Bus Facility Capacity

May 2, 2006

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Today's Topics

- **Types of bus facilities**
- **Bus facility capacity**
- **Person capacity**

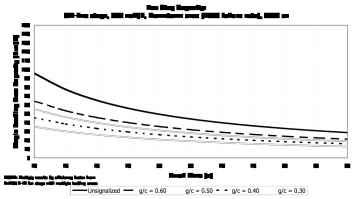
Review: Major Bus Stop Capacity Factors

- **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

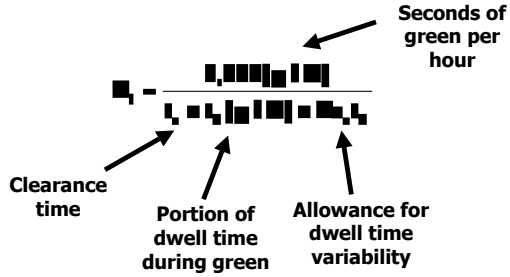


Loading Area Vehicle Capacity

% 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



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**

	Passenger Service Time (s/p)	
Situation	**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

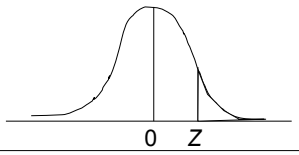
*Includes no fare, bus pass, free transfer, and pay-on-exit
Add 0.5 s/p to boarding times when standees are present.
Subtract 0.5 s/p from boarding times and alighting times on low-floor buses.

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



Bus Stop Failure Rate Values

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- **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%**

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

Re-Entry Delay Values

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

Effective Loading Areas

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- Each additional linear loading area is less effiecient 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

Loading Area Capacity Example

$$[redacted] = \frac{[redacted]}{[redacted]}$$

$$[redacted] = \frac{[redacted]}{[redacted]}$$

$$[redacted]$$

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

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

Bus Route Frequency **x** Allowed Loading **x** Peak Hour Factor

- **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

Bus Facility Capacity **x** Allowed Loading **x** Peak Hour Factor

- **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:**

[redacted]

Peak Hour Factor (PHF)

- **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/PHF (in this case 25%) higher than the average loading during the peak hour**

Peak Hour Factor (PHF)

- **PHF = 0.25: all demand occurs during peak 15 minutes**
- **PHF = 1.00: demand is evenly distributed (usually means that demand exceeds capacity and a queue of passengers exists)**

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?**

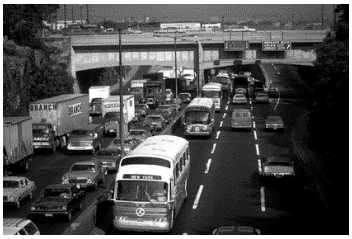
Person Capacity Example

- **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

Bus Facility Types



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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

Busways

Tom Parkinson

Ottawa

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

Busways

Adelaide

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

Busways

Seattle

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

Busways

Justin Jahnke

Brisbane

- **Potential capacity constraints**
  - On-steet 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

Busway Definition Issues

- **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

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Houston

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

Freeway HOV Lanes

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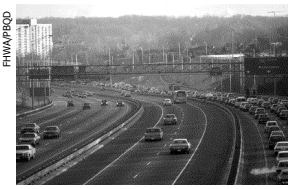

Northern Virginia

- **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


FHWA/PROD

Seattle

- **Often used in association with park-and-ride lots**
- **Express service from P&R to downtown or other major destinations**

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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**

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Arterial Street Bus Lanes

Portland

- **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**

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Arterial Street Bus Lanes

Montréal

- **Variety of designs**
  - 1 & 2 lanes
  - Same direction & contraflow
  - Physically separated or not
  - Part-time & full-time

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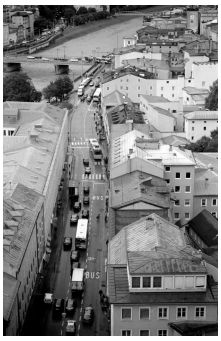
Exclusive Bus Lane Types

- **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



Salzburg, Austria

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Type 1 Bus Lanes

Orlando

- **Single lane**
- **No passing opportunities at stops**
- **May be physically separated from other traffic**

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Type 1 Bus Lanes

Denver

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

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Type 2 Bus Lanes

San Antonio

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

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Type 2 Bus Lanes

Montréal

- **Typical applications**
  - Streets with frequent bus service
  - Part-time lanes created by removing parking
- **Enforcement issues**
  - Double-parking
  - Non-bus use

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Type 3 Bus Lanes

FHWA/PBQD

New York

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

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Type 3 Bus Lanes

Miami

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

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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**

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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**

Bus Lane Capacity Factors

Critical Bus Stop Capacity | Bus Lane Design | **Traffic Characteristics**

- **Right-turn volumes (may block curb lane)**
- **Adjacent lane volumes (inhibit passing)**
- **Conflicting ped volumes (may impede right turns)**

Bus Lane Capacity Factors

Critical Bus Stop Capacity | Bus Lane Design | Traffic Characteristics | **Bus Operations**

- **Skip stops**
  - Buses divided into groups, with assigned sets of stops
- **Platoons**
  - Buses organized to travel together, like cars of a train

Mixed Traffic Operations

Los Angeles

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

Mixed Traffic Operations

Portland

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

Arterial Bus Lane Capacity

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*

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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

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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

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Planning Methodology Inputs

- **For exclusive bus lanes:**
  - Right-turn volume at critical stop
    - *Ranges from 0-400 vehicles/hour*
  - Conflicting pedestrian volume at critical stop
    - *Ranges from 0-800 peds/hour*
- **For mixed traffic lanes:**
  - Curb-lane volume at critical stop
    - *Ranges from 0-400 vehicles/hour*

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Planning Methodology Defaults

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

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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**

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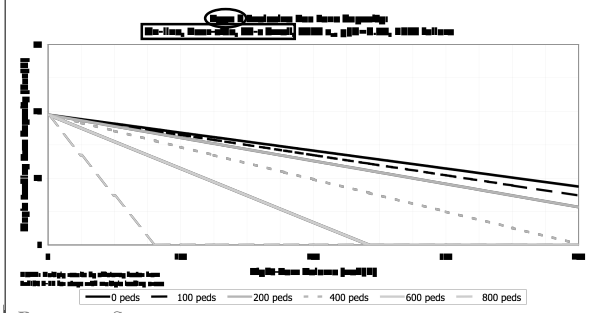
Planning Methodology Example



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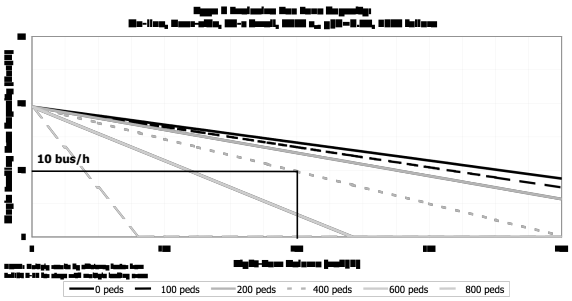
Planning Methodology Example



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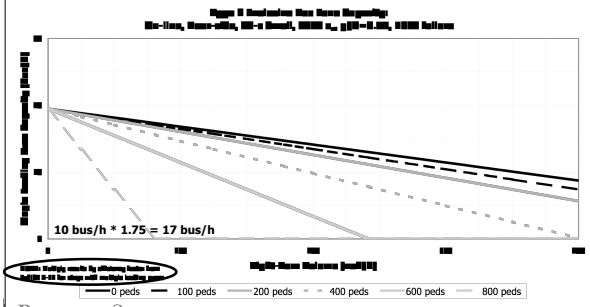
Planning Methodology Example



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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?**

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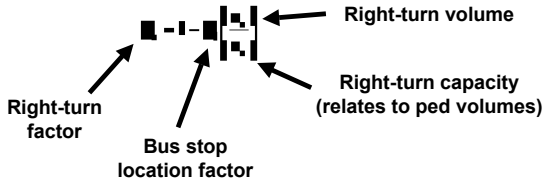
Bus Lane Capacity

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



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Bus Stop Location Factor (f_l)

Bus Stop Location	Bus Lane Type		
	Type 1	Type 2	Type 3
Near-side	0.0	0.0	0.0
Mid-block	0.0	0.0	0.0
Far-side	0.0	0.0	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.

- **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**

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Right-Turn Capacities

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[illegible]

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

Operations Method Example

- **Same data as planning example from before**
- **Stop location factor:**

[illegible]	[illegible]		
	[illegible]	[illegible]	[illegible]
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Operations Method Example

- **Right-turn capacity:**

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Operations Method Example

- **Right-turn factor:**

[illegible]

[illegible]

[illegible]

Operations Method Example

- **Critical bus stop capacity:**

[illegible]

[illegible]

[illegible]

Operations Method Example

- **Bus lane capacity:**

[illegible]

[illegible]

[illegible]

Mixed Traffic Bus Capacity

- **Same basic procedure as exclusive lanes**
- ***v/c* ratio of right (curb) lane substituted for *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**

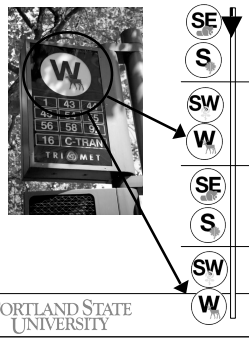
Typical Bus Lane Operation

- **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 2nd, 3rd, or 4th 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

Bus Lane Capacities With Skip-Stops

$$[illegible] = [illegible] + [illegible] + [illegible] + \ldots + [illegible]$$

- **Bus lane capacity is ideally the sum of the capacity of each group in the pattern (B_1, B_2, etc.)**
- **The need for buses to pass each other reduces efficiency—accounted for by a skip-stop impedance factor, f_k**

Skip-Stop Factor

$$[illegible] = \frac{[illegible] - [illegible]}{[illegible]}$$

- **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

$$[illegible] = \frac{[illegible]}{[illegible]}$$

- f_i = adjacent lane impedence factor (reflects bus' ability to pass each other)

$$[illegible]$$

- 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

Group	Stop	t_d	c_v	B_s
SW	Oak	43	0.13	75
W	Stark	39	0.38	57
SE	Stark	36	0.87	39
S	Wash.	41	0.90	34

$$[illegible] = [illegible] + [illegible] + \ldots + [illegible]$$

$$[illegible] = [illegible] + [illegible] + [illegible] + [illegible]$$

Portland Mall (5th Avenue) Example

$$[illegible] = \frac{[illegible]}{[illegible]}$$

- 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)

Portland Mall (5th Avenue) Example

$$[illegible] = \frac{[illegible]}{[illegible]} = \frac{[illegible]}{[illegible]} = [illegible]$$

$$[illegible] = [illegible] = [illegible]$$

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

Additional Reading

- **TCQSM, Part 4**

PORTLAND STATE UNIVERSITY