Outline

- Real Time Control Strategies for Rail Transit
  - Prior Research
  - Shen/Wilson Model Formulation
  - Model Application and Results
  - Implementation Issues
  - Conclusions
- Follow-on Subjects
- Final Exam

Prior Research

O’Dell and Wilson (1999):

- Formulated and solved to optimality holding and (restricted) short-turning models
- Active control strategies resulted in significant passenger wait time savings
- Train impact set need not be large and can be restricted to trains ahead of the blockage
- Hold-at-first station strategy is recommended
- Short-turning is most effective where:
  - -- blockage is long relative to short-turn time
  - -- number of stations outside short-turn loop is small
- Solution time is typically 30 seconds or less

Prior Research

Limitations:

- only specified short-turns included in solution
- expressing not included
- objective function ignored in-vehicle delay time
- did not recognize the stochastic nature of disruption duration

Model Formulation

Key Features:

- station specific parameters: passenger arrival rates, alighting fractions, minimum safe headways
- station dwell time a linear function of passengers boarding, alighting and crowding
- train order is variable
- train capacity constraint

Simplifications:

- predictable disruption length
- passenger flows estimated from historical data
- system is modelled as deterministic
- strategies selected to produce minimum inter-station travel times.

Shen/Wilson Model Formulation*

Decision variables:

- departure time of train *i* from station *k*
- short-turning binary variables
- expressing binary variables

Objective function:

- minimization of weighted sum of passenger waiting time at stations and in-vehicle delay

Control set:

- set of trains and stations where control actions may be applied, typically:
  - -- 2-4 holding candidates ahead of the disruption
  - -- 1-2 expressing candidates behind the disruption
  - -- 1-3 short-turning candidates

*Reference: Shen, S. and N.H.M. Wilson, "Optimal Integrated Real-Time Disruption Control Model for Rail Transit Systems", Computer-Aided Scheduling of Public Transport, Lecture Notes in Economics and Mathematical

Systems #505 (S. Voss and J. Daduna, co-editors), pp. 335-364, April 2001.

Model Formulation

Impact set:

- consider a finite set of trains and stations over which to evaluate the impacts of the control strategies

Constraints include:

- train running time and minimum safe separation
- train dwell time = f (passengers boarding and alighting)
- passenger loads and train capacity

Model Structure:

- mixed integer program

Model Simplifications

A. Piece-wise linear approximation of quadratic terms in objective function:

- waiting time
- holding time

B. Simplification of non-separable terms

- additional waiting time for passengers left behind:

  -- approximate headway by minimum headway

- in-vehicle delay:

  -- approximate passengers on train by normal passenger load at that time and point on route

Model Applications

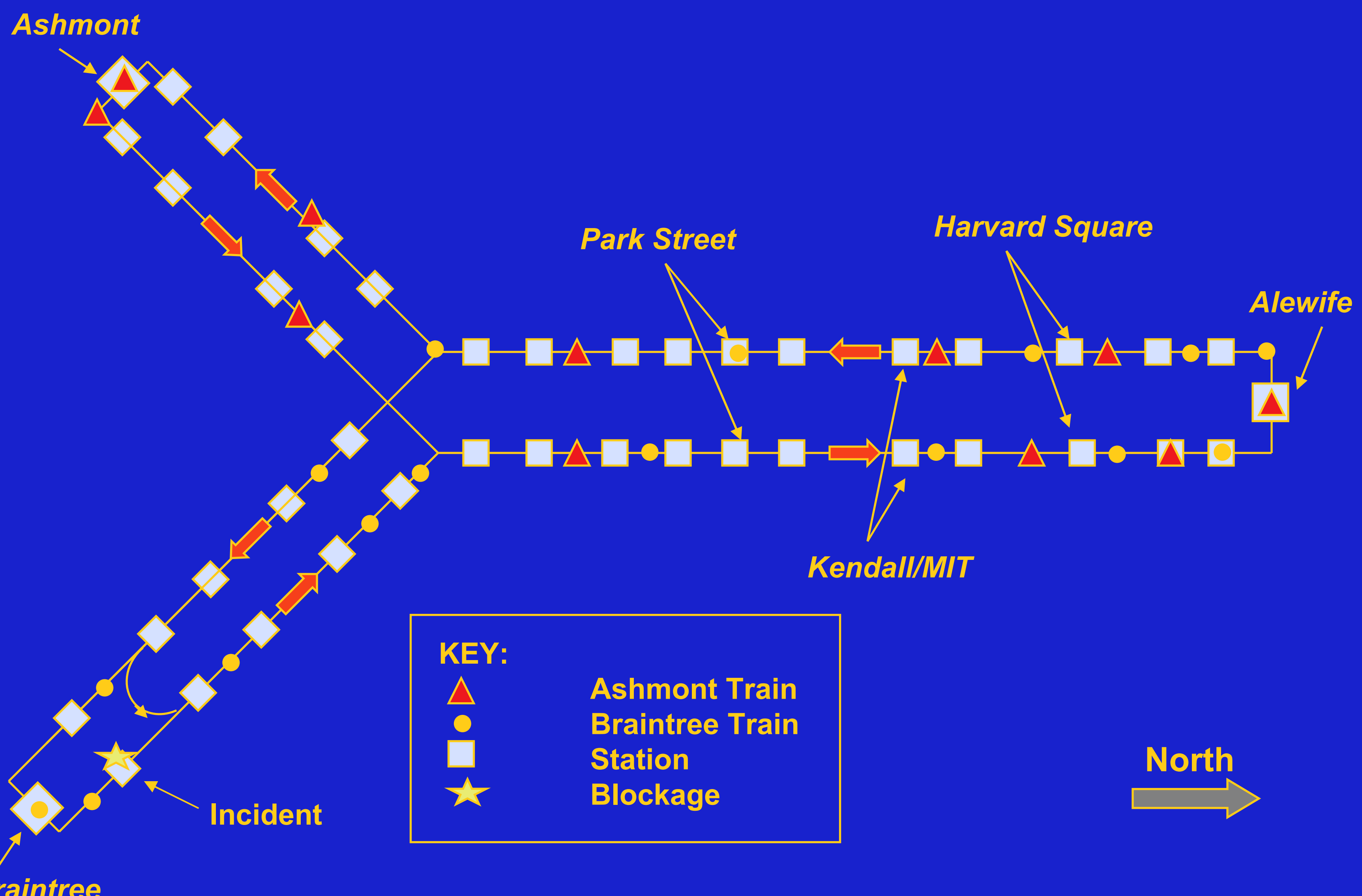
MBTA Red Line Characteristics:

- 23 stations (including 3 terminals)
- 27 six-car trains in A.M. peak
- 3.4 minute trunk headways (6 and 8 minutes on branches)
- 30,000 passengers in peak hour

Simplified system:

- single loop
- scaled passenger arrival rates and minimum safe separation on trunk portion of line
- 6-minute headways

Scenario Description



Comparison of Strategy Effectiveness for 10-Minute Disruption Scenario

Control Strategy	Mean Platform Waiting Time (min)	Mean In-Vehicle Delay (min)	Mean Weighted Waiting Time (min)	Saving over NC
ND	3.00	0.00	3.00	-
NC	5.70	0.15	5.78	-
H	4.53	1.39	5.23	10%
HE	4.59	0.83	5.00	13%
HET	3.55	0.39	3.74	35%

ND = No Disruption NC = No Control H = Holding Only

HE = Holding and Expressing Only HET = Holding, Expressing, and Short-Turning

Comparison of Strategy Effectiveness for 20-Minute Disruption Scenario

Control Strategy	Mean Platform Waiting Time (min)	Mean In-vehicle Delay (min)	Mean Weighted Waiting Time (min)	Saving over NC
NC	9.11	0.19	9.20	-
H	6.57	1.98	7.56	18%
HE	6.23	1.75	7.10	23%
HET	3.79	0.35	3.97	57%

NC = No Control H = Holding Only HE = Holding and Expressing Only

HET = Holding, Expressing, and Short-Turning

Sensitivity Analysis:
Effect of Under-estimating Disruption Duration

Blockage Duration Estimate	15 Minutes			10 Minutes		
Control Schemes	H	HE	HET	H	HE	HET
Mean Weighted Waiting Time (min)	6.34	5.97	3.77	6.37	6.21	4.31
Increase due to Inaccurate Estimate				+0.5%	+4.0%	+14.3%

H = Holding Only

HE = Holding and Expressing Only

HET = Holding, Expressing, and Short-Turning

Sensitivity Analysis:
Effect of Over-estimating the Disruption Duration

Blockage Duration Estimate	5 Minutes	10 Minutes	
Control Schemes	H, HE, HET	H & HE	HET
Total Weighted Waiting Time (min)	14875	14888	14968
Increase due to Wrong Estimate		-	+0.6%

H = Holding Only HE = Holding and Expressing Only

HET = Holding, Expressing, and Short-Turning

Solution Times

- Micron P-II, 300 MHz, 64 MB RAM computer
- C-PLEX v. 4.0

Solution Times with and without Expressing (in seconds)				
Scenario	H	HE	HET	HT
10-Minute	2.91	5.60	11.28	12.06
20-Minute	12.10	155.01	68.32	24.72

H = Holding Only
HE = Holding and Expressing Only
HET = Holding, Expressing, and Short-Turning
HT = Holding and Short-Turning Only

Conclusions

- Holding provides 10-18% passenger waiting time savings over the no-control case
- Expressing provides little incremental benefit over holding
- Short-turning combined with holding can provide substantial savings: in the case analyzed, 35-57% savings.
- Holding is not sensitive to errors in estimating disruption deviation, but short-turning can be
- Solution time is typically less than 30 seconds

Future Directions

- Develop robust disruption control models recognizing key stochastic elements such as disruption duration, running time, dwell time, and passenger loads
- Develop fast routine control models incorporating control strategies such as speed variation and dwell time variation

Follow-on Subjects

- Optimization
  - 15.057 Systems Optimization
  - 15.093 Optimization Methods
  - 15.094 Systems Optimization: Models and Computation
  - 15.081 Introduction to Mathematical Programming
  - 15.082 Network Optimization
  - 15.083 Combinatorial Optimization
  - 15.084 Nonlinear Programming
- Transportation and Logistics/Optimization
  - 1.206J/16.77J Airline Schedule Planning
  - 1.258J/11.541J/ESD.226J Public Transportation Service and Operations Planning
  - 1.270J/ESD.270J Logistics and Supply Chain Management

Final Exam

- Tuesday, December 16, Room 4-149, 9 AM - noon
- 1 8.5x11" page of notes, both sides
- Focus on modeling and basics of optimization