Bus Facility Capacity

May 2, 2006

Today's Topics
- Types of bus facilities
- Bus facility capacity
- Person capacity

Review: Major Bus Stop Capacity Factors
- Dwell time
- Variability of dwell times among buses using stop
- Delay re-entering street after serving passengers
  - "Clearance time"
- Can a bus enter a stop as soon as it arrives?
  - "Failure rate"
- Traffic signal timing
- Number of loading areas per stop

Review: Bus Capacity Process
- Capacity of a single loading area (bus berth)
- Capacity of a bus stop
  - Provides one or more loading areas
- Facility capacity
  - Determined by the capacity of the "critical" bus stop along the facility— the stop with the lowest capacity
  - Generally the stop with the longest average dwell time

Review: Planning & Operations Methods

Loading Area Vehicle Capacity
% of hour when buses are able to enter/leave the stop

Time an average bus occupies the loading area, plus an allowance for unusually long dwells
Loading Area Vehicle Capacity

- Seconds of green per hour
- Clearance time
- Portion of dwell time during green
- Allowance for dwell time variability

Dwell Time

- Time required to serve passengers, plus door opening & closing time
- TCQSM recommends field measurements, but also provides default values and passenger service times

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<th>Measure</th>
<th>Downtown</th>
<th>CBD</th>
<th>Elsewhere</th>
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<tr>
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</tr>
<tr>
<td>Total</td>
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Dwell Time Variability

- Used in developing "operating margin"—a dwell time that won’t be exceeded more than a desired percentage of the time
- Dwell time variability is measured by the coefficient of variation of dwell times (c_v)
  - Standard deviation of dwell time / average dwell time

Bus Stop Failure Rate

- Measured by Z
  - Statistical value representing the area under one tail of a normal distribution curve

Clearance Time

- Dead time for a bus stop — the time for one bus to start up and clear the stop and the next bus to enter
- Start up and exit time = 10 seconds
- For "off-line" stops (out of traffic flow), add re-entry delay
  - Depends on curb-lane volumes
  - Depends on yield-to-bus laws and motorist compliance
  - Nearby signals will affect

Bus Stop Failure Rate Values

- Average dwell time * Z * c_v equals added dwell time that will not be exceeded more than x% of the time
- For design, use 7.5-15% (CBDs), 2.5-7.5% (elsewhere)
- For maximum capacity, use 25%
**Re-Entry Delay Values**

- Assumes random traffic arrivals on street
- At signals, estimate time for queue to clear instead

**Effective Loading Areas**

- Each additional linear loading area is less efficient than the one before it

**Loading Area Capacity Example**

- Market Street at Presa Street, San Antonio, Texas

**Loading Area Capacity Example**

- Based on real-world data from San Antonio, reported in TCRP Digest 38
- Average dwell time = 30 sec
- Coefficient of variation = 53%
- Assume a desired 10% failure rate (downtown)
- g/C ratio = 0.55
- On-line stop
- 3 loading areas

**Bus Stop Capacity Example**

- 42 buses per hour is the capacity of a single loading area
- This stop has three on-line loading areas (2.45 effective loading areas)
- 42 * 2.45 = 102 buses per hour (round down)
- Agency experience was that about 100 buses per hour was as many as could be scheduled without having operational problems
**Person Capacity**

“The number of people that can be carried past a given location during a given time period under specified operating conditions without unreasonable delay, hazard, or restrictions, and with reasonable certainty.”

**Person Capacity: Scheduled**

- The number of people that can be served day after day under the current schedule, without exceeding the loading standard on any bus

**Person Capacity: Design**

- The maximum number of people that reasonably could be carried at a stop or at the maximum load point of a facility, with no limit on the supply of buses

**Allowed Loading**

- Maximum number of people on a given bus
  - Vehicle characteristics
    - Length, width, floor height, seating arrangement
  - Agency loading standards
    - Standees allowed?
    - Maximum schedule load
      - Average over the hour, or not to be exceeded during the hour?
    - Crush loading

**Peak Hour Factor (PHF)**

- Passengers typically will not arrive at a stop at an even rate
- Need sufficient capacity to handle peaks in demand without causing pass-ups
- Not all of the available capacity (seats and standing space) will be utilized because of these variations in passenger arrivals
Peak Hour Factor (PHF)

- Used to adjust hourly volumes to reflect flow rates during a shorter peak period
- In traffic engineering, a 15-minute peak is usually used:

\[
\text{PHF} = \frac{\text{Volume during peak 15 minutes}}{\text{Volume during peak hour}}
\]

- A PHF of 0.80, for example, means that average hourly volumes are 80% of the volumes during the peak 15 minutes (if they were sustained for an entire hour)
- Looked at another way, average vehicle loading during the peak 15 minutes is \(1/\text{PHF}\) (in this case 25%) higher than the average loading during the peak hour

Typical Peak Hour Factors

- Bus: 0.60 to 0.95
  - Use 0.75 as default if no other info
  - Higher value (e.g., 0.85) appropriate if scheduled headways are varied to even out passenger loads
  - Value close to 1.00 may indicate a need for more service
- TCQSM also gives typical values for rail modes
  - Light rail = 0.60 to 0.80 (0.75 default)
  - Commuter rail = 0.56 to 0.75 (0.60 default)

Vehicle Capacity is a Constraint

- A stop or facility’s vehicle capacity sets an upper limit on the number of passengers that could be carried during a given time

Person Capacity Example

- A light rail line has a capacity of 20 trains per hour, but only 8 trains per hour are currently scheduled
- Each train currently has 2 cars, but platforms allow up to 3-car trains
- Each car has a maximum schedule load of 150 passengers
- What is the person capacity?
Person Capacity Example

- Each train can carry 300 passengers under maximum schedule load conditions (2 cars * 150 p/car)
- Over the course of an hour, not all of this offered capacity will be able to be used, due to variations in passenger arrivals
  - Default PHF = 0.75

Person Capacity Example

- Person capacity (current schedule):
  - (8 trains/h) * (300 p/train) * 0.75 = 1,800 p/h
- Person capacity (ultimate):
  - (20 trains/h) * (450 p/train) * 0.75 = 6,750 p/h

Busways

- Most exclusive facility type
- 40-50 mph running speeds typical between stations
- Extensive infrastructure

Types of Bus Facilities

- Grade-separated busways
- Freeway HOV lanes
- Arterial street bus lanes
  - At-grade busways (in street median or parallel to street)
  - Exclusive lanes
  - Bus streets
- Mixed traffic
  - Most common facility type

Uninterrupted flow
- No traffic signals, stop signs
- Exclusive use by buses
- Grade-separated
- Off-line bus stops, or passing lane at stops
Busways

- Often scheduled for a mix of express and local service
- Can provide bus-only access points
- CBD access
- CBD distribution

Potential capacity constraints
- On-street operations in or near the CBD
- Busway supplies more buses than can be served
- High-dwell time stations
- Stations without passing lanes

Busway Definition Issues

- Term "busway" has been applied to a number of exclusive bus facilities with greatly different speed & capacity characteristics
  - Fully grade-separated facilities
  - Exclusive, interrupted-flow facilities (e.g., South Dade Busway) with some traffic signals
  - Median bus lanes (common in South America) with frequent signals

TCQSM defines several busway types:
- Grade-separated busways (Ottawa, Pittsburgh, Brisbane)
- Median busways (Vancouver, Cleveland)
- At-grade busways (Miami, Los Angeles)
- Busways with traffic signals are treated as arterial street bus lanes for capacity purposes
  - Exception: full signal pre-emption (like some LRT lines) can be treated as grade-separated for capacity purposes

Freeway HOV Lanes

- High Occupancy Vehicle lanes
- Generally found in larger cities
- Range in length from miles to short congestion bypasses
- Provide faster operations for HOVs

Uninterrupted flow
- May be shared with 2+ or 3+ carpools
- Lanes may or may not be separated from other traffic
- Off-line bus stops, if any
Freeway HOV Lanes
- Often used in association with park-and-ride lots
- Express service from P&R to downtown or other major destinations

Freeway HOV Lane Capacity
- Bus capacity generally will be constrained before or after HOV lanes
  - CBD bus distribution needs to be addressed
- Other than the Lincoln Tunnel, bus volumes do not approach a freeway lane’s capacity
  - Lincoln Tunnel: 735 bus/h & 32,000 p/h
- HCM procedures can be used to calculate the vehicle capacity of an HOV lane shared with carpools

Arterial Street Bus Lanes
- Interrupted flow
- At least one lane reserved exclusively for buses
  - Right turn, taxi exceptions
- Buses may or may not share other lanes with general traffic

Arterial Street Bus Lanes
- Variety of designs
  - 1 & 2 lanes
  - Same direction & contraflow
  - Physically separated or not
  - Part-time & full-time

Exclusive Bus Lane Types
- Type 1
  - Buses must remain in a single lane
- Type 2
  - Buses may use adjacent lane, if traffic permits
- Type 3
  - Two lanes reserved for buses, or
  - Single lane, with off-line bus stops

Type 1 Bus Lanes
- Single lane
- No passing opportunities at stops
- May be physically separated from other traffic
Type 1 Bus Lanes

- **Typical applications**
  - Single, frequent, headway-based route
  - Downtown circulators & distributors
  - Bus streets
  - Median busways

Denver

Type 2 Bus Lanes

- **Single lane reserved for buses**
  - Right turns may be allowed
  - Taxis, HOVs may be allowed
  - Buses may use general-purpose lanes for passing

San Antonio

Type 2 Bus Lanes

- **Typical applications**
  - Streets with frequent bus service
  - Part-time lanes created by removing parking

- **Enforcement issues**
  - Double-parking
  - Non-bus use

Montréal

Type 3 Bus Lanes

- **Two lanes reserved for buses**
  - Single exclusive lane with passing opportunities at stops
  - Other traffic not allowed to turn right from lanes

New York

Type 3 Bus Lanes

- **Typical applications:**
  - Downtown streets with very high bus volumes (New York, Portland)
  - At-grade busways

Miami

Bus Lane Capacity Factors

- **Critical Bus Stop Capacity**
  - The most important facility capacity factor
  - Sets an upper limit to the capacity of stops used by the same group of buses
Bus Lane Capacity Factors

- Critical Bus Stop Capacity
- Bus Lane Design

- Bus lane type determines bus freedom to maneuver around obstacles
- Bus stop location affects how right turns will impede bus movements

Mixed Traffic Operations

- Two bus lane types:
  - Type 1: One travel lane in direction of travel
  - Type 2: Two or more lanes in direction of travel

- Most common bus environment
- Buses share their lane with other traffic
- Interrupted flow
- Potential for delays from a variety of sources

Portland Arterial Bus Lane Capacity

- Type 1:
  - One travel lane in direction of travel
- Type 2:
  - Two or more lanes in direction of travel

- Right-turn volumes (may block curb lane)
- Adjacent lane volumes (inhibit passing)
- Conflicting ped volumes (may impede right turns)
Capacity Methodologies for Bus Facilities

- Same as for bus stops
  - Planning method
    - Graphical method
    - Uses default values for inputs
    - Useful for narrowing list of alternatives to evaluate before jumping into an operations analysis or simulation
  - Operations method
    - Computational method
    - Use when input values are known

Critical Stop Identification

- Both methods require identifying the critical stop
- Usually the stop with the greatest passenger activity (longest dwell times)
- Other factors to check:
  - Near-side stop with high right-turn and pedestrian volumes
  - Traffic signal with low green time for bus movements

Planning Methodology Inputs

- Facility type
  - Exclusive—Type 1, 2, or 3
  - Mixed—Type 1 or 2
- Critical stop location
  - Near-side, far-side
- Critical stop average dwell time
  - 30 or 60 seconds

Planning Methodology Example

- Curb bus lane in downtown
- Critical stop information:
  - On-line
  - Near-side
  - 200 right turns per hour
  - 400 conflicting peds per hour
  - 2 loading areas
  - 60 seconds dwell time
- Passing allowed from curb lane

Planning Methodology Defaults

- Downtown location
  - 10% failure rate
  - $g/C = 0.45$
- 60% dwell time variability
- On-line stops
- TCQSM spreadsheets can be used to develop graphs for different sets of default and input values
**Planning Methodology Example**

Bus Lane Capacity

- Bus lane capacity is the capacity of the critical bus stop, reduced by a factor \( f \) accounting for right-turning cars that impede buses.

- Right-turn volume
- Right-turn capacity (relates to ped volumes)
- Bus stop location factor

**Planning Method Next Steps**

- Bus lane capacity of 17 buses per hour is less than the volume that guidelines suggest are needed for a bus lane.
- What could be done to increase capacity?

**Bus Stop Location Factor \( (f) \)**

- Near-side stops are affected more by right turns than far-side stops.
- Contraflow and median lanes unaffected by right turns.
- Type 3 lanes prohibit right turns: bus lane capacity = bus stop capacity.

- \( f \) values:
  - Type 1: 0.5
  - Type 2: 0.3
  - Type 3: 0.0

Initial Right-turn Volume:

- 10 buses/h × 1.75 = 17 buses/h
Right-Turn Capacities

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</table>

- Approximate values
- Consult the HCM if more precise values are required

Operations Method Example

- Right-turn capacity:

Operations Method Example

- Right-turn factor:

Operations Method Example

- Critical bus stop capacity:

Operations Method Example

- Bus lane capacity:
Mixed Traffic Bus Capacity

- Same basic procedure as exclusive lanes
- \( \frac{v}{c} \) ratio of right (curb) lane substituted for \( \frac{v}{c} \) ratio of right-turn movement—use HCM to determine capacity
- Procedure has not been field-verified, but theoretical basis exists
- Planning and operations methods

Typical Bus Lane Operation

- All buses stop at every stop
- Bus stops located every 2-3 blocks
- Capacity generally limited to no more than 100 buses per hour, depending on:
  - Dwell time at critical stop
  - Right-turn volumes
  - Number of loading areas provided

Skip-Stop Operation

- Routes divided into 2-4 groups
- Bus stops located in every block
- Buses stop at every 2\textsuperscript{nd}, 3\textsuperscript{rd}, or 4\textsuperscript{th} stop—the one assigned to their group
- Can significantly increase capacity, but makes system more complex for passengers

Skip-Stop Example

4 stops in the pattern

WASHINGTON ST
ALDER ST
MORRISON ST

Skip-Stop Factor

- \( f_a \) = arrival type factor (ability to fully utilize bus stops)
  - 0.50: random arrivals (poor scheduling/schedule adherence)
  - 0.75: typical arrivals (imperfect schedule adherence)
  - 1.00: platooned arrivals
Skip-Stop Factor

- \( f_i \) = adjacent lane impedance factor (reflects bus' ability to pass each other)
- \( N_{ss} \) = number of stop patterns (e.g., four for Portland on 5th & 6th Ave.)

Portland Mall (5th Avenue) Example

- Data from Transportation Research Record 38
  - July 1997
  - Prior to opening of Westside MAX—bus mall scheduled at close to its capacity
- Used to develop speed estimation procedures now in the TCQSM
  - Speed estimation will be covered later

Portland Mall (5th Avenue) Example

- Data cover Oak to Morrison
- \( g/C = 0.45 \)
- \( t_c = 10 \) seconds
  - Bus operating rule on mall requires buses in the middle lane to yield to buses exiting stops
- 2 on-line loading areas: \( N_{el} = 1.75 \)
- Assume 7.5% failure rate: \( Z = 1.28 \)
- No right turns allowed from bus lanes

Portland Mall (5th Avenue) Example

- \( f_a = 0.75 \) (imperfect schedule adherence)
- \( N_{ss} = 4 \)
- \( f_i = 1.00 \)
  - scheduled volume = 160 bus/h
  - capacity = 765 bus/h (from HCM)

Number of buses scheduled (160) was close to the mall's capacity (166), at a 7.5% failure rate.
### Additional Reading

- TCQSM, Part 4