TRANSIT CAPACITY

TRANSIT CAPACITY

- From a capacity standpoint, there are some basic differences between t and the automobile. For example, while roadway capacity is generally available 24 hours a day, seven days a week, transit capacity and availability depends upon the operating policy of the transit agency (e.g., number of vehicles. hours of operation, etc.). In addition, **transit capacity** deals with **the movement both people and vehicles.** This means that, for transit, we have to deal with vehicle capacity as well as with person capacity.

Vehicle capacity

refers to the **number of transit units** (buses or trains) that can be served by a given transit facility. Typically, vehicle capacity is defined for three locations: **(1) loading areas or berths. (2) transit stop and stations. and (3) bus lanes and transit routes.** As is discussed later, starting: with the loading areas, each of these locations directly affects the next location. The vehicle capacity of a transit station, for example. is a direct far of the vehicle capacities of the loading areas of that station. In addition the capacity of a transit route is controlled by the capacity of the critical stops along that route. One of the most important factors affecting vehicle capacity is the vehicle's dwell time, which refers to the time required to serve passengers plus the time required to open and close the doors of the transit vehicle

Person capacity

- refers to the **number of people** that can be carried past a particular location during a given period of time, under specified **operating conditions** and without unreasonable delay, hazard. or restriction. Person capacity is typically defined **for transit stops and stations**. as well as for the maximum load point along a transit route or a bus lane. The following three basic factors control person capacity:

Person capacity

1. **Operator policy:** The transit agency's policy has a direct impact on transit person capacity. For example, the agency's policy regarding whether standing passengers are allowed or not would directly impact the number of passengers that a given transit vehicle can carry

Person capacity

2. **Passenger demand characteristics:** The spatial and temporal distribution of passenger demand directly impacts the number of boarding passengers that can be carried. Because of the spatial distribution of passenger demand, passenger capacity is typically defined for the maximum load point along a transit route, and not for the route as a whole. In addition, a transit system should be designed to provide for adequate capacity during peak demand periods. In analysis, this is typically accounted for using the PHF.

Person capacity

3. **Vehicle capacity:** This also has a direct impact on the passenger capacity, since it establishes an upper limit to the number of passengers that can use a transit stop or that can be carried past the maximum load point.

TRANSIT CAPACITY

- The following sections will briefly describe the analysis procedures that can be used to determine the capacity (both vehicle as well as person capacity) and level of service for transit. While there are several transit modes (for example, buses, streetcars, light rail, rapid rail, and automated guideways), these different modes from a capacity analysis standpoint can be broadly categorized into: (1) **buses**; (2) **on-street rail modes**, such as streetcars and light rail; and (3) **offstreet or grade-separated** rail modes. The following sections will describe the capacity analysis procedures for these different groups.

TRANSIT CAPACITY

- The following sections will briefly describe the analysis procedures that can be used to determine the capacity (both vehicle as well as person capacity) and level of service for transit. While there are several transit modes (for example, buses, streetcars, light rail, rapid rail, and automated guideways), these different modes from a capacity analysis standpoint can be broadly categorized into: (1) **buses**; (2) **on-street rail modes**, such as streetcars and light rail; and (3) **offstreet or grade-separated** rail modes. The following sections will describe the capacity analysis procedures for these different groups.

TRANSIT CAPACITY Concepts

- Vehicle capacity for transit is typically defined for three locations:
- **(1) loading areas or berths,**
- **(2) transit stops and terminals, and**
- **(3) bus lanes or rail segments**. Each of these three locations is briefly described next.

TRANSIT CAPACITY Concepts

- **Loading Areas**
- For buses, a loading area (sometimes called bus berth) refers to the space dedicated for the bus to stop in order to load and unload passengers. A bus stop, as will be discussed later, consists of one or more loading areas. Bus stops along street curbs are the most common type of loading areas, and these could either be in the travel lane itself (i.e., on-line) or in the form of a pullout out of the travel lane (i.e., off-line).

TRANSIT CAPACITY Concepts

(4) the transit vehicle type (for low-floor buses, for example, the time needed for passengers boarding and alighting is reduced and particularly for the elderly and persons with disability);

(5) on-board passenger circulation and wheelchair and bicycle boarding.

required to open and close the doors of the

(3) the fare payment procedures (i.e., whether payment is by coins, tokens, passes, or smart cards);

Dwell-time variability accounts

- for the fact that the dwell time at a given stop is likely to vary depending upon the actual passenger demand present in analysis, this variability is accounted for using the coefficient of variation of dwell time. This is computed by **dividing the standard deviation of the observed dwell times at the stop by the dwell time mean value.**

Clearance time

- is the time that elapses after the moment the vehicle **closes its doors until it clears the stop**. During that time, the loading area is not available for use by another vehicle. For on-line bus stops and rail transit station the clearance time is equal to the time needed by the vehicle to start up and travel its own length, thus clearing the stop. For off-line bus facilities, an additional component is needed that is equal to the time required for the stopped bus to find an adequate gap in the adjacent lane's traffic stream, allowing it to reenter traffic.

Stations and Terminals

- These are the second locations where vehicle capacity is determined and, for buses, they typically consist of one or more loading areas. Given this, the capacity of a bus stop is directly related to the capacities of the individual loading areas making up the stop. Bus stops can be generally **divided into two groups** (1) bus terminals, and (2) on-street bus stops. **Bus terminals** are typically located off-street, whereas on-street buses are located curbside in one of three locations: (a) **nearside** (i.e., buses stop immediately before the intersection) (b) **farside** (buses stop after the intersection); and (3) **midblock**. From a capacity standpoint, farside stops have the least negative impact on capacity followed by midblock stops and nearside stops.

Bus Lanes and Rail Segments

- In addition to the bus lane type, there are other factors that affect the capacity of bus lanes. For example, bus lane capacity can be increased by **dispersing bus stops** so that only a subset of the buses in the bus lane uses a certain set of steps. This is often referred to as skip-stop operation and can help increase capacity as well as allow for faster trips. The effectiveness of the skip-stop operation pattern is maximized when buses are gathered into platoons, and each platoon is assigned a group of stops. Moreover, the location of the bus stop can impact bus lane capacity-**farside stops provide for the highest bus lane capacity**, followed by midblock and finally nearside stops. These two issues (i.e., skip-stop operations and bus stop location) are not applicable to grade-separated rail.

Quality of Service Concepts

- Different measures are available for assessing the performance of transit. These could reflect the standpoint of the operator or the passengers. The operator point is typically assessed using what is commonly referred to **as productivity measures**, which include annual ridership, passenger trips/revenue mile, vehicle operating expenses/revenue mile, and so on. The productivity measures, however, do not directly measure passenger satisfaction with the transit quality of service.

Quality of Service Concepts

- Transit quality of service is defined so as to reflect the **perceived performance from the passenger's standpoint.** In general, measures of transit quality of service can be divided into two main categories: **(1) assessing transit service availability**, and **(2) assessing transit comfort and convenience**. In addition, these measures would depend upon the particular element of the transit system being evaluated. As previously mentioned, a transit system can be regarded as consisting of the following three basic elements**: (1) transit stops, (2) route segments, and (3) systems**. For transit stops, the quality of service measures need to evaluate transit availability and convenience at a single location. For route segments, the measures should address availability and convenience along a route segment, which would consist of two or more stops. Finally, measures are needed for describing availability and convenience of the whole transit system, which would typically consist of several routes covering a specified geographic region.

Quality of Service Concepts

- **The measures with a superscript are those used for defining LOS. There are four transit service measures that are used to define the LOS: frequency, hours of service, passenger loads, and reliability**

TABLE 4.5

Transit Quality of Service Framework

Source: Adapted from HCM 2000.

	Service & Performance Measures		
Category	***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 tim • Travel time • Safety

Note:
a. Service measure that defines the corresponding LOS.

Q-Bus Capacity Analysis Methodology

- Transit capacity for buses is calculated for three locations: loading areas, bus stops and bus lanes. Several factors affect the capacity of transit facilities:
- **(1)** dwell time, **(2)** the coefficient of variation of dwell time, **(3)** clearance time, **(4)** failure rate, **(5)** passenger loads, and **(6)** skip-stop operation. A discussion of these factors is presented first before the details of the capacity analysis procedures for different types of transit facilities.

Bus Capacity Analysis Methodology

- **Dwell Time**
- Dwell time refers to **the time that elapses** while a **bus is stopped at a bus stop serving passengers**. Specifically, it is the time required to serve passengers at the busiest door plus the time of opening and closing the doors. The HCM recommends a value ranging between 2 and 5 sec for door opening and closing under normal operations.

Bus Capacity Analysis Methodology

- The best way to determine the dwell time is to **directly**

where

- t_d = dwell time in seconds
- P_a = alighting passengers/bus through the busiest door during peak 15 minutes
- t_a = passengers' alighting time (sec/person)
- P_b= boarding passengers/bus through the busiest door during peak 15 minutes
- t_b= passengers' boarding time (sec/person)
- t_{oc} = door opening and closing time (sec)

is assumed, or 10 sec for typical studying stops. Equation 4-23 can also be used to compute dwell time:

- $t_d = P_a t_a + P_b t_b + t_{oc}$

	Availability Doors or Channels		Typical Boarding Service Times (s/p)		
Bus Type	Number	Location	Prepayment[b]	Single Coin Fare	Typical Alighting Service Times (s/p)
Conventional (rigid body)	1	Front	2.0	2.6 to 3.0	1.7 to 2.0
	1	Rear	2.0	NA	1.7 to 2.0
	2	Front	1.2	1.8 to 2.0	1.0 to 1.2
	2	Rear	1.2	NA	1.0 to 1.2
	2	Front, rear[c]	1.2	NA	0.9
	4	Front, rear[d]	0.7	NA	0.6
Articulated	3	Front, rear, center	0.9[d]	NA	0.8
	2	Rear	1.2[e]	NA	—
	2	Front, center[c]	—	—	0.6
	6	Front, rear, center[c]	0.5	NA	0.4
Special single unit	6	3 double doors[f]	0.5	NA	0.4

Note:
NA: data not available.

a. Typical interval in seconds between successive boarding and alighting passengers. Does not allow for clearance times between successive buses or dead time at stop. If standers are present, 0.5 sec should be added to the boarding times.
b. Also applies to pay-on-leave or free transfer solution.
c. One each.
d. Less use of separated doors for simultaneous loading and unloading.
e. Double-door near loading with single exits, typical European design. Provides one-way flow within vehicle, reducing internal congestion. Desirable for line-haul, especially if two-person operation is feasible. May not be best configuration for busway operation.
f. Examples: Denver 16th Street Mall shuttle, airport buses used to shuttle passengers to planes. Typically low-floor buses with few seats serving short, high-volume passenger trips.

Q- Determining Dwell Time and Maximum Load Point

- **EXAMPLE 4.9**
- Plans are underway for a bus route serving the central business district and having 10 stops. The route will

Studies have shown that the boarding time is 3 sec/passenger when no standees are present and that the presence of standees increases the boarding time to 3.50 sec/passenger. Alighting time is estimated to be equal to 2 sec/ passenger.

Determine the dwell time at the maximum load point.

to follow the pattern shown below:

Stop number	1	2	3	4	5	6	7	8	9	10
Alighting passengers	0	5	8	10	12	9	14	17	15	5
Boarding Passengers	25	20	15	16	10	4	3	2	0	0

Determining Dwell Time and Maximum Load Point

Since the bus can only seat 42 passengers, the bus will have standees when arriving at stops 4,5,6, and 7. With this determined, we proceed to determine the alighting and boarding times by multiplying the number of passengers by the given alighting and boarding time/passengers. For stops 4 through 7, the boarding time for the case where standees are present is used. Finally, the bus dwelling time is computed by adding the door opening and closing time (4 sec) to the larger of the alighting and boarding times, since the bus has two doors-one dedicated for alighting and the other for boarding. The results are shown below:

Boarding times govern for stops 1 through 5 and alighting times govern for stops 6 through 10. Stop 1 is the critical bus stop requiring the longest dwell time.

Coefficient of Variation of Dwell Time

- Coefficient of Variation of Dwell Time is computed by dividing the ***standard deviation of the observed dwell times at a bus stop by the mean dwell time***. Experience has shown that this coefficient ranges **between 40 and 80%**. A value equal to 60% can be assumed in the absence of field observations.

Clearance Time

- The clearance time consists of two components: **(1) the time needed for the bus to start up and travel its own length, thus exiting the bus stop; and (2) the time needed by the bus to reenter traffic in case of off-line bus stop**s. Studies have shown that the start-up time for buses is typically in the range of **2 to 5 sec** and that the time needed by the bus to travel its length ranges between 5 and 10 sec. Therefore, for on-line bus stops, the clearance time can be assumed to be equal to 10 sec.
- For off-line stops, the time needed by the bus to reenter the traffic stream needs to be added to the start-up time and time required by the bus to travel its own length. The reentry delay will depend upon the traffic volume in the adjacent lane. In the absence of other information, Table 4.7 can be used to estimate the reentry time.

TABLE 4.8

Values of Percent Failure Associated with Z_a

Source: Adapted from HCM 2000.

Failure Rate (%)	Z_a
1.0	2.330
2.5	1.960
5.0	1.645
7.5	1.440
10.0	1.280
15.0	1.040
20.0	0.840
25.0	0.675
30.0	0.525
50.0	0.000

In general, for CBD bus stops, a value of Z_a between l.04 and 1.441 is selected (this corresponds to a failure rate between 7.5 and 15%).

For outlying stops, a value of l.96 is assumed, which corresponds to a failure rate of less than 2.50%.

TABLE 4.7

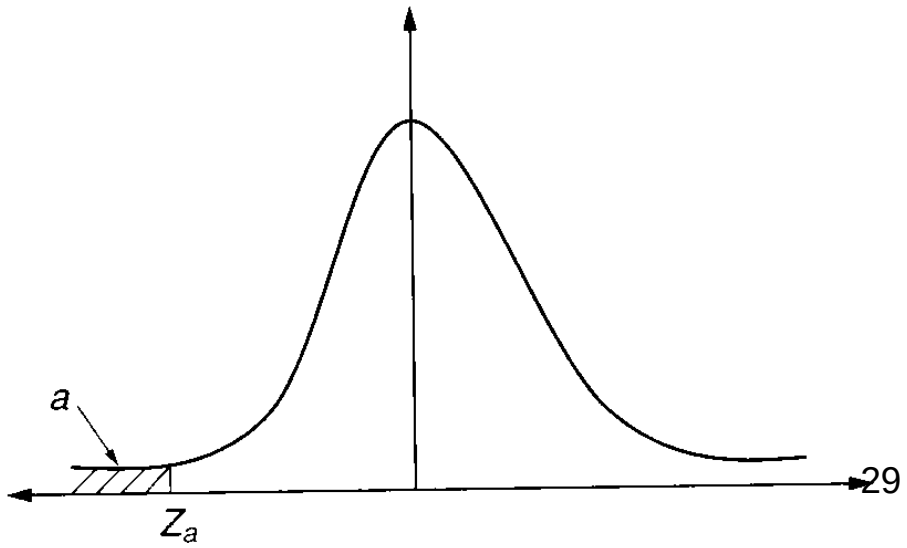
Transit Average Reentry Delay

Source: Adapted from HCM 2000.

Adjacent-Lane Mixed-Traffic Volume (veh/hr)	*Average Reentry Delay (s)*
100	0
200	1
300	2
400	3
500	4
600	5
700	7
800	9
900	11
1000	14

FIGURE 4.10

Normal curve distribution.



Passenger Loads

- Passenger **loads** refer to the **number of passengers in a single transit unit**. Passenger loads are often expressed in terms of what is known as a **load factor**, which gives the ratio of the n*umber of passengers to the number of seats on the transit vehicle* (i.e., a load factor value of 1 would mean that all seats are occupied). In general, for long distances, one should attempt to keep the load factor below 1. For inner-city service, however, load factors are allowed to approach 1.50 or even 2 (which means that there are twice as many passengers on the bus as there are seats).
- In transit, we often refer to what is called the maximum scheduled load and the crush load. The maximum scheduled load represents an upper limit for scheduling purposes and is equivalent to the capacity of the vehicle, assuming a reasonable number of standing passengers (**load factors typically range between 1.25 and 1.50**). Crush loads correspond to load factors exceeding 1.50. Under these circumstances, standing passengers are subject to unreasonable discomfort, and circulation becomes difficult, which in turn increases dwell time and reduces vehicle capacity.

Skip-Stop Operation

- **Skip-stop operation** refers to a type of operation in which the stops are spread and an alternating route stop pattern is implemented (e.g., two- or three-block stop patterns). As previously mentioned, skip-stop operation reduces the total trip time and the number of buses stopping at each bus stop. With an alternating block stopping pattern, the capacity of a bus lane is nearly equal to the sum of the capacities of the two critical bus stops.

Loading Area Capacity

- The first locatio[illegible]eeds to be determined is the loading ar[illegible]n number of buses/berth/hr. [illegible]om Equation 4.26:

$$B_{bb} = \frac{3600(\frac{g}{C})}{t_c + (\frac{g}{c})t_d + Z_a c_v t_d}$$

where

- B_{bb} = maximum number of buses/berth/hr (buses/hr)
- g/C = effective signal green time divided by the cycle length
- t_c = clearance time between successive buses (seconds)
- t_d = average dwell time (seconds)
- Z_a = one-tail normal variate corresponding to the allowable failure rate for queue
- formation
- c_v = coefficient of variation of dwell times

Bus Stop Capacity

- The capacity of a bus stop is a direct function of the individual capacities of the **bus loading areas** that it contains. However, the increase in the bus stop capacity is not a linear function of the number of loading areas (i.e., doubling the number of loading areas will not result in doubling the capacity). This is because the loading areas of multiple berths are not used equally, which means that the efficiency,) of multiple loading areas decreases with the increase in the number of loading areas.

Bus Stop Capacity

- The capacity of a bus stop is therefore computed by multiplying the individual capacity of the loading area by the nu oading areas, N_{eb}. The effective be less than the actual areas. The capacity of the bus stop is then given by:

$$B_s = N_{eb} B_{bb}$$

where

B_s = maximum number of buses/bus stop/hr

N_{eb} = effective number of loading areas

-

Bus Lane Capacity

- For bus lanes, we consider two cases:
- (1) the case of **exclusive urban bus lane** and
- (2) the case of **mixed-traffic bus lanes**.

Bus Lane Capacity

- **Exclusive Urban Bus Lanes**
- In general, the vehicle capacity of an exclusive bus lane is equal to the capacity of the critical bus stop along that lane. However. several factors that affect the vehicle capacity of bus lanes have to be accounted for in the calculation. These factors include
- (1) *the type of bus lane* (i.e., whether it is Type 1, 2, or 3),
- (2) whether *skip operation is implemented*,
- (3) the *volume to capacity ratio traffic in the adjacent lane* for Type 2 bus lanes; and
- (4) the *bus stop location and right-turning* vehicles from the bus lane.

Bus Lane Capacity

(2) whether skip

TABLE 4.9

Effective Number of Loading Areas for Multiple Linear Loading Bus Stops, N_{eb}

Source: Adapted from HCM 2000.

	On-Line Loading Areas		Off-Line Loading Areas	
Loading Area No.	Efficiency, %	No. of Cumulative Effective Loading Areas	Efficiency, %	No. of Cumulati Effective Loading Area
1	100	1.00	100	1.00
2	85	1.85	85	1.85
3	60	2.45	75	2.60
4	20	2.65	65	3.25
5	5	2.70	50	3.75

Bus Stop Location	Bus Lane Type		
	Type 1	Type 2	Type 3
Near-side	1.0	0.9	0.0
Midblock	0.9	0.7	0.0
Far-side	0.8	0.5	0.0

Note:
f_l = 0.0 for contraflow bus lanes and median bus lanes regardless of bus stop location or bus lane type, since right turns are either prohibited or do not interfere with bus operations.
Source: St. Jacques and Levinson (*10*).

where

f_r= right-turn adjustment factor

f_l = bus stop location factor

v_r = volume of right turns at specific intersection (veh/hr)

c_r = capacity of right turns at specific intersection (veh/hr)

by

Adjustment for Skip-Stop Operation:

where

f_k = capacity adjustment factor for skip-stop operations

K = adjustment factor for ability to fully utilize bus stops in a skip-stop operation

a = adjacent-lane impedance factor

N_s = number of alternating skip stops in sequence

$$f_k = \frac{1 + K_a(N_s - 1)}{N_S})$$

Adjustment for Skip-Stop Operation:

- Skip-stop operation is most efficient when buses arrive in **platoons**. To account for this, the adjustment factor, K, is introduced in Equation 4.29.This factor depends upon the arrival pattern of buses. A value of **0.50** is assumed for **andom arrivals**, ***0.75 for typical arrivals***, and ***1.00 for platooned arrivals***. The value of the adjacent-lane impedance factor, a, can be computed from Equation 4.30:

$$a = 1 - 0.8\left(\frac{v}{c}\right)^3$$



- **Non-skip-stop operation:**
- $$B = B_1 = B_{bb} \cdot N_{eb} \cdot f_r$$

where

- B = bus lane vehicle capacity (buses/hr)
- B_{bb} = bus loading area vehicle capacity at critical bus stop (buses/hr)
- N_{eb} = number of effective loading areas at critical bus stop (Table 4.9)
- f_r = right-turn adjustment factor (Equation 4.28)

- **Skip-stop operation:**
- $$\mathbf{B = f_k(B_1 + B_2 + \ldots + B_n)}$$

where

- B_1 ……. , B_n = vehicle capacities of each set of routes at their respective critical bus stops that use the same alternating skip-stop pattern (buses/hr)
- f_k = capacity adjustment factor for skip-stop operations (Equation 4.29)

Adjustment for Skip-Stop Operation:

- Skip-stop operation is most efficient when buses arrive in **platoons**. To account for this, the adjustment factor, K, is introduced in Equation 4.29.This factor depends upon the arrival pattern of buses. A value of **0.50** is assumed for **andom arrivals**, ***0.75 for typical arrivals***, and ***1.00 for platooned arrivals***. The value of the adjacent-lane impedance factor, a, can be computed from Equation 4.30:

$$a = 1 - 0.8\left(\frac{v}{c}\right)^3$$

Mixed- Traffic Bus Lanes

- With the exception of large cities with high transit demand, **mixed-traffic bus lanes are the more common type** compared to exclusive lanes. The capacity is computed in essentially the same way for mixed-traffic bus lanes as for exclusive lanes; however, the **interference of other traffic** on **bus operations** must be considered. This interference is most obvious when **off-line bus stops are used** and buses have to wait for adequate gaps in the adjacent lane traffic stream to reenter traffic.

Mixed- Traffic Bus Lanes

- For mixed-traffic bus lanes, the different bus lane types (i.e., Type 1, 2, or 3) describe different lane configurations compared to the lane types of exclusive bus lanes. Type 1 mixed-traffic lane has one traffic lane in the direction of bus travel. Type 2 has two or more lanes, and there are no Type 3 lanes for mixed traffic lanes.

Mixed- Traffic Bus Lanes

- In general, the impact of traffic on bus operations on mixed-traffic bus lanes can take one of two forms. **First, it may interfer** $f_m = 1 - f_l(\frac{v}{c})$ **perations especially close to an intersec ed vehicles may actually prevent hing its stop. Second, for off-**

where

f_m = mixed traffic adjustment factor

f_l = bus stop location factor from Table 4.10

v **= curb lane traffic volume at critical bus stop (veh/hr)**

c **= curb lane capacity at critical bus stop (veh/hr)**

The mixed-traffic bus lane vehicle capacity is then computed as

$$B = B_{bb} \cdot N_{eb} \cdot f_m \qquad (4.34)$$

where B is the vehicle capacity for the mixed-traffic bus lanes, and all other notations are as defined before.

EXAMPLE 4.10

- **Calculating Bus Lane Capacity**
- *Determine the bus lane capacity*, given that it is desired that the probability that a queue of buses will form behind a bus stop does not exceed 7.50%.With the exception of large cities with high transit demand, mixed-traffic bus lanes are the more common type compared to exclusive lanes. The capacity is computed in essentially the same way for mixed-traffic bus lanes as for exclusive lanes; however, the interference of other traffic on bus operations must be considered. This interference is most obvious when off-line bus stops are used and buses have to
- The number of loading areas at bus stop S is limited to two berths
- Buses are allowed to use the adjacent lane

wait for adequate gaps in the adjacent lane traffic stream to reenter traffic.

EXAMPLE 4.10

- **Step 1:** *Calculate the loading area capacity*, B_{bb} In order to do this, we use Equation 4.26 as follows:

$$B_{bb} = \frac{3600(\frac{g}{c})}{t_c + (\frac{g}{c})t_d + Z_a c_v t_d}$$

In our case,

•• g/C = 40/90 = 0.444

•• For on-line stops, the clearance time, t_c is assumed to be equal to 10 Sec

•• The dwell time t_d = 40 sec

•• Since the failure rate is required not to exceed 7.50%, the value of (from Table 4.8) is found to be equal to 1.44

•• The coefficient of variation of dwell time, c_v is assumed to be equal 0.60 in the absence of field observations

Therefore, the loading area capacity, B_{bb} is equal to:

$$B_{bb} = \frac{36000.444}{10 + 0.444.40 + 1.44.0.60.40} = 25 buses$$

EXAMPLE 4.10

- **Step 2:** Calculate the **bus stop capacity**. From Equation 4.27, the bus Stop capacity, B_s is given as
- $B_s = N_{eb}B_{bb}$
- For two linear on-line loading areas, the effective number of loading are; N_{eb} from Table 4.9 is equal to 1.85. Therefore,
- $B_s = 1.85 \cdot 25 = 46$ buses

EXAMPLE 4.10

- **Step 3:** Calculate the mixed traffic bus lane capacity. For mixed-traffic bus lanes, the first step is to compute the mixed-traffic adjustment factor, f_m: using Equation 4.33:
- $$f_m = 1 - f_l\left(\frac{v}{c}\right)$$
- The bus s an be found from Table 4.10. For Type es are allowed to use the adjacent lane) and for nearside bus stops $f_l = 0.90$.
- Therefore,
- $$f_m = 1 - 0.9\left(\frac{450}{700}\right) = 0.42$$
- The mixed-traffic bus lane vehicle capacity, B, is then computed from Equation 4.34 by multiplying the bus stop capacity by the mixed-traffic adjustment factor, f_m
- Therefore,
- B = 0.42 . 46 = 19 buses/hr

EXAMPLE 4.12

- **In our case,**
  K = 0.50 (random arrivals)
  N_s = 2.0 (every other stop)
  Using Equation 4.30, a is computed as

$$a = 1 - 0.8\left(\frac{v}{c}\right)^3$$

where (v/c) is the volume to capacity ratio in the adjacent lane. Therefore,

$$a = 1 - 0.8\left(\frac{600}{1100}\right)^3 = 0.87$$

- For skip-stop operations, the capacity is to determine the impedance factor.!k' using Equation 4.29:

$$f_k = \frac{1 + 0.50 \,.\, 0.87 \,.\, (2 - 1)}{2} = 0.72$$

On-Street Rail Capacity Analysis Procedure

The train headway used for calculating the capacity is therefore the largest of the following three potential controlling headways:

1. **The on-street segment headway, which, similar to buses, is primarily a function of the dwell time of vehicles at stations;**
2. **The block-signaled segment headway; and**
3. **The single-track headway.**

On-Street Segment Headway

- Similar to buses, the minimum headway for the on-street segment of light rail or streetcars is primarily a function of the dwell time at stations. The dwell time is equal to the sum of (1) the time needed to serve passengers at the busiest door divided by the number of the available channels per door (typically two channels/door); and (2) the time required to open and close the doors, which is typically assumed to be equal to 5 sec for modern light rail vehicles. The dwell time can therefore be expressed as follows:
- $$t_d = \frac{P_d t_{pf}}{N_{cd}} + t_{oc} \qquad (4.35)$$
- where
- t_d = dwell time in seconds
- N_{cd} = number of channels per door for moving passengers
- t_{oc} = door opening and closing time in seconds

On-Street Segment Headway

- Similar to buses, the minimum headway for the on-street segment of light rail or streetcars is primarily a **function of the dwell time at stations.** The dwell time is equal to the sum of:

(1) the time needed to **serve passengers at the busiest door** divided by the number of the available channels per door (typically two channels/door); and

(2) the time required to open and close the doors, which is typically assumed to be **equal to 5 sec** for modern light rail vehicles. The dwell time can therefore be expressed as follows:

On-Street Segment Headway

- Similar to bus[illegible]way for the on-street segment of li[illegible]rimarily a **function of the dwell ti**[illegible]well time is equal to the sum of:

$$t_d = \frac{P_d t_{pf}}{N_{cd}} + t_{oc}$$

where

t_d = dwell time in seconds

N_{cd} = number of channels per door for moving passengers

t_{oc} = door opening and closing time in seconds

Transit Person Capacity

- Our focus so far has been on computing the vehicle capacity of transit facilities, which involves determining the maximum number of buses or trains that can be accommodated at a station or along a transit line/hr. For transit facilities, in addition to determining the vehicle capacity, we are also interested in determining the **person capacity**. For buses, this can be calculated easily by multiplying the bus lane vehicle capacity at the maximum load point, by the allowed passenger loads on board an individual bus, by the peak hour factor (typically assumed to be equal to 0.75 for buses).

Transit Person Capacity

$P = TLP_m (PHF)$ (4.44)

where

P = person capacity (person/hr)

T = vehicle capacity (trains/hr)

L = length of train (ft)

P_m = linear passenger loading level (person/ft)

1.8 passenger/ft length for heavy rail and 1.5 passenger/ft length for light rail

PHF = peak hour factor (0.80 for heavy rail, 0.75 for light rail, and 0.60 for commuter rail)

EXAMPLE 4.16

Solution

As determined in Example 4.12, the bus route has a capacity equal to 41 buses/hr. Out of these 41 buses, standees are not allowed on 10 buses (the express buses) whereas they are allowed on the remaining 31 buses.

Therefore,

Passenger capacity = [(10·43) + (31 ·43·1.50)] ·0.75 = 1822 passengers/hr

Q- Quality of Service Measures

- As discussed previously, measures of transit quality of service can be divided into two main categories:
- (1) **assessing transit service availability**: and
- (2) **assessing transit comfort and convenience**. Table 4.5 also showed that for LOS designation, four quality of service measures are employed:

(1) frequency, (2) hours of service, (3) passenger loads, and (4) reliability. This section defines these four measures and describes how they can be used to determine the LOS for transit stops and routes.

Quality of Service Measures

- **Frequency**
- Service frequency is the measure used to evaluate the *transit availability LOS at transit stops*. It determines the

LOS	Headway (min)	Veh/h	Comments
A	< 10	> 6	Passengers don't need schedules
B	≥ 10–14	5–6	Frequent service; passengers consult schedules
C	> 14–20	3–4	Maximum desirable time to wait if bus/train missed
D	> 20–30	2	Service unattractive to choice riders
E	> 30–60	1	Service available during hour
F	> 60	< 1	Service unattractive to all riders

to headways that are less than 10 minutes. It should be noted that a transit agency could decide to operate its vehicles at different LOS throughout the day. For example, during the peak hours, the service may operate at LOS B, whereas it could operate at LO D at midday

Quality of Service Measures

- **Hours of Service**

LOS	Hours per Day	Comments
A	> 18–24	Night or owl service provided
B	> 16–18	Late evening service provided
C	> 13–16	Early evening service provided
D	> 11–13	Daytime service provided
E	> 3–11	Peak-hour service/limited midday service
F	0–3	Very limited or no service

Notes:
Fixed route: number of hours per day when service is provided at least once an hour.
Paratransit: number of hours per day when service is offered.

Quality of Service Measures

- **Passenger Loads**

LOS	Bus		Rail		Comments
	ft^2/p	p/seat[a]	ft^2/p	p/seat[a]	
A	>12.90	0.00–0.50	<19.90	0.00–0.50	No passenger need sit next to another
B	8.60–12.89	0.51–0.75	14.00–19.90	0.51–0.75	Passenger can choose where to sit
C	6.50–8.59	0.76–1.00	10.20–13.99	0.76–1.00	All passengers can sit
D	5.40–6.49	1.01–1.25	5.40–10.19	1.01–2.00	Comfortable loading for standees
E	4.30–5.39	1.26–1.50	3.20–5.39	2.01–3.00	Maximum schedule load
F	<4.30	>1.50	<3.20	>3.00	Crush loads

Note:
a. Approximate values for comparison. LOS is based on area per passenger.

Quality of Service Measures

- **Route Segment Reliability**

TABLE 4.18

Reliability LOS for Schedule Adherence

Source: Adapted from HCM 2000.

LOS	*Coefficient of Variation*
A	0.00–0.10
B	0.11–0.20
C	0.21–0.30
D	0.31–0.40
E	0.41–0.50
F	>0.50

Note:
Applies to routes with frequencies greater than or equal to 6 buses/hr scheduled.

Quality of Service Measures

- **Route Segment Reliability**
- From a passenger's standpoint, the o*n-time performance* is the measure that most accurately reflects the user's perception of service reliability. However, when vehicles run at frequent headways, headway adherence becomes more important.

Quality of Service Measures

- **Route Segment Reliability**
- For on-time performance, the common practice is to define a transit vehicle as late when it *is more than 5 min behind schedule*. Early departures are generally considered as being equivalent to a vehicle being late by the amount of one headway, since passengers would have to wait for the next vehicle. Table 4.17 lists the reliability LOS thresholds for transit vehicles operating with frequencies of fewer than 6 veh/hr.

TABLE 4.18

Reliability LOS for Schedule Adherence

Source: Adapted from HCM 2000.

LOS	*Coefficient of Variation*
A	0.00–0.10
B	0.11–0.20
C	0.21–0.30
D	0.31–0.40
E	0.41–0.50
F	>0.50

Note:
Applies to routes with frequencies greater than or equal to 6 buses/hr scheduled.



PEDESTRIAN FACILITIES

- In this section, we discuss the capacity analysis and LOS determination procedures for pedestrian facilities, which include **walkways and sidewalks, shared offstreet paths, pedestrian crosswalks, and pedestrian facilities along urban streets.**

Pedestrian Flow Characteristics

- ***Pedestrian flow:*** **This refers to the number of pedestrians crossing a line of sight across the width of the pedestrian facility perpendicular to the pedestrian path in unit time (p/min). The pedestrian flow/unit width is equal to the pedestrian flow divided by the effective width of the pedestrian facility, in units of pedestrians/min/ft (p/min/ft).**

Pedestrian Flow Characteristics

Pedestrian density: **This is computed as the average number of pedestrians/unit area of the pedestrian facility (p/ft^2).**

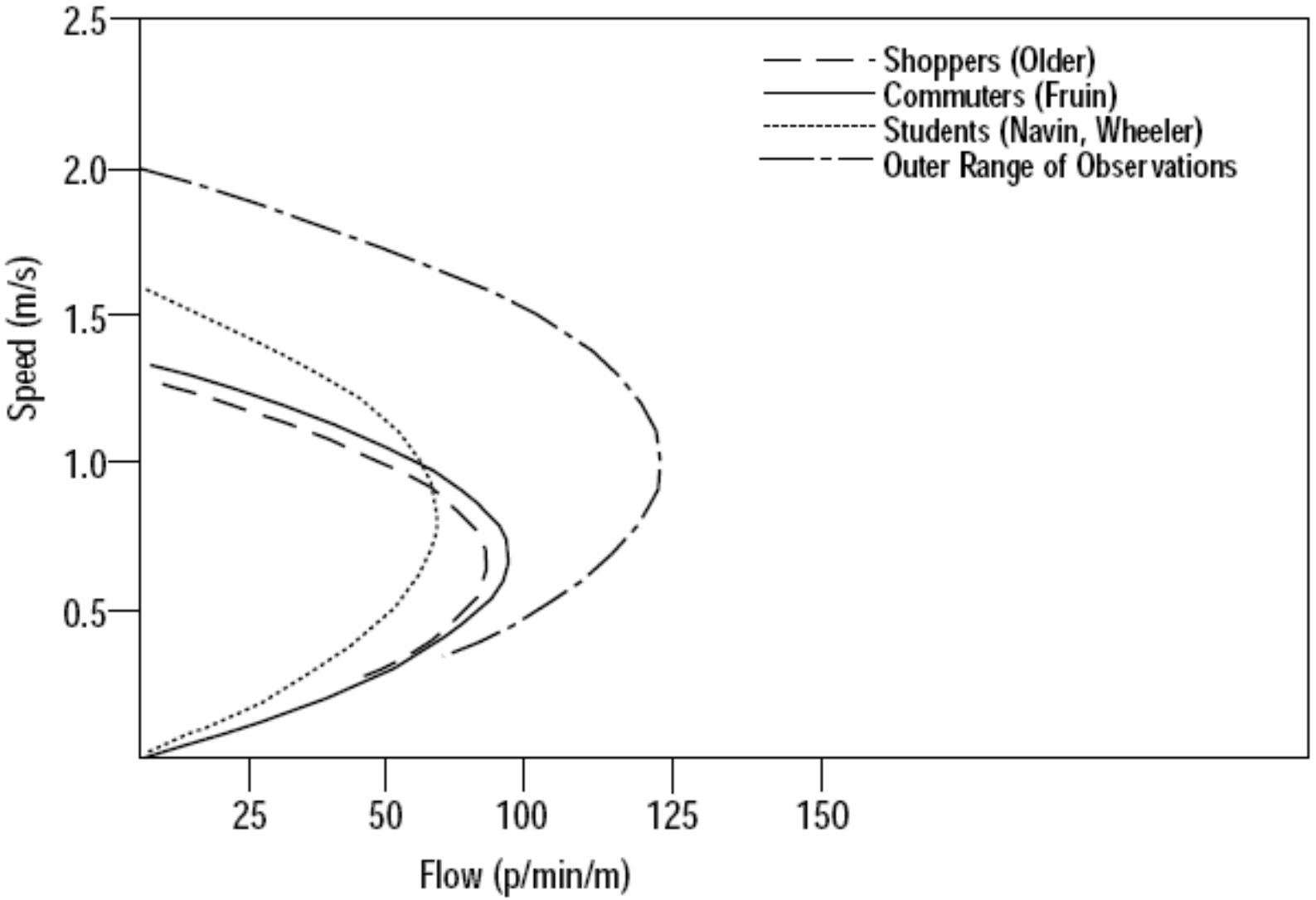
Pedestrian space: **This refers to the average area provided for each pedestrian. It is equal to the inverse of the density and is expressed in units of sq ft/pedestrian (ft^2/p).**

Flow-Speed-Density Relationships for Pedestrian Traffic

- The parameters just defined are related to one another in a manner that is similar to the fundamental relationships among the vehicle traffic flow parameters (Figure 4.2). Similar to vehicle traffic flow, pedestrian flow, density, and speed are related to one another by the following equation:
- $v_{ped} = S_{ped} \cdot D_{ped}$
- where
- V_{ped} = pedestrian flow rate (p/min/ft)
- S_{ped} = pedestrian speed (ft/min)
- D_{ped} = pedestrian density (p/ft^2)

Flow-Speed-Density Relationships for Pedestrian Traffic

EXHIBIT 11-3. RELATIONSHIPS BETWEEN PEDESTRIAN SPEED AND FLOW



Capacity Analysis and LOS Concepts

- In the absence of other data, the capacity of a pedestrian facility or walkway can reasonably be assumed to be equal to 23 p/min/ft or 1380 p/hr/ft. At capacity, however, pedestrians' speed is severely impaired and would generally be around 2.5 ft/sec, which is way below the typical average value of 4 ft/sec or 5 ft/sec. Given this, pedestrian facilities are typically designed to operate well below capacity-level operation.

Capacity Analysis and LOS Concepts

- For LOS determination, the basic idea is to define ranges for the **space/pedestrian** flow rates, and/or speeds that correspond to different LOS. Speed is an important measure since it can be easily measured in the field. The speed at capacity is generally around 2.5 ft/sec or 150 ft/min. Figure 4.17 shows a graphic illustration and a description of the different LOS for a walkway and the range of values for pedestrian space and flow rates that correspond to each LOS.

Capacity Analysis and LOS Concepts

- The LOS criteria shown in Figure 4.17 are based on average flow conditions and do not consider platoon conditions. However, for pedestrian facilities such as sidewalks, for example, the interruption of flow and queue formation at traffic signals can result in surges in traffic demand and in the formation of platoons of pedestrians. Within the platoon, the LOS will generally be one level lower than the LOS that is based on average conditions. The decision as to whether to design the facility for average or for platoon conditions depends upon available space, cost, and policy.

Pedestrian level of service

LOS F

Pedestrian Space ≤ 8 ft²/p Flow Rate varies p/min/ft At LOS F, all walking speeds are severely restricted, and forward progress is made only by shuffling. There is frequent, unavoidable contact with other pedestrians. Cross- and reverse-flow movements are virtually impossible. Flow is sporadic and unstable. Space is more characteristic of queued pedestrians than of moving pedestrian streams.

to flow.

Capacity Analysis and LOS Concepts

- The LOS criteria shown in Figure 4.17 are based on average flow conditions and do not consider platoon conditions. However, for pedestrian facilities such as sidewalks, for example, the interruption of flow and queue formation at traffic signals can result in surges in traffic demand and in the formation of platoons of pedestrians. Within the platoon, the LOS will generally be one level lower than the LOS that is based on average conditions. The decision as to whether to design the facility for average or for platoon conditions depends upon available space, cost, and policy.