Macro Design Models for a Single Route

Outline

1. Green Line Dwell Time Model
2. Introduction to analysis approach
3. Bus frequency model
4. Bus size model
5. Stop/station spacing model

Models with Crowding Term

A. One-car trains:

$$\underset{(8.94)}{DT = 12.50} + \underset{(3.76)}{0.55*TONS} + \underset{(2.03)}{0.23*TOFFS}$$

$$+ \underset{(6.70)}{0.0078*SUMASLS} \qquad (R^2 = 0.62)$$

SUMASLS = TOFFS*AS + TONS*LS

B. Two-car trains:

$$\underset{(7.43)}{DT = 13.93} + \underset{(2.92)}{0.27*TONS} + \underset{(3.79)}{0.36*TOFFS}$$

$$+ \underset{(2.03)}{0.0008*SUMASLS} \qquad (R^2 = 0.70)$$

Predicted Dwell Times

ONS	LPL	1-Car DT	2-Car DT
0	any #	12.5	13.9
10	<53	20.3	20.2
10	150	35.6	21.0
20	<53	28.1	26.5
20	150	58.7	28.1
30	<53	35.9	32.8
30	150	81.8	35.1

Findings

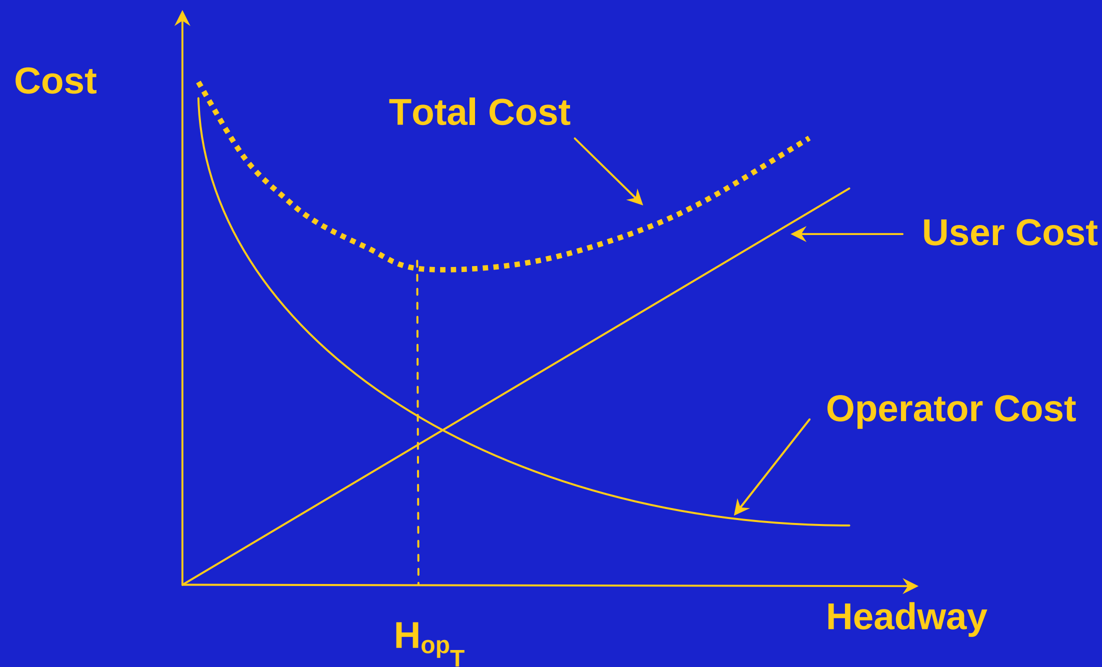
- Dwell times for ALRVs are quite sensitive to:
  - Passenger flows
  - Passenger loads
- The crowding effect may well be non-linear.
- Dwell times for multi-car trains are different form those for one-car trains.
- The dwell time functions suggest high sensitivity of performance to perturbations
- Effective real-time operations control essential
- Running mixed train lengths dangerous
- Simulation models of high frequency, high ridership light rail lines need to include realistic dwell time functions.

Introduction to Analysis Approach

- Basic approach is to establish an aggregate total cost function including:
  - operator cost as *f*(design parameters)
  - user cost as *g*(design parameters)
- Minimize total cost function to determine optimal design parameter (s.t. constraints)

Variants include:

- Maximize service quality s.t. budget constraint
- Minimize consumer surplus s.t. budget constraint



Bus Frequency Model: the Square Root Model

Problem: define bus service frequency on a route as a function of ridership

Total Cost = operator cost + user cost

$$Z = c \bullet \frac{t}{h} + b \bullet r \bullet \frac{h}{2}$$

where Z = total (operator + user) cost per unit time

c = operating cost per unit time

t = round trip time

h = headway – the decision variable to be determined

b = value of unit passenger waiting time

r = ridership per unit time

Minimizing Z w.r.t. h yields:

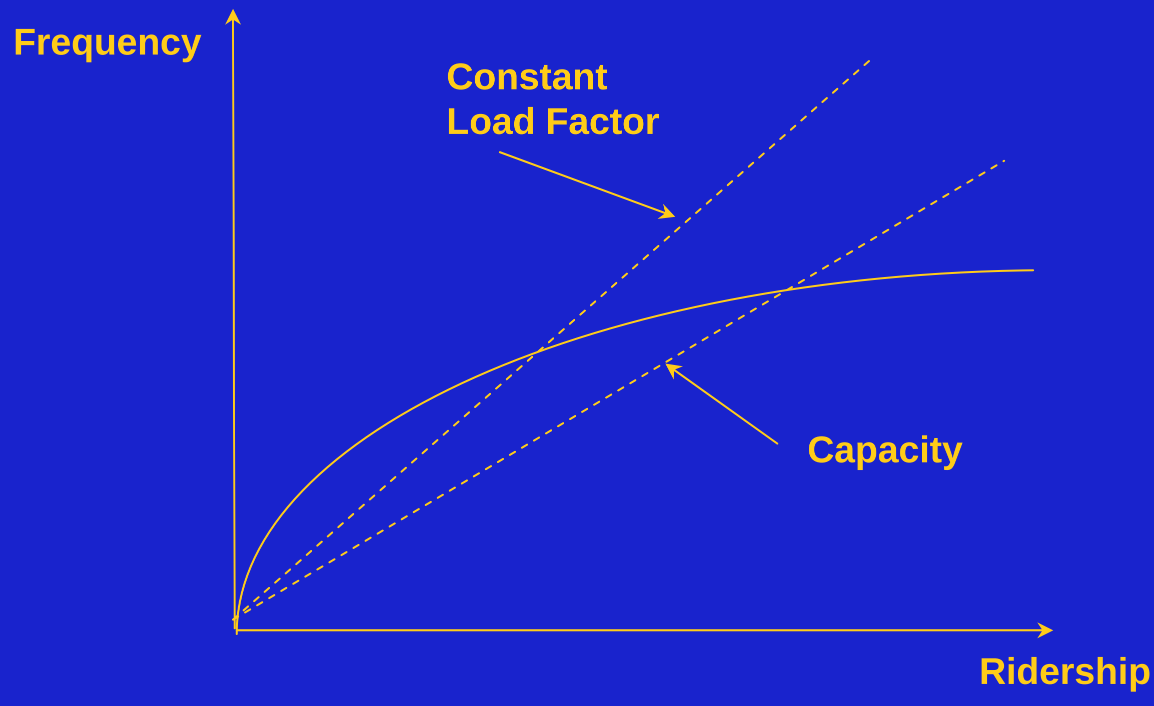
$$h = \sqrt{\frac{2ct}{br}} \ or \ \sqrt{2\left(\frac{c}{b}\right)\left(\frac{t}{r}\right)}$$

Square Root Model (cont'd)

This is the Square Rule with the following implications:

- **high frequency is appropriate where (cost of wait time/cost of operations time) is high**
- **frequency is proportional to the square root of ridership per unit time for routes of similar length**

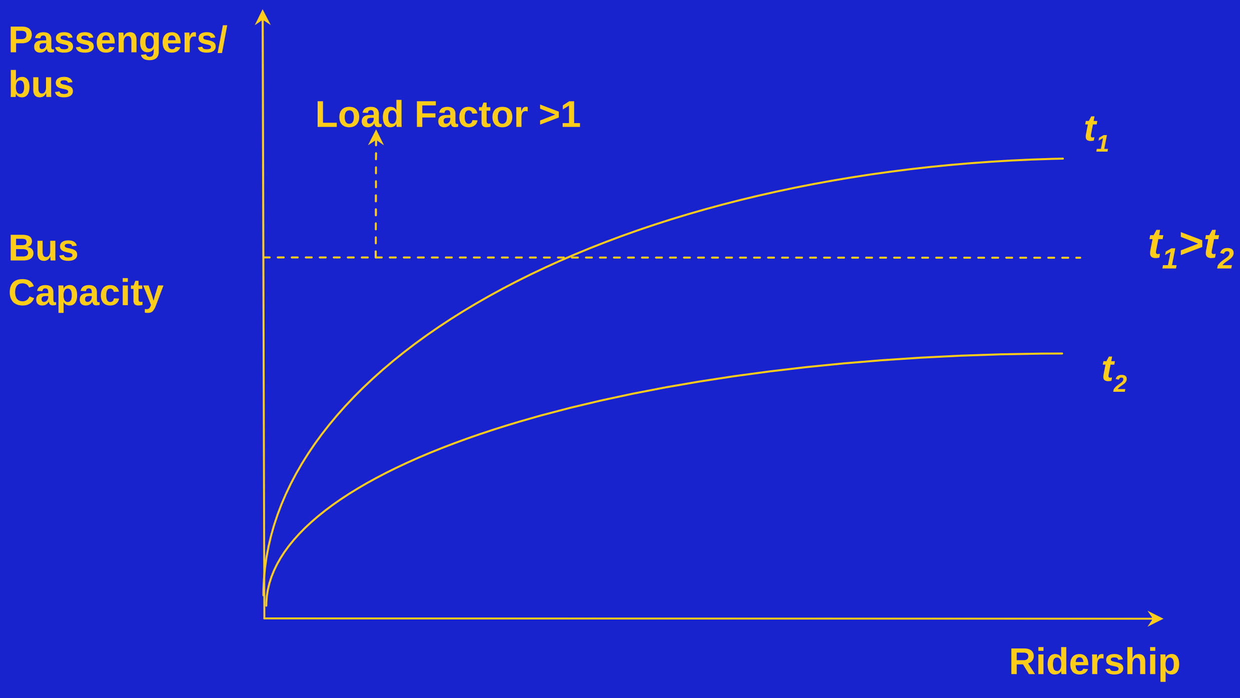
Frequency-Ridership Relationship



Square Root Model (cont'd)

- load factor is proportional to the square root of the product of ridership and route length.

<u>Bus Capacity-Ridership Relationship</u>



Square Root Model (cont'd)

Critical Assumptions:

- bus capacity is never binding
- only frequency benefits are wait time savings
- ridership $\neq f$ (frequency)
- simple wait time model
- budget constraint is not binding

Possible Remedies:

- introduce bus capacity constraint
- modify objective function
- introduce $r=f(h)$ and re-define objective function
- modify objective function
- introduce budget constraint

Bus Frequency Example

If: c = \$90/bus hour,

b = \$10/passenger hour.

t = 90 mins,

r = 1000 passengers/hour,

Then: h_{OPT} = 11 mins

Bus Size Model

Problem: define optimal bus size on a route

Assumptions:

- Desired load factor is constant
- Labor cost/bus hour is independent of bus size
- Non-labor costs are proportional to bus size
- Bus dwell time costs per passenger are independent of bus size

Using same notation as before plus:

w = labor cost per bus hour
p = passenger flow past peak load point
k = desired bus load - the decision variable to be determined

Then $$Z = w \bullet \frac{t}{h} + b \bullet r \bullet \frac{h}{2}$$

Now $h = \frac{k}{p}$ by assumption above

$$\therefore \quad Z = \frac{wtp}{k} + \frac{brk}{2p}$$

Minimizing Z w.r.t. k gives: $$k_{OPT} = \sqrt{\frac{2p^2wt}{rb}}$$

Bus Size Model (cont'd)

Result is another square root model, implying that optimal bus size increases with:

- round trip time
- ratio of labor cost to passenger wait time cost
- peak passenger flow
- concentration of passenger flows

Previous example extended with:

p = 500 pass/hour,

w = $40/bus hour;

all other parameters as before:

Then:

h_{OPT} = 55

Stop/Station Spacing Model

Problem: determine optimal stop or station spacing

Trade-off is between walk access time (which increases with station spacing), and in-vehicle time (which decreases as station spacing increases) for the user, and operating cost (which decreases as station spacing increases)

Define	Z	=	**total cost per unit distance along route and per headway**
and	T_{st}	=	**time lost by vehicle making a stop**
	c	=	**vehicle operating cost per unit time**
	s	=	**station/stop spacing - the decision variable to be determined**
	N	=	**number of passengers on board vehicle**
	v	=	**value of passenger in-vehicle time**
	D	=	**demand density in passenger per unit route length per headway**
	v_{acc}	=	**value of passenger access time**
	w	=	**walk speed**
	c_s	=	**station/stop cost per headway**

Stop/Station Spacing Model (cont'd)

$$Z = \frac{T_{st}}{s}(c + N \bullet v) + \frac{c_s}{s} + \frac{s}{4} \bullet D \bullet \frac{v_{acc}}{w}$$

Minimizing Z w.r.t. s gives:

$$s_{OPT} = \left[\frac{4w}{Dv_{acc}}\left[c_s + T_{st}(c_v + Nv)\right]\right]^{1/2}$$

Yet another square root relationship, implying that station/stop spacing increases with:

- walk speed
- station/stop cost
- time lost per stop
- vehicle operating cost
- number of passengers on board vehicle
- value of in-vehicle time

and decreases with:

- demand density
- value of access time

Bus Stop Spacing

U.S. Practice

- 200 m between stops (8 per mile)
- shelters are rare
- little or no schedule information

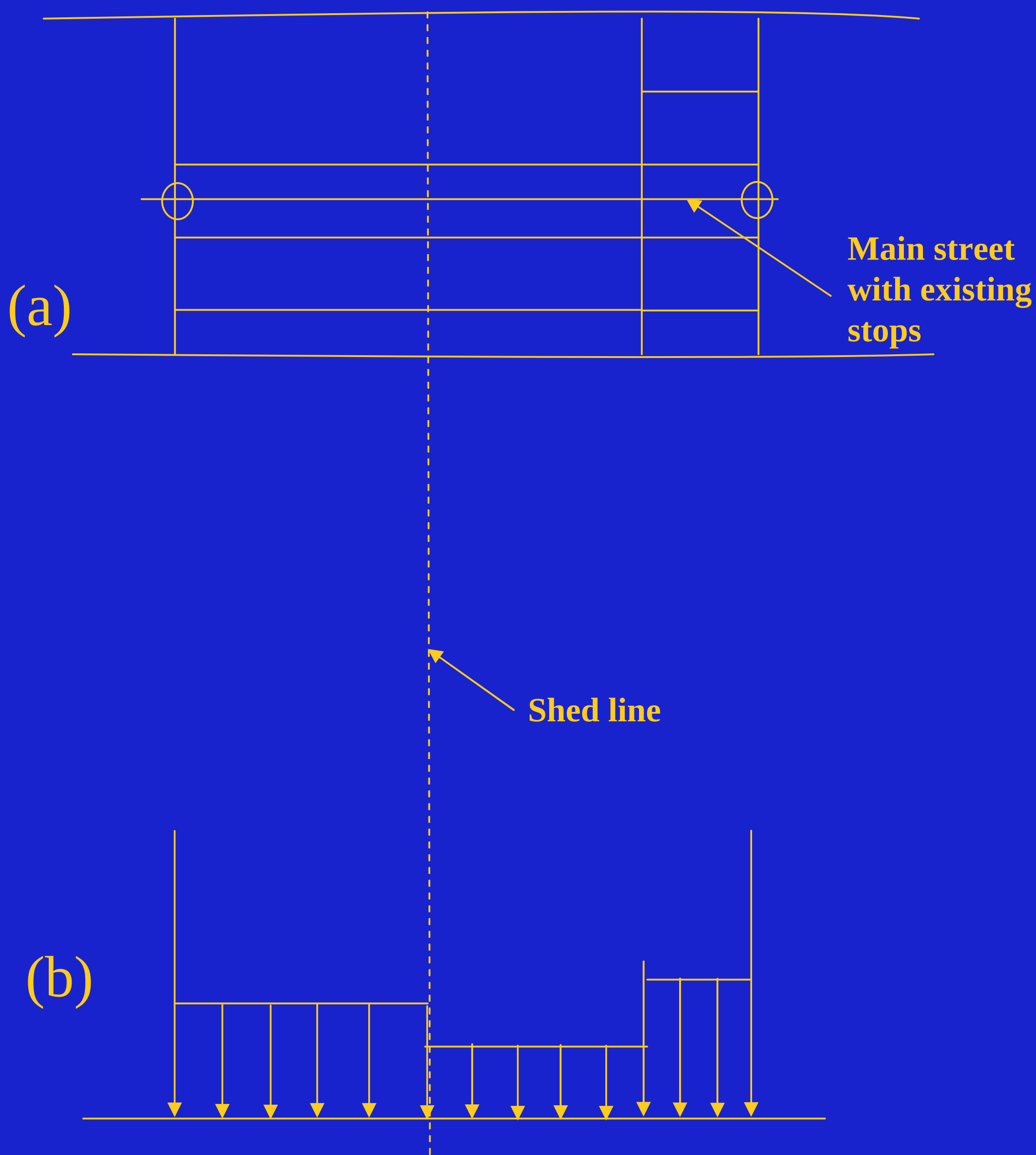
European Practice

- 320 m between stops (5 per mile)
- named & sheltered
- up to date schedule information
- scheduled time for every stop

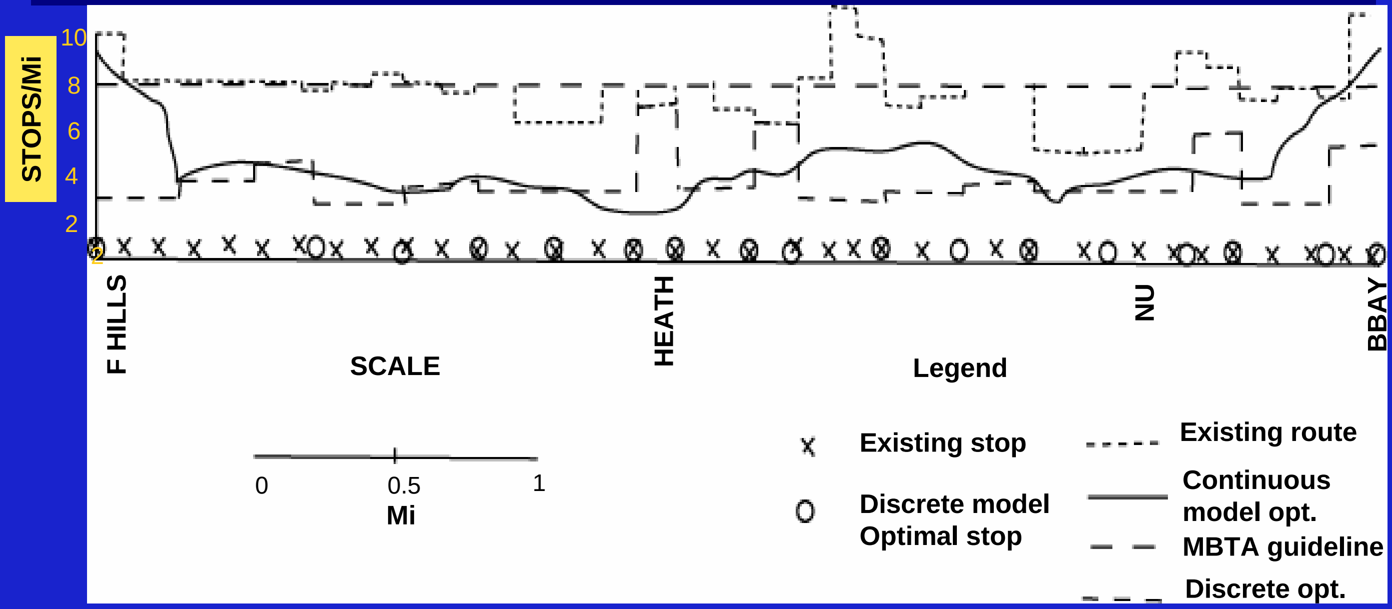
Stop Spacing Tradeoffs

- Walking time
- Riding time
- Operating cost
- Ride quality

Walk Access: Block-Level Modeling



Results: MBTA Route 39*



Adapted from: Furth, P.G. and A. B. Rahbee, "Optimal Bus Stop Spacing Using Dynamic Programming and Geographic Modeling." Transportation Research Record 1731, pp. 15-22, 2000.

AM Peak Inbound results

- Avg walking time up 40 s
- Avg riding time down 110 s
- Running time down 4.2 min
- Save 1, maybe 2 buses

Bus Stop Locations and Policies

- Far-side (vs. Near-side)
  - less queue interference
  - easier pull-in
  - fewer ped conflicts
  - snowbank problem demands priority in maintenance

- Curb extensions benefit transit, peds, and traffic (0.9 min/mi speed increase)
- Pull-out priority (it's the law in some states)
- Reducing dwell time (vehicle design, fare collection, fare policy)