Transit Capacity and Quality of Service

CIVL3420 Transportation Systems Engineering
Semester 2, 2005
Dr Jon Bunker
j.bunker@qut.edu.au

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Transit Capacity Analysis

- Transit (public transport) includes:
  - bus
  - heavy rail (e.g. Citytrain)
  - ferry
  - light rail (incl. tram)
  - minor modes e.g. cablecar, monorail

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Capacity and Quality of Service of a Transit Facility

- Capacity is a measure of a transit facility or service's *ability to accommodate a moving stream of persons or vehicles*

Capacity and Quality of Service of a Transit Facility

- Quality of Service is *the overall measured or perceived performance of transit service from the passenger's point of view*
- Estimates of both are needed for most transit planning decisions and actions

Transit Capacity Analysis

- capacity concepts are general to all modes
- for capacity we consider the movement of both:
  - vehicles
  - persons (passengers) in those vehicles

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Transit Facility Person Capacity (TCQSM)

"the maximum 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"

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Transit Facility Person Capacity

- *facility* is used as a term to represent e.g. rail line or bus corridor
- capacity is usually defined for the busiest segment along the facility
  - termed the *maximum load segment*
- transit facility person capacity =
  vehicle passenger carrying capacity *
  transit facility vehicle capacity

Exh 1-5 Factors that Influence Transit Capacity (TCQSM)

VEHICLE CHARACTERISTICS	
• Allowable number of units per vehicle (i.e., single-unit bus, or multiple-car train) • Vehicle dimensions • Seating configuration and capacity • Number of wheelchair securement positions	• Number and height of steps • Maximum speed • Acceleration and deceleration rates • Type of door opening mechanism • Number, location, and width of doors
RIGHT-OF-WAY CHARACTERISTICS	
• Cross-section design (# of lanes, tracks) • Degree of separation from other traffic	• Intersection design and control • Horizontal and vertical alignment
STOP CHARACTERISTICS	
• Amount of time stopped • Stop spacing • Platform height vs. vehicle floor height • Number and length of loading positions	• Fare collection method • Type of fare • Common vs. separate boarding/alighting areas • Passenger access to stops
OPERATING CHARACTERISTICS	
• Intercity vs. suburban operations at terminals • Layover and schedule adjustment practices	• Time losses to obtain clock headways, provide driver relief • Regularity of arrivals at a given stop
PASSENGER TRAFFIC CHARACTERISTICS	
• Passenger concentrations and distribution at major stops	• Ridership peaking characteristics
STREET TRAFFIC CHARACTERISTICS	
• Volume and nature of other traffic	• Presence of at-grade intersections
METHOD OF HEADWAY CONTROL	
• Automatic or by train operator	• Policy spacing between vehicles

Vehicle Passenger Carrying Capacity

- operation at physical capacity of the vehicle (*crush load*) is unsustainable due to passenger comfort constraints
- instead we consider capacity under an *allowed passenger loading* for a desired quality of service
- capacity affected by seating configuration and vehicle size (e.g. Citytrain fleet data)

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QR Passenger Fleet Examples

Length (3-car set) 72.4m

Tare Weight (3-car set) 122.1 t

Maximum Speed 100 km/h

Door Operation Automatic opening/closing. Button beside door.

Seating Capacity (3-car set) 236

Service Standing Capacity (3-car set) 266

Total Service Capacity (3-car set) **502**

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QR Passenger Fleet Examples

Length (3-car set) 72.4m

Tare Weight (3-car set) 131.8 t

Maximum Speed 140 km/h

Door Operation Automatic opening/closing. Button beside door.

Seating Capacity (3-car set) 224

Service Standing Capacity (3-car set) 275

Total Service Capacity (3-car set) 499

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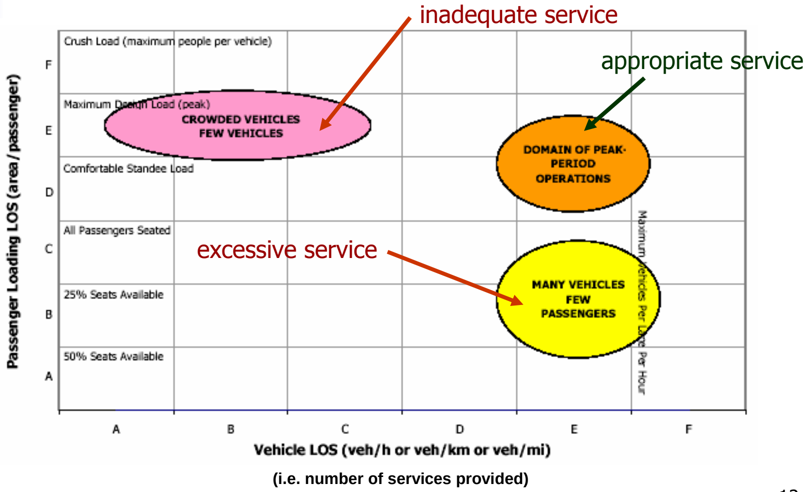
Exh 1-4 Relationship between Person and Vehicle Capacity (TCQSM)



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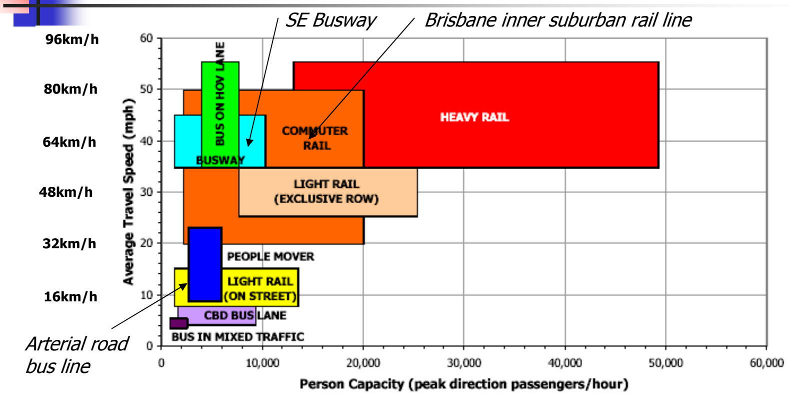
Exh 1-7 Typical Travel Speed and Person Capacity Ranges



SOURCES: TCQSM speed and capacity estimation procedures, *TCRP Report 13* (R5), *Transportation Planning Handbook* (R2), *Characteristics of Urban Transportation Systems* (R1)

NOTES: ROW = right-of-way
Speed ranges primarily reflect differing assumptions on stop spacing and dwell time. Capacity ranges primarily reflect differing assumptions for dwell time and number of cars per train. Peak hour factor and passenger loading assumptions reflect TCQSM recommendations.

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Transit Facility Capacity

- The following transit modes are considered:
  - Bus
  - Rail
  - Ferry
- principles are similar for other modes

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Bus Facility Capacity

- depends on vehicle capacity of:
  - bus facilities (lanes within corridors, which may be shared with general traffic)
  - bus stops (which may contain multiple loading areas)
  - loading areas (bus berths)
- and buses' passenger carrying capacity

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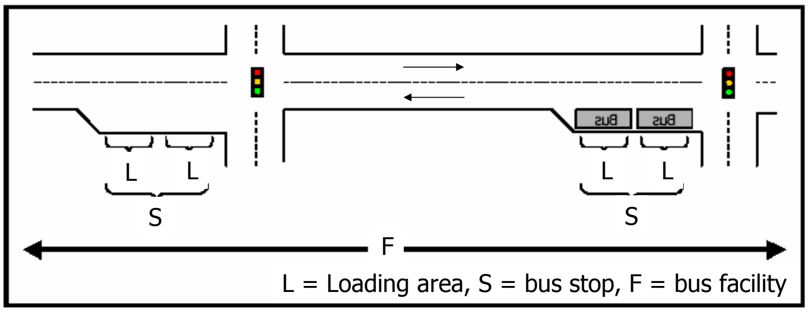
Exh 4-1 Bus Loading Areas, Stops, Facilities



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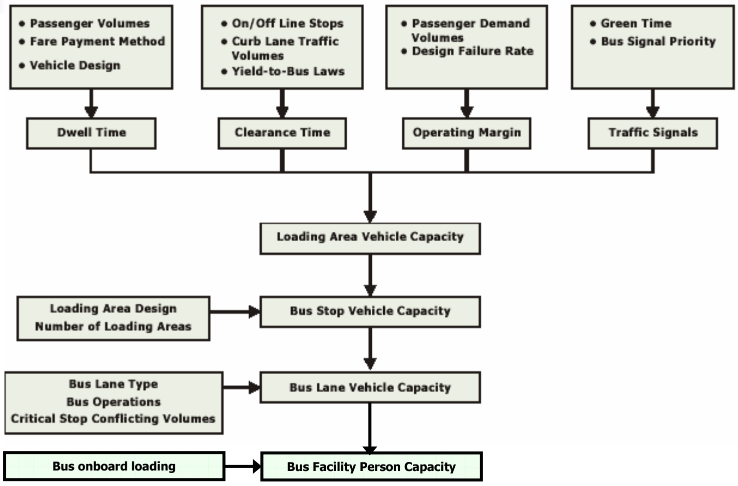
Exh 4-15 Bus Facility Capacity Factors



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Loading Area Bus Capacity

- *dwell time*
  - Average amount of time a bus is stopped to serve passenger movements including time to open/close doors
- *clearance time*
  - Minimum time required for one bus to pull out and clear loading area and the next bus to pull into loading area, including any time spent waiting for gap in traffic

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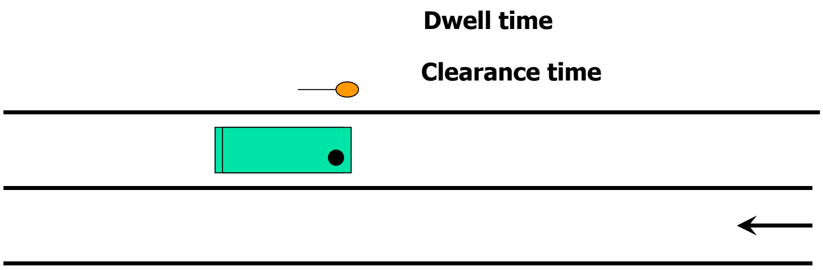
Loading Area Bus Capacity



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Loading Area Bus Dwell Times

- For a bus facility capacity analysis, dwell times at the busiest stop typically govern
- Default peak period av. dwell times (s):
  - 60s at a major stop (CBD, busway, park and ride, express)
  - 30s at a major outlying stop
  - 15s at a typical outlying stop

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Estimating Average Bus Dwell Times

$$t_d = P_a t_a + P_b t_b + t_{oc} \qquad [1]$$

- where:
  - P_a is alighting pass/bus through busiest door (p)
  - t_a is the alighting passenger service time (s/p)
  - P_b is boarding pass/bus through busiest door (p)
  - t_b is the boarding passenger service time (s/p)
  - t_{oc} is the door opening and closing time (s)
    - (typically 2 to 5s)

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Exh 4-2 Passenger Service Times (Single Channel)

Situation	Passenger Service Time (s/p) Observed Range	Suggested Default
BOARDING		
Pre-payment*	2.25-2.75	2.5
Single ticket or token	3.4-3.6	3.5
Exact change	3.6-4.3	4.0
Swipe or dip card	4.2	4.2
Smart card	3.0-3.7	3.5
ALIGHTING		
Front door	2.6-3.7	3.3
Rear door	1.4-2.7	2.1

*includes no fare, bus pass, free transfer, and pay-on-exit
Add 0.5 s/p to boarding times when standees are present.
Subtract 0.5 s/p from boarding times and alighting times on low-floor buses.

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Exh 4-3 Passenger Service Times (Multiple Channels)

Available Door Channels	Default Passenger Service Time (s/p) Boarding*	Front Alighting	Rear Alighting
1	2.5	3.3	2.1
2	1.5	1.8	1.2
3	1.1	1.5	0.9
4	0.9	1.1	0.7
6	0.6	0.7	0.5

*Assumes no on-board fare payment required

Increase boarding times by 20% when standees are present. For low-floor buses, reduce boarding times by 20%, front alighting times by 15%, and rear alighting times by 25%.

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Estimating Average Bus Clearance Times

- Range widely from 9s to 90s
- Typically 10s for bus to clear own length from rest
- Also need to add any re-entry delay (while bus waits for a gap)

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Exh 4-5 Average Bus Re-entry Delay (Random Vehicle Arrivals)

Adjacent Lane Mixed Traffic Volume (veh/h)	Average Re-Entry Delay (s)
100	1
200	2
300	3
400	4
500	5
600	6
700	8
800	10
900	12
1,000	15

SOURCE: Computed using HCM 2000 unsignalized intersection methodology (minor street right turn at a stop sign), assuming a critical gap of 7 seconds and random vehicle arrivals. Delay based on 12 buses stopping per hour.

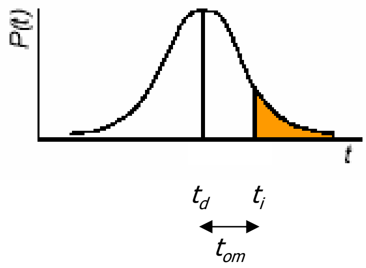
Loading Area Bus Capacity

- Dwell Time variability
  - Consistency or lack thereof of dwell times among buses using loading area
- Failure Rate
  - Probability that one bus will arrive at a loading area only to find another bus already occupying it
- Operating Margin
  - Added to dwell and clearance times to ensure failures do not occur more than the desired failure rate

Estimating Bus Operating Margin

- Dwell time distribution
- t_d = av. dwell time (s)
- t_i = dwell time not exceeded at desired failure rate (s)
- tail (orange) to right of t_i represents desired failure rate
- t_{om} = operating margin (s)

Standard normal distribution.



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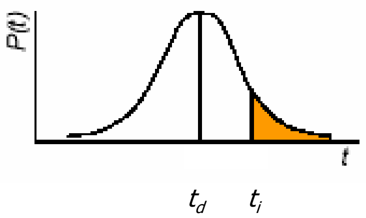
Estimating Bus Operating Margin

- s = standard deviation of dwell times
- c_v = coefficient of variation of dwell times (non-dimensional)

  $c_v = s/t_d$
- c_v typically ranges from 0.4 to 0.8
- Default value of $c_v = 0.6$ recommended

Standard normal distribution.



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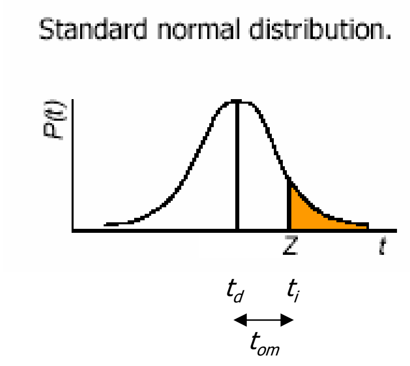
Estimating Bus Operating Margin

- Z = standard normal variate corresponding to desired failure rate (also non-dimensional)
- Z = no. of standard deviations away from mean that desired failure rate lies



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

$$t_{om} = sZ = c_v t_d Z \qquad [2]$$

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Exh 4-6 Values of Z associated with Given Failure Rates

Failure Rate	Z = no. of std deviations from mean
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

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Loading Area Average Bus Processing Time

- *Av. processing time* $= t_c + t_d + t_{om}$

- But what about interruptions due to nearby traffic signals?

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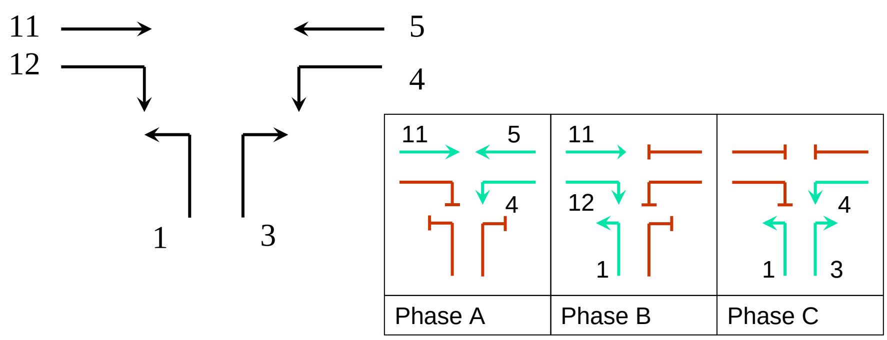
Signalised Intersections Example T Junction

movements



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Signalised Intersections

- We assign phase durations in proportion to the movements' demands
- We run the phases consecutively, then repeat them
- one series is called a "cycle" - refer ring diagram

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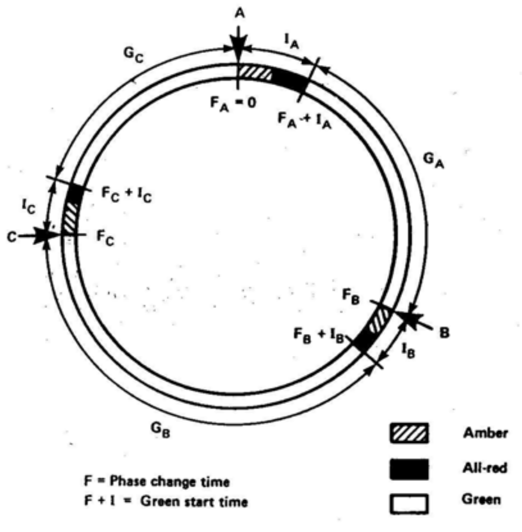
Signalised Intersection Ring Diagram



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Signalised Intersections

- Cycle consists of phases split into:
  - Intergreen Time (yellow + all red), I
  - Displayed Green Time, G
- in the 3 phase example times are:

$$C = I_A + G_A + I_B + G_B + I_C + G_C$$

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Signalised Intersections on a Bus Corridor

- Consider if eastbound buses operate along the through road (corridor) on movt 11
- This movement's *effective green time* is approximately:

$$g_{11} \approx G_A + G_B$$

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Signalised Intersections on a Bus Corridor

- Its *effective green time ratio* or proportion of cycle available is:

  $u = g/C$

- If there are 3,600s per hour then for the bus loading area:

  Available processing time = 3,600 g/C

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Signalised Intersections on a Bus Corridor

- Also need to consider effect of signals on loading area's processing time per bus
- If buses dwell randomly, only a proportion of buses' dwell time (=*g/C*) occurs during available processing time. Consequently:

  Av. processing time $= t_c + g/C\, t_d + t_{om}$

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Loading Area Bus Capacity

$$B_l = \frac{3{,}600(g/C)}{t_c + (g/C)t_d + t_{om}} \qquad [3]$$

Available processing time

average processing time during green

- where:
  - B_l is the loading area bus capacity (bus/h)
  - g/C is effective green time ratio for adjacent signalised intersection
  - t_c is the clearance time between successive buses

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Exh 4-8 Estimated Capacity of a Loading Area (bus/h)

	Clearance Time	
Dwell Time (s)	**10 s**	**15 s**
15	116	100
30	69	63
45	49	46
60	38	36
75	31	30
90	26	25
105	23	22
120	20	20

NOTE: Assumes 25% failure rate, 60% coefficient of variation of dwell times, and g/C = 1.0.

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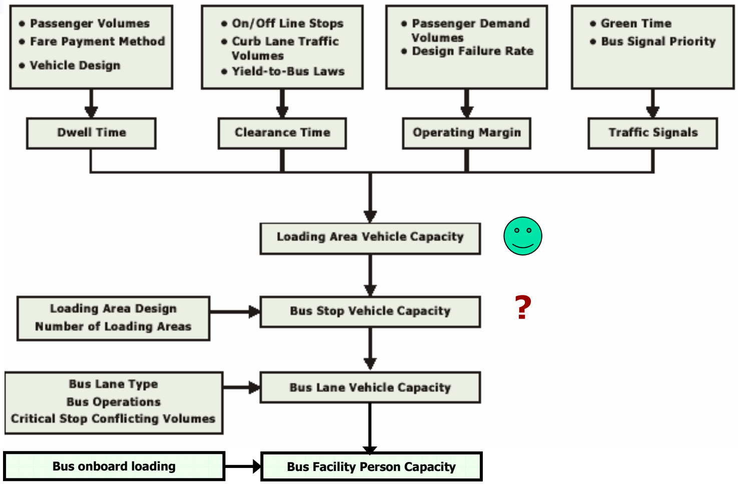
Exh 4-15 Bus Facility Capacity Factors



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Bus Loading Area Types

- On-line
  - following buses cannot overtake stopped bus
- Off-line
  - following buses can overtake stopped bus
  - Improved efficiency

Off-line example

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Bus Stop Vehicle Capacity

- $B_s = N_{el} * B_l$ [4]
  - where:
    - B_s is the bus stop vehicle capacity (bus/h)
    - B_l is the loading area vehicle capacity (bus/h)
    - N_{el} is number of *effective* loading areas

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Exh 4-12 Efficiency of Multiple Linear Loading Areas at Bus Stops

	On-Line Loading Areas				Off-Line Loading Areas	
	Random Arrivals	N_{el}	Platooned Arrivals	N_{el}	All Arrivals	N_{el}
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	80	2.65
4	20	2.65	25	2.90	65	3.25
5	10	2.75	10	3.00	50	3.75

NOTE: On-line values assume that buses do not overtake each other.

- Platooned arrivals also improve efficiency

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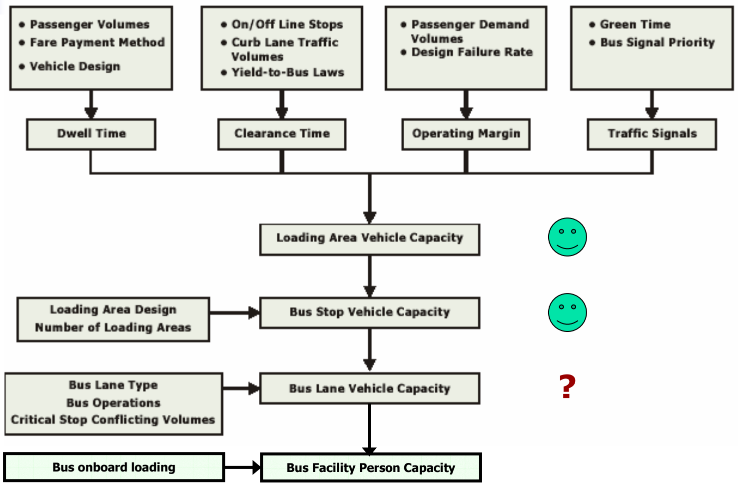
Exh 4-15 Bus Facility Capacity Factors



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Bus Facility Vehicle Capacity

- Bus facility vehicle capacity in mixed lane flow:
- $B = B_s * f_{adj}$ [6]
  - B = bus facility vehicle capacity (bus/h)
  - B_s = *critical* bus stop capacity (bus/h)
  - f_{adj} = adjustment for capacity loss due to general traffic in lane used by buses (usually kerb lane)

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Bus Facility Vehicle Capacity

- Examples of general traffic in the lane:
  - general traffic using a general traffic lane shared by the buses
  - left turners using a bus lane at intersection
  - permitted high occupancy vehicles using a HOV (Transit) lane shared by the buses

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Bus Facility Vehicle Capacity

- $f_{adj} = 1 - f_l\,(v/c)$ [5]
- Where:
  - f_l is a bus stop location and bus lane type *adjustment factor*
  - v/c is the degree of saturation for general traffic in lane used by buses at *controlling intersection* near *critical stop*
    - v = volume of general traffic (veh/h)
    - c = capacity for general traffic (veh/h)

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Exh 4-48 Exclusive Bus Lane Types

Condition at Busway station with no passing lanes

Typical general traffic condition

Typical Busway station/ dual bus lane condition
f_{adj} = 1.0

Type 1

- Buses have no use of adjacent lane
- Contraflow lanes
- Physically channelized lanes

(a) Denver, (b) Orlando

Type 2

- Buses have partial use of adjacent lane, depending on other traffic
- Right turns by other vehicles may or may not be prohibited

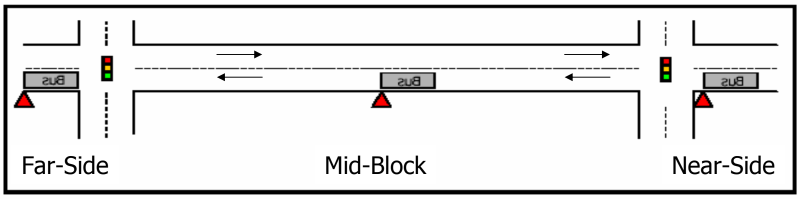
(c) Montréal, (d) Madison

Type 3

- Buses have full use of adjacent lane
- Right turns prohibited (except buses)
- Includes at-grade busways with single lanes, but passing lanes at stops

(e) New York, (f) Miami

Exh 4-51 Bus stop location factors, f_l



	Bus Lane Type		
Bus Stop Location	**Type 1**	**Type 2**	**Type 3**
Near-side	1.0	0.9	0.0
Mid-block	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, as right turns are either prohibited or do not interfere with bus operations.

Exh 4-50 Left-turn General Vehicle Capacities *c* (veh/h) in Bus Lanes

Conflicting ped volume (ped/h)	*g/C* Ratio for Bus Lane 0.35	0.40	0.45	0.50	0.55	0.60
0	510	580	650	730	800	870
100	440	510	580	650	730	800
200	360	440	510	580	650	730
400	220	290	360	440	510	580
600	70	150	220	290	360	440
800	0	0	70	150	220	290
1,000	0	0	0	0	70	150

SOURCE: Chapter 16 of the HCM 2000 (R15), based on 1450*(*g/C*)*(1-((ped. volume)/(*g/C*))/2000).
NOTE: Values shown are for CBD locations, multiply by 1.1 for other locations. Calculations assume that the bus lane acts as an exclusive right-turn lane for all vehicles other than buses.

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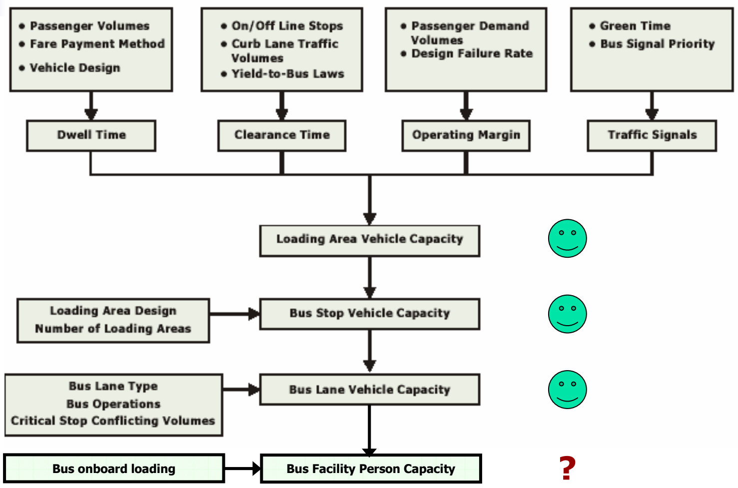
Exh 4-15 Bus Facility Capacity Factors



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Bus Facility Person Capacity

$$P = \min\begin{cases} P_{\max} f(PHF) \\ P_{\max} B(PHF) \end{cases} \qquad [8]$$

- Where:
  - P is bus facility person capacity (p/h)
  - B is bus facility theoretical capacity (bus/h)
  - f is scheduled bus frequency (bus/h)
  - P_{max} is maximum schedule passenger load per bus (p/bus)
  - *PHF* is a peak hour factor accommodating "lumpiness" of arrival patterns of passengers in the peak hour

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Bus Facility Person Capacity

- Peak Hour Factor:
  - $PHF = P_h/(4*P_{15})$ [7]
- Where:
  - P_h is the passenger volume during peak hour (p)
  - P_{15} is the passenger volume during peak 15 minutes (p)
- PHF will be less than 1, usually 0.60 to 0.95

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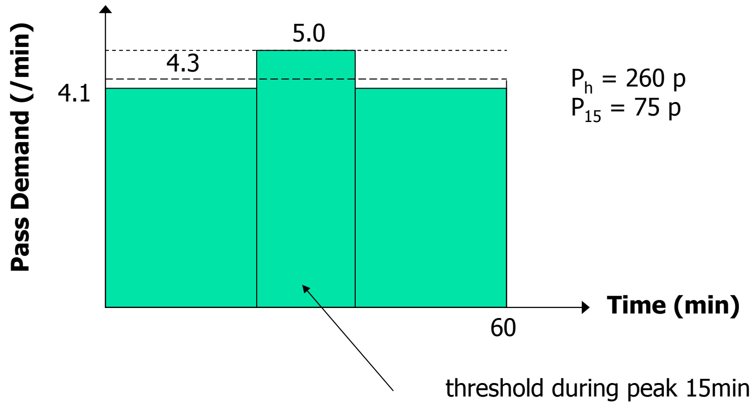
Bus Facility Person Capacity Peak Hour Factor Example



PHF = 260/(4*75) = 0.43/5.0 = 0.87

Exh 4-17 Maximum Schedule Passenger Load P_{max}

- Typically 125% to 150% of seating capacity
- Crush loads (>150%) should not be used for transit capacity analysis

Bus Type	Length (ft)	Width (ft)	Typical Passenger Capacity Seated	Standing	Total
Small Bus/Minibus	18-30	6.5-8.5	8-30	0-10	8-40
Transit Bus (high floor)	35	8.0-8.5	35-40	20-30	50-60
	40	8.5	40-45	20-35	65-75
Transit Bus (low floor)	35	8.0-8.5	30-35	20-35	55-70
	40	8.5	35-40	25-40	55-70
Articulated (high floor)	60	8.5	65	35-55	100-120

SOURCES: 1985 Highway Capacity Manual,[R40] manufacturer specifications.
NOTE: In any transit vehicle, the total passenger capacity can be increased by removing seats and by making more standing room available; however, this lowers the passengers' quality of service. The upper ends of the total capacity ranges represent crush capacity and should not be used for transit capacity calculations.

Bus Facility Capacity Example: Problem Statement

- *what is the controlling stop dwell time for a bus facility (corridor) with the following characteristics?*

- Bus details:
  - articulated high floor buses capacity 110p
  - one double stream front door (entry/exit)
  - fare collection by magstripe and operator cashier
  - one single stream rear door (exit only)

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Bus Facility Capacity Example : Problem Statement

- Busiest stop details (peak 15 min period):
  - P_a = 3 alighting pass/bus through front door
  - (Also have 3 alighting pass/bus through rear door)
  - P_b = 12 boarding pass/bus through front door
  - standees present in buses at busiest stop

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Bus Facility Capacity Example : Dwell Time Calculation

- Assume door opening/closing time t_{oc} = 3.5s
- Alighting time/p t_a = 3.2s

- Boarding time/p t_b = 4.8s assuming:
  - 2/3 use magstripe @ 4.2 s/p
  - 1/6 use exact fare @ 3.9 s/p
  - 1/6 require change @ 5.0s /p
  - 0.5 s/pass additional due to standees

  (Exh 4-2)

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Bus Facility Capacity Example : Dwell Time Calculation

- Apply double stream door adjustment of 0.6 to boarding passengers (Exh 4-2 and Exh 4-3)

  dwell time:

  t_d = 3.2*3 + 4.8*12*0.6 + 3.5 = 48s [1]

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Bus Facility Capacity Example : Problem Statement

- *what is the bus line person capacity at maximum scheduled load?*

- Line schedule characteristics:
  - Buses operate at 3min headways, $f = 20$ *bus/h*
  - $PHF = 0.85$

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Bus Facility Capacity Example : Bus Stop Vehicle Capacity

- busiest stop assumptions:
  - clearance time per articulated bus $t_c = 18s$
  - adjacent signalised intersection $g/C = 0.45$
  - dwell time coefficient of variation $c_v = 0.57$
  - failure probability for loading areas 20%

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Bus Facility Capacity Example : Bus Stop Vehicle Capacity

- busiest stop assumptions:
  - two loading areas on line, platooned arrivals
  - type 2 bus lane with 115 left turn veh/h conflicting with 100 peds/h
  - located on far side of intersection

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Bus Facility Capacity Example : Bus Stop Vehicle Capacity

- Loading area vehicle capacity:

Z_a = 0.84 for 20% failure (Exh 4-6)

t_{om} = 0.57 * 48s *0.84 = 23.0s [2]

$$B_l = \frac{3{,}600(0.45)}{18+(0.45)48+23.0} = 25.9 bus/h \qquad [3]$$

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Bus Facility Capacity Example : Bus Stop Vehicle Capacity

- Bus stop vehicle capacity:

N_{el} = 1.85 (Exh 4-12)

B_s = 1.85*25.9 = 47.9 bus/h [4]

Bus Facility Capacity Example : Bus Facility Vehicle Capacity

- Bus facility vehicle capacity:

Bus stop location factor f_l = 0.5 (Exh 4-51)

Shared bus lane left turning vehicle capacity,
c = 580 veh/h (Exh 4-50)
v/c = 115/580 = 0.19

Bus Facility Capacity Example : Bus Facility Vehicle Capacity

- Bus facility vehicle capacity:

Mixed lane adjustment factor

f_{adj} = 1 - 0.5*0.19 = 0.9 [5]

B = 47.9 * 0.9 = 43.1 bus/h [6]

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Bus Facility Capacity Example Person Capacity

$$P = \min\begin{cases} 110 * 20 * 0.85 \\ 110 * 43.1 * 0.85 \end{cases} = 1{,}870\, p/h \qquad [8]$$

- Minimum achievable headway at facility theoretical vehicle capacity would be 1.4min
- Schedule frequency can be accommodated

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Rail Transit Capacity

- line train capacity
- line person capacity
- other factors
- example

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Rail Line Train Capacity

- Rail line train capacity T (trains/h) given by:

$$T = \frac{3{,}600}{t_{cs} + t_d + t_{om}} \qquad [9]$$

  - where
    - t_{cs} is minimum train control separation (close-in) (s)
    - t_d is dwell time at critical station (s)
    - t_{om} is operating margin (s)

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Exh 5-1 Basic Train Signal Operation

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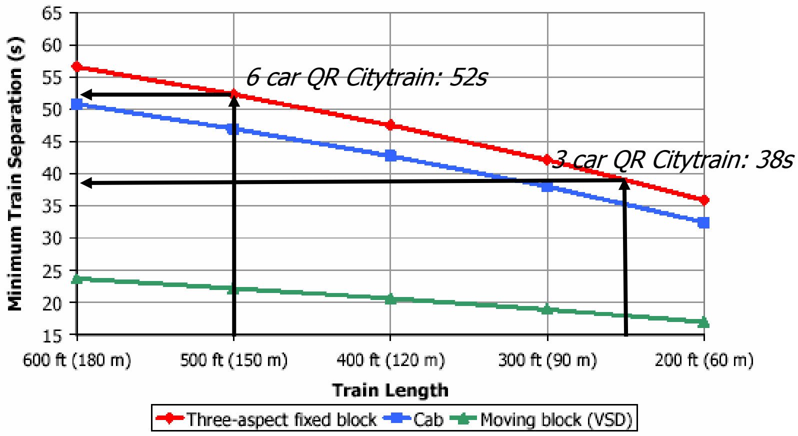
Exh 5-4 Minimum Train Separation t_{cs} Vs Length



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Rail Line Train Capacity: Critical Station Dwell Time, t_d

- Main constituents of dwell time:
  - Passenger flow time at busiest door
  - Ramaining (unused) door open time
  - Waiting to depart time (with doors closed)

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Rail Line Train Capacity: Critical Station Dwell Time, t_d

- Typical peak period dwell times:
  - Major stations 30s to 45s
  - Lesser stations 15s to 20s
  - Depends on passenger processing and schedule adherence policy

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Rail Line Train Capacity: Operating Margin, t_{om}

- To allow for variability in dwell time etc. to reduce train-train interference
- Recommended to aim for 25s and back down to 20s or even 15s if necessary to provide sufficient service to meet estimated demand

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Rail Line Person Capacity

- Rail line person capacity P (p/h) given by:

$$P = \min \begin{cases} fLP_m(PHF) \\ TLP_m(PHF) \end{cases} \qquad [10]$$

  - where
    - f is scheduled train frequency (trains/h)
    - T is line train capacity (trains/h)
    - L is train length (m)
    - P_m is linear loading passenger level (p/m)
    - PHF is the peak hour factor for passenger demand diversity

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Exh 5-63 Peak 15min Linear Loading Passenger Levels

System & City	Trunk Name	Mode	Car Length (ft)	Seats	Avg. Pass/Car	Pass/ ft
NYCT (New York)	53rd Street Tunnel	HR	*see note*	50/70	197/227	3.2
NYCT (New York)	Lexington Ave. Local	HR	51.0	44	144	2.8
NYCT (New York)	Steinway Tunnel	HR	51.0	44	144	2.8
NYCT (New York)	Broadway Local	HR	51.0	44	135	2.7
TTC (Toronto)	Yonge Subway	HR	74.5	80	197	2.7
NYCT (New York)	Lexington Ave. Ex.	HR	51.0	44	123	2.4
NYCT (New York)	Joralemon St. Tun.	HR	51.0	44	122	2.4
NYCT (New York)	Broadway Express	HR	51.0	44	119	2.3
NYCT (New York)	Manhattan Bridge	HR	74.7	74	162	2.2
NYCT (New York)	Clark Street	HR	51.0	44	102	2.0
CTS (Calgary)	South Line	LR	79.6	64	153	1.9
GO Transit (Toronto)	Lakeshore East	CR	85.0	162	152	1.8
SkyTrain (Vancouver)	SkyTrain	HR	40.7	36	73	1.8
PATH (New York)	World Trade Center	HR	51.0	31	92	1.8
PATH (New York)	33rd St.	HR	51.0	31	88	1.7
CTA (Chicago)	Dearborn Subway	HR	48.0	46	82	1.7
NYCT (New York)	60th Street Tunnel	HR	74.7	74	126	1.7
NYCT (New York)	Rutgers St. Tunnel	HR	74.7	74	123	1.6
CTS (Calgary)	Northeast Line	LR	79.6	64	125	1.6
CTA (Chicago)	State Subway	HR	48.0	46	75	1.6
CalTrain (San Fran.)	CalTrain	CR	85.0	146	117	1.4
LIRR (New York)	Jamaica - Penn Sta.	CR	85.0	120	117	1.4
Metra (Chicago)	Metra Electric	CR	85.0	156	113	1.3
MARTA (Atlanta)	North/South	HR	75.0	68	82	1.1
MARTA (Atlanta)	East/West	HR	75.0	68	77	1.0

HR: heavy rail, LR: light rail, CR: commuter rail

NOTE: Service through NYCT's 53rd Street Tunnel in 1995 was provided by line E, operating 60-ft cars, and line F, operating 75-ft cars. Seats and car loadings are presented as "E/F." The number of passengers per foot given is for the combined lines; individually this value is 3.3 for the E and 3.0 for the F. The F was moved to the 63rd Street Connector in December 2001, and a new line V shared the 53rd Street Tunnel with line E.

= 7.3p/m closest to QR Citytrain

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Rail Line Person Capacity: Train Service Capacity

- Train service capacity = $L*P_m$
- QR Citytrain service capacities:
  - 3 car set: $L*P_m$ = 500 p
  - 6 car set: $L*P_m$ = 1,000 p

  http://www.citytrain.qr.com.au/passenger_services/passenger_services.asp
- Corresponding QR Citytrain linear loading passenger level = 6.9 p/m
  - Lower value may be due to narrow car width used on narrow gauge system

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Rail Line Person Capacity: Peak Hour Factor

- Recommended default peak hour factors:
  - Heavy rail: 0.80
  - Light rail: 0.75
  - Commuter (interurban) rail: 0.60

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Exh 5-64 Diversity of Peak Hour and Peak 15min Loading

System & City	Routes	Peak Hour Factor
Commuter Rail		
LIRR (New York)	13	0.56
Metra (Chicago)*	11	0.63
Metro-North (New York)	4	0.75
NJT (New Jersey)*	9	0.57
SEPTA (Philadelphia)	7	0.57
Light Rail		
CTS (Calgary)	2	0.62
RTD (Denver)	1	0.75
SEPTA (Philadelphia)	8	0.75
TriMet (Portland)	1	0.80
Rapid Transit		
BC Transit (Vancouver)	1	0.84
CTA (Chicago)	7	0.81
MARTA (Atlanta)	2	0.76
MDTA (Baltimore)	1	0.63
NYCT (New York)	23	0.81
PATH (New York)	4	0.79
STM (Montréal)	4	0.71
TTC (Toronto)	3	0.79

* Mainly diesel-hauled—not electric multiple unit.

Similar to Brisbane

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Other Factors Influencing Rail Line Train and Person Capacity

- Train control systems
- Turnouts and junction configurations
- Number of tracks upstream, downstream of critical station
- Number of platforms at critical station

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Train Line Capacity Example: Problem Statement

- *What is the person capacity of a rail line with the following characteristics?*
  - six car trains used with service capacity 1000 p:
    - $L\ P_m$ = 1,000 p
  - 3 min headways during peak hour
    - f = 20 trains/h
  - PHF = 0.85

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Train Line Capacity Example: Problem Statement

- Busiest station details:
  - Minimum train separation 55s for safety
  - Peak period dwell time 40s
  - System policy dictates operating margin of 30s

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Train Line Capacity Example: Rail Line Train Capacity

- Rail line train capacity given by:

$$T = \frac{3{,}600}{55 + 40 + 30} = 28.8 trains / h \qquad [9]$$

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Train Line Capacity Example: Person Capacity

$$P = \min \begin{cases} 20 * 1000 * 0.85 \\ 28.8 * 1000 * 0.85 \end{cases} = 17{,}000\, p \qquad [10]$$

- Minimum achievable headway at line train capacity would be 2.1min
- Schedule frequency can be accommodated

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Ferry Line Transit Capacity

- Capacity concepts similar to bus and rail modes

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Ferry Berth Vessel Capacity

- Ferry berth vessel capacity V_b (vessels/h) given by:

$$V_b = \frac{3{,}600}{t_v} \qquad [13]$$

  - where
    - t_v is vessel service time (s)

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Vessel Service Time

$$t_v = t_{ed} + Zc_v t_{ed} + t_c \qquad [12]$$

where:

t_v	=	vessel service time (s/vessel);
t_{ed}	=	average total embarking and disembarking time (s/vessel);
t_c	=	clearance time (s/vessel);
c_v	=	coefficient of variation of the embarking and disembarking time; and
Z	=	standard normal variable corresponding to the probability that the embarking and disembarking time will be more than c_v percent longer than average, from Exhibit 4-6.

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Vessel Service Time

$$t_{ed} = 60\left(\frac{P_d}{C_d} + \frac{L_w}{v_d} + \frac{P_e}{C_e} + \frac{L_w}{v_e}\right) \qquad [11]$$

where:

t_{ed} = total embarking and disembarking time (s/vessel);
60 = number of seconds in 1 minute;
C_d = disembarking capacity at the constraining point (p/min);
C_e = embarking capacity at the constraining point (p/min);
P_d = disembarking passenger volume (p);
P_e = embarking passenger volume (p);
L_w = walkway length (ft, m);
v_d = disembarking passenger speed on walkway, from Exhibit 7-1 (U.S. customary units) or Exhibit 7-1m (metric units) (ft/min, m/min);
v_e = embarking passenger speed on walkway (ft/min, m/min);

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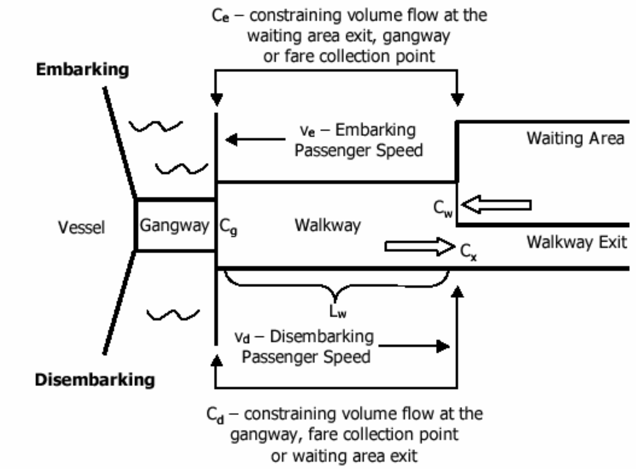
Exh 6-13 Embarking and Disembarking Parameters



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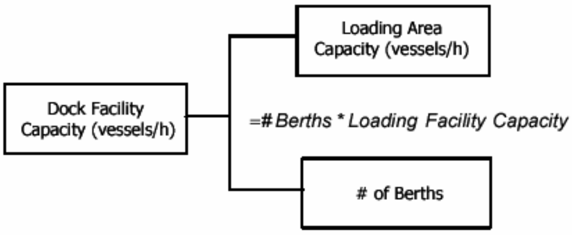
Ferry Dock Vessel Capacity



The vessel capacity of a loading area is given by Equation 6-7:

$$V = \sum_{i=1}^{N_b} V_{bi} \qquad [14]$$

where:

V = dock vessel capacity (vessels/h);
V_{bi} = vessel capacity of berth i (vessels/h); and
N_b = number of berths at the dock.

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Ferry Route Person Capacity

$$P = \min \begin{cases} f.V_c(PHF) \\ V.V_c(PHF) \end{cases} \qquad [15]$$

where:

P = person (auto) capacity on the route's maximum load segment (p/h, autos/h);
V_c = passenger (auto) capacity of the vessel (p/vessel, autos/vessel);
f = vessel frequency (vessels/h); and
PHF = peak hour factor.

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Resources You Should Locate

- Transit Capacity and Quality of Service Manual (TRB 2004)
  - http://trb.org/publications/tcrp/tcrp100/part%201.pdf (Capacity: p1-7 to 1-21)
  - http://trb.org/publications/tcrp/tcrp100/part%204.pdf (Bus: p4-14-1 to 4-18, 4-34 to 4-52, 4-57 to 4-58)
  - http://trb.org/publications/tcrp/tcrp100/part%205.pdf (Rail: p5-58 to 5-69)
  - http://trb.org/publications/tcrp/tcrp100/part%206.pdf (Ferry: p6-1 to 6-18)

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Examples

- Transit Capacity and Quality of Service Manual (TRB 2004)
  - http://trb.org/publications/tcrp/tcrp100/part%204.pdf (Bus: p4-70 to 4-73, 4-77 to 4-80)
  - http://trb.org/publications/tcrp/tcrp100/part%205.pdf (Rail: p5-106 to 5-107, p5-110 to 5-111)
  - http://trb.org/publications/tcrp/tcrp100/part%206.pdf (Ferry: p6-22 to 6-23, p6-25)

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References

- TRB 2004, *Transit Capacity and Quality of Service Manual*, Transportation Research Board, Washington, D.C.
- Ryus P 2002, *Transit in North America*, CEB508 guest lecture notes
- QT *et al* 1999, *Shaping Up*, 2nd ed., Brisbane

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