Bus Transit Capacity

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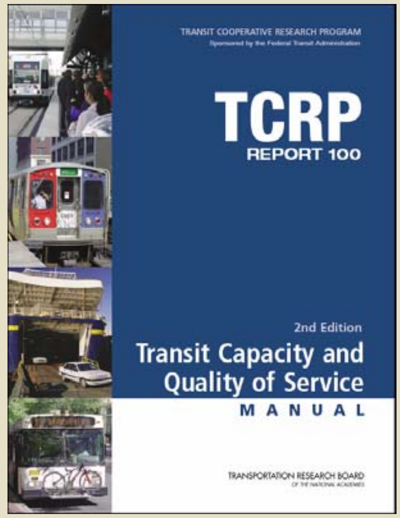

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Bus Transit Capacity

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

- Obtain user feedback on the TCQSM 2nd Edition (2003)
- 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)

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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

www.tcqsm.org

Bus Vehicle and Service Types

Bus Vehicle Types

Standard Bus

Articulated

Low-floor

Over-the-road coach

Lee Rodegerdts

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

Rory Giles / QUT

Off-Road Busway

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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

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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

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Bus Capacity

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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

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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

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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

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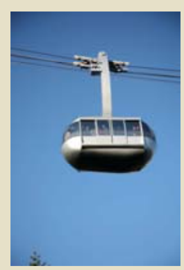
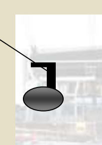
A Simple Capacity Example: OHSU Aerial Tram



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



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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

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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?

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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."

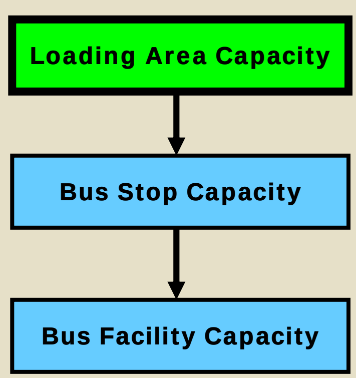
- More theoretical than practical
  - For quality of service and operational reasons, one usually wouldn't want to try schedule service based on maximum capacity
- However, it's an input to the TCQSM's speed estimation procedure

Scheduled Capacity

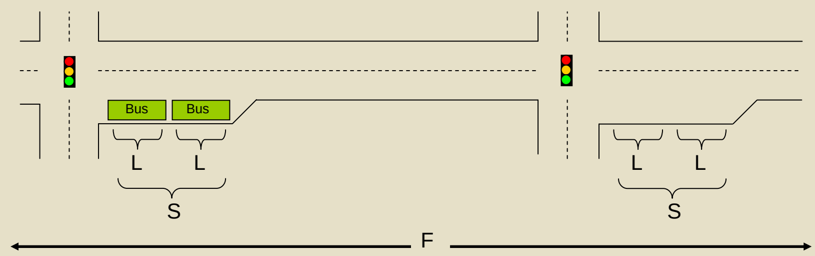
"The greatest number of people a transit facility can serve using a particular set of vehicles, at a desired level of reliability, given a particular schedule."

- 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?



Where Is Bus Capacity Measured?



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

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Loading Area Vehicle Capacity Factors

$$\text{Capacity} = \frac{\text{\% of hour when buses are able to enter/leave the stop}}{\text{Time an average bus occupies the loading area, plus an allowance for unusually long dwells}}$$

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Loading Area Vehicle Capacity Factors

Traffic signal timing

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)

Dwell time, delay re-entering street

Dwell time variability, desired level of reliability

Bus Stop Vehicle Capacity Factors

Capacity = Loading area vehicle capacity × # of "effective loading areas"

Bus Stop Vehicle Capacity Factors

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

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

Actual # of loading areas, bus stop location & design

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Bus Facility Vehicle Capacity Factors

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

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Bus Facility Vehicle Capacity Factors

Usually the stop with the highest dwell time

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

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

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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

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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

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

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

$$B_l = \frac{3{,}600(g/C)}{t_c + t_d(g/C) + Zc_v t_d}$$

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

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Bus Transit Capacity

Loading Area Vehicle Capacity

$$B_l = \frac{3{,}600(g/C)}{t_c + t_d(g/C) + Zc_v t_d}$$

- **Seconds of green per hour:** $3{,}600(g/C)$
- **Clearance time:** t_c
- **Portion of dwell time during green:** $t_d(g/C)$
- **Allowance for dwell time variability:** $Zc_v t_d$

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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

	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

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

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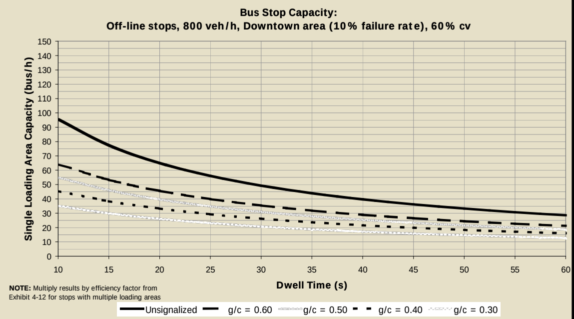
Calculating Capacity

- TCQSM provides two basic methods



- Planning (graphical)
- Operations (equations)

$$B_l = \frac{3{,}600(g/C)}{t_c + t_d(g/C) + Zc_v t_d}$$

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

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Calculating Speed

$$S_t = \left(\frac{60}{t_r + t_l} \right) f_s \, f_b$$

Minutes in an hour

Base running time (min/mi)

Additional running time losses (min/mi)

Skip-stop factor

Bus-bus interference factor

Determining Running Time

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

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

Condition	Bus Lane	Bus Lane, No Right Turns	Bus Lane With Right Turn Delays	Bus Lanes Blocked by Traffic	Mixed Traffic Flow
CENTRAL BUSINESS DISTRICT					
Typical		1.2	2.0	2.5-3.0	3.0
Signals Set For Buses		0.6	1.4		
Signals More Frequent Than Bus Stops		1.5-2.0	2.5-3.0	3.0-3.5	3.5-4.0
ARTERIAL ROADWAYS OUTSIDE THE CBD					
Typical	0.7				1.0
Range	0.5-1.0				0.7-1.5

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

- Values in minutes per mile

Bus Preferential Treatments

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

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Operational Treatments

- Bus stop relocation
- Bus stop consolidation
- Skip-stop bus stop patterns
- Bus platooning

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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

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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

www.tcqsm.org

- Do you go to the Transportation Research Board's Annual Meeting?
  - Attend the meeting of the Transit Capacity and Quality of Service Committee (AP015)