volume door determines how long it will take to serve all passengers. If standees are present on a transit vehicle as it arrives at a stop, or if all seats are filled as passengers board, service times will be higher than normal because of congestion in the vehicle.
- Stop and station spacing. The fewer the stops along a route, the greater the number of passengers boarding at each stop. A balance must be found between too few stops and too many. Too few stops increase both the distance riders must walk to gain access to transit and the amount of time a vehicle occupies a loading area. Too many stops reduce overall travel speeds due to the time lost in accelerating and decelerating as well as waiting at traffic signals because stops were made.
- Fare payment procedures. The amount of time passengers spend paying fares is a major factor in the total time for passenger boarding. This time can be reduced by minimizing the number of bills and coins required to pay a fare; encouraging the use of prepaid tickets, tokens, passes, or smart cards; using a proof-of-payment fare collection system; or collecting fares before boarding. Besides eliminating the time required for each passenger to pay a fare onboard, proof-of-payment and paid-fare waiting-area collection systems allow an even distribution of boarding passengers among the vehicle doors, rather than concentrating them at a single door.
- Vehicle types. Low-floor buses decrease passenger service time by eliminating the need to ascend and descend steps. This particularly applies to routes frequently used by the elderly, persons with disabilities, or persons with strollers or bulky carry-on items. Wide doors also allow more passengers to board and alight simultaneously.
- On-board circulation. Encouraging people to exit via the rear doors of buses with more than one door decreases passenger congestion at the front door and reduces passenger service times.

Wheelchair and bicycle boarding times need to be considered when calculating dwell time

- Wheelchair and bicycle boarding. Dwell time also can be affected by the time to board and disembark passengers in wheelchairs and for bicyclists to load and unload bicycles onto a bus-mounted bicycle rack.

II. BUS CONCEPTS

TYPES OF SERVICE

Fixed-route, demand-responsive, and route- and point-deviation service

Bus transit service can be either fixed route or demand responsive. Fixed-route service is ideal for large, densely populated urban areas. In less dense areas, which cannot support fixed-route service, demand-responsive transit can be an essential part of transportation for the nondriving population. With this type of service, the passenger calls a dispatcher, who then radios the caller's location to a driver. Generally taxicabs or vans provide this type of door-to-door service.

Demand-responsive service accounts for less than 0.1 percent of U.S. transit passengers. It is used primarily for custom services for senior citizens and persons with disabilities. A variant is route-deviation service. In selected low-density areas, buses operate on fixed routes according to a set schedule. Passengers may ask the driver for a deviation from the fixed route. These deviations usually are limited in distance and number per run. Passengers must telephone or prebook a route deviation beforehand.

Public transportation service in which the transit vehicle arrives at designated transit stops on a prearranged schedule but does not follow a specific route between stops is referred to as point-deviation service. This allows the vehicle to provide curbside service on request.

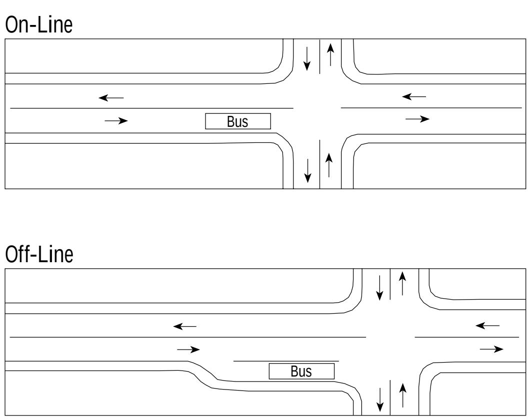
BUS CAPACITY CONCEPTS

Loading Areas

On-line and off-line loading areas defined

A loading area, or bus berth, is a space for buses to stop to pick up and discharge passengers. Bus stops, discussed below, contain one or more loading areas. The most common form of loading area is a linear bus stop along a street curb. In this case, loading areas either can be provided in the travel lane (i.e., on-line), so that following buses cannot pass the stopped bus; or they can be pullouts out of the travel lane (i.e., off-line), so that following buses may pass. Exhibit 14-5 depicts these two types of loading areas.

EXHIBIT 14-5. ON-LINE AND OFF-LINE BUS LOADING AREAS

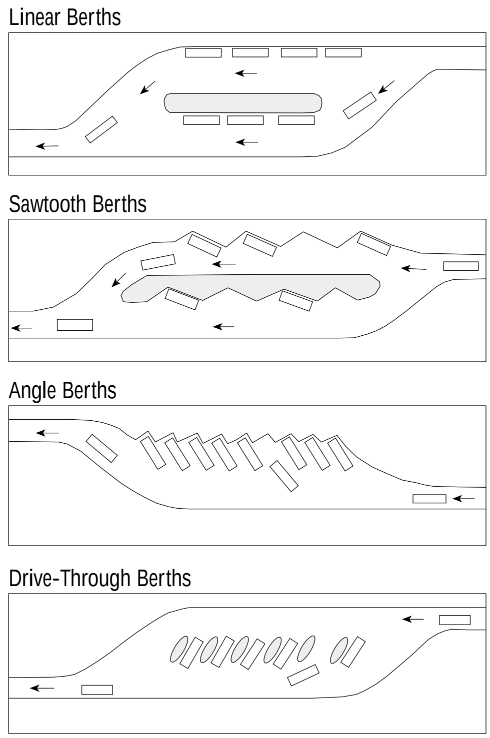


Source: Fitzpatrick et al. (*5*).

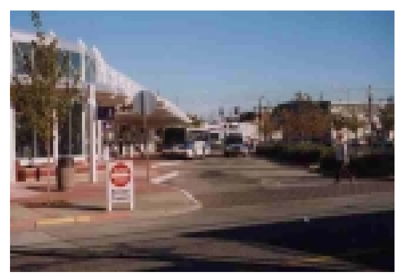
Sawtooth, drive-through, and angle loading-area designs should provide positive protection (such as bollards) to shield pedestrians from errant buses

Loading areas in bus terminals may be linear or may take other forms. Angle berths are limited to one bus per berth and require the buses to back out. Drive-through berths are also feasible and may accommodate multiple vehicles. Shallow sawtooth berths are popular in urban transit centers, because they permit independent movements into and out of each berth. Exhibit 14-6 and Illustration 14-2 show common bus loading-area configurations. The National Transportation Safety Board recommends that transit facility designs incorporating sawtooth berths or other similar types of berths provide a positive separation (such as bollards) along the roadway, to stop an errant bus at parking-area speed from intruding into the pedestrian area (*6*).

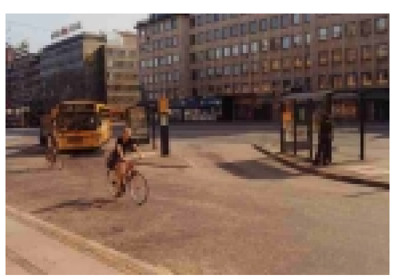
EXHIBIT 14-6. BUS LOADING AREA (BERTH) DESIGNS



Linear (Miami)



Sawtooth (San Diego)



Drive-through (Copenhagen)

Angle (Newark Airport)

ILLUSTRATION 14-2. Bus loading area (berth) examples.

Linear berths are not as efficient as the other types and typically are used when buses occupy a berth for only a short time (for example, at an on-street bus stop). Sawtooth berths allow independent movements by buses into and out of berths and are commonly used at bus transfer centers. Angle berths, which require buses to back out, typically are used when a bus occupies a berth for a long time (for example, at an intercity bus terminal). Drive-through berths allow bus stops to be located in a compact area, and also can allow all buses to wait with their front destination signs facing the direction from which passengers arrive (e.g., from a rail station exit).

Dwell-time variability

The main elements that determine loading area capacity are dwell time, dwell-time variability, and clearance time. Dwell time was discussed earlier. Dwell-time variability recognizes that buses do not stop for the same amount of time at a stop because of fluctuations in passenger demand for buses and routes. The effect of variability in bus dwell times on bus capacity is reflected by the coefficient of variation of dwell times, which is the standard deviation of dwell-time observations divided by the mean dwell time. Dwell-time variability is influenced by the same factors that influence dwell time.

The time required for a bus to start up and travel its own length is fixed; re-entry delay for off-line stops depends on traffic volumes in the curb lane

Once a bus closes its doors and prepares to depart from a stop, there is a period, known as the clearance time, during which the loading area is not available for use by the following bus. Part of this time is fixed, consisting of the time for a bus to start up and travel its own length, clearing the stop. For on-line stops, this is the only component of clearance time. For off-line stops, however, there is another component of clearance time: the time required for a suitable gap in traffic to allow the bus to reenter the traffic stream and accelerate. This reentry delay varies depending on the traffic volume in the curb lane—it increases as the traffic volumes increase. The delay also depends on the platooning effect due to upstream traffic signals. Some states have laws requiring motorists to yield to buses reentering a roadway; motorist compliance can reduce or even eliminate the reentry delay. Many bus operators forgo using off-line stops on busy streets to avoid reentry delay.

Bus Stops

A bus stop is an area where one or more buses load and unload passengers. It consists of one or more loading areas. Bus stop capacity is related to the capacity of the individual loading areas at the stop, loading area design (linear or nonlinear), and the number of loading areas. Off-line bus stops provide greater capacity than on-line stops for loading areas, but in mixed traffic, bus speeds may be reduced if heavy volumes delay the buses exiting a stop. On the other hand, skip-stop operations are possible with off-line stops, but not with on-line stops.

Bus Terminals

Bus stop design for bus terminals must consider passengers and take into account longer loading area occupancies by buses

The design of off-street bus terminals and transfer centers involves additional considerations—not only estimates of passenger service times of buses, but also a clear understanding of how each bus route will operate. Therefore, schedule recovery times, driver relief times, and layovers to meet scheduled departure times become key in establishing loading area requirements and in sizing the facility. In addition, good operating practice suggests that each bus route, or geographically compatible groups of routes, should have a separate loading position clearly distinguished for passengers.

Loading-area space requirements should recognize the specific type of transit operations, fare collection practices, bus door configurations, passenger arrival patterns, amount of baggage, driver layover-recovery times, terminal design, and loading area configuration. They should reflect both scheduled and actual peak-period bus arrivals and departures, since intercity bus services regularly run extra vehicles during the busiest travel periods. Bus routes and service patterns also influence loading area requirements. Under good operating practices a maximum of two distinct routes (i.e., services) share a loading position.

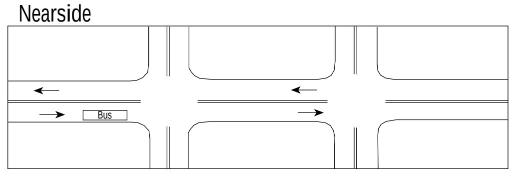
On-Street Bus Stops

The three typical on-street bus stop locations are nearside, farside, and midblock

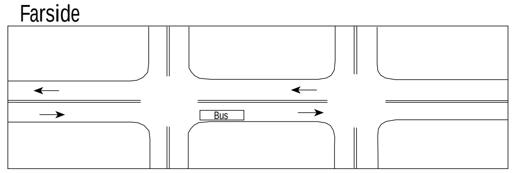
On-street bus stops typically are located curbside in one of three locations: (a) nearside, when the bus stops immediately before an intersection; (b) farside, when the bus stops immediately after an intersection; and (c) midblock, when the bus stops in the middle of a block, between intersections. Under certain circumstances, such as when buses share a stop with streetcars running in the center of the street, or when exclusive bus lanes are located in the center of the street, a bus stop may be located on a boarding island within the street rather than curbside. When boarding islands are used, pedestrian safety and Americans with Disabilities Act (ADA) accessibility issues should be carefully considered. Exhibit 14-7 depicts typical on-street bus stop locations.

EXHIBIT 14-7. ON-STREET BUS STOP LOCATIONS

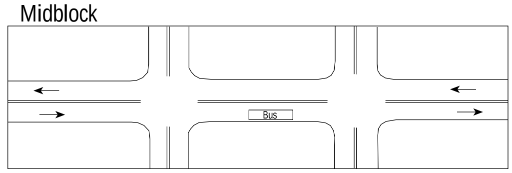
Nearside



Farside



Midblock



Source: Morrall and Bolger (*4*).

The bus stop location influences capacity, particularly when passenger vehicles are allowed to make right turns from the curb lane (as is the case in most situations, except for certain kinds of exclusive bus lanes). Farside stops have the least effect on capacity (when buses are able to use an adjacent lane to avoid right-turn queues), followed by midblock stops, and nearside stops.

Bus Stop Loading-Area Requirements

The key factors influencing the number of loading areas required at a bus stop are the following:

- Bus volumes. The number of buses scheduled to use a bus stop during an hour directly affects the number of buses that may need to use the stop. If loading areas are insufficient, buses will queue behind the stop, decreasing its vehicle capacity. This increases passenger travel times and decreases on-time reliability, negatively affecting quality of service.

Failure rate

- Probability of queue formation. The failure rate—the probability that queues of buses will form at a bus stop—is a design factor that should be considered when sizing a bus stop.

Linear loading areas are less efficient than other loading area designs

- Loading area design. With the exception of the linear model, loading area designs—such as sawtooth and drive through—are 100 percent effective: the bus-stop vehicle capacity equals the number of loading areas times the vehicle capacity of each loading area, since buses are able to maneuver in and out of the loading areas independently of other buses. Linear loading areas, on the other hand, decrease in effectiveness as the number of loading areas increases, because it is not likely that the loading areas will be used equally. Buses entering or leaving a linear loading area also may be blocked and delayed by buses stopped in adjacent loading areas.

• Traffic signal timing. The amount of green signal time provided to a street that buses operate on affects the maximum number of buses that potentially can arrive at a bus stop during an hour. The amount of red signal time influences how much additional time a bus occupies a stop after passenger movements are completed.

Bus Lanes

For the purpose of determining capacity, a bus lane is any lane on a roadway in which buses operate. It may be used exclusively by buses, or it may be shared with other traffic. The vehicle capacity of a bus lane is influenced by the capacity of the critical bus stop located along the lane, typically the stop with the highest volume of passengers. However, the critical stop also might have an insufficient number of loading areas. Bus lane capacity also is influenced by the following:

• Bus lane type. The vehicle capacity procedures identify three types of bus lanes (*7*). Type 1 bus lanes have no use of the adjacent lane; Type 2 bus lanes have partial use of the adjacent lane, which is shared with other traffic; and Type 3 bus lanes provide for exclusive use of two lanes by buses. The curb lane of Type 1 and 2 lanes may or may not be shared with other traffic. When the lane is primarily for mixed traffic, typically there is no formal designation of a bus lane either with signing or with pavement markings. The greater the degree of exclusivity of the bus lane and the greater the number of lanes available for buses to maneuver, the greater the bus lane capacity. Bus lane types are illustrated and discussed in more detail in Chapter 27.

• Skip-stop operation. Bus lane capacity can be increased by dispersing bus stops, so that only a portion of the buses use the bus lane stop at a particular set of stops. This block-skipping pattern allows for a faster trip and reduces the number of buses stopping at each stop, although it also increases the complexity of the bus system for new riders and may increase passenger walking distances to bus stops. Skip-stop operation is discussed further in Chapter 27.

• Platooning. When skip stops are used, gathering buses into platoons at the beginning of the skip-stop section maximizes the efficiency of the operation. Each platoon is assigned a group of stops, and the platooned buses travel as trains past the skip-stop section. The number of buses in each group ideally should equal the number of loading areas at each stop.

• Bus stop location. Farside stops provide the highest bus lane capacity, but other factors, such as conflicts with other vehicles, transfer opportunities, and traffic signal timing, also must be considered when siting bus stops.

Exhibit 14-8 summarizes the main elements that determine the bus vehicle capacity of loading areas, stops, and lanes.

GENERAL CAPACITY RANGES

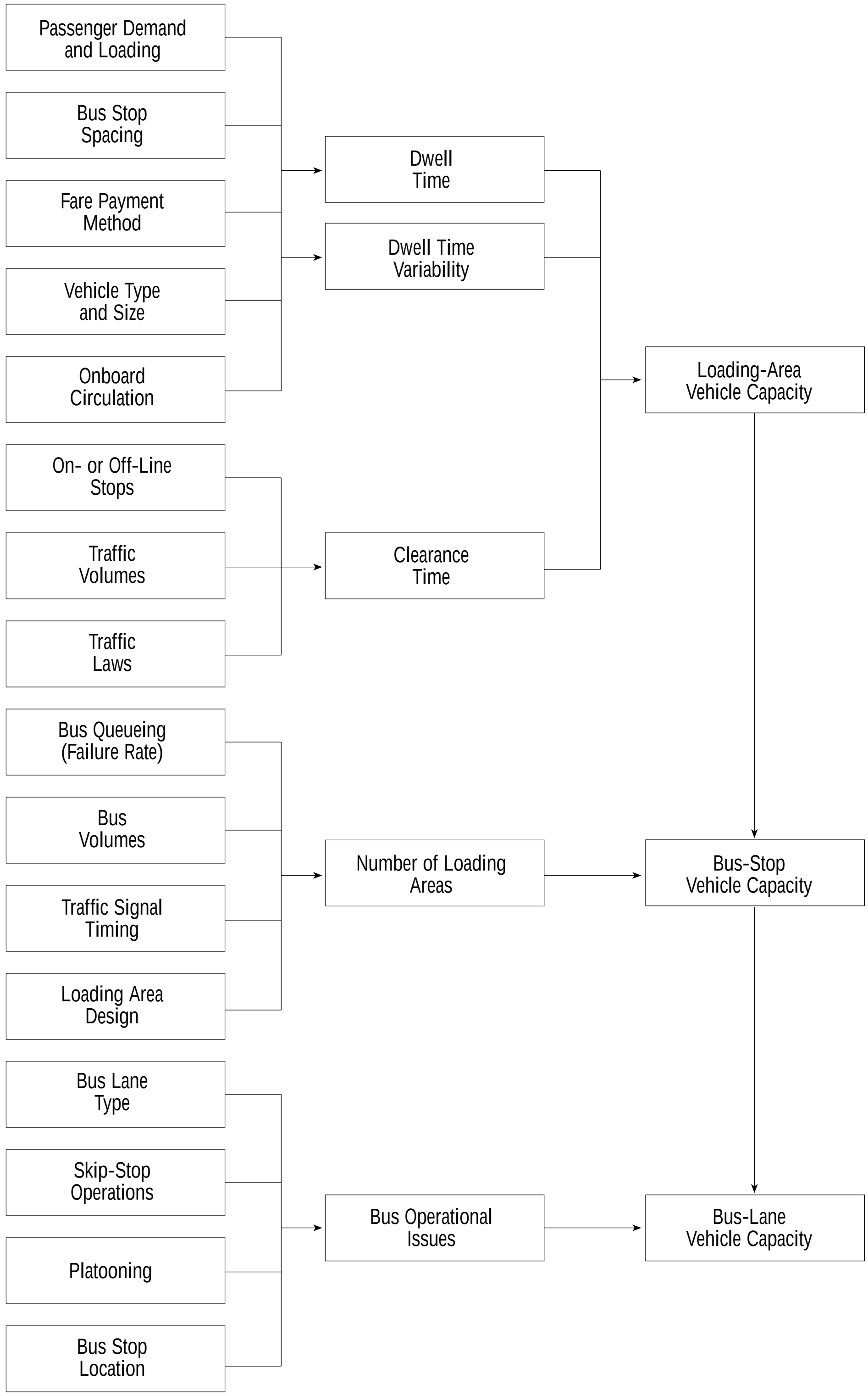
Suggested peak-hour factors for use in calculating person capacity

This section provides estimates of vehicle capacity for loading areas, bus stops, and bus lanes, based on defaults applied to the capacity estimation procedures given in Chapter 27. Vehicle capacities shown are generally maximums based on a 25 percent failure rate (i.e., one in four buses will have to wait for a loading area when arriving at a stop). Schedule reliability concerns may dictate scheduling fewer buses than the maximums shown below. Person capacities may be obtained by multiplying the values given in the exhibits by the maximum allowed passenger load per vehicle (set by policy) times a PHF. The typical PHF for bus routes ranges from 0.60 to 0.95 (*8,9*). In general, capacities are governed by the busiest stop and by the distribution of passengers among stops.

Bus vehicle capacity is commonly calculated at three locations: loading areas (bus berths), bus stops, and bus lanes.

The capacity of each of these locations is influenced by one or more elements (middle column), each of which in turn is influenced by a number of factors (left column).

EXHIBIT 14-8. INFLUENCES ON BUS VEHICLE CAPACITY



Loading Areas

Exhibit 14-9 identifies the estimated bus vehicle capacity at loading areas, based on various values of dwell time and the ratio of green traffic signal time to total cycle length (g/C ratio). Other values not provided in the exhibit may be interpolated.

Maximum vehicle capacity of loading areas. Multiply by the peak 15-min passenger boardings and alightings per vehicle and a PHF to obtain person capacity.

EXHIBIT 14-9. ESTIMATED VEHICLE CAPACITY OF ON-STREET LOADING AREAS
(SEE FOOTNOTE FOR ASSUMED VALUES)

	Capacity (buses/h)	
Dwell Time (s)	g/C = 0.50	g/C = 1.00
15	63	100
30	43	63
45	32	46
60	26	36
75	22	30
90	19	25
105	16	22
120	15	20

Note:
Assumes 15-s clearance time, 25 percent queue probability, and 60 percent coefficient of variation of dwell times.

Bus Stops

Exhibit 14-10 lists estimated vehicle capacities of on-line linear bus stops. Note that increasing the number of loading areas at a linear bus stop has an ever-decreasing effect on capacity as the number of loading areas increases (i.e., doubling the number of loading areas at a linear bus stop does not double capacity). Nonlinear designs are 100 percent efficient, since doubling the number of loading areas also doubles the capacity of the stop.

Vehicle capacity of on-line linear bus stops. Multiply by the maximum allowed passenger load per vehicle and a peak-hour factor to obtain maximum person capacity.

EXHIBIT 14-10. ESTIMATED CAPACITY OF ON-LINE LINEAR BUS STOPS
(SEE FOOTNOTE FOR ASSUMED VALUES)

	Capacity (buses/h)									
	g/C 0.50	g/C 1.00	g/C 0.50	g/C 1.00	g/C 0.50	g/C 1.00	g/C 0.50	g/C 1.00	g/C 0.50	g/C 1.00
	Number of On-Line Linear Loading Areas									
Dwell Time (s)	1		2		3		4		5	
30	43	63	79	117	105	154	113	167	115	170
60	26	36	48	67	64	89	69	96	70	98
90	19	25	35	47	46	62	49	67	50	69
120	15	20	27	36	36	48	39	52	39	53

Note:
Assumes 15-s clearance time, 25 percent queue probability, and 60 percent coefficient of variation of dwell times. To obtain the vehicle capacity of nonlinear on-line bus stops, multiply the single loading area values by the number of loading areas provided.

Busways

If a busway extends into the CBD and has a limited number of stations in the downtown area, the passenger distribution characteristics will be similar to those of a subway or other rail line. A reasonable design assumption is that 50 percent of the maximum load-point volume is served at the heaviest CBD busway station, assuming a minimum of three stops in the downtown area.

Exclusive busways with a limited number of CBD stops have passenger distribution characteristics similar to those of subways

Busway vehicle and person capacities for central areas are given in Exhibit 14-11 for a variety of bus types and service conditions. Data on passenger service times and the effectiveness of linear loading areas are given in Chapter 27. The key assumptions used in the exhibit are:

• Fares are prepaid at busway stations. This allows all doors to be used for loading, which greatly decreases the service time per passenger, since several passengers may board at the same time.

• Fifty percent of the maximum load-point passengers board at the heaviest stop. A PHF of 0.67 is assumed.

• No delays are due to signals (i.e., it is a grade-separated busway).

• The clearance time is 10 s. The design failure rate is 7.5 percent and a 60 percent coefficient of variation is assumed.

• Three linear loading areas are provided at each station.

• The maximum load-point passenger volume is limited to 40 passengers per bus for standard buses and 60 passengers per bus for articulated buses; this provides a seat for all passengers.

This exhibit presents vehicle and person capacities for busways under typical conditions, rather than maximum capacities

EXHIBIT 14-11. EXAMPLES OF CBD BUSWAY CAPACITIES
(SEE FOOTNOTE FOR ASSUMED VALUES)

	Loading Condition							
	A		B		C		D	
Stations: On-Line/Off-Line	On	Off	On	Off	On	Off	On	Off
	Passengers Boarding at Heaviest Station							
Boarding passengers per bus	20	20	20	20	20	20	30	30
Boarding time per passenger (s)	2.0	2.0	1.2	1.2	0.7	0.7	0.5	0.5
Dwell time (s)	40.0	40.0	24.0	24.0	14.0	14.0	15.0	15.0
	Vehicle Capacity							
Loading area capacity (bus/h)	42	42	65	65	100	100	95	95
Effective loading areas	2.45	2.60	2.45	2.60	2.45	2.60	2.45	2.60
Station capacity (bus/h)	103	109	159	169	245	260	233	247
	Passengers/Hour - Maximum Load Point							
Peak-flow rate (15 min * 4)	4120	4360	6360	6760	9800	10,400	13,980	14,820
Average peak hour (with PHF)	2760	2920	4260	4530	6570	6970	9370	9930

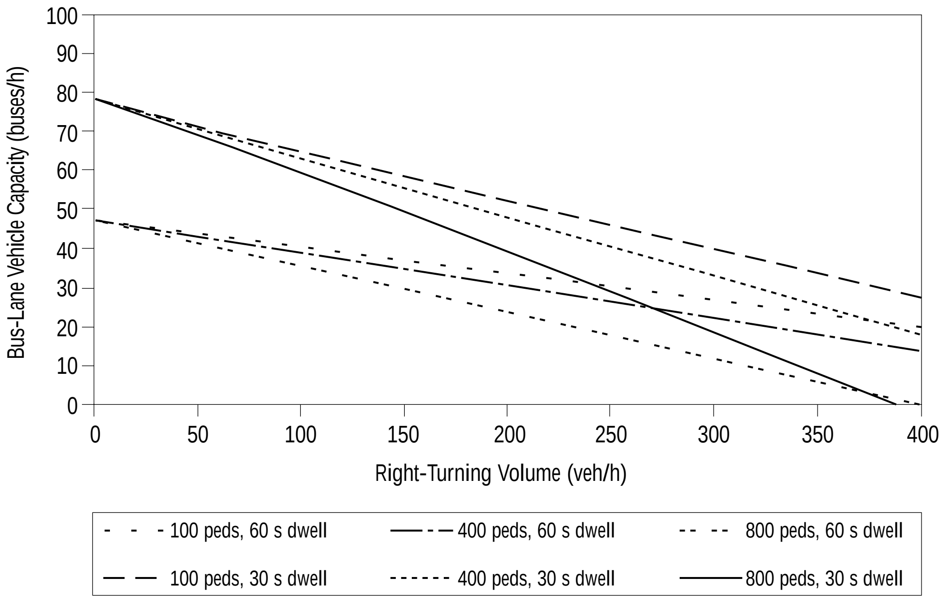
Notes:
Loading Condition A: single-door conventional bus, simultaneously loading and unloading.
Loading Condition B: two-door conventional bus, both doors loading or double-stream doors simultaneously loading and unloading.
Loading Condition C: four-door conventional bus, all double-stream doors loading.
Loading Condition D: six-door articulated bus, all doors loading.
Assumes 10-s clearance time, 7.5 percent failure rate, 60 percent coefficient of variation of dwell times, 3 linear loading areas, g/C = 1.0, PHF = 0.67, 50 percent of passengers board at heaviest CBD station, 40 seats per conventional bus, 60 seats per articulated bus, no standees allowed.

Exclusive Arterial-Street Bus Lanes

Exhibit 14-12 illustrates the effects of dwell time, right-turning volume from the bus lane, and conflicting pedestrian volumes on bus-lane vehicle capacity. It assumes conflicting pedestrian volumes ranging from 100 to 800/h, dwell times of 30 or 60 s, and right-turning volumes of 0 to 400 vehicles, as well as other assumptions, held constant, that are listed in the exhibit. Buses are assumed to stop at every bus stop in the CBD.

It can be seen that as dwell time decreases, bus vehicle capacity increases. Conflicting pedestrian volumes under 200/h have little effect on bus vehicle capacity, but have substantial effects at higher conflicting volumes, especially as right-turning volumes increase. However, when there are no right-turn conflicts, pedestrian volumes have no impact on vehicle capacity, and the lines for a given dwell time converge to a single point. It also can be seen that the lines for a given pedestrian volume converge toward a point at which the right-turn capacity is exceeded and the bus-lane vehicle capacity drops to zero. Between these two extremes, bus vehicle capacity steadily declines as right-turning volumes increase.

EXHIBIT 14-12. EXCLUSIVE BUS-LANE VEHICLE CAPACITY: NON–SKIP-STOP OPERATION
(SEE FOOTNOTE FOR ASSUMED VALUES)



Note:
Assumes 15-s clearance time, 25 percent queue probability, 60 percent coefficient of variation of dwell times, permitted right-turn signal phasing, shared right-turn lane, g/C = 0.5, nearside stops, 2 linear berths, and bus volumes minimal in relation to right-turn volumes (P_{RT} = 1.0).

To compute person capacity, multiply the values shown in the exhibits by the allowed passenger load per bus and a peak-hour factor

Exhibit 14-13 illustrates the same situations with the buses in a two-stop skip-stop operation and the adjacent lane assumed to have a v/c ratio of 0.5. For a given right-turning volume, the corresponding bus-lane vehicle capacity is about 67 percent higher than if skip stops were not used.

Mixed-Traffic Lanes

In mixed traffic, on-line stops may provide greater capacity than off-line stops, depending on traffic volumes and the number of loading areas

Exhibit 14-14 depicts the decline in bus vehicle capacity in mixed traffic when curb-lane volumes increase, as well as the variation in bus vehicle capacity by bus stop location. In mixed traffic, off-line linear stops may provide less bus vehicle capacity than on-line stops with identical dwell times, since the benefits of additional loading areas at off-line stops can be outweighed by the additional delay as buses reenter traffic.

BUS PRIORITY TREATMENTS

Bus Preferential Treatments at Intersections

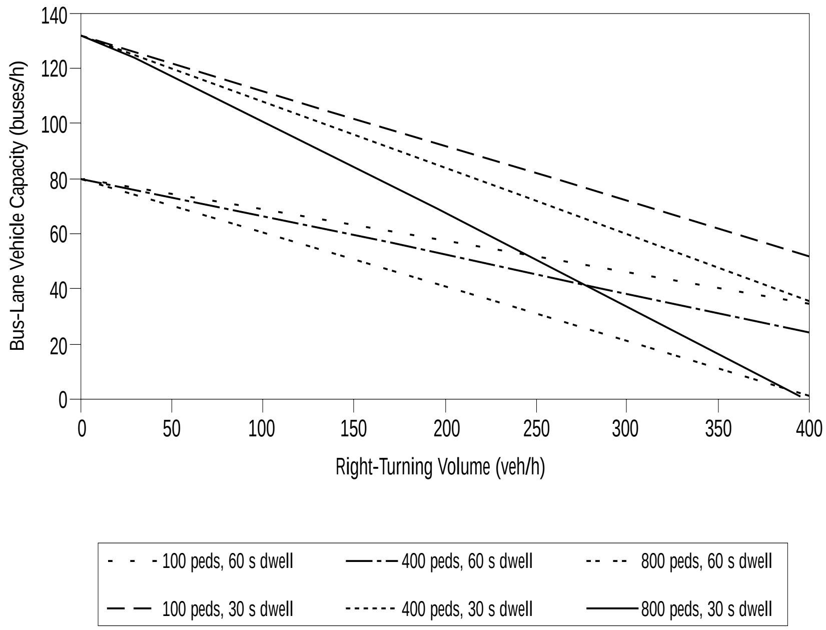
Bus priority treatments provide faster, more reliable bus operations, improving passenger quality of service

When buses operate in mixed traffic, the interference decreases bus speeds and lowers overall bus-vehicle and person capacity. The bus preferential treatments described in this section compensate by removing or reducing sources of delay, increasing bus speeds. When considering bus preferential treatments, the total change in person delay (both for passengers in buses and for motorists) should be taken into account.

To compute maximum person capacity, multiply the values shown by the allowed passenger load per bus and a PHF

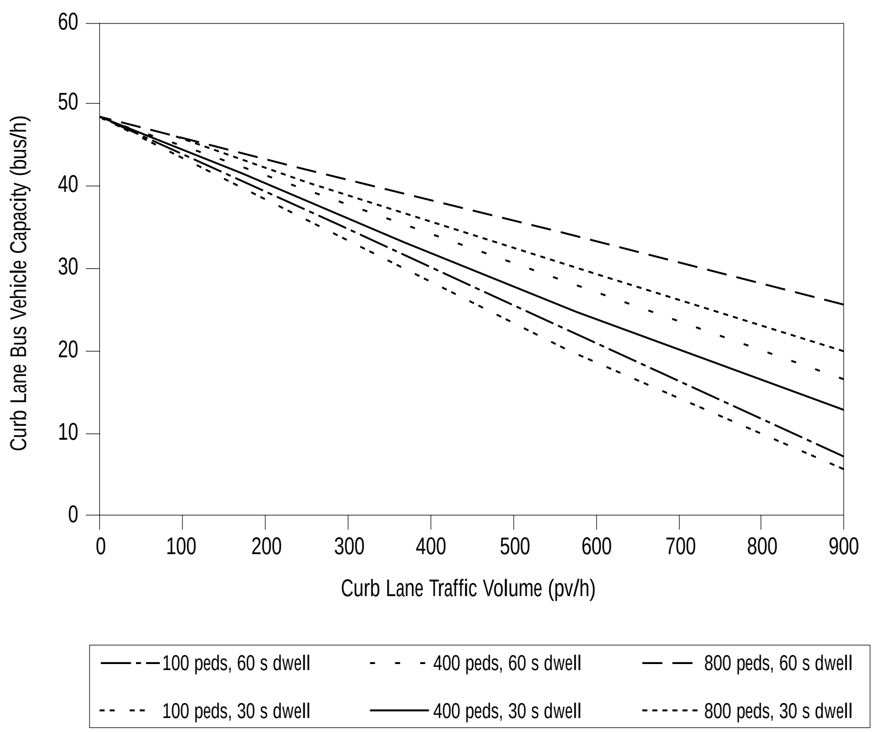
The mixed-traffic bus-capacity procedures are an extension of the exclusive bus-lane capacity procedures developed by the Transit Cooperative Research Program A-7 project. The theoretical basis for mixed-traffic procedures has not been validated in the field.

EXHIBIT 14-13. EXCLUSIVE BUS-LANE VEHICLE CAPACITY: SKIP-STOP OPERATION
(SEE FOOTNOTE FOR ASSUMED VALUES)



Note:
Assumes 15-s clearance time, 25 percent queue probability, 60 percent coefficient of variation of dwell times, permitted right-turn signal phasing, shared right-turn lane, g/C = 0.5, nearside stops, 2 linear berths, v/c = 0.5, and bus volumes minimal in relation to right-turn volumes (P_{RT} = 1.0).

EXHIBIT 14-14. MIXED-TRAFFIC-LANE BUS VEHICLE CAPACITY
(SEE FOOTNOTE FOR ASSUMED VALUES)



Note:
Assumes a Type 1 mixed bus lane, one linear loading area per stop, g/C = 0.5, 30-s dwell time, 25 percent failure rate, and a 60 percent coefficient of variation of dwell times.

Signal Priority

Bus-signal priority measures at signalized intersections include passive systems, which are pretimed treatments adjusted manually to determine the best transit benefit while minimizing the effect on other vehicles, and active systems, which adjust the signal timing after sensing the arrival of a bus. Exhibit 14-15 lists the most common bus-signal priority systems at intersections.

Bus-signal priority measures can be passive (pretimed) or active (operated when a bus is detected)

EXHIBIT 14-15. BUS-SIGNAL PRIORITY SYSTEMS

Treatment	Description
Passive Priority	
Adjust cycle length	Reduce cycle lengths at isolated intersections
Split phases	Apply multiple phases while maintaining original cycle length
Areawide timing plans	Preferential progression for buses through signal offsets
Bypass metered signals	Buses use special reserved lanes, special signal phases, or are rerouted to nonmetered signals
Active Priority[a]	
Phase extension	Increase phase time
Early start	Reduce other phase times
Special phase	Addition of a bus phase
Phase suppression	Skipped nonpriority phases
Preemption (unconditional)	Bus phase begins when all other intervals are satisfied
Preemption (conditional)	Same as above except certain conditions are used to determine when the bus phase should begin

Note:
a. Occurs after bus detection.
Source: Bullard and Nungesser (*10*).

Active priority should be implemented only at intersections operating at less than capacity, so that the changes to signal timing whenever a bus passes through the intersection do not worsen the intersection LOS. Automated systems that do not require bus driver intervention are preferable, since drivers might not always remember to activate the system. When coupled with two-way data communication and automatic vehicle location (AVL) equipment, on-bus signal priority systems can be set to activate signal priority only when a bus is behind schedule (*11*).

Queue Bypass

Queue bypasses allow buses to avoid queues of vehicles (such as those that develop at signalized intersections or freeway ramp meters) by providing a special lane. Queue bypass lanes can be shared with carpools and van pools.

Queue bypasses at freeway ramp meters allow buses to avoid delay

Queue Jump

Queue jumps allow buses to move past long queues of vehicles at signalized intersections by using right-turn lanes or long off-line bus stops. Buses are exempted from any right-turn requirements at the intersection.

Queue jumps allow buses to bypass long queues of vehicles at signalized intersections

A special right-lane signal provides a green indication for a brief time before the green for the adjacent general traffic lanes. The bus then exits the right lane and merges into the lane to the left, ahead of the other traffic still stopped for the signal. Alternatively, the bus can pull into the right-turn lane on a red signal and proceed to a farside off-line bus stop on green, avoiding the delay behind the queue in the regular lanes of the intersection.

Curb extensions allow the bus to stop in the travel lane and provide more room for transit amenities at the bus stop

Curb Extensions

Where streets have curbside parking and high traffic volumes, it may not be desirable for a bus to pull to the curb to stop, because it must then wait for a gap in traffic to pull back into the travel lane. In these situations, the curb can be extended into the parking lane so that buses can stop in the travel lane to pick up and discharge passengers. The additional area curbside can provide a clear area to load and unload wheelchair passengers in compliance with the ADA, to provide a bus shelter where otherwise there would not have been enough space, and to provide more room for passengers waiting for the bus. Curb extensions also can create more on-street parking, as the area before the bus stop, previously used for buses to pull to the curb, now can be used for additional parking. If there are bicycle lanes, they can be routed around the curb extension; but this can introduce potential bicycle-pedestrian conflicts. At intersections, curb extensions benefit pedestrians by reducing the width of street to cross.

Boarding islands allow buses to avoid congestion in the right lane but require careful consideration of pedestrian safety

Boarding Islands

Significant parking activity, stopped delivery vehicles, heavy right-turning traffic volumes, and other interferences often slow traffic in the right lane of a street with multiple lanes in the same direction. In these situations, buses might be able to travel faster in the lane to the left. Boarding islands allow bus stops between travel lanes; buses then can remain in a faster lane without merging to the right before every stop. However, pedestrian safety must be addressed in conjunction with boarding islands.

Other Measures

Other preferential treatments for transit at intersections include the following (*11*):

- Parking restrictions. When high parking turnover interferes with the flow of traffic on a street, restricting parking will improve transit and traffic flow. However, the impacts on adjacent land uses from the loss of on-street parking also must be considered. Parking restrictions sometimes are applied during peak hours, often in conjunction with bus lane operations.
- Bus stop relocation. On streets with good traffic signal progression for passenger vehicles, moving a bus stop from the nearside to the farside of an intersection may allow buses to use the signal timing to their advantage, passing through intersections on a green signal and dwelling on a red signal.
- Turn restriction exemptions. The most direct route for a bus might not be possible because of left-turn restrictions at intersections, particularly if there is no room to develop left-turn lanes. If this restriction is due to traffic congestion, rather than safety, it might be feasible to exempt buses from the restriction without a negative impact on the intersection's operation.
- Bus lanes, busways, and high-occupancy vehicle (HOV) lanes. Where there is a relatively high volume of buses operating on a roadway, coupled with a high degree of bus and general traffic congestion, exclusive bus lanes might be considered, to provide more attractive and reliable bus service. Most bus lanes take the form of reserved lanes on city streets, usually in the same direction as the general traffic flow. In North America, busways and reserved lanes on freeways are mainly in larger cities, usually with a large downtown employment and a heavy peak-hour bus ridership. HOV lanes either on freeways or on urban streets also can provide higher bus speeds.

The net change in person delay is an important consideration before implementing transit priority measures

Person-Delay Considerations

In many cases, providing transit priority involves tradeoffs among the various users of a roadway. A bus queue jump at a traffic signal, for example, provides a time-saving benefit for bus passengers but causes additional delay for motorists, their passengers, bicyclists, and some pedestrians. Any consideration of transit priority measures should include the net change in person delay to all roadway users as a result of the priority treatment. Of course, other factors, such as cost, change in transit quality of service, and local policies encouraging transit use, also should be considered. Exhibit 14-16 summarizes the advantages and disadvantages of the bus preferential treatments presented in this section.

EXHIBIT 14-16. COMPARISON OF BUS PREFERENTIAL TREATMENTS

Treatment	Advantages	Disadvantages
Signal Priority	• Reduces delay • Improves reliability	• Risks interrupting coordinated traffic signal operation • Risks lowering intersection LOS, if intersection is close to capacity • Requires ongoing interjurisdiction coordination • Buses on cross streets may incur added delay greater than the time saved by the favored route
Queue Bypass	• Reduces delay from queues at ramp meters or other locations	• Bus lane must be available and longer than the back of queue
Queue Jump	• Reduces delay to queues at signals • Buses can leapfrog stopped traffic	• Right lane must be available and longer than the back of queue • Right-turn or special transit signal required • Reduces green time available to other intersection traffic • Bus drivers must be alert for the short period of priority green time
Curb Extensions	• Reduces delay due to merging back into traffic • Increases riding comfort because buses don't need to pull in and out of stops • Increases on-street parking by eliminating need for taper associated with bus pullouts • Increases space for bus stop amenities • Reduces pedestrian street crossing distances	• Requires at least two travel lanes in bus direction of travel to avoid blocking traffic while passengers board and alight • Bicycle lanes require special consideration
Boarding Islands	• Increases bus speed by allowing buses to use faster-moving left lane	• Requires at least two travel lanes in bus direction of travel and a significant speed difference between the two lanes • Requires more right-of-way than other treatments • Pedestrian and ADA accessibility, comfort, and safety issues must be carefully considered
Parking Restrictions	• Increases bus and auto speeds by removing delays caused by automobile parking maneuvers	• May significantly impact adjacent land uses (both business and residential) • Requires ongoing enforcement
Bus-Stop Relocation	• Uses existing signal progression to bus' advantage	• May increase walking distance for passengers transferring to a cross-street bus
Turn Restriction Exemption	• Increases bus speed by eliminating need for detours to avoid turn restrictions	• Potentially lowers intersection LOS • Safety issues must be carefully considered
Exclusive Bus Lanes	• Increases bus speed by reducing sources of delay • Improves reliability • Increases transit visibility	• Traffic and parking effects of eliminating a travel or parking lane must be carefully considered • Requires ongoing enforcement

Source: Portland Office of Transportation (*11*).

III. LIGHT-RAIL AND STREETCAR CONCEPTS

This section provides a brief overview of peak-hour light-rail and streetcar transit ridership in the United States and Canada and its implications for passenger capacity. Streetcars operate exclusively on city streets. Light-rail transit (LRT) started as a modification, separating streetcar operation from street traffic to allow higher speeds.

LRT is characterized by versatility of operation—it can operate separated from other traffic below grade, at grade, on an elevated structure, or together with road vehicles on the surface (*12*). More detailed information on rail transit ridership and capacity is available in a variety of other resources (*9,12–19*).

LRT operations differ in station spacing and design, fare structure and collection methods, train length and propulsion, degree of access control, and markets served. Unlike streetcars, travel times between light-rail stations are relatively unaffected by increased passenger volumes or service.

GENERAL CAPACITY RANGES

The capacity of a rail line is determined by station (or stop) capacity or way capacity, whichever is smaller; in most cases, it is station capacity. Capacity depends on car size and station length, allowable standees, and the minimum spacing (or headway) between trains. This minimum headway is a function not only of dwell times at major stations, but also of train length, acceleration and deceleration rates, and train control systems. Exhibit 14-17 illustrates the main factors affecting rail vehicle capacity.

Time-space diagrams can be used to estimate the safe separation or minimum headway between trains. Sometimes theoretical approaches are used. A more common practice is to obtain the minimum spacing between trains based on actual experience, station dwell times, and signal control systems.

The passenger capacity of LRT depends on vehicle size, train length, and headway. However, the achievable LRT capacities also depend on design and policy considerations that reflect specific local constraints of station design, at-grade operations, and type of right-of-way.

If trains operate on-street, capacity estimates can be derived by adapting the equations for bus transit to the differing vehicle sizes, train lengths, and clearance. Capacity estimates for off-street operations may be derived from the approaches for rail transit, described in Chapter 27.

Train length is constrained by the length of a city block

LRT trains usually are limited to a maximum of three cars for on-street operation. Longer trains usually cannot operate on city streets without simultaneously occupying more than the space between adjacent cross streets on short blocks, cannot clear at-grade intersections rapidly, and require long platform lengths at stations.

Minimum headways for light-rail systems depend on train length, platform and car design (high floor versus low floor), fare collection methods (prepayment versus pay on train), wheelchair accessibility, and headway controls (manual versus block signals). Manual operations can accommodate 80 to 100 single-unit cars per track per hour. When trains run under block signal controls, as is common with rapid-transit systems, 120-s headways are possible. Shorter headways can be realized with moving-block signals. Most North American light-rail systems are signaled for a minimum headway of 3 min.

At 120-s headways, a light-rail system operating on mainly reserved right-of-way with three-car trains would have a line capacity of up to 7,500 seated and 15,000 total passengers/h (30 three-car trains at 170 persons/car). Under single-vehicle manual operation at lower speeds, closer headways are feasible. At 60-s headways, single LRT units have a capacity of 4,000 seated and 10,000 total passengers/h (schedule load) (*20*). However, in practice these capacities are not realized because of lower ridership demands. Typical ranges in person capacities are listed in Exhibit 14-18.

Current operating experience in the United States and Canada suggests maximum realizable capacities of 12,000 to 15,000 persons/track/h. However, European experience shows up to 20,000 persons/h.

One of the variables determining capacity is light-rail and streetcar travel time when operating in two directions using a single track. Chapter 27 provides equations to calculate travel time on a single-track section. Exhibit 14-19 lists values for these variables, where local data are not available. The value of the maximum single-track section speed should be the most appropriate speed limit for that section. A 60-km/h speed limit is a suitable value for most protected, grade-separated lines. If the single-track section is on-street, then a speed at or below the vehicle speed limit should be used. If there are signalized intersections, an allowance of half the signal cycle should be added to the travel time for each such intersection, adjusted for any improvements possible from preemption.

EXHIBIT 14-17. INFLUENCES ON RAIL VEHICLE CAPACITY

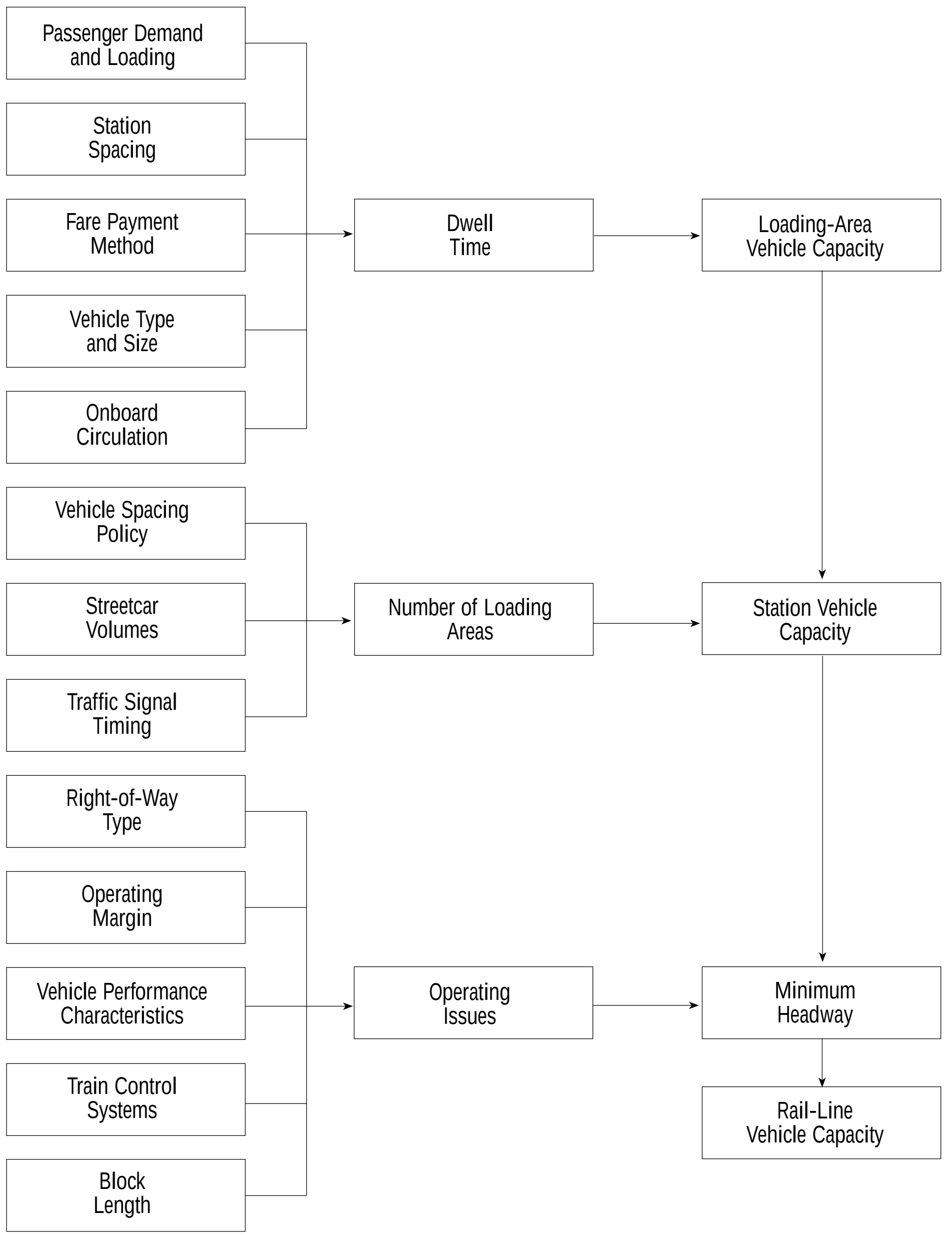


EXHIBIT 14-18. TYPICAL LIGHT-RAIL TRANSIT PERSON CAPACITIES: 30 TRAINS/TRACK/h, 28- TO 30-m ARTICULATED CARS

Cars/	Passengers/Car				
Train	75[a]	100	125	150	175
1	2250	3000	3750	4500	5250
2	4500	6000	7500	9000	10,500
3	6750	9000	11,250	13,500	15,750
4	9000	12,000	15,000	18,000	21,000

Note:
a. All passengers seated.

EXHIBIT 14-19. DEFAULT VALUES FOR SINGLE-TRACK LIGHT-RAIL AND STREETCAR TRAVEL TIME

Term	Default Value
Jerk limiting time	0.5 s
Brake system reaction time	1.5 s
Dwell time	15–25 s
Service braking rate	1.3 m/s^2
Speed margin	1.1–1.2
Operating margin	10–30 s

Source: Parkinson and Fisher (*12*).

RAIL PRIORITY TREATMENTS

Operating variability caused by traffic congestion has been reduced for the recently built on-street light-rail lines that operate in reserved lanes. Some older systems still operate extensively in mixed traffic and are subject to the variability in train throughput caused by a reduced effective green time for trains. Traffic queuing, left turns, and parallel parking can reduce LRT capacity.

Traffic signals can be a major impediment to LRT operation if they are not designed for the needs of LRT. Poor traffic signaling can make train operation slow, unreliable, and unattractive to potential passengers. These problems can be addressed through the use of signal priority or preemption and signal progression. Signal priority allows the light-rail train to extend a green phase or to speed the arrival of the next one. Depending on the frequency of intersections and traffic congestion, this can have a substantial impact on the flow of general traffic. As a result, LRT signal priority in congested areas is often limited in scope to avoid negative effects on other traffic.

Signal progression has supplanted priority or preemption for light-rail trains in many congested downtown areas. This technique gives trains a green window during which they can depart and travel to the next station on successive green signals. The benefits of progression increase with greater station spacing as less accumulated time is spent waiting for the progression to start at each station. The progression frequently is part of the normal traffic-signal phasing and is fully integrated with signaling for automobiles on cross streets. This reduces delays for transit and motorists alike. Station stops are accommodated by the train missing one traffic-signal cycle and then proceeding on the next. Ideally, the cycle length will be slightly longer than a long average dwell, allowing the majority of trains to leave shortly after passenger activity has ended.

IV. QUALITY-OF-SERVICE CONCEPTS

Quality of service reflects the passenger's perception of transit performance. It measures both the availability of transit service and its comfort and convenience. Quality of service depends on the operating decisions made by a transit system, especially concerning where, how often, and for how long service should be provided, and what kind it should be.

Quality of service is a measure of both availability and comfort and convenience

DEFINITIONS

In the North American transit industry, many definitions are not standardized or are specific to a particular system. Caution is needed with the terms quality of service and level of service, which carry a variety of meanings.

This manual uses the following definitions of transit performance measures, transit quality of service, service measures, and LOS:

- Transit performance measure. A quantitative or qualitative factor used to evaluate a particular aspect of transit service.
- Transit quality of service. The overall measured or perceived performance of transit service from the passenger's point of view.
- Transit service measure. A quantitative performance measure that best describes a particular aspect of transit service and represents the passenger's point of view. It is also known as a measure of effectiveness.
- LOS. Six designated ranges of values for a particular service measure, graded from A (best) to F (worst) based on a transit passenger's perception of a particular aspect of transit service.

TRANSIT PERFORMANCE MEASURES

There are as many different transit performance measures as there are transit systems. To understand what quality of service is, it is useful to know what it is not. Exhibit 14-20 illustrates one possible way that transit performance measures can be categorized and shows how quality of service fits into the spectrum of transit performance measures.

Operator point of view

The operator point of view encompasses the measures routinely collected in the United States for the Federal Transit Administration's National Transit Database (formerly Section 15) annual reporting process. Most of these measures relate to economy or productivity. These measures are important to the operator, and indirectly to passengers, because they indicate the amount of service an operator can afford to provide on a route or on the system as a whole. The productivity measures (e.g., ridership) indirectly measure passenger satisfaction with the quality of service.

Vehicle operation

The vehicle operation includes measures of vehicular speed and delay routinely calculated for streets and highways using the procedures given in this manual. This also includes measures of facility capacity in terms of the number of transit vehicles that can be accommodated.

Passenger point of view

The passenger point of view, or quality of service, directly measures passengers' perception of the availability, comfort, and convenience of transit. There are several possible performance measures, but availability and comfort and convenience are most appropriate for transit. LOS ranges developed for these and other service measures are presented in Chapter 27.

QUALITY-OF-SERVICE FRAMEWORK

Transit Trip Decision Making

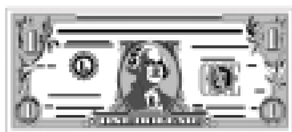
Urban transport involves many individual decisions. Some decisions occur infrequently, such as planning the commute to a new job, or locating a home outside an area with transit service, or purchasing a second automobile. Some decisions, however, are made for every trip, through a two-step process illustrated in Exhibit 14-21 and Exhibit 14-22.

Transit performance measures apply to the operator, passenger, or vehicle

EXHIBIT 14-20. TRANSIT PERFORMANCE MEASURE CATEGORIES AND EXAMPLES

Transit Performance Measures

- Operator Point of View



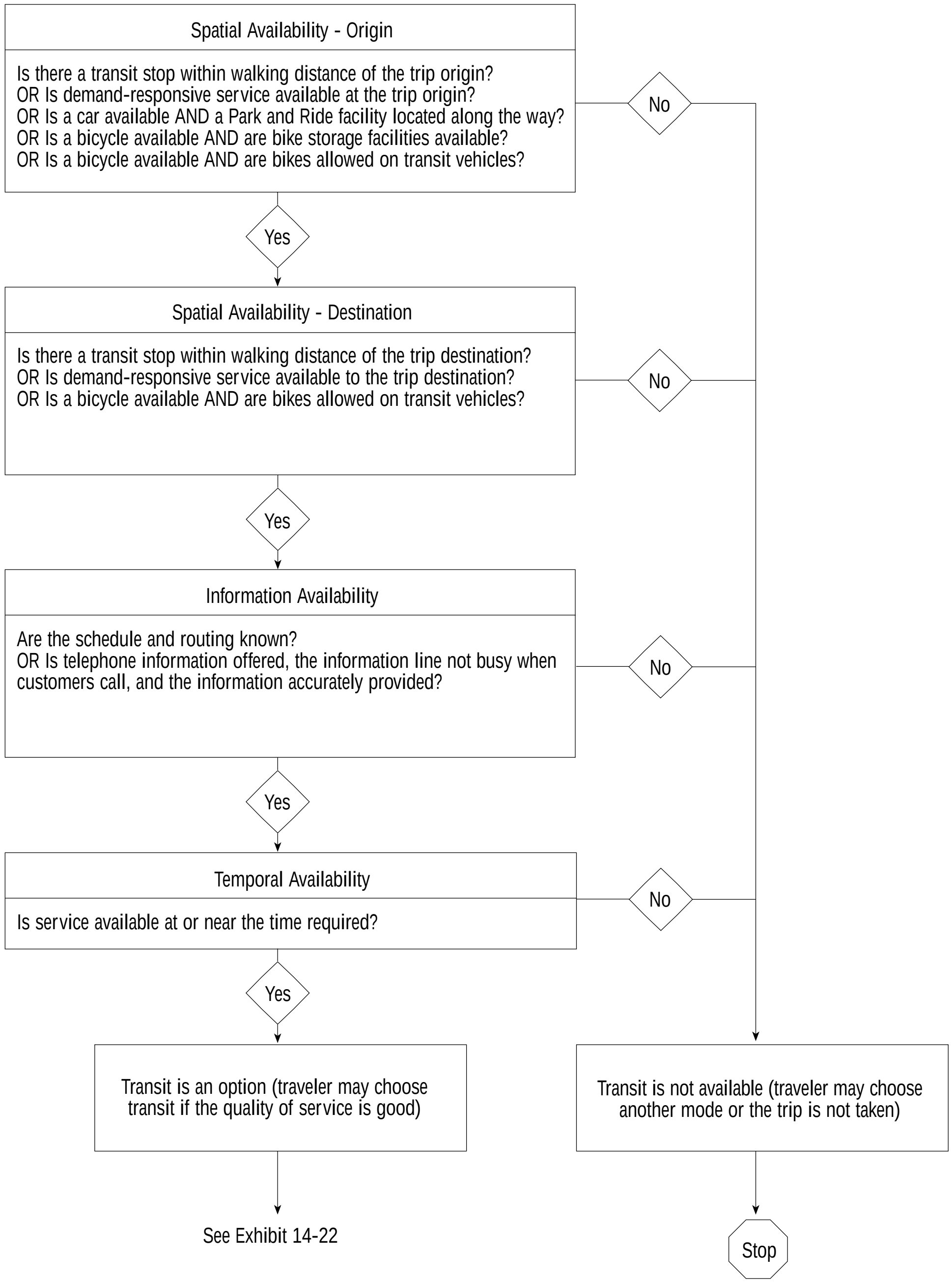
  - Service Offered/Utilization
    - Annual ridership
    - Vehicles operated in maximum service
  - Economics
    - Passenger trips/revenue km
    - Passenger km/revenue hour
    - Vehicle operating expense/revenue km
- Passenger Point of View (Quality of Service)

  - Availability
    - Service frequency
    - Hours of service
    - Sidewalk condition
    - Park and Ride spacing
  - Convenience
    - Passenger loading
    - Reliability
    - Amenities
    - Safety
- Vehicle Operation

  - Vehicular Capacity
    - Bus berth capacity
    - Bus lane capacity
    - Rail line capacity
  - Speed/Delay
    - Average travel speed
    - Average intersection delay per vehicle

Quality of service reflects the passenger point of view. Levels of service are developed for some of these important passenger performance measures.

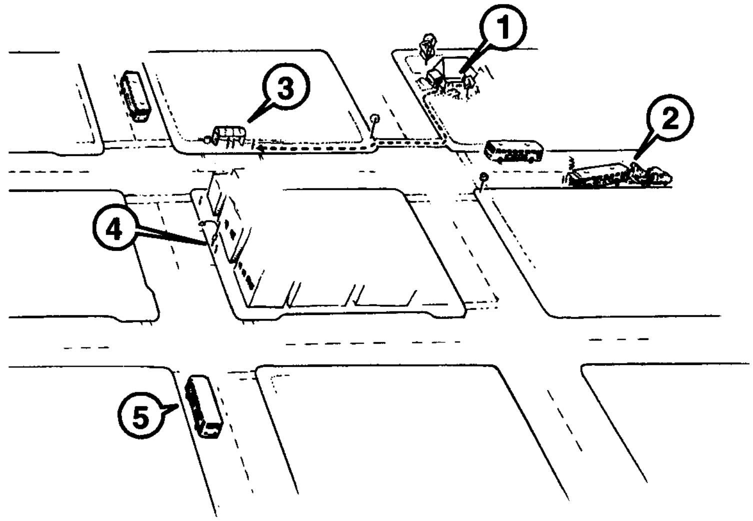
EXHIBIT 14-21. TRANSIT TRIP DECISION MAKING: TRANSIT AVAILABILITY



Is transit service available to a potential passenger?

If transit service is available, will a potential passenger find it convenient?

EXHIBIT 14-22. TRANSIT TRIP DECISION MAKING: TRANSIT CONVENIENCE



1. How long is the walk? Are there sidewalks and pedestrian signals?
2. Is the service reliable?
3. How long is the wait? Is there a shelter at the stop?
4. Are there security concerns—walking, waiting, or riding?
5. How crowded is the vehicle? Are the vehicles and shelters clean?

- How much will the trip cost?
- How many transfers are required?
- How long will the total trip take? How long would it take with other modes?

The first step is to decide whether or not transit is a possibility—that is, to assess the availability of transit service. As Exhibit 14-21 indicates, there are several factors that enter into this determination. If any factor is not met, transit is not viable and the traveler must either use another mode or not make the trip. However, transit becomes an option if service is available at the trip origin and destination (or the traveler can use another mode to get to and from transit); if information is available on where, when, and how service is provided; and if service is provided at or near the time the trip needs to be made.

In the second step, the decision maker weighs the comfort and convenience of transit service against competing modes, as depicted in Exhibit 14-22. These questions do not necessitate an all-or-nothing outcome. Individuals apply differing values to each factor, and each person weighs the factors differently. Regular transit users familiar with the service tend to perceive transit more favorably than nonusers. In the end, the choice depends on the availability of other modes and how the quality of transit service compares.

Quality-of-Service Factors

Service Coverage

If transit service is located too far from a potential passenger, it may not be an option

Whether or not transit service is provided near a person's origin and destination is key in use of transit. Ideally, transit service is provided within a reasonable walking distance of the origin and destination, or demand-responsive service is available. The reasonableness of the walking distance varies from source to source and depends on the situation. For example, people will walk farther to rail stations than to bus routes and the elderly will not walk as far as younger adults. As discussed later, potential barriers, such as wide or busy streets, hills, or the absence of pedestrian facilities, also play an important role. In general, 400 m or 5 min of walk time is the limit for a bus route’s typical service area; for a rail transit station, these figures can double (*21*).

If transit service is not provided near the origin, other options include driving to a park-and-ride lot or riding a bicycle to transit. Both of these options require that the transit operator provide additional facilities, such as parking lots, bicycle storage facilities, and bicycle racks.

Driving or biking to transit may be an option

However, if transit service is not provided near the destination, the choices are more limited. A bicycle might be carried in a bicycle rack, but a customer must have some degree of confidence that space will be available in the bike rack when the bus arrives. A small number of systems allow bicycles onboard transit vehicles (typically rail), but often not during peak commute hours or in the peak commute direction.

Service coverage must consider both ends of a trip

Pedestrian Environment

Even if a transit stop is located within a reasonable walking distance of an origin and destination, the walking environment may not be amenable. Lack of sidewalks or poorly maintained sidewalks, lack of street lighting, and steep terrain all discourage pedestrian travel. Wide or busy streets without signalized crosswalks at regular intervals, or without pedestrian refuges in the median, also discourage pedestrian travel. A lack of pedestrian refuges poses difficulties, too, for transit operators providing service on urban streets.

Even if transit service is theoretically located within walking distance of both origin and destination, the areas around the transit stops must provide a comfortable walking environment for transit to be considered available

Passengers with disabilities must have sidewalk facilities, curb cuts, and bus-stop loading areas that comply with ADA standards for the entire distance between their origin and a transit stop and between their destination and a transit stop, to have access to fixed-route transit. Without these, passengers with disabilities must rely on paratransit service, which generally offers fewer choices in travel times, and usually costs substantially more to provide.

Scheduling

How often and when transit service is provided are important factors in the decision to use transit. The more frequent the service, the shorter the wait when a bus or train is missed or when the exact schedule is not known, and the greater the flexibility customers will have in selecting travel times. The number of hours during the day when service is provided is also important. It does not matter whether a transit stop is located within walking distance if service is not provided at the desired time of travel; transit then cannot be an option.

Transit service must be available near the time of a trip or it cannot be an option

Amenities

The facilities provided at transit stops and stations and on transit vehicles help make transit more comfortable and convenient. Typical amenities include the following (*5*):

- Benches, so that passengers can sit while waiting;
- Shelters to protect from wind, rain, snow, and sun;
- Informational signage, identifying the routes, their destinations, and scheduled arrivals;
- Trash receptacles for litter;
- Telephones, so that passengers can make personal calls while waiting or emergency calls when necessary;
- Vending facilities, from newspaper racks at commuter bus stops to manned newsstands, flower stands, food carts, transit ticket and pass sales, and similar facilities at rail stations and bus transfer centers; and
- Air conditioned vehicles, to provide a comfortable ride during hot and humid weather.

Transit stop amenities make transit service more comfortable and convenient

The kinds of amenities provided are generally related to the number of boarding passengers at a stop

Transit operators usually relate the kinds of amenities at a stop to the number of daily riders boarding there. Research has provided guidelines for installing transit amenities (*5*). These amenities and their space requirements should be considered when determining the size of passenger waiting areas at transit stops.

Transit Information

Riders need to know where and when transit service is available and how to use it

Potential riders need to know where and when transit service is available before they can begin using the service. Regular riders also should be informed about service changes that affect them. This information can be provided by a variety of means:

- Printed maps, schedules, and brochures. Passengers can pick these up on transit vehicles, at transit facilities, and at local businesses.
- Posted information on vehicles and at transit facilities. As transit systems adopt AVL systems, they can display schedule information onboard buses, at bus stops, and at bus terminals.
- Telephone. Information should be available by phone at the convenience of potential passengers (including weekends and evenings).
- Personal computers. Transit information can be posted on the Internet, and users can subscribe to e-mail lists that automatically send out service changes and other announcements.

Transfers

Transfers can make service more efficient for operators but less convenient for passengers

Requiring transfers between routes adds to a passenger's total trip time; this can be minimized with timed transfers. A missed transfer also can increase the length of a transit trip. Required transfers increase the complexity of a transit trip for a first-time passenger. Transfer surcharges also inhibit ridership.

Total Trip Time

A longer trip by transit than by automobile may be seen by passengers as being less convenient. This may be mitigated if the onboard transit time can be used productively.

Total trip time includes the travel time from the origin to a transit stop, waiting time for a transit vehicle, travel time onboard a vehicle, travel time from transit to the destination, and any time required for transfers between routes during the trip. In general, both the absolute travel time and the travel time in relation to competing modes will factor in a traveler's decision about transit. However, the apparent inconvenience of a longer transit trip can be mitigated if the passenger can use the time onboard productively—for example, reading, preparing or reviewing work, or even catching up on sleep.

Total trip time is influenced by several factors, including the route spacing (affecting the walking distance to transit), the service frequency (affecting the waiting time), the frequency of stops, traffic congestion, signal timing, and the fare collection system (affecting time onboard).

Cost

Potential passengers weigh the cost and value of using transit against the out-of-pocket costs and value of using other modes. Out-of-pocket transit costs consist of the fare for each trip or the cost of a monthly pass. Out-of-pocket automobile costs, in contrast, only include road and bridge tolls and parking charges, because other automobile costs—such as fuel, maintenance, insurance, taxes, and the automobile's purchase price—generally are not part of the consideration for a particular trip. Thus, if a person does not have to pay a toll and parking is free, transit may appear less desirable because driving incurs no immediate out-of-pocket costs.

Safety and Security

Passengers' perceptions of safety must be considered in addition to actual conditions

Riders' perceptions—as well as the actual conditions—of the safety and security of transit enter into the mode-choice decision. Riders consider not only personal safety in relation to potential transit crime and vehicular crashes, but also such personal irritants as unruly passengers or someone else's loud radio. Security can be improved by placing stops in well-lit areas with public telephones available for emergency calls. Transit systems use a variety of methods to enhance security on transit vehicles, including uniformed and plainclothes police officers, community volunteer programs, two-way radios and silent alarms for emergency communication, and video cameras.

Passenger Loads

The availability of seating on a transit vehicle is important for longer trips

Transit is less attractive when passengers must stand for long periods of time, especially in crowds. Crowded vehicles also slow down transit operation, adding time for passengers to get on and off. Most transit agencies assess passenger crowding based on the occupancy relative to the number of seats, expressed as a load factor. A factor of 1.0 means that all seats are occupied. The importance of vehicle loading varies by the type of service. In general, transit provides load factors at or below 1.0 for long-distance commuting and high-speed, mixed-traffic operations. Inner-city service may approach a load factor of 2.0 or more, but other services will be between 1.0 and 2.0. Because the number of seats varies among otherwise identical rail vehicles operated by different transit systems, rail capacity calculations apply passengers per unit of vehicle length more often than load factors.

Appearance and Comfort

Having clean, graffiti-free transit stops, stations, and vehicles improves transit's image, even among nonriders. Some transit systems have established specific standards for transit facility appearance and cleanliness and also have established inspection programs (*22,23*). Passengers are interested in ride comfort, which includes seat comfort, temperature control, and minimizing the amount of vehicle acceleration and deceleration.

Reliability

Reliability includes both on-time performance and the consistency of headways between transit vehicles

Reliability affects the amount of time passengers must wait at a transit stop, as well as the consistency of a passenger's arrival time at a destination from day to day. Reliability encompasses on-time performance as well as the regularity of headways between successive transit vehicles. Uneven headways result in uneven passenger loadings, so that a transit vehicle arriving late picks up not only its regular passengers but others who have arrived early for the following vehicle. As a result, the vehicle falls further and further behind schedule. In contrast, the vehicles following will have lighter-than-normal passenger loads and will tend to run ahead of schedule.

Reliability is influenced by traffic conditions (in on-street, mixed-traffic operations), staff availability and vehicle maintenance (reflecting whether a vehicle can leave the yard or is likely to break down on the road), and by how well vehicle operators adhere to schedules.

Framework

Transit quality-of-service measures are divided into two main categories: availability, and comfort and convenience. According to the measures addressing spatial and temporal availability, if transit is located too far away or if it does not run at the times it is needed, a potential user would not consider the transit service available, and therefore the quality of service would be poor. However, if transit service is available, the quality measures to evaluate user perceptions of comfort and convenience can be applied.

The different elements of a transit system require different performance measures:

- Transit stops. Measures should address transit availability and convenience at a single location. The performance measures in this category will vary from one location to another, since they depend on passenger volumes, scheduling, routing, and stop and station design.
- Route segments. Measures should address availability and convenience along a portion of a route, which can range from two stops to the entire length. These measures will tend to stay the same for the length of a route segment, regardless of conditions at an individual stop.
- Systems. Measures should describe availability and convenience for more than one route in a specified area (e.g., a district, city, or metropolitan area) or for a specified type of service (e.g., fixed route vs. demand responsive). System measures also can address door-to-door travel.

Combining the two performance measure categories with the three transit system elements produces the matrix shown in Exhibit 14-23.

EXHIBIT 14-23. TRANSIT QUALITY-OF-SERVICE FRAMEWORK

Category	Service & Performance Measures		
	Transit Stop	Route Segment	System
Availability	• Frequency[a] • Accessibility • Passenger loads	• Hours of service[a] • Accessibility	• Service coverage • % person-minutes served
Comfort and Convenience	• Passenger loads[a] • Amenities • Reliability	• Reliability[a] • Travel speed • Transit/auto travel time	• Transit/auto travel time • Travel time • Safety

Note:
a. Service measure which defines the corresponding LOS in Chapter 27.

Some measures appear in more than one cell of the table, but only one service measure is assigned to each cell, as best representing the passenger's point of view of availability or convenience. In total, there are four transit service measures: frequency, hours of service, passenger loads, and reliability.

Availability

Transit Stops

Frequency as service measure

The spatial aspect of transit availability at a transit stop is a given. During a typical hour-long analysis period, the hours of service are also a given. Therefore, frequency is the service measure for this category.

Although not easy to quantify, transit stop accessibility by foot, bicycle, or automobile is also an important measure of availability; moreover, persons with disabilities require special consideration. Passenger loads determine whether there is room for additional passengers to board, another aspect of transit availability.

Route Segments

Hours of service as service measure

Of the three primary measures of transit availability as shown in Exhibit 14-23—frequency, hours of service, and service coverage—frequency is used for transit stops, and service coverage is a given, since the route exists. Therefore, hours of service become the service measure for route segments. This is appropriate, since more than one route, each operating with different frequencies and travel times, can serve the same origins and destinations. In these cases, the focus is on the total span of time during which a given pair of origins and destinations can be accessed.

As with transit stops, accessibility to transit routes by foot, bicycle, automobile, and wheelchair is important. Because pedestrian and bicycle access can vary significantly from one stop to the next, access by these modes is better addressed on a stop-by-stop basis. In contrast, in the same amount of time it takes to walk or bike to a stop, motorists can choose among several stops to drive to, park, and board transit. As long as one of these stops meets the needs, the motorist has access to transit. The vehicle equipment used along a route helps determine whether or not fixed-route transit service is available to persons with disabilities. All new U.S. transit buses must meet ADA requirements, but older buses in a fleet might not.

System

Service coverage as service measure

System availability measures relate to how many people have access to transit and how often. Service coverage within a transit area that has a population or job density to support at least hourly bus service (equivalent to a service frequency LOS E) is chosen as the service measure. Service coverage determines how many people within the service area have access to transit. Once the areas with service have been identified, frequency and hours of service can be used to determine the amount of service within smaller areas. The combination of frequency, hours of service, and service coverage together provide a reasonable planning-level assessment of the availability of transit service, requiring a minimum of data collection and analysis.

Comfort and Convenience

Transit Stops

Passenger loads as service measure

Whether or not one can find a seat on a transit vehicle is an important measure of transit comfort. Passenger loads, the selected service measure, also influence boarding and alighting times, which in turn affect total dwell time and the capacity of transit routes.

The amenities provided at transit stops are another aspect of transit comfort but are not a service measure because they depend on the daily boarding volumes at a given stop. Achieving better levels of service would require facilities that might not be justified economically. Reliability is a measure of convenience at a transit stop but also applies to a transit route and will tend to have consistent values for a series of stops along a route segment.

Route Segments

Reliability as service measure

Reliability is used as the service measure for route segments because it not only measures an aspect of service quality important to users, whether or not they get to their destination on time, but also affects other service measures. If transit vehicles arrive in a bunch, or not at all, the effective service frequency is reduced. Vehicles arriving late also have higher passenger loadings, since they pick up not only their regular passengers but others who have arrived early for the next vehicle.

Other measures of transit convenience on a route segment are the travel time difference between transit and automobile (used as the system service measure) and travel speed, both of which relate to the time it takes to make a trip by transit. Travel speed is also important to transit operators. For example, if bus speeds can increase sufficiently along a higher-frequency route to produce a time savings of one headway, the number of buses required to operate the route can decrease, along with the operating costs.

System

The travel time difference between transit and automobile (the absolute difference in travel time from origin to destination by automobile and by transit) is an important consideration in a passenger’s decision to use transit. Systemwide, this measure can be calculated by sampling locations and trip purposes within the analysis area, or by using a transportation planning model that can calculate trip times for all combinations of origins and destinations by transit and by automobile, for a variety of trip purposes.

An alternative performance measure is travel time, useful for indicating when higher-speed service (such as limited-stop or express service) should be considered between two locations. Since travel time varies with the size of a community and the amount of traffic congestion (for transit modes operating in mixed traffic), travel time is not suitable as a service measure without defining different categories of city sizes. Safety, in terms of both accident and crime rates, affects the image of the entire transit system and is another systemwide comfort and convenience measure.

Chapter 27 presents specific threshold levels and applications for the service measures related to transit facilities (transit stops and route segments). Chapters 29 and 30 describe applications for service measures related to transit systems. Specific threshold levels for system-related transit service measures are found in the *Transit Capacity and Quality of Service Manual* (*1*).

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