Transit Service Reliability

- Impacts of unreliability
- Causes of unreliability
- Reliability Metrics
- Real-Time Control Strategies

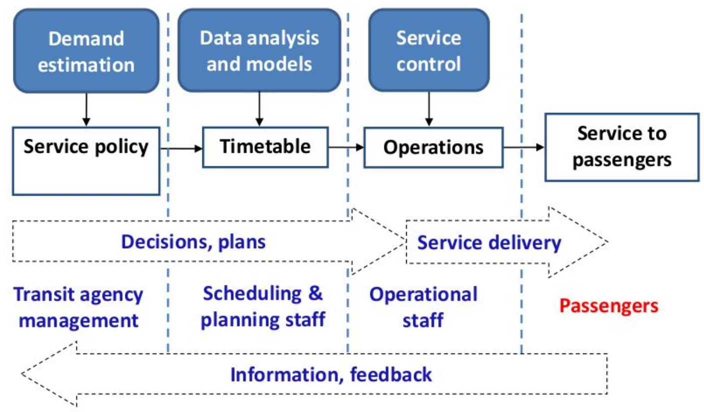
Impacts of Unreliability

- Passenger impacts
  - Longer wait times
  - Need for trip time reliability buffer
  - Higher loads (uncomfortable and slow rides)
- Agency impacts
  - Increased costs
  - Reduced ridership and revenue
  - Reduced operator morale
  - Public and political problem
  - Reduced effective capacity

Causes of Unreliability

- External
  - Traffic and traffic signals
  - Demand
  - Incidents (e.g. medical emergency)
- Internal
  - Equipment failure
  - Insufficient resources
  - Poor operations planning
  - Lack of supervision and control
  - Human driver behavior

Transit Service Delivery as a Business Process



Source: "Diagnosis and Assessment of Operations Control Interventions: Framework and Applications to a High Frequency Metro Line." MST Thesis, André Carrel; MIT, 2009.

Data-Driven Reliability Management

- Automated Data Collection Systems (AVL, AFC, APC) make it easier to measure reliability
- Automated scheduling systems make it easier to revise schedules
- Improved communications makes it easier to adjust operations plans in real time

Reliability as a Performance Measure

- Reliability is not the only service dimension of value
  - Speed/trip time
  - Productivity
- Reliability means different things
  - To different customers
  - On different services
- A single measure of effectiveness focused on reliability may lead to poor decisions

… but …

- We do need to measure performance with respect to reliability

Reliability on Low Frequency Service

Most customers time their arrival at stops/stations based on expected service departure times (e.g. schedule)

- On-time performance is critical, for example:
  - 1 minute early to 5 minutes late
  - 0 minutes early to 3 minutes late
  - 0 minutes early to 1 minutes late
- Little interaction between successive vehicles
- Real-time information is changing this
  - Poorly understood
    - In what manner?
    - To what extent?
    - What are the implications?

Reliability on High Frequency Service

- Most customers do not time their arrival at stops with service departures
- Expected wait time depends on mean and variance of headways
- Punctuality is not so critical
- Extensive interaction between successive vehicles:
  - Vehicle bunching
  - Long gaps

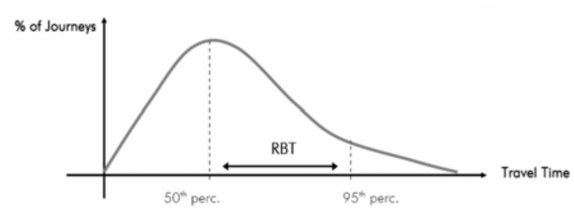
… but …

- High frequency routes can have branches and short route variants, so many customers may still behave like those on low frequency routes
- Schedule control is much easier than headway control

Reliability Buffer Time

High Frequency Service, Closed Fare System

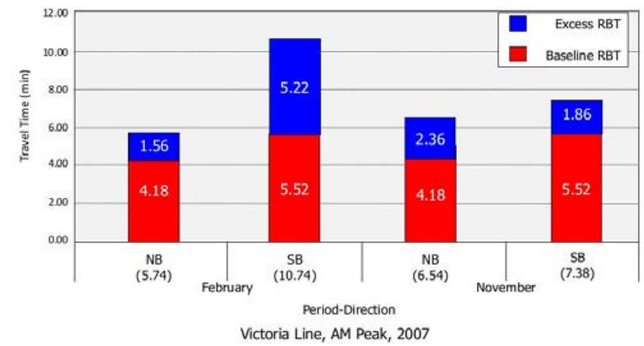
- use tap-in and tap-out times to measure actual station-station journey times
- characterize journey time distributions measures such as Reliability Buffer Time (at O-D level)



RBT = 95th percentile travel time – median travel time
additional time a passenger must budget to arrive late no more than 5% of the time

Reliability Metrics - Rail

- Aggregate to line level by distinguishing between *normal* and *incident days*

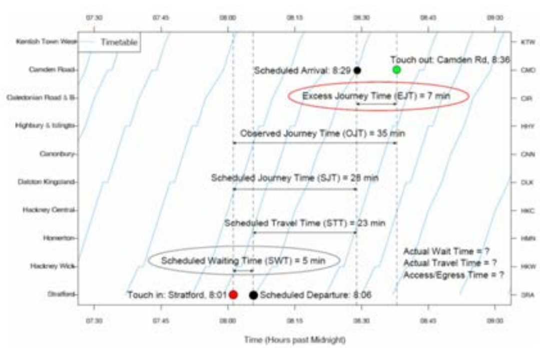


David Uniman, MST thesis, MIT 2009. "Service Reliability Measurement Framework using Smart Card Data: Application to the London Underground."

Reliability Metrics - Rail

Low-Frequency Service, Closed Fare System

- compare actual journey times with scheduled times



Michael Frumin, MST thesis, 2010 "Automatic Data for Applied Railway Management: Passenger Demand, Service Quality Measurement, and Tactical Planning on the London Overground Network."

Reliability Metrics - Bus

In contracted service delivery context, need to distinguish between:

1. Contractor performance: measure against contracted service expectations
2. Performance as seen by passenger

If service is unreliable, *the passenger* doesn't care whether the problem was caused by traffic or poor operator behavior, but *the authority* must be sure which caused the problem.

Reliability Metrics - Bus

Challenge to measure passenger journey time because

- (typically) no tap-off, just tap-on
- tap-on occurs after wait at stop, but wait is an important part of journey time

Strategy to use

- Infer destinations using trip-chaining (ODX)
- Use AVL to estimate
    - average passenger wait time
        - based on assumed passenger arrival process
    - actual in-vehicle time

Reliability Management Strategies

Preventive

- Maintain normal service; robust operating plans
- Reduce probability of problems occurring

Corrective

- Return to normal service once problems arise
- Minimize impact on passengers

Preventive Strategies

- Reserve fleet of drivers and vehicles
- Exclusive bus lanes
- Traffic signal priority
- Route design strategies: shorter routes, less stops
- Schedule planning
- Supervision

Impact of Schedules

Critical decisions

- Cycle time/half cycle time: impacts cost and terminal departure reliability
    - Allocation of time between running and recovery time
- Time Points: impacts cycle time and/or recovery time, reliability along route and passenger trip time
    - Number and location
    - Schedule at each time point

Impact of Schedules

Traditional scheduling approach

- Set half cycle time so that 90-95% of vehicle departures are on time
- Set time point scheduled times at 65 percentile of observed running times

… but …

- This doesn't recognize the feedback between scheduled time and operating speed
- It is not sensitive to the ratio of passengers on board versus passengers waiting at time point and further down route

Corrective Strategies

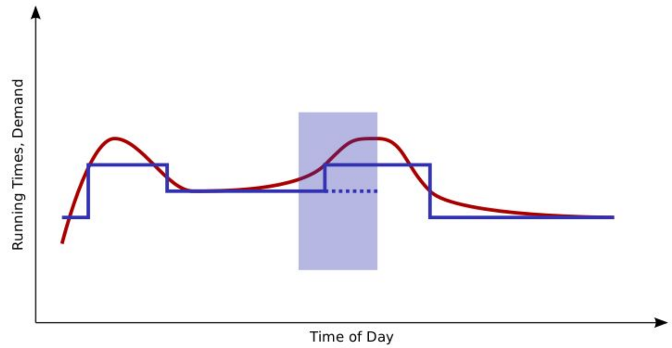
- Supervision, operations control
- Holding: schedule-based vs. headway-based
- Transit Signal Priority
- Deadheading
- Expressing
- Short-turning
- Use of reserve vehicles

major disruption strategies for high-frequency service

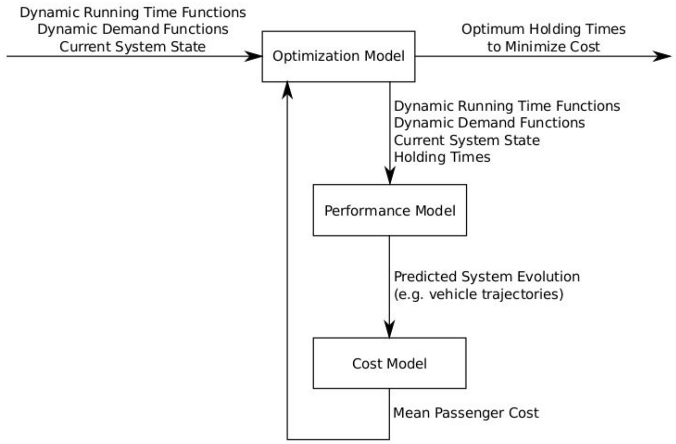
Holding Strategies

- Schedule adherence
- Scheduled headway adherence
- Threshold headway adherence
- Headway regularity (even headways)
- Optimization (rolling horizon)
  - Models passenger costs explicitly
    - Trade-off between waiting time and in-vehicle time
  - Reduces excessive holding
    - Avoids holding full vehicles
    - Prevents unnecessary reduction of effective capacity
  - Potentially considers operating constraints
    - Excessively late drivers

Rolling Horizon Optimization: Static vs. Dynamic Inputs



Optimal Holding with Dynamics



GE Sánchez-Martínez, HN Koutsopoulos, NHM Wilson. Real-time control for high-frequency transit with dynamics. Transportation Research Part B: Methodological 83, 1-19, 2016.

Optimal Holding with Dynamics

$$\underset{h_{v,s}\ \forall v\in V\ \forall s\in S}{\text{minimize}} \quad \frac{W_V+\theta_S W_S}{P}$$

subject to vehicle movement constraints

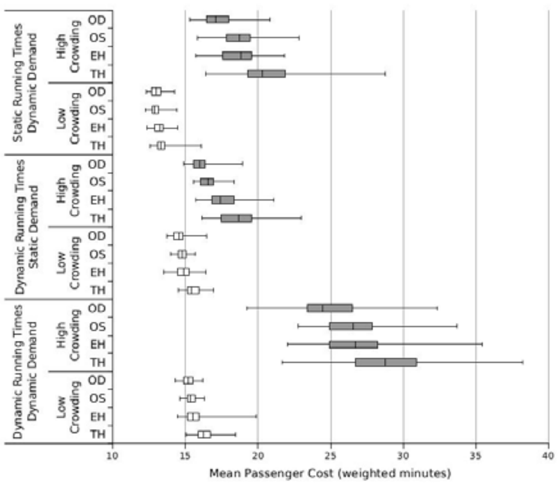
passenger activity constraints

$$0 \le h_{v,s} \le h_s^{\text{max}} \quad \forall v \in V \quad \forall s \in S$$

	static	dynamic
running times	$a_{v,s}=d_{v,s-1}+r_{s-1}$	$a_{v,s}=d_{v,s-1}+r_{s-1}(d_{v,s-1})$
demand	$\beta_{v,s_b,s_a}=\lambda_{s_b,s_a}(d_{v,s_b}-d_{v-1,s_b})$	$\beta_{v,s_b,s_a}=\int_{d_{v-1,s_b}}^{d_{v,s_b}}\lambda_{s_b,s_a}(t)\mathrm{d}t$

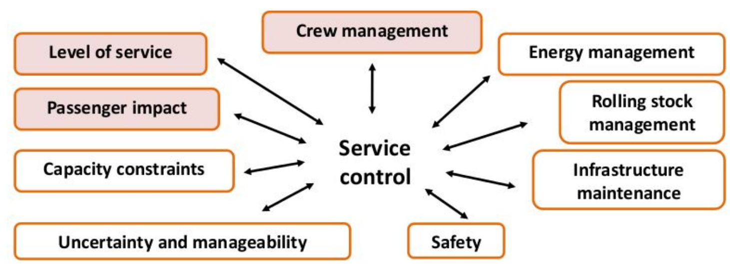
GE Sánchez-Martínez, HN Koutsopoulos, NHM Wilson. Real-time control for high-frequency transit with dynamics. Transportation Research Part B: Methodological 83, 1-19, 2016.

Optimal Holding with Dynamics



GE Sánchez-Martínez, HN Koutsopoulos, NHM Wilson. Real-time control for high-frequency transit with dynamics. *Transportation Research Part B: Methodological* 83, 1-19, 2016.

Rail Operations Control: Decision Factors



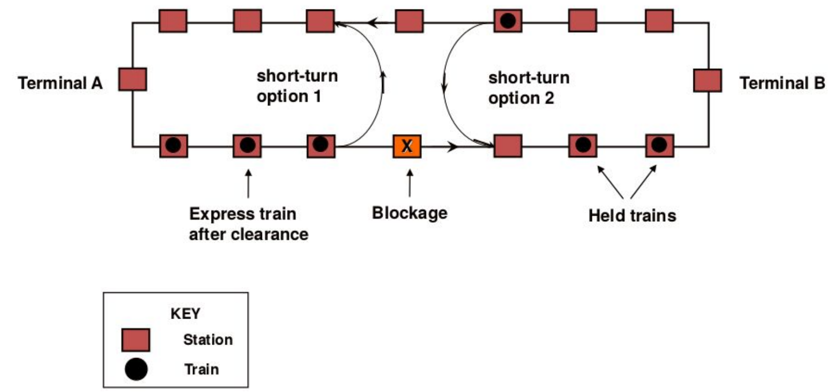
- These factors can trigger service control interventions or place constraints on interventions performed for other reasons
- Conflicts between objectives are frequent
- Service control can cause unreliability!
- How can we best coordinate and integrate these objectives and constraints?

"Diagnosis and Assessment of Operations Control Interventions: Framework and Applications to a High Frequency Metro Line." MST Thesis, André Carrel; MIT, 2009.

Three Levels of Control Problems

- **Routine disturbances** few minutes deviation from schedule
  - speed adjustment
  - dwell time adjustment (selective holding)
  - terminal recovery
- **Short-term disruptions** 5-30 minute blockages
  - holding
  - short-turning
  - expressing
- **Longer-term disruptions** >30 minute blockages
  - single-track reverse direction operations
  - replacement bus service around blockage

Disruption Response Strategies



State of Practice in Operations Control

- Advances in train control systems help minimize impacts of small incidents
- Major disruptions still handled in individual manner based on judgment and experience
- Little effective decision support for controllers
- Simplistic view of objectives and constraints in model formulation
- Substantial opportunities for more effective models

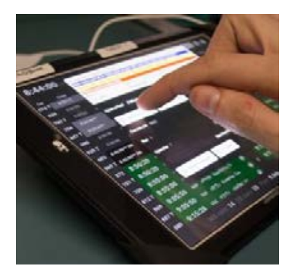
MBTA Green Line Headway Dispatching

Current Operations

- Trains dispatched by on-site inspectors following the schedule

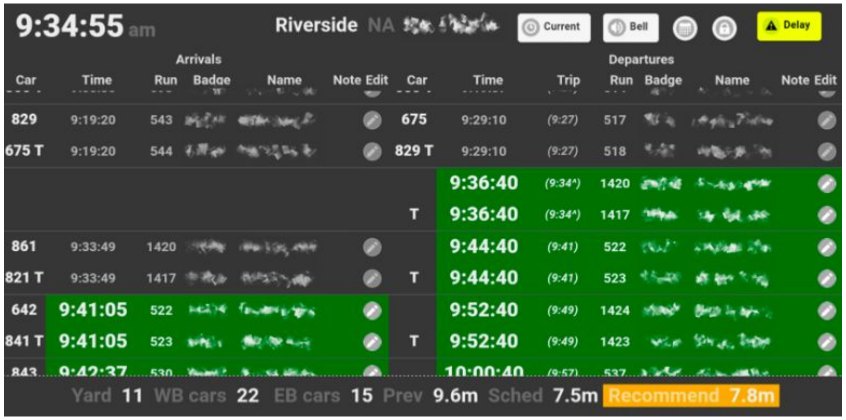
Headway Dispatching Pilot

- Decision support tool delivered on touchscreen tablet
- Even headway dispatching, with constraints
- Contains vehicle and driver information



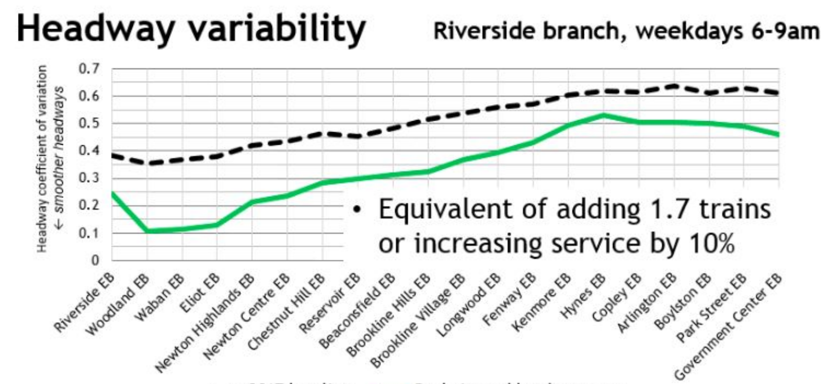
JJ Fabian. Improving Transit Reliability: A Case Study of the MBTA Green Line Through Simulation and Field Experiments. MST Thesis, MIT, 2017.

MBTA Green Line Headway Dispatching



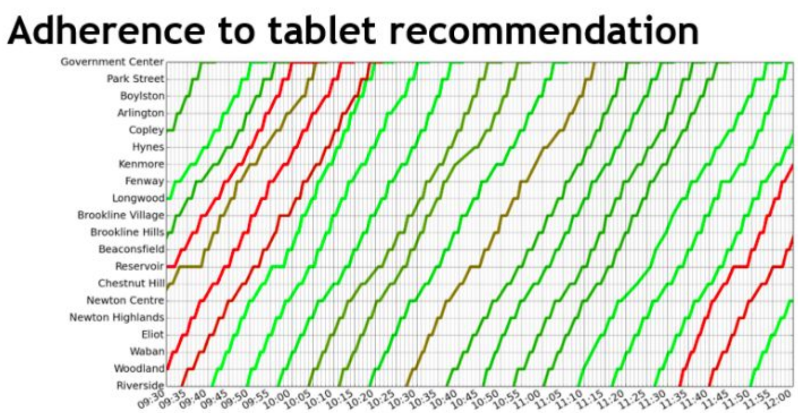
JJ Fabian. Improving Transit Reliability: A Case Study of the MBTA Green Line Through Simulation and Field Experiments. MST Thesis, MIT, 2017.

MBTA Green Line Headway Dispatching



JJ Fabian. Improving Transit Reliability: A Case Study of the MBTA Green Line Through Simulation and Field Experiments. MST Thesis, MIT, 2017.

MBTA Green Line Headway Dispatching



JJ Fabian. Improving Transit Reliability: A Case Study of the MBTA Green Line Through Simulation and Field Experiments. MST Thesis, MIT, 2017.