Bus Transit Capacity

Presentation Overview

- Brief introduction to the project
- Bus vehicle and service types
- Bus capacity estimation
- Bus speed estimation
- Bus preferential treatments
- Questions to think about
Project Overview

- Recommend additions, revisions, format
- Conduct gap-filling research
- Prepare TCQSM 3rd Edition
- Prepare information program

TCQSM Webinar Series Objectives

- Provide background on TCQSM material for focus group and online survey participants
- Expand industry’s awareness of the manual and its potential uses
- Lay groundwork for updated training material when the new manual is published (2013)
Webinar Series Topics

- Overview of the TCQSM 2nd Edition
- Fixed Route Quality of Service
- Bus Transit Capacity
- Rail Transit Capacity
- Ferry Transit Capacity
- Stop, Station, and Terminal Capacity
- Demand Response Capacity and Quality of Service

Bus Vehicle and Service Types
Bus Vehicle Types

- Standard Bus
- Articulated
- Low-floor
- Over-the-road coach
- Electric
- Double-deck
- Purpose-built
- Replica trolley

Bus Vehicle Considerations

- Passenger capacity
  - Operating costs
- Passenger quality of service
- Environmental concerns
- Neighborhood concerns
- Maintenance, durability
- Service type
  - Local bus, commuter service, tourist service, etc.
Bus Right-of-Way Examples

- Mixed traffic
- Bus lane
- Median busway
- Off-Road Busway

Bus Right-of-Way Considerations

- Exclusive bus facilities cost more to build, but:
  - Provide more capacity, and
  - Provide better passenger quality of service
    - Faster travel times
    - Better reliability
Bus Service Types

- Fixed-route
  - Hail-and-ride
  - Local
  - Limited-stop
  - Express
- Deviated route

Bus Rapid Transit (BRT)

- A flexible, rubber-tired form of rapid transit that combines stations, vehicles, services, running ways, and ITS elements into an integrated system with a strong identity
BRT Toolbox

- Frequent service
- Longer stop spacing
- Stations
- Special running ways and intersection priority
- Distinctive identity
- ITS elements
- Off-vehicle fare collection
Why Should We Be Interested in Capacity?

- The same factors that influence capacity also influence speed and reliability
  - Impacts quality of service (and thus ridership)
  - Impacts agency operations costs

Why Should We Be Interested in Capacity?

- Planning
  - Arterial bus lanes
    - Maximum number of buses that can be served
    - Speed of buses, with and without the bus lane
  - Bus rapid transit (BRT)
    - Potential speed improvements due to increasing stop spacing, decreasing dwell time
  - Assessing potential impacts of changes
    - Will another bus need to be added on a route to meet loading standards if low-floor buses are purchased?
    - Impacts of changing fare-collection procedures
Why Should We Be Interested in Capacity?

- **Planning**
  - Special event service
    - Number of buses required to serve a given demand
- **Design**
  - Number of bus berths required at stops & transit centers
  - Locating bus stops

A Simple Capacity Example: OHSU Aerial Tram

- An aerial tram departs a station every 5 minutes
- Each tram can hold up to 78 passengers
Vehicle Capacity

“The number of transit vehicles that can be served by a loading area, stop, station, or facility during a specified period of time.”

- Tram departs a station every 5 minutes
- Vehicle capacity = 12 trams/h

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.”

- Line capacity = 12 trams/h
- Individual trams can carry 78 passengers/trip
- Maximum person capacity = 936 passengers/h
- Is this a reasonable result?
Design Capacity

“The greatest number of people/vehicles a transit facility can serve, at a desired level of reliability.”

- Use for scheduling
  - For vehicles, incorporates a safety ("operating") margin so that a given bus will delay a following bus no more than "x"% of the time (typically 5-15%)
  - For persons, the demand that can be served day after day without overcrowding occurring
- What the TCQSM means by “capacity” when the word is used by itself

Maximum Capacity

“The greatest number of vehicles/people a transit facility can serve, without regard to reliability.”

- More theoretical than practical
  - For quality of service and operational reasons, one usually wouldn’t want to try schedule service based on maximum capacity
- However, it’s an input to the TCQSM’s speed estimation procedure
**Scheduled Capacity**

“The greatest number of people a transit facility can serve using a particular set of vehicles, at a desired level of reliability, given a particular schedule.”

- Will usually be less than the design capacity
  - Cost constraints
  - Insufficient demand to require more service
- Difference between how many people can you serve and how many could you serve

**Where Is Bus Capacity Measured?**

- Loading Area Capacity
- Bus Stop Capacity
- Bus Facility Capacity
Where Is Bus Capacity Measured?

L = loading area, S = bus stop, F = bus facility

Loading Area Vehicle Capacity Factors

% of hour when buses are able to enter/leave the stop

\[
\text{Capacity} = \frac{\text{Time an average bus occupies the loading area, plus an allowance for unusually long dwells}}{\text{Time an average bus occupies the loading area, plus an allowance for unusually long dwells}}
\]
Loading Area Vehicle Capacity Factors

\[
\text{Capacity} = \frac{\text{Traffic signal timing} \times \% \text{ of hour when buses are able to enter/leave the stop}}{\text{Dwell time, delay re-entering street}} \times \text{Time an average bus occupies the loading area, plus an allowance for unusually long dwells}} \times \text{Dwell time variability, desired level of reliability}}
\]

Bus Stop Vehicle Capacity Factors

\[
\text{Capacity} = \text{Loading area vehicle capacity} \times \# \text{ of “effective loading areas”}
\]
Bus Stop Vehicle Capacity Factors

Traffic signal timing, dwell time, dwell time variability, delays re-entering the street, desired reliability

Loading area vehicle capacity × # of “effective loading areas”

Actual # of loading areas, bus stop location & design

Bus Facility Vehicle Capacity Factors

Lowest bus stop capacity along the facility × adjustment factors
Bus Facility Vehicle Capacity Factors

Capacity = Lowest bus stop capacity along the facility × adjustment factors

- Usually the stop with the highest dwell time
- Facility design (mixed traffic vs. bus lanes), traffic volumes, bus operations

Dwell Time

- Time spent stopped to serve passengers, including opening and closing the doors
- The single most important factor in determining bus capacity
- Influenced by
  - Passenger demand
  - Fare payment method
  - Vehicle design
  - Whether or not standees are present on buses
TCQSM Guidance on Dwell Time

- Passenger service times for different fare payment systems
- Vehicle design impacts on dwell time
  - Floor height
  - Number & size of doors used for boarding
- Wheelchair & bicycle loading times
  - Often random events; addressed by dwell time variability
- Impact of standees on boarding/alighting times

Dwell Time Variability

- Some buses will dwell longer than the average
- Capacity will be lower than if all buses dwelled the same amount of time
- This variability is measured by the coefficient of variation of dwell times ($c_v$)
  - Standard deviation of dwell time / average dwell time
Dwell Time Variability

- $c_v = 0\%$: dwell times are always the same
- Dwell time $c_v$ typically ranges from 40-80%
  - Field measure or use 60% as default

Clearance Time

- Average minimum time between one bus pulling out of the stop and the next bus pulling in
- Includes:
  - Time waiting for a gap in traffic
  - Time for a bus to travel its length, clearing the stop
- Doesn’t include:
  - Time waiting for a traffic signal
**TCQSM Guidance on Clearance Time**

- Average delays re-entering the street, for various curb-lane volumes
- Average time for a bus to travel its length and the next bus to pull in

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

**Bus Stop Failure Rate**

- The probability that a bus will arrive at a stop and have to wait for other buses to leave before it can serve passengers
  - A higher failure rate means a stop is used more efficiently
    - The stop is unoccupied less often during the hour
    - However, reliability suffers as buses are more likely to be delayed waiting for other buses
- Failure rate can be observed in the field, or set as a design value to use when planning service
  - Converts maximum bus capacities to design capacities
**TCQSM Guidance on Failure Rate**

- **Recommended design failure rates**
  - Downtown vs. other locations

- **Failure rate for maximizing capacity**
  - Used for TCQSM bus speed calculations

- **Table giving statistical Z values corresponding to different failure rates**
  - Z values are used when using equations to calculate capacity

**Traffic Signal Timing**

- Traffic signals meter the flow of buses into and out of bus stops
  - Buses are delayed if they are still stopped after the doors close (near-side stop), or if they have to stop twice (far-side stop)

- The capacity reduction is related to the g/C ratio—the % of time a green signal is given to the bus’ direction of travel

- g/C = 1.0 at unsignalized locations
Loading Area Vehicle Capacity

% of hour when buses are able to enter/leave the stop

\[
B_l = \frac{3,600(g / C)}{t_c + t_d (g / C) + Z_c t_d}
\]

Time an average bus occupies the loading area, plus an allowance for unusually long dwells.

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Notes:
- \( B_l \): Loading Area Vehicle Capacity
- \( g \): Seconds of green per hour
- \( t_c \): Clearance time
- \( t_d \): Portion of dwell time during green
- \( Z_c \): Allowance for dwell time variability
How Many Loading Areas?

- Bus stops may have enough room to serve more than one bus at a time
  - Each stopping position is called a loading area or bus berth
- Having multiple loading areas at a stop provides additional capacity, but in most cases the relationship isn’t 1:1
- TCQSM provides guidance on the number of “effective loading areas” associated with different bus stop designs

### Effective Loading Area Table

<table>
<thead>
<tr>
<th>Loading Area #</th>
<th>On-Line Loading Areas</th>
<th>Off-Line Loading Areas</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Random Arrivals</td>
<td>Platooned Arrivals</td>
</tr>
<tr>
<td></td>
<td>Efficiency %</td>
<td>Cumulative %</td>
</tr>
<tr>
<td></td>
<td># of Effective Areas</td>
<td># of Effective Areas</td>
</tr>
<tr>
<td>1</td>
<td>100</td>
<td>1.00</td>
</tr>
<tr>
<td>2</td>
<td>75</td>
<td>1.75</td>
</tr>
<tr>
<td>3</td>
<td>70</td>
<td>2.45</td>
</tr>
<tr>
<td>4</td>
<td>20</td>
<td>2.65</td>
</tr>
<tr>
<td>5</td>
<td>10</td>
<td>2.75</td>
</tr>
</tbody>
</table>

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

- TCQSM provides two basic methods
  - Planning (graphical)
  - Operations (equations)

\[
B_l = \frac{3,600(g / C)}{t_c + t_d(g / C) + Zc_t d}
\]

Bus Speed
**Speed Factors**

- Factors also related to capacity:
  - Dwell time
  - Traffic signal timing
  - Traffic volumes
  - Bus facility type (exclusive facility, bus lane or mixed traffic)

- Other factors:
  - Stop spacing
  - Scheduled bus volumes

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**Arterial Street Speed Estimation Procedure**

- Determine the base running time — how fast buses would travel without signal and traffic delays (but with dwell times)

- Add additional time losses due to signal & traffic delays (estimate from table or measure in the field)

- Convert the total running time into a speed

- Adjust for bus congestion
  - Speeds drop when more than 1/2 of a facility’s maximum bus capacity is scheduled
**Transit Capacity and Quality of Service Manual, 3rd Edition**

**Bus Transit Capacity**

### Calculating Speed

\[ S_i = \left( \frac{60}{t_r + t_i} \right) f_s f_b \]

- **Base running time (min/mi)**
- **Additional running time losses (min/mi)**
- **Skip-stop factor**
- **Bus-bus interference factor**

**Minutes in an hour**

### Determining Running Time

<table>
<thead>
<tr>
<th>Dwell Time (s)</th>
<th>2</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>10</th>
<th>12</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>2.40</td>
<td>3.27</td>
<td>3.77</td>
<td>4.30</td>
<td>4.88</td>
<td>5.53</td>
<td>7.00</td>
<td>8.75</td>
</tr>
<tr>
<td>20</td>
<td>2.73</td>
<td>3.93</td>
<td>4.60</td>
<td>5.30</td>
<td>6.04</td>
<td>6.87</td>
<td>8.67</td>
<td>10.75</td>
</tr>
<tr>
<td>30</td>
<td>3.07</td>
<td>4.60</td>
<td>5.43</td>
<td>6.30</td>
<td>7.20</td>
<td>8.20</td>
<td>10.33</td>
<td>12.75</td>
</tr>
<tr>
<td>40</td>
<td>3.40</td>
<td>5.27</td>
<td>6.26</td>
<td>7.30</td>
<td>8.35</td>
<td>9.53</td>
<td>12.00</td>
<td>14.75</td>
</tr>
<tr>
<td>50</td>
<td>3.74</td>
<td>5.92</td>
<td>7.08</td>
<td>8.30</td>
<td>9.52</td>
<td>10.88</td>
<td>13.67</td>
<td>16.75</td>
</tr>
<tr>
<td>60</td>
<td>4.07</td>
<td>6.58</td>
<td>7.90</td>
<td>9.30</td>
<td>10.67</td>
<td>12.21</td>
<td>15.33</td>
<td>18.75</td>
</tr>
</tbody>
</table>

**NOTE:** Data based on field measurements. Interpolation between dwell time values is done on a straight-line basis.

- **Values in minutes per mile**
- **Dwell time is an average of all stops along the portion of the facility being analyzed**
## Determining Running Time Losses

<table>
<thead>
<tr>
<th>Condition</th>
<th>CENTRAL BUSINESS DISTRICT</th>
<th>ARTERIAL ROADWAYS OUTSIDE THE CBD</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Bus Lane, No Right Turns</td>
<td>Bus Lane, No Right Turn Delays</td>
</tr>
<tr>
<td>Typical</td>
<td>1.2</td>
<td>2.0</td>
</tr>
<tr>
<td>Signals Set For Buses</td>
<td>0.6</td>
<td>1.4</td>
</tr>
<tr>
<td>Signals More Frequent</td>
<td>1.5-2.0</td>
<td>2.5-3.0</td>
</tr>
<tr>
<td>Than Bus Stops</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Typical</td>
<td>0.7</td>
<td>1.0</td>
</tr>
<tr>
<td>Range</td>
<td>0.5-1.0</td>
<td></td>
</tr>
</tbody>
</table>

*NOTE:* Data based on field measurements. Traffic delays shown reflect peak conditions.

- Values in minutes per mile
Bus Preferential Treatments

- Techniques to speed up buses and improve overall system efficiency

- Examples include:
  - Dedicated bus lanes
  - Traffic signal priority
  - Queue jumps
  - Boarding islands
  - Curb extensions
  - Turn restriction exemptions
  - Yield-to-bus laws

Operational Treatments

- Bus stop relocation
- Bus stop consolidation
- Skip-stop bus stop patterns
- Bus platooning
TCQSM Guidance on Preferential Treatments

- Examples of existing facilities (as of 2003)
- Advantages and disadvantages of various types of treatments
- Guidelines for application
  - Minimum bus/passenger volumes
  - Physical, operational conditions
- Observed ranges of benefits due to treatments

Questions to Think About
Questions to Think About

- What is the impact of new bus models on capacity?
- What added information on impact of fare collection systems on bus dwell time can be provided?
- What is the role of simulation analysis in addressing bus capacity?
- What is the impact of large items carried onto buses on dwell time and capacity?
- What are the impact of different bus preferential treatments on speed, capacity, and reliability?

We Want Your Input on the TCQSM!

- Take our online survey to help shape the 3rd Edition’s content
- Stay involved with the project
  - Give us your e-mail address after completing the survey and we’ll keep you informed of future opportunities to provide input
- Do you go to the Transportation Research Board’s Annual Meeting?
  - Attend the meeting of the Transit Capacity and Quality of Service Committee (AP015)

www.tcqsm.org