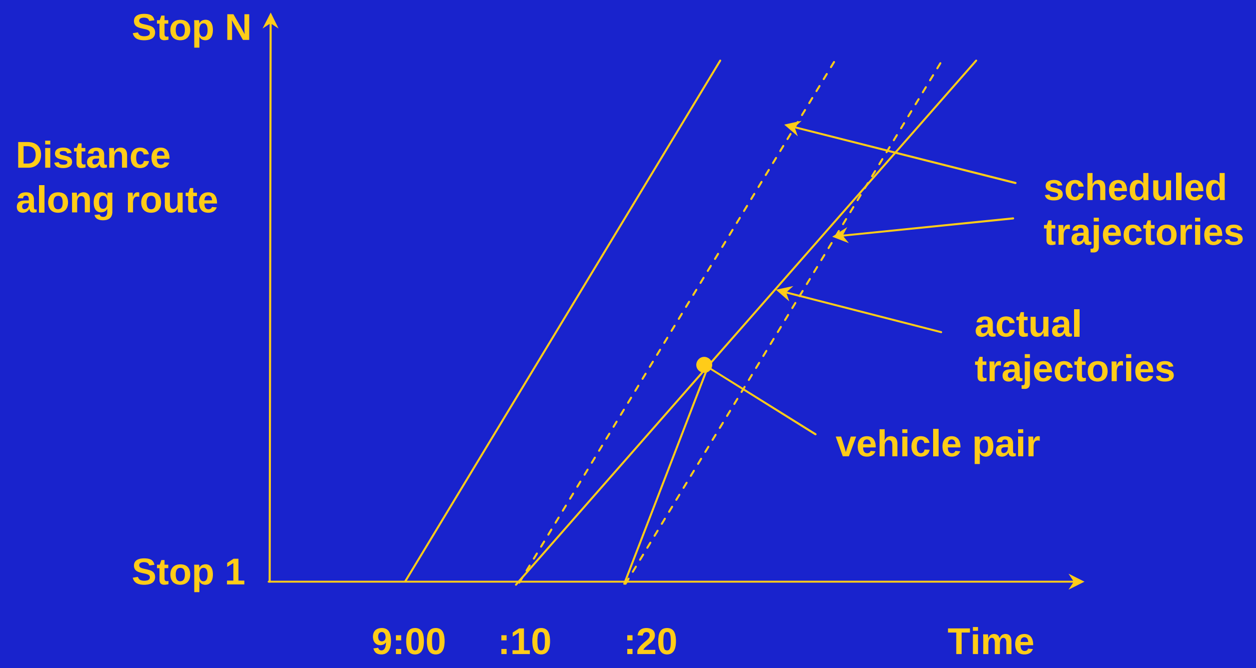
Performance of a Single Route

Outline

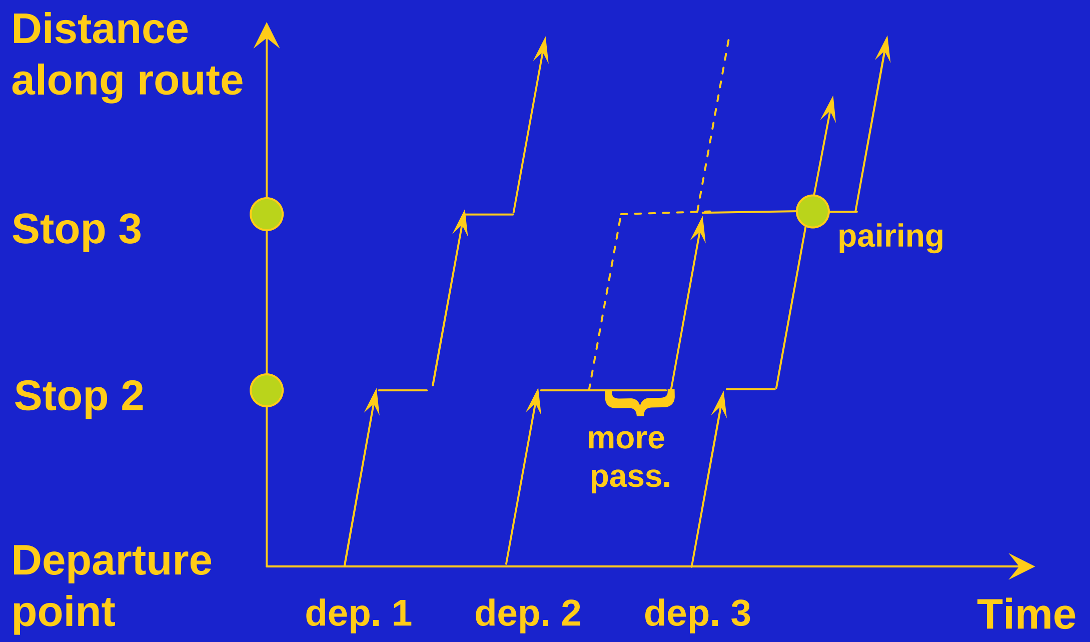
1. Service variation along route
2. Running time models
3. Dwell time models

Service Variation Along Route

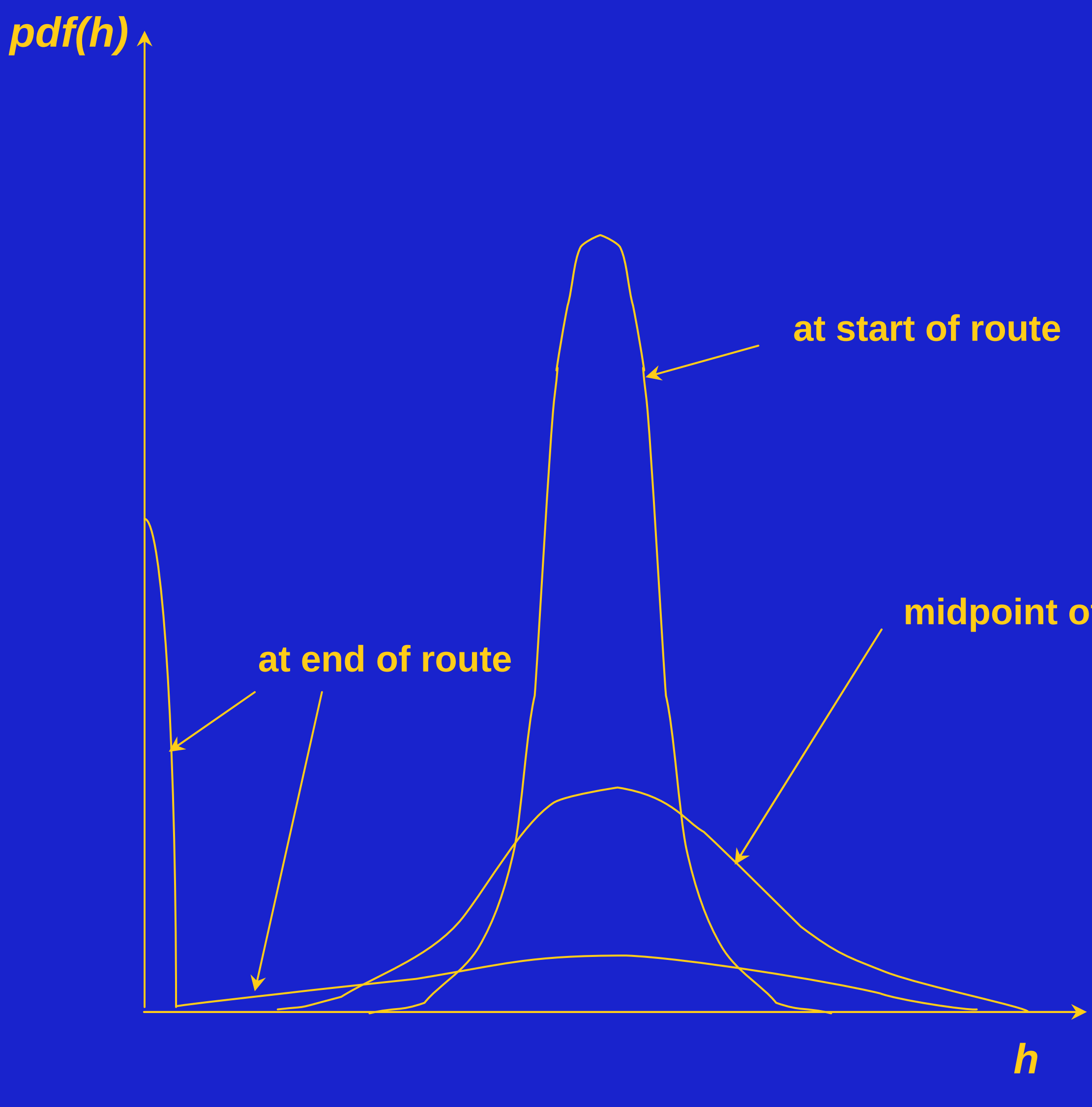
- Service may vary along route even without capacity becoming binding:
  - the headway distribution can vary along the route, affecting E(w)
  - at the limit vehicles can be paired, or bunched
  - this can also result in passenger load variation between vehicles



Service Variation Along Route (cont'd)



Service Variation Along Route (cont'd)



Factors Affecting Headway Deterioration

- Length of route
- Marginal dwell time per passenger
- Stopping probability
- Scheduled headway
- Driver behavior

Simple model:

$e_i = (e_{i-1} + t_i)(1 + p_{i-1} \cdot b)$

where e_i = headway deviation (actual-scheduled) at stop i

t_i = travel time deviation (actual-scheduled) from stop $i-1$ to i

p_i = passenger arrival rate at stop i

b = boarding time per passenger

Mathematical Model for Headway Variance*

$$
\begin{aligned}
\text{var}(h_i) = {} & \text{var}(h_{i-1}) + \text{var}(\Delta t_{i-1}) + 2p_{i-1}(1-p_{i-1})(c \bullet \bar{q}_{i-1} + l)^2 \\
& + 2c^2 \,\text{var}(q_{i-1})\left[1-\rho_q + p_{i-1}\rho_q\right](1-p_{i+1}) \\
& + c(1-p_{i-1})^2 \bullet \text{cov}(\Delta q_{i-1}, h_{i-1})
\end{aligned}
$$

where:

- $\text{var}(h_i)$ = headway variance at stop i
- $\text{var}(\Delta t_i)$ = variance of the difference in running time between successive buses between stops $i-1$ and i
- p_i = probability bus will skip stop i
- c = marginal dwell time per passenger served at a stop
- $\bar{q}_i$ = mean number of passengers per bus served at stop i
- l = the constant term of the dwell time function
- $\text{var}(q_i)$ = variance of the number of passengers served per bus at stop i
- ρ_q = correlation coefficient between the passengers served by successive buses at a stop
- $\text{cov}(\Delta q_i, h_i)$ = covariance of the difference in number of passengers served by successive buses and the headway at stop i

* Adebisi, O., "A Mathematical Model for Headway Variance of Fixed Bus Routes." Transportation Research B, Vol. 20B, No. 1, pp 59-70 (1986).

Vehicle Running Time Models

Different levels of detail:

A. Very detailed, microscopic simulation:
- represents vehicle motion and interaction with other vehicles, e.g. buses operating in mixed traffic, or train interaction through control system

B. Macroscopic:
- identify factors which might affect running times
- collect data and estimate model

Running Time includes dwell time, movement time, and delay time:

- dwell time is generally a function of number of passengers boarding and alighting as well as technology characteristics
- movement time and delay depend on other traffic and control system attributes

Typical bus running time breakdown in mixed traffic:

50-75% movement time

10-25% stop dwell time

10-25% traffic delays including traffic signals

Dwell Times

- Vehicle dwell time affects:
  - system performance
  - service quality
- A critical element in vehicle bunching resulting in:
  - high headway variability
  - high passenger waiting times
  - uneven passenger loads
- Dwell time impact on performance depends on:
  - stop/station spacing
  - mean dwell as proportion of trip time
  - mean headway
  - operations control procedures

EXAMPLES:

Commuter rail ---> little impact of dwell time on performance

Long, high-frequency bus route ---> major impact

Light rail ?

Dwell Time Theory

- Dwell time depends on many factors:
  - Human, modal, operating policies & practices, mobility, weather, etc.

- For a given system we have the following possible models:

1. Single door, no congestion and interference:

   DOT = a + b(DONS) + c(DOFFS)

2. Single door with congestion and interference:

   DOT = a + b(DONS) + c(DOFFS)
   + d(DONS+DOFFS)(DTD)

Dwell Time Theory (cont'd)

- For a given system we have the following possible models ...

3. Single car with m doors:

   $DT = \max(DOT_1 ..., DOT_m)$

   With balanced flows:

   DT = a + b/m(CONS) + c/m(COFFS) + d/m(CONS+COFFS)(STD)

4. *n*-car train:

   $DT = \max(DT_1, ..., DT_n)$

   With balanced flows:

   DT = a + b/nm(TONS) + c/nm(TOFFS) + d/nm(TONS+TOFFS)(STD)

MBTA Green Line Analysis

- Branching network of 28 miles (45 km) and 70 stations
- 52-seat ALRVs operate in 1-, 2-, and 3-car trains
  - high floor, low platform configuration
  - 3 doors per car on each side
  - single side boarding/alighting
- Trunk service in central subway:
  - 10 or 14 stations on round-trip
  - 1- to 2-minute headways
  - peak flows ≈10,000 passengers/hour

Models with Crowding Term

A. One-car trains:

DT = 12.50 + 0.55*TONS + 0.23*TOFFS
(8.94) (3.76) (2.03)

+ 0.0078*SUMASLS ($R^2 = 0.62$)
(6.70)

SUMASLS = TOFFS*AS + TONS*LS

B. Two-car trains:

DT = 13.93 + 0.27*TONS + 0.36*TOFFS
(7.43) (2.92) (3.79)

+ 0.0008*SUMASLS ($R^2 = 0.70$)
(2.03)

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.