Outline
1. Objectives of Maintenance Programs
2. Program Elements
3. Framework for Program Design
4. Maintenance Indicators
5. MBTA Experience
Objectives of Maintenance Programs

• Safety
  -- paramount, must avoid unsafe operations if at all possible
  -- key question is, are there identifiable precursors to safety failures?

• Supply
  -- very common measure of maintenance effectiveness is % of scheduled pullouts met
  -- a tension between this and reliability on the road

• Reliability
  -- mean distance between failures a universal measure of maintenance effectiveness
  -- inconsistent definitions of "failures" makes comparisons hard

• Cost
Maintenance activities can be classified as scheduled or unscheduled

A. Scheduled

A.1 Daily Servicing
   -- fueling, fluid checks, minor maintenance
   -- following up on operator defect reports
   -- may account for 20% of total maintenance effort
   -- early problem identification opportunity
   -- vehicle diagnostics and computer-based monitoring of performance
A. Scheduled, cont'd

A.2 Inspections

-- scheduled check on parts or systems to detect emerging problems before they result in in-service failure

-- typical inspection program may have 2-5 inspection intervals ranging from 1,000 to 24,000 miles

-- package each part or system into specific inspection interval to take advantage of scale economies

-- inspections typically done in off-peak or overnight periods
A. Scheduled, cont'd

A.3 Preventive Parts Replacement

-- replace certain parts before failure to avoid high failure costs

-- integrated into an inspection cycle

-- replacement can be based on mileage (automatic) or on condition at inspection

-- examples are rebuilding motors or transmissions
B. Unscheduled: events which occur unpredictably

B.1 Repairs
   -- after a failure, typically in-service

B.2 Unscheduled Preventive Maintenance
   -- replace a defective part to avoid failure
   -- triggered by inspection, driver report, or diagnostic
Framework for Program Design

The diagram illustrates the relationship between cost, PM resource, repair resources, and PM expense. The graph shows how total cost decreases as PM resource increases, reaching an optimum point where repair resources and PM expense are balanced. Beyond this point, PM expense increases significantly, highlighting the importance of managing resources effectively to minimize costs.
A. Benefits of Preventive Maintenance

- reduce probability of in-service failure
- improve system performance
- extend system life
- bring maintenance activity under management control, ease of scheduling
Analysis Framework

B. Effect of In-Service Failure

- safety risk
- effect on customers -- varies by mode
- additional mechanic cost for lower productivity work in the field, plus travel time
- surplus vehicle costs + service vehicle costs
- extra operator costs
C. Questions to address for each system/part:

- What is impact of in-service failure on:
  -- safety
  -- missed trips
  -- other parts/systems

- How predictable is failure:
  -- are there clear precursors
  -- what is pdf for life of part/system

- What is cost of new part relative to other impacts

- What is cost of inspection
Performance Measures

Mean Distance Between Failures (MDBF)

Fleet Availability

Maintenance Cost or Productivity
MDBF

• **Vehicle Design and Technology**
  -- Badly designed vehicle will never have a good MDBF no matter how good the maintenance

• **Operating Conditions**
  -- MDBF is per vehicle? per train? Six car train less likely to fail than four (Why?)
  -- What happens to MDBF in the snow?
MDBF

• **Definition**
  -- What is a failure? What if a door is stuck, but pax could exit other doors?
  -- MBTA: Four or more minutes’ delay on the road caused by the same fault (strict)

• **Rewards Wrong Behaviour**
  -- Maintain the train, regardless of the costs
  -- MDBF > target == slashed budget?
  -- No measure of residual asset value
Fleet Availability

- Vehicle Design and Technology
- Operating Conditions
- Good Measure for Operators
  -- Equivalent to “bottom line”, as long as the requested availability is realistic
- Duct tape and strings?
  -- Vehicle that will barely limp out of the depot is still “available” for traffic
- Spare Ratio Effects
Maintenance Costs

- **Maintenance Unit Costs**
  -- per Vehicle-hour? Vehicle-mile? Vehicle?

- **Maintenance Regime and Strategy Affects Costs**
  -- Very easy to “skimp” on maintenance to produce a low cost, esp. on rail assets
  -- Low maintenance costs can produce a low reliability

- **Cost Allocation**
  -- Large fixed costs for depot and facilities
  -- Renewal-enhancements seem expensive

- **Extraneous Variables**
  -- Cost of labor, and others
Transit Managers must:
-- Understand the pitfalls of each performance measure

Performance Trends: the “Why”

Key Points to Consider
-- MDBF, Availability
-- Costs: Inspection or Repair
-- Residual Asset Value
-- Reliability/Service Level/Cost trade-off
**Current US Transit Industry Maintenance Indicators**

<table>
<thead>
<tr>
<th></th>
<th>Bus</th>
<th>Heavy Rail</th>
<th>Light Rail</th>
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<tbody>
<tr>
<td><strong>MDBF (miles) (T2000)</strong></td>
<td>7,000</td>
<td>28,000-45,000</td>
<td>4,000</td>
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<tr>
<td><strong>(T 1985 winter)</strong></td>
<td>5,000</td>
<td>1,000-4,000</td>
<td>1,000</td>
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<tr>
<td><strong>Industry-wide:</strong></td>
<td></td>
<td></td>
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<tr>
<td><em>Veh Maint Employees</em></td>
<td>0.7-0.9</td>
<td>1.0-1.2</td>
<td>1.6-1.8</td>
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<tr>
<td><em>Vehicle Operators</em></td>
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<tr>
<td><em>Non-Veh Maint Employees</em></td>
<td>0.1-0.3</td>
<td>1.8-2.2</td>
<td>1.1-1.7</td>
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<tr>
<td><em>Vehicle Operators</em></td>
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# Failure Modes (MBTA)

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<thead>
<tr>
<th>Failure Mode</th>
<th>Red 01500 01600</th>
<th>Red 01700</th>
<th>Red 01800</th>
<th>Green Boeing</th>
<th>Green Kinki</th>
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<tbody>
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<td>Air</td>
<td>33</td>
<td>9</td>
<td>8</td>
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<td>Brake</td>
<td>7</td>
<td>6</td>
<td>17</td>
<td>143</td>
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<tr>
<td>Carbody</td>
<td>3</td>
<td>1</td>
<td>0</td>
<td>10</td>
<td>10</td>
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<tr>
<td>Doors</td>
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<td>9</td>
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<td>2</td>
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<td>0</td>
<td>3</td>
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<tr>
<td>Couplers</td>
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<td>0</td>
<td>0</td>
<td>6</td>
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<tr>
<td>Propulsion</td>
<td>14</td>
<td>16</td>
<td>5</td>
<td>89</td>
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<td>Trucks</td>
<td>4</td>
<td>3</td>
<td>1</td>
<td>4</td>
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<tr>
<td>A.T.O.</td>
<td>16</td>
<td>10</td>
<td>8</td>
<td>0</td>
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<tr>
<td>Other</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>5</td>
<td>5</td>
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<tr>
<td># Fleet</td>
<td>24+52</td>
<td>58</td>
<td>86</td>
<td>144</td>
<td>120</td>
</tr>
</tbody>
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Designing a Maintenance Regime

Maintenance economies of scope
• Shopping a car costs money, thus if a car is shopped, you should rectify all faults

Acknowledging different component life-cycles
• Silicon never dies, but motors burn up
• Decreasing rate of failure components: air valves you leave alone once you install
Designing a Maintenance Regime

Determining the optimal # spares

- Incremental benefit of marginal train versus marginal benefit of more reliable fleet or cheaper maintenance practices

Target the problem car or the problem subsystem (MBTA)

- Incremental increases in time between inspections might be possible
Applying Formal Maintenance Theory

Theory works better when

- Consequences of failure is less severe and easily evaluated
- Component life cycles are well known
- Costs of in-service repair are well defined

Current MBTA regime is

- Block replacement of most consumables
Applying Formal Maintenance Theory

MBTA is improving by

• Developing a better maintenance information system

MBTA could improve by

• More aggressively keep track of component life cycles, permitting some to be replaced every other inspections

• Reexamine coverage ratios requested, with integrated maintenance/operations cost-benefit analysis