Outline

1. Problem description
2. General Approach
3. Strategic Level Case Study
4. Tactical Level Case Study
5. Operational Level Case Study
Basic Variables Affecting Manpower Level Decisions

- Existing Operators (+)
- New Hires (+)
- Existing Scheduled Service (+)
- Scheduled/Unscheduled Service Additions (+)

Operator Availability

- Attrition (-)
- Absence (-)
- Day Off (-)

Operator Demand

Service Deletions

Availability Demand

- Less Than
- Greater Than
- Equal To

Additional Overtime Cost
Less Benefit Cost
No Additional Cost
Additional Guarantee Cost
Additional Benefit Cost

Nigel Wilson
1.258J/11.543J/ESD.226J
Spring 2010, Lecture 20
General Approach

Strategic Level

• workforce size
• hiring plan
• vacation allocation

Tactical Level

• extra staff by day of week

Operational Level

• report times for unassigned extra staff
Problem Description

By period of year:
- absence hours
- required extra work
- attrition

By garage and day of week:
- absence hours
- required extra work

By garage and time of day:
- absence hours
- required extra work

Strategic Level:
- workforce size
- vacation allocation
- hiring patterns

Tactical Level:
- extraboard allocation by garage and day of week

Operational Level:
- report times for available extraboard operators

- Budget
- Service Plan
- Vacation Liability
- Work Rules
- Policies

- Work Rules
- Policies

- Work Rules
- Policies

Nigel Wilson
1.258J/11.543J/ESD.226J
Spring 2010, Lecture 20
A. Quarterly Hiring

Implications:
- Unassigned cover time at start of timetable
- Large amounts of overtime at end of timetable
- Poor reliability at end of timetable
Total Unscheduled Pay

- Workday-Off and Second Run Premium Pay with Associated Variable Fringe Benefits
- Guarantee and Associated Variable Fringe Benefits
- Optimal Location
- Fixed Fringe Benefits

Cost

Number of Extradboard Operations
Optimal Extraboard Size and Unscheduled Guarantee and Premium

- Optimal Extraboard
- Workday-Off/Second Run Premium
- No Work Available Guarantee

$p(x) = 16\%$
The Strategic Level Approach

1. Decision Variables
   - Workforce Size for Each Period
   - Vacation Allocation for Each Period
   - Optimal Hiring Levels for Each Period

2. Objective: Minimize Workforce Cost
   - Scheduled Runs
   - Extraboard
   - Overtime
3. Constraints
   - Vacation Liability
   - Overtime
   - Service Reliability
   - Part-time Operation Constraints
   - Other Policy Constraints
1. Regular Overtime
   • the result of more required work than available extraboard on a given day

2. Excess Overtime
   • the result of inherent inefficiency in assigning daily report times
The Excess Overtime Curve

• Excess overtime is a maximum when the number of required work hours exactly matches the number of extraboard hours available.

• Excess overtime decreases with fewer required work hours or available workforce hours.

Daily Excess Overtime Curve

Available Cover - Required Cover

Excess Overtime Hours

k

-b 0 +b
Expected Overtime for the Period

- Takes into account of variation of both the required work hours and day-to-day variability of the size of the extraboard

**REGULAR AND EXCESS OVERTIME**

**WORKFORCE - AVERAGE REQUIRED WORK**
Overtime Effects on Total Workforce Costs

TOTAL WORKFORCE COSTS

TOTAL COST

SCHEDULED WORKFORCE

TOTAL OT

REGULAR OT

EXCESS OT

COSTS

WORKFORCE - AVERAGE REQUIRED WORK

Nigel Wilson

Spring 2010, Lecture 20
A Reliability Model

Open Work

Overtime Available

Operator Available

Missed Trips

Willingness to Work Overtime

Yes

Overtime Worked

No

No

Yes
Missed Service Hours

Missed Service Hours = 0.28 \times \text{Open Work Hours}

Missed Service Hours = 0.28 \times \text{Open Work Hours}

Nigel Wilson

1.258J/11.543J/ESD.226J
Spring 2010, Lecture 20
(Based on Massachusetts Bay Transportation Authority Bus Operations)

Characteristics

- Part-time workforce sized to 40% of the full-time workforce
- Large variability in the required work hours
  - Mean Daily Absence and Extra Work: 1250 hours
  - Daily Standard Deviation of Absence and Extra Work: 290 Hours
<table>
<thead>
<tr>
<th></th>
<th>Overtime</th>
<th>Part-Timer</th>
<th>Full-Timer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wage Rate ($/Hour)</td>
<td>29.04</td>
<td>19.36</td>
<td>19.36</td>
</tr>
<tr>
<td>Full Cost/Hour Worked</td>
<td>32.72</td>
<td>31.24</td>
<td>34.78</td>
</tr>
<tr>
<td>Marginal Cost if last extraboard used 75% of time</td>
<td>--</td>
<td>41.65</td>
<td>46.37</td>
</tr>
<tr>
<td>Marginal Cost if last extraboard used 50% of time</td>
<td>--</td>
<td>62.48</td>
<td>69.56</td>
</tr>
</tbody>
</table>
Available Operator Hours

O = regular time cost
o = regular time cost + regular OT cost
x = total cost
## Results of Constant Hiring and Constant Vacation Constraints

<table>
<thead>
<tr>
<th></th>
<th>Base Case</th>
<th>Constant Hiring</th>
<th>Constant Vacation</th>
<th>Constant Hiring &amp; Vacation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>FT Oper</strong></td>
<td>1256.50</td>
<td>1256.50</td>
<td>1290.60</td>
<td>1315.90</td>
</tr>
<tr>
<td><strong>PT Oper</strong></td>
<td>653.90</td>
<td>653.90</td>
<td>665.70</td>
<td>684.80</td>
</tr>
<tr>
<td><strong>Overtime (%)</strong></td>
<td>1.50</td>
<td>1.50</td>
<td>0.90</td>
<td>0.30</td>
</tr>
<tr>
<td><strong>OT cost</strong></td>
<td>1.45</td>
<td>1.45</td>
<td>0.88</td>
<td>0.30</td>
</tr>
<tr>
<td><strong>Reg cost</strong></td>
<td>96.37</td>
<td>96.37</td>
<td>98.78</td>
<td>100.93</td>
</tr>
<tr>
<td><strong>Tot cost</strong></td>
<td>97.82</td>
<td>97.82</td>
<td>99.65</td>
<td>101.23</td>
</tr>
<tr>
<td><strong>Reliability (%)</strong></td>
<td>99.60</td>
<td>99.60</td>
<td>99.80</td>
<td>99.90</td>
</tr>
</tbody>
</table>
## Results for Different Overtime Constraints

<table>
<thead>
<tr>
<th></th>
<th>Base Case 1.5% OT</th>
<th>no OT Const</th>
<th>5% OT Const</th>
<th>1% OT Const</th>
</tr>
</thead>
<tbody>
<tr>
<td>FT Oper</td>
<td>1266</td>
<td>1104</td>
<td>1202</td>
<td>1267</td>
</tr>
<tr>
<td>PT Oper</td>
<td>654</td>
<td>575</td>
<td>625</td>
<td>660</td>
</tr>
<tr>
<td>Overtime (%)</td>
<td>1.5</td>
<td>12.2</td>
<td>5.0</td>
<td>1.0</td>
</tr>
<tr>
<td>OT cost*</td>
<td>1.4</td>
<td>11.8</td>
<td>4.8</td>
<td>1.0</td>
</tr>
<tr>
<td>reg cost*</td>
<td>96.4</td>
<td>84.7</td>
<td>92.2</td>
<td>97.2</td>
</tr>
<tr>
<td>tot cost*</td>
<td>97.8</td>
<td>96.5</td>
<td>97.0</td>
<td>98.2</td>
</tr>
<tr>
<td>reliability (%)</td>
<td>99.6</td>
<td>97.0</td>
<td>98.8</td>
<td>99.8</td>
</tr>
</tbody>
</table>

* Costs are in millions of dollars per year
Objective: minimize weighted sum of
- overtime
- missed trips

Decision variables: allocate extra staff
- by garage (area of depot)
- by day of week

Inputs:
- operator timetable requirements by day of week and garage
- mean and standard deviation of absence and required extra work by day of week and garage
Tactical Level
(Timetable/Rating Level)

Constraints: total available operators

Key relationships:
- requested overtime as a function of total available operators, timetable requirements, absence, and required extra work
- missed service as a function of requested overtime

Method: heuristic or optimization method
## Application of Tactical Model to Single MBTA Garage

<table>
<thead>
<tr>
<th></th>
<th>Open Work (hours)</th>
<th>Extraboard Allocation (days)</th>
<th>Exp. Overtime (hours)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>Std. dev.</td>
<td>Actual FTOs</td>
</tr>
<tr>
<td>Monday</td>
<td>259</td>
<td>36</td>
<td>20</td>
</tr>
<tr>
<td>Tuesday</td>
<td>200</td>
<td>31</td>
<td>20</td>
</tr>
<tr>
<td>Wednesday</td>
<td>212</td>
<td>36</td>
<td>20</td>
</tr>
<tr>
<td>Thursday</td>
<td>233</td>
<td>30</td>
<td>20</td>
</tr>
<tr>
<td>Friday</td>
<td>278</td>
<td>52</td>
<td>20</td>
</tr>
<tr>
<td>Saturday</td>
<td>185</td>
<td>24</td>
<td>17</td>
</tr>
<tr>
<td>Sunday</td>
<td>84</td>
<td>25</td>
<td>7</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Tactical Level Findings

- Significant variation in absence and required extra work
  - by garage
  - by day of week

- Variably sized extraboard is appropriate
  - by garage
  - by day of week

- Data required on absence and extraboard utilization by garage and day of week
Objective: minimize weighted sum of

- overtime
- missed trips

Decision variables: extra staff report times in ranked order

- by garage (area or depot)
- by day of week

Inputs:

- operator timetable requirements by time of day
- known extra work by time of day
Operational Level (Daily Level)

Constraints: extraboard work rules

Key relationships:

• likelihood of missed trip resulting if no cover operator available, by time of day

Method: heuristic or optimization method
Probability of Open Run Profile

- Actual
- Smoothed

TIME OF DAY

PROBABILITY OF RUN BEING OPEN

Nigel Wilson
1.258J/11.543J/ESD.226J
Spring 2010, Lecture 20
## Unexpected Absences by Day-of-Week

<table>
<thead>
<tr>
<th></th>
<th>Max</th>
<th>Min</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>Known Absence Hours</th>
<th>Scheduled Hours</th>
<th>Avg. Prob. of Open Runs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sat</td>
<td>98.0</td>
<td>30.5</td>
<td>68.7</td>
<td>18.8</td>
<td>112.0</td>
<td>2044</td>
<td>0.034</td>
</tr>
<tr>
<td>Sun</td>
<td>48.0</td>
<td>0.0</td>
<td>23.6</td>
<td>12.8</td>
<td>59.6</td>
<td>815</td>
<td>0.029</td>
</tr>
<tr>
<td>Mon</td>
<td>130.0</td>
<td>51.5</td>
<td>93.7</td>
<td>23.9</td>
<td>163.7</td>
<td>2282</td>
<td>0.041</td>
</tr>
<tr>
<td>Tue</td>
<td>78.5</td>
<td>39.0</td>
<td>62.6</td>
<td>12.3</td>
<td>135.3</td>
<td>2282</td>
<td>0.027</td>
</tr>
<tr>
<td>Wed</td>
<td>77.0</td>
<td>22.5</td>
<td>54.1</td>
<td>21.2</td>
<td>157.3</td>
<td>2282</td>
<td>0.024</td>
</tr>
<tr>
<td>Thu</td>
<td>115.5</td>
<td>46.5</td>
<td>75.4</td>
<td>20.4</td>
<td>155.3</td>
<td>2282</td>
<td>0.033</td>
</tr>
<tr>
<td>Fri</td>
<td>140.5</td>
<td>55.5</td>
<td>88.4</td>
<td>28.0</td>
<td>188.9</td>
<td>2282</td>
<td>0.039</td>
</tr>
<tr>
<td>Avg. Weekday</td>
<td>74.8</td>
<td></td>
<td></td>
<td></td>
<td>160.1</td>
<td>2282</td>
<td>0.033</td>
</tr>
</tbody>
</table>
## Expected Weighted Uncovered Open Work

<table>
<thead>
<tr>
<th>Day of Week</th>
<th>DHS</th>
<th>HS</th>
<th>FLAT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monday</td>
<td>53.34</td>
<td>54.96</td>
<td>53.12</td>
</tr>
<tr>
<td>Tuesday</td>
<td>19.36</td>
<td>19.18</td>
<td>19.42</td>
</tr>
<tr>
<td>Wednesday</td>
<td>41.42</td>
<td>41.31</td>
<td>41.89</td>
</tr>
</tbody>
</table>

Assumes 6 FTOs, 4 PTOs available on extraboard

**Key:**

- **DHS** = day and hour specific absence rates
- **HS** = assumes hour specific absence rates only
- **FLAT** = assumes constant absence rate for all days and hours
Evaluating Current Practice: Weighted Uncovered Open Work (Hours)

<table>
<thead>
<tr>
<th>Date</th>
<th>Rep. Oper. (FTO-PTO)</th>
<th>Actual Rep.</th>
<th>Model Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>6/29</td>
<td>11-7</td>
<td>36.1</td>
<td>26.9</td>
</tr>
<tr>
<td>7/06</td>
<td>3-0</td>
<td>118.1</td>
<td>112.3</td>
</tr>
<tr>
<td>7/13</td>
<td>6-6</td>
<td>64.0</td>
<td>54.3</td>
</tr>
<tr>
<td>7/20</td>
<td>8-12</td>
<td>40.1</td>
<td>22.0</td>
</tr>
<tr>
<td>7/27</td>
<td>10-5</td>
<td>53.0</td>
<td>36.6</td>
</tr>
</tbody>
</table>

Data are for 5 consecutive Mondays for a specific MBTA garage
## Actual vs. Recommended Report Times

<table>
<thead>
<tr>
<th>MONDAY, 7/13</th>
<th>MONDAY, 7/27</th>
</tr>
</thead>
<tbody>
<tr>
<td>Actual</td>
<td>Recommended</td>
</tr>
<tr>
<td>4.45</td>
<td>4.30</td>
</tr>
<tr>
<td>5.00</td>
<td>5.00</td>
</tr>
<tr>
<td>5.30</td>
<td>5.45</td>
</tr>
<tr>
<td>6.00</td>
<td>6.00</td>
</tr>
<tr>
<td>6.00</td>
<td>6.00</td>
</tr>
<tr>
<td>7.00</td>
<td>6.00</td>
</tr>
<tr>
<td>7.00</td>
<td>6.00</td>
</tr>
<tr>
<td>7.00</td>
<td>6.00</td>
</tr>
<tr>
<td>7.00</td>
<td>6.00</td>
</tr>
<tr>
<td>8.00</td>
<td>6.00</td>
</tr>
<tr>
<td>8.00</td>
<td>6.00</td>
</tr>
<tr>
<td>13.45</td>
<td>6.15</td>
</tr>
<tr>
<td>14.00</td>
<td>14.00</td>
</tr>
<tr>
<td>14.00</td>
<td>14.15</td>
</tr>
<tr>
<td>14.15</td>
<td>15.30</td>
</tr>
<tr>
<td>15.30</td>
<td>15.45</td>
</tr>
<tr>
<td>16.00</td>
<td>18.15</td>
</tr>
<tr>
<td>14.15</td>
<td>20.00</td>
</tr>
<tr>
<td>16.00</td>
<td>14.45</td>
</tr>
</tbody>
</table>
Operational Level Findings

• Significant improvements possible
  • reduced overtime
  • reduced missed trips

• Single set of ranked report times can be used across all weekdays and seasons for each garage
  • separate ranked report times required for Saturdays, Sundays

• Constant absence rates can be assumed
  • by hour of day
  • by day of week