Transit capacity and quality of service

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Discussion

- Why do you use transit?
  - Will you still use it if you have a car?
- Why don't you use transit?
- How would you measure transit quality of service?

Quality of service

Definition (Quality of service or QoS [TCQSM]). It is the overall measured or perceived performance of transit service from the passenger's point of view.

It focuses on two areas:

- Is transit service an option for a given trip?
- If it is an option, how attractive it is to the potential passengers?

QoS depends on the decisions made by a transit agency within the constraints of its budget, particularly where to provide service, how often and how long it is provided, and how it is provided. Better QoS attracts higher ridership.

Capacity

Definition (Capacity [TCQSM]). It refers to the maximum number of transit vehicles, passengers, or both, that can travel past a particular location in a given period of time under specified conditions.

Types

- Maximum (theoretical) capacity reflects the greatest number of persons or transit vehicles that can be served under any circumstance.
  - Maximum capacity is unstable-and thus unreliable - form of operations.
  - It should not be used for planning and operations.
- Design (achievable, practical) capacity reflects the number of persons or transit vehicles that can be served at a specified QoS (e.g., design loading level or design reliability level).
- Vehicle (bus, train, vessel) capacity is measured in vehicles per hour and expresses how many transit vehicles can pass a point in an hour.
- Passenger capacity is measured in persons per vehicle and expresses how many persons a transit vehicle can carry at a design passenger loading level.
- Person capacity is measured in persons per hour and expresses how many persons can pass a point in an hour. It is the product of vehicle/facility/line capacity (veh per hr) and passenger capacity (person per veh).

Why should we be concerned about capacity?

- Speed and reliability: Factors influencing capacity also influence speed and reliability
  - Reliable service is attractive to passengers and help reduce the recovery time[1].
  - Speed improvement will help cover the route length faster.
- Managing passenger loads: Capacity help determine the number of buses, trains, or railcars required to provide a desired quality of service wrt pax loading.
- Forecasting the effects of change of fare collection procedure, vehicle types, etc.
  - Dwell time (time required to load and unload passengers) affects speed and capacity.

[1] time included in the schedule between trips to allow late arriving buses to start their next trip on time

Why should we be concerned about capacity?

- Planning for the future: To plan for a travel demand, we require capacity information for various options.
- Analyzing the operation of major bus streets: Capacity analysis can help understand the delays caused on major streets where multiple bus routes converge.
- Special event: To serve the demand for special events (fair, festivals, sports, etc.)
- Transportation systems management: Increasing transit capacity can increase the person capacity as compared to automobile.

Factors influencing person capacity

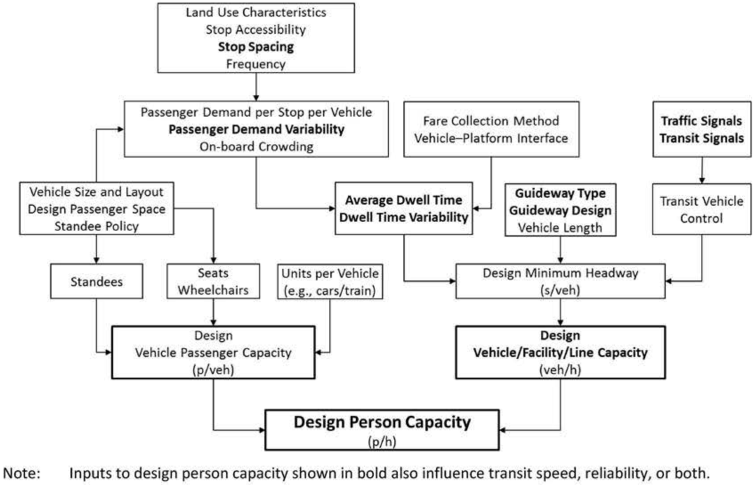


Figure: Exhibit 3-1 TCQSM

Speed

- impacts the time required by passengers to make a trip.
  - which further influences the attractiveness of transit compared to other modes.
- impacts the cost of operating a route
  - number of vehicles required to provide a given frequency depends on the cycle time[2].

[2] time required to make a round-trip on a route, plus driver layover time and recovery time.

Factors influencing speed

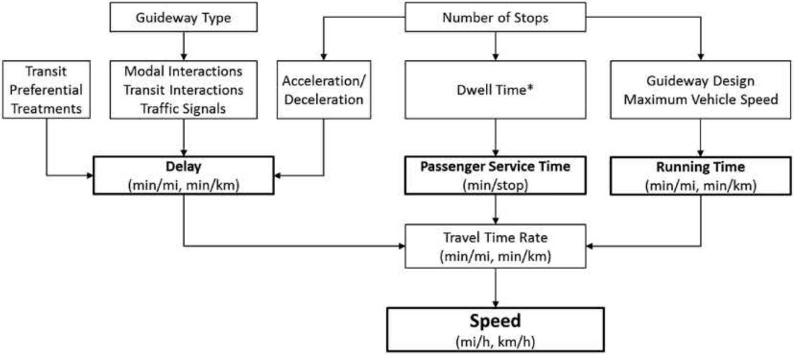


Figure: Exhibit 3-3 TCQSM

Reliability

- important for passengers
  - to arrive on time at their destination
  - having not to wait too long at a stop/station
- impacts the schedule recovery time
  - which further influences the operating cost when recovery time requires extra vehicle
- Unreliable operations can cause bus bunching.

Factors influencing reliability

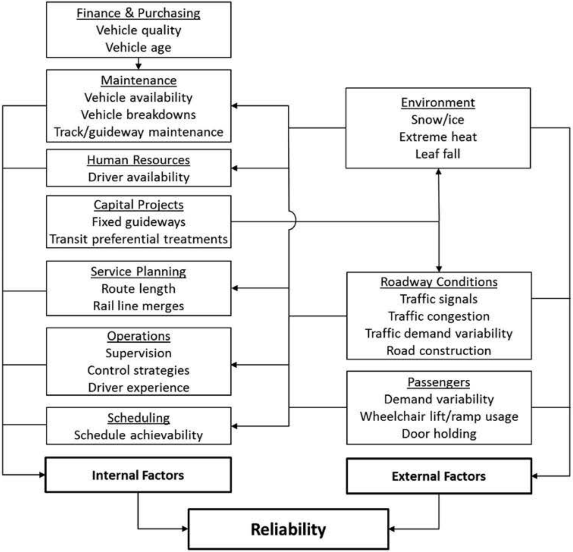


Figure: Exhibit 3-5 TCQSM

Dwell time

Definition (Dwell time). Time spent at a stop/station serving passengers movements, including the time required to open and close doors[3].

Dwell time components

- Passenger boarding and alighting counts
- Fare payment procedure
- Vehicle type and size
  - Low-floor buses require less dwell time
  - Multiple doors in metro require less dwell time
- In-vehicle circulation
  - Boarding and alighting occurs slowly when standees are present
  - Passengers using front door to alight

Remark. More dwell time decreases the capacity and average speed.

[3] time spent at stop for other reasons (waiting for traffic signal, etc.) is not counted part of dwell time.

Operating environment

- Mixed traffic: shared lane operation with general traffic
- Semi-exclusive: a lane partially reserved for transit use, but others can use it ar certain times/locations
- Exclusive: a lane, portion of roadway, or ROW reserved for transit use at all times, but still affected by some traffic interference
- Grade-separated: a facility dedicated to exclusive use of transit vehicles

More exclusive the ROW, less is the interaction of transit vehicles with other modes resulting in more speed and lesser headway variability. The interaction can be in form of traffic control, traffic delays, or speed restriction.

Stop and station characteristics

- Vehicle-platform interface affects transit speed and capacity
  - height differential between vehicle and platform
  - platform position relative to guideway
  - no. of transit vehicles that can stop simultaneously
- Vehicle characteristics affects dwell time and maneuvering
  - # of doors available for use
  - seating arrangement inside the vehicle
- Fare collection affects dwell time
  - on-board (whether separate conductor present)
  - fare collection procedure
- Stop spacing
  - more frequently vehicle stops, more time lost in accelerating and decelerating
  - interference due to signal control

Transit performance points of view

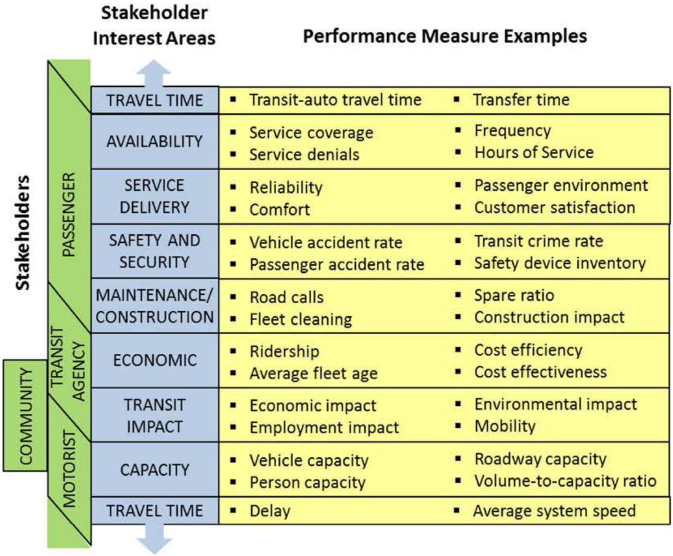


Figure: Exhibit 4-1 TCQSM

QoS factors: survey results

Comfort, nuisances, scheduling, fares, cleanliness, in-person information, passive information, safety, transfers, hours of service, frequency of service, convenience of routes, on-time performance, travel time, transferring, cost, information availability, vehicle cleanliness, ride comfort, employee courtesy, perception of safety, bus stop locations, and overall satisfaction.

Transit trip decision making process: Availability

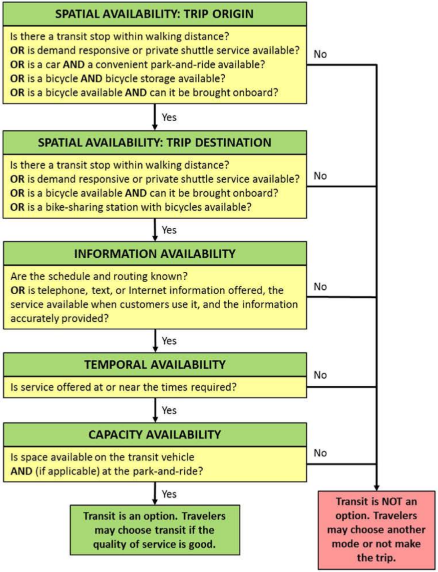


Figure: Exhibit 4-9 TCQSM

Transit trip decision making process: Comfort and convenience

- Passenger loading
  - less attractive if passengers have to stand for long periods of time due to crowding
- Reliability
  - affects wait time at stop for a transit vehicle to arrive and time of arrival at destination
  - encompasses both on-time performance and regularity of headways between successive transit vehicles
  - causes: traffic conditions, road constructions and track maintenance, vehicle and staff availability, line merges, route length, etc.
- Travel time
  - access, waiting, in-vehicle, transfer, egress time
- Safety and security
- Cost
- Appearance and comfort (climate control, seat comfort, ride comfort, and amenities)
- Costumer relations

Fixed route QoS (quantifiable)

Availability

- Frequency
- Service span
- Access

Comfort and convenience

- Passenger load
- Reliability
- Travel time

Bus capacity methodology

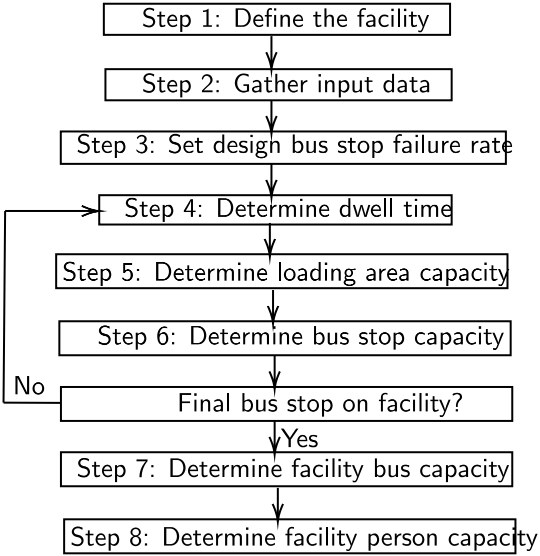


Figure: Exhibit 6-53 TCQSM

Step 1: Define the facility

Bus capacity is calculated for three key locations:

1. Bus loading areas (berths), curbside spaces where a single bus can stop to load and unload passengers;
2. Bus stops, consisting of one or more adjacent loading areas
3. Bus facilities, continuous sections of roadways used by buses that include at least one stop, but typically many more.

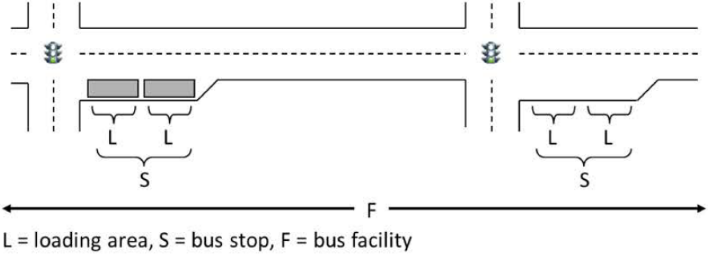


Figure: Exhibit 6-11 TCQSM

Step 1: Define the facility

- A facility can be defined in a flexible manner. It can be
  - discrete piece of infrastructure (e.g., median busway)
  - defined section of roadway (e.g., portion between two cross streets)
  - streets followed by a particular route (e.g., BRT route)
- A facility can include a mix of
  - operating environments (e.g., mix of bus lanes and mixed traffic operations)
  - physical roadways (e.g., turn from one street to another)
  - stopping patterns
- All bus stops located along the defined length of facility need to be included in the analysis.

Step 2: Gather input data

Bus stop demand data[4]

1. Average dwell time: based on passenger volumes, fare collection method, vehicle design, and passenger loads or estimated based on default values.
2. Dwell time variability: measured by coefficient of variation ($CV = \frac{\sigma}{\mu}$) of dwell times.
3. Failure rate: percentage of buses that arrive at the bus stop to find all available loading areas already occupied. It can be also be specified as a design value based on desired QoS.
4. Passenger demand peak-hour factor (PHF): hourly passenger demand at a bus stop (sum of boarding and alighting passengers), divided by four times the passenger demand during the peak 15 min of the hour.

[4] All data are for a defined hour (typically peak hour) and can be field measured or estimated based on default values

Bus stop location data[5]

1. Position relative to the roadway

(a) On-line (Portland)

(b) Off-line (Albuquerque)

Figure: Exhibit 6-5 TCQSM: on-line (the bus stops in the travel lane) or off-line (the bus pulls out of the travel lane to serve a stop)

2. Position relative to an intersection

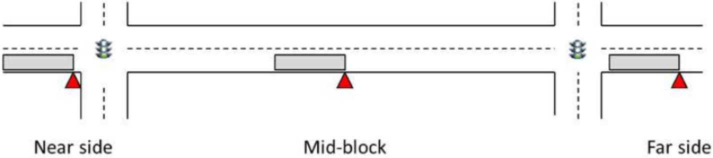


Figure: Exhibit 6-8 TCQSM

[5] All data are for a defined hour (typically peak hour) and can be field measured or estimated based on default values.

3. Bus stop design type: Linear vs non-linear loading areas

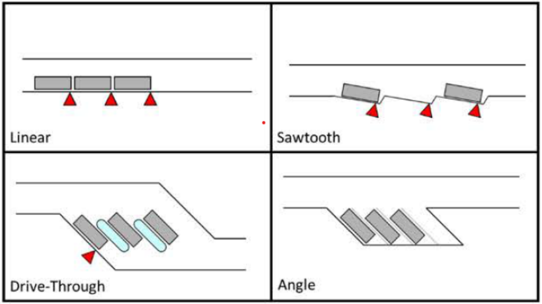


Figure: Exhibit 6-12 TCQSM

4. Number of loading areas
5. Bus facility type:
   - Type 1 bus lanes do not allow buses to leave their lane.
   - Type 2 bus lanes allow buses to move into the adjacent lane, traffic permitting, to move around other vehicles using the lane.
   - Type 3 bus lanes provide two lanes for the exclusive use of buses.

Type 1

Buses have no use of adjacent lane

- Channelized bus lanes (a, b)
- Contraflow bus lanes (b, c)
- Busway stations without passing lanes (c)
- Mixed-traffic operations with only one travel lane (d)

(a) Denver, (b) Orlando, (c) Eugene, (d) Portland

Type 2

Buses may move into adjacent lane, traffic permitting

- Part-time exclusive bus lanes (e)
- Full-time exclusive bus lanes with passing opportunities (f)
- Mixed-traffic operations with two or more lanes (g, h)

(e) Montréal, (f) Madison, (g) Portland, (h) Milwaukee

Type 3

Buses have full use of adjacent lane

- Dual bus lanes (i)
- Busway stations with passing lanes (j)

(i) New York, (j) Miami

6. Traffic signal timing: g/C ratio (green time divided by cycle time) If transit signal priority is provided, the amount of extra green time potentially provided should be included
7. Curb lane traffic volume: measured in vehicles per hour.
8. Left-turning traffic volume and capacity: measured in vehicles per hour.
9. Parallel pedestrian crossing volume: conflicting with left-turning traffic, measured in pedestrians per hour.

Skip-stop data When a skip-stop stopping pattern is used

1. Number of stops in the stopping pattern
2. Bus arrival pattern: random, typical, or platooned
3. Traffic volume and capacity of the adjacent lane (i.e., lane to the left of the curb lane) measured in vehicles per hour. If no adjacent lane, $\frac{v}{c}$ ratio of the adjacent lane is set to 1.0.

Step 3: Set a design bus stop failure rate

- For existing conditions, it can be measured in the field. Otherwise, we can set
  - 7.5-15% in CBD areas
  - 2.5% in other areas
- Failure rate is used in combination with dwell time variability and the average dwell time to provide an operating margin[6]
  - Lower the design failure rate, the greater the operating margin and schedule reliability and the lower the loading area capacity.
- Given average dwell time (s) t_d, standard deviation of dwell times (s) s, and operating margin (s) t_{om}, the dwell time value t_i corresponding to standard normal variable Z is incorporated in (1)

$$Z = \frac{t_{om}}{s} = \frac{t_i - t_d}{s} \tag{1}$$

[6] maximum amount of time that an individual bus dwell time can exceed the average dwell time without creating the likelihood of a bus stop failure, when the number of buses scheduled to use the stop approaches the stop's capacity.

- This gives the operating margin required to achieve a design failure rate, when a bus operates close to its capacity:

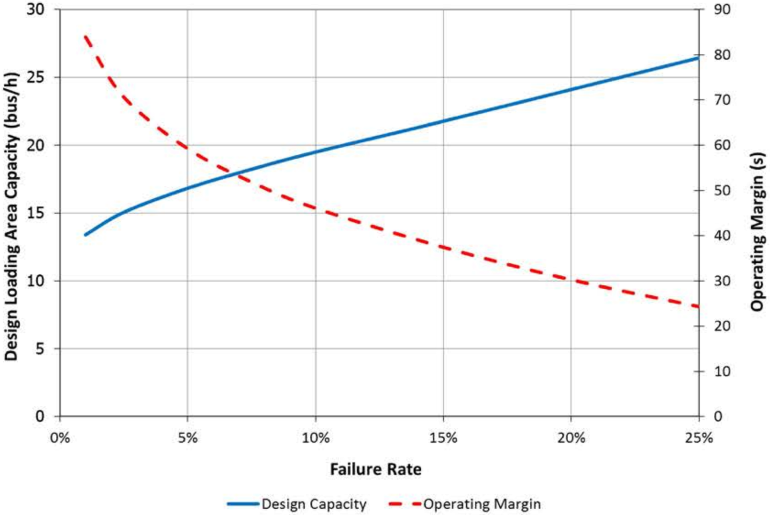
$$t_{om} = sZ = c_v t_d Z \tag{2}$$

Design Failure Rate	Z
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

Source: *TCRP Report 26* (*21*).

Figure: Exhibit 6-56 TCQSM

Relationships between failure Rate, operating margin, and design loading area bus capacity



ote: Assumes 60-s average dwell time and 0.6 coefficient of variation of dwell times.

Step 4: Determine dwell time

Method 1. Field measurement

- For existing bus route, measure the dwell time using field observations or using AVL data

Method 2. Default values

- If the field data or passenger counts are unavailable for a bus stop, use
  - 60s for CBD or major transfer point
  - 15-30 for other stops

Method 3. Calculation

- If passenger boarding and alighting counts are available
- Determine passenger flow time for each bus door channel

$$t_{pf,i} = P_{a,i}t_{a,i} + P_{b,i}t_{b,i} \tag{3}$$

where,

- $t_{pf,i}$: passenger flow time for door channel i (s)
- $P_{a,i}$: alighting passengers through door channel i (pax)
- $t_{a,i}$: average alighting passenger service time for door channel i (s/pax)
- $P_{b,i}$: boarding passengers through door channel i (pax)
- $t_{b,i}$: average boarding passenger service time for door channel i (s/pax)

- Calculate the dwell time

$$t_d = t_{pf,max} + t_{oc} + t_{bl} \tag{4}$$

where,

- t_d: average dwell time (s)
- $t_{pf,max}$: maximum passenger flow time of all door channels (s)
- t_{oc}: door opening and closing time (s), 2-5 s typical
- t_{bl}: boarding lost time (s)
  - If a bus stop consists of one loading area, boarding lost time is zero
  - For three loading areas, typical value 4s

- Dwell time variability usually captured using c_v
- Impacts of infrequent events on dwell time
  - Wheelchair movements
  - Bicycles
  - Timepoint holding

Step 5: Determine loading area capacity

It depends on the following factors:

- operating margin t_{om} (s) (accounts accounts for longer-than-average dwells to ensure that most buses will be able to immediately use the loading area upon arriving.)
- dwell time t_d (s)
- clearance time t_c (s)
- traffic signal timing

Remark.

- $t_d + t_c =$ average time a given bus occupies a loading area.
- $t_d + t_c + t_{om} =$ minimum headway between buses needed to limit bus stop failure to the design level (for one loading area)

Loading area capacity

Loading area capacity $B_l = \frac{\text{Seconds in an hour available for bus movement}}{\text{Seconds that a design bus occupies the loading area}}$

$$B_l = \frac{3600(\frac{g}{C})}{t_c + t_d(\frac{g}{C}) + t_{om}} = \frac{3600(\frac{g}{C})}{t_c + t_d(\frac{g}{C}) + Zc_v t_d} \tag{5}$$

where,

- B_l: loading area bus capacity (bus/hr)
- g/C: green time ratio (1 for unsignalized intersections)
- t_c: clearance time (s) $= t_{su} + t_{re}$
- t_{su}: minimum time for a bus to start up, travel its own length, and the next bus to pull into the loading area (s) (default of 10 s);
- t_{re}: reentry delay (s) time spent waiting for a gap to pull back into traffic (depends on the intersection if stop near-side)
- Z: standard normal variable corresponding to a desired failure rate

Step 6: Determine bus stop capacity

Bus stop capacity (bus/h) is given by

$$B_s = N_{el} B_l f_{tb} = N_{el} f_{tb} \frac{3600(\frac{g}{C})}{t_c + t_d(\frac{g}{C}) + Z c_v t_d} \tag{6}$$

where,

- N_{el}: number of effective loading areas at the bus stop
- f_{tb}: traffic blockage adjustment factor

Step 6a: Determine the number of effective loading areas

- For linear loading areas, buses may have to wait for the bus(es) in front of them to depart before they can depart.
- Non-linear loading areas are 100% efficient

	On-Line Loading Areas				Off-Line Loading Areas	
	Random Arrivals		Platooned Arrivals		All Arrivals	
Loading Area #	Efficiency %	Cumulative # of Effective Loading Areas	Efficiency %	Cumulative # of Effective Loading Areas	Efficiency %	Cumulative # of Effective Loading Areas
1	100	1.00	100	1.00	100	1.00
2	75	1.75	85	1.85	85	1.85
3	70	2.45	80	2.65	75	2.60
4	20	2.65	25	2.90	65	3.25
5	10	2.75	10	3.00	50	3.75

Sources: *TCRP Report 26* (*21*) and *TCRP Research Results Digest 38* (*37*).

Notes: On-line values assume that buses do not overtake each other.
Values apply only to linear loading areas; non-linear designs are 100% effective.

Figure: Exhibit 6-63 TCQSM

Step 6b: Adjust capacity for traffic blockage at traffic signals

$$f_{tb} = 1 - f_l \left(\frac{v_{cl}}{c_{cl}} \right) \tag{7}$$

where,

- f_{tb}: traffic blockage adjustment factor
- f_l = bus stop location factor, from Exhibit 6-66;

	Lane Type		
Bus Stop Location	Type 1	Type 2	Type 3
Near side	1.0	0.9	0.0
Mid-block before or after traffic signal	0.9	0.7	0.0
Far side	0.8	0.5	0.0

Source: *TCRP Report 26* (21).
Note: f_l = 0.0 for contraflow bus lanes, median busways, and grade-separated busways regardless of bus stop location or lane type, as right turns are either prohibited or do not interfere with bus operations.

Figure: Exhibit 6-66 TCQSM

- v_{cl}: curb lane traffic volume at intersection (veh/h)
- c_{cl}: curb lane capacity at intersection (veh/h).

Step 7: Determine bus facility capacity

Facility capacity without skip-stop operation

- facility capacity is equal to the capacity of the critical stop (bus stop with the lowest capacity) along the facility.

Facility capacity with skip-stop operation

- bus facility capacity is equal to the sum of the capacities of the critical bus stops of each skip-stop group, multiplied by an adjustment factor f_k reflecting inefficient arrival patterns and the effects of high vehicular traffic volumes in the adjacent lane

$$B = f_k(B_1 + \cdots + B_n) \tag{8}$$

Step 8: Determine facility person capacity

The final step is to determine how many persons can be served by the bus facility over the course of an hour. It depends on

- The facility's bus capacity,
- Transit agency policy regarding passenger loads,
- Scheduled headways, and
- Passenger demand diversity.

Scheduled person capacity P_s (pax/hr)

Number of passengers that can be carried through the facility's maximum load section, given the existing schedule and bus model(s) used.

$$P_s = \sum_{i=1}^{N_{bm}} P_{max,i} N_i \tag{9}$$

- $P_{max,i}$: maximum schedule load for bus model i (pax/hr)
- N_{bm}: number of different bus models operated on the facility
- N_i: number of buses of bus model i scheduled to use the facility during the hour (bus/hr)

Remark. If a transit agency's policy is that passenger loading should not regularly exceed P_{max} passengers per bus model during an hour, then

$$P_s = \sum_{i=1}^{N_{bm}} P_{max,i}(PHF)N_i \tag{10}$$

Design person capacity P (pax/hr)

Number of people that could be carried through the facility's maximum load section, if buses were scheduled to use the facility at its full capacity, under a specified set of conditions (e.g., design failure rate, vehicle types, fare collection method).

$$P = P_{max}(PHF)B \tag{11}$$

where,

- P_{max}: weighted average maximum schedule load for buses using the facility (pax/bus)
- B: bus facility design capacity

Suggested reading

All material is taken from the following report:

- Transit capacity and quality of service manual, 3rd Edition [Link] (Chapters 1-6)

Thank you!