# **RELATIONSHIPS** BETWEEN **MAINTENANCE** & **SERVICE** PLANNING


*Assisted by*

MIT department of CIVIL & ENVIRONMENTAL ENGINEERING

REEBIE

Massachusetts Bay Transportation Authority

*Lexcie Lu, Transit Analyst*
*Dorchester, Mass.*

# Outline

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2. Social Externalities of Maintenance
3. Decision Support Framework
4. Discussion
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    b. Consumer Perception of Service Failures
    c. Stochasticity of Transit Operations
    d. Effect of Reduced Maintenance on MDBF
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    b. Maintenance Scheduling
    c. Engineering Research

# Problem Statement

*"How do we maximize the benefits provided by fixed resources on a crowded transit corridor, considering such user benefits as frequency, timeliness, reliability, safety, and agency traincrew, maintenance, capital costs?"*

or

"**Should you run your EMU's till they drop in their tracks?**"

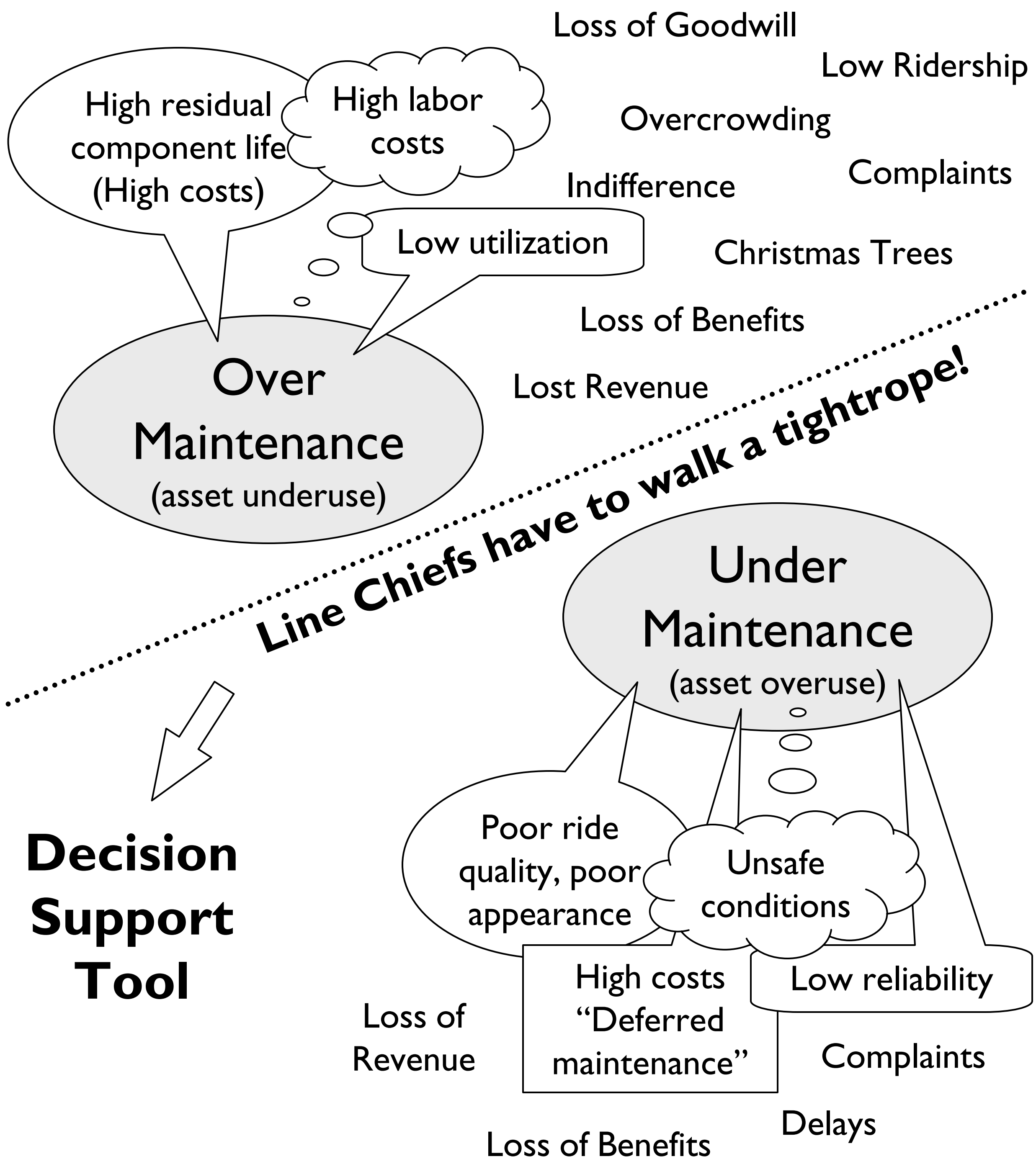
# Hidden Cost of Maintenance

| Track Possession | "Train" Possession |
| --- | --- |
| ↓ | ↓ |
| Trains Detoured, Cancelled | Trains Annulled |
| ↓ | ↓ |
| Lost Revenue<br>Lost Goodwill (read "Future Revenue")<br>Unrecoverable Fixed Costs<br>(e.g. Rolling Stock Lease) | Lost Revenue<br>Lost Goodwill (e.g Overcrowding)<br>Unrecoverable Fixed Costs<br>(e.g. Crew Guaranteed Pay) |

- British Rail (West Coast Route Modernization)
- "Big Dig" in Boston
  - Avoided I-93 clousure
- Chicago CTA
  - Green Line rebuild lost ridership
  - Cermak: weekend construction

- Airlines – off peak maintenance
- Rush hour elevator
  - All vehicles used!

# Maintenance Planning is a Balancing Act



# Decision Support Framework

- Four models and an assumption
  - Passenger Spill Model

$$\text{Spill} = \sum_{\text{all time periods}} D - \left(\frac{1}{ht} \cdot sc\right) \quad \text{where}$$

D = Transit link-flow demand
$h$ = Headway, in hours
$t$ = Time periods, in periods per hour
$s$ = Capacity per vehicle
$c$ = Vehicles per train

**Read about this in the paper**

  - Probabilistic Maintenance Impact Model

$$\text{p(Fail)} = \frac{1}{\text{MDBF}} \cdot m\ l\ c \qquad \text{Cost(Fail)} = \text{p(Fail)} \cdot d \cdot \tfrac{1}{2} r\ v$$

  - Operating Cost Model
  - Wait-Time Savings Model
  - Life-cycle Cost Assumption

$$\text{Cost(Wait)} = \tfrac{1}{2}h \cdot 2r\ v$$

$h$ = Headway, in hours
$r$ = One-way rush-hour ridership
$v$ = Average passenger value of time

- Cost-Benefit Analysis Framework

*Cost*(Operations & Maintenance) =
*Cost*(Failures) + *Cost*(Spill) + *Cost*(Wait-Time) + *Cost*(Crew) + *Cost*(Equipment Life-cycle)

- Compare different O&M scenarios
  - Some costs dominates others
  - Some benefits swamps costs… and vice-versa!

# Orange Line Results

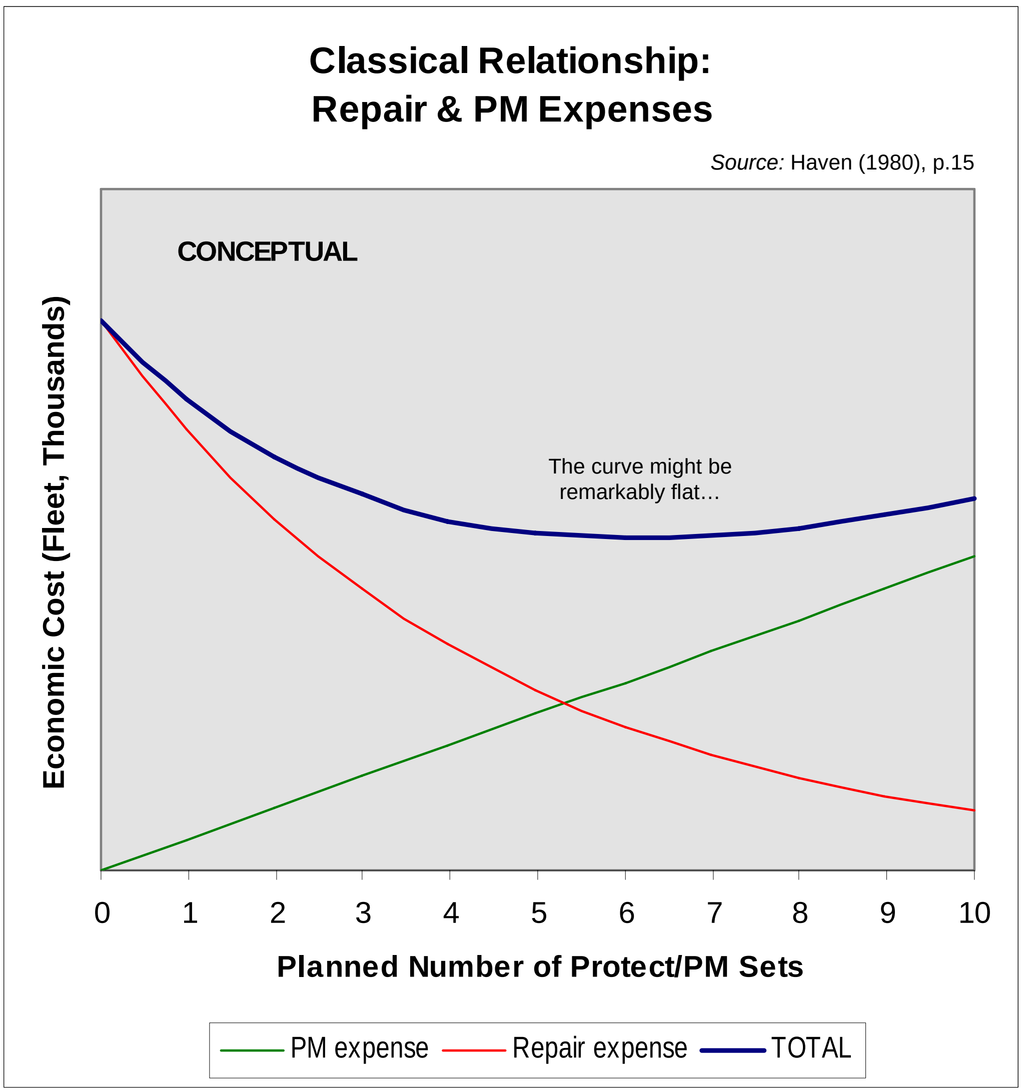
- Risk and Reward
  - More maintenance = less service

| | A | B | C | D | E | F |
|---|---|---|---|---|---|---|
| 1 | **Operating & Maintenance Plan Alternatives Analysis, MBTA Orange Line** | | | | | |
| 2 | *Lexcie Lu*, Transit Analyst (22/12/03) | | | | | |
| 3 | | | | | | |
| 4 | | Base Case | Reduced Consist | Increased Frequency | All Fleet (50% less Reliable) | All Fleet (75% less Reliable) |
| 5 | Headway (mins) | 5 | 5 | 3.4 | 2.8 | 2.8 |
| 6 | Spill (pax) | 80,880 | 225,645 | 86,220 | 37,530 | 37,530 |
| 7 | *Cost (Spill)* | $26,960 | $75,215 | $28,740 | $12,510 | $12,510 |
| 8 | Cars | 102 | 68 | 100 | 120 | 120 |
| 9 | *Cost (Crew)* | $9,520 | $9,520 | $14,000 | $16,800 | $16,800 |
| 10 | MDBF | 27,738 | 41,607 | 27,738 | 13,869 | 6,935 |
| 11 | *Cost (Fail)* | $28,271 | $12,565 | $27,716 | $66,527 | $133,039 |
| 12 | Wait-Time Saved | 0 | 0 | -101,285 | -139,267 | -139,267 |
| 13 | *Cost (Wait)* | $0 | $0 | ($33,762) | ($46,422) | ($46,422) |
| 14 | Total | $64,751 | $97,300 | $36,695 | $49,415 | $115,926 |
| 15 | Δ vs Base Case | $0 | ($32,549) | $28,056 | $15,336 | ($51,176) |

- ‘Protect’ set is a scheduled cancellation
  - Generates little value, so run all you’ve got
  - Determine headways based on 6am availability
- Do inspections at night (less demand)
- Do repairs in rush
  - It’s already broken, don’t send it out!

# Discussion: Inspection v.s. Repair

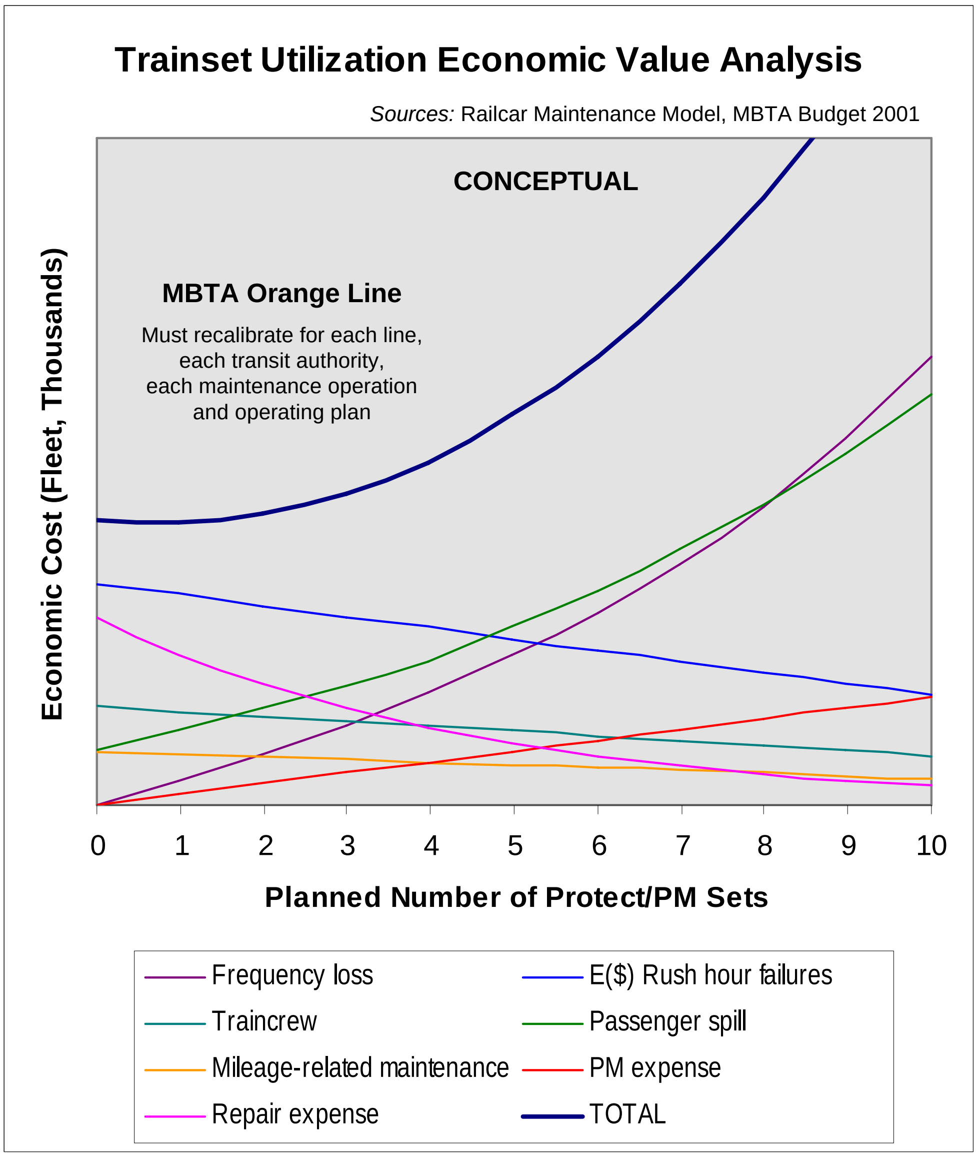
- Deferred maintenance leads to additional repair maintenance in the longer term




or does it?

# Inspection + Repair + Operating + Customer Costs

- If PM takes a trainset out of rush use, think hard about how you might break the job into two sessions, or defer it!



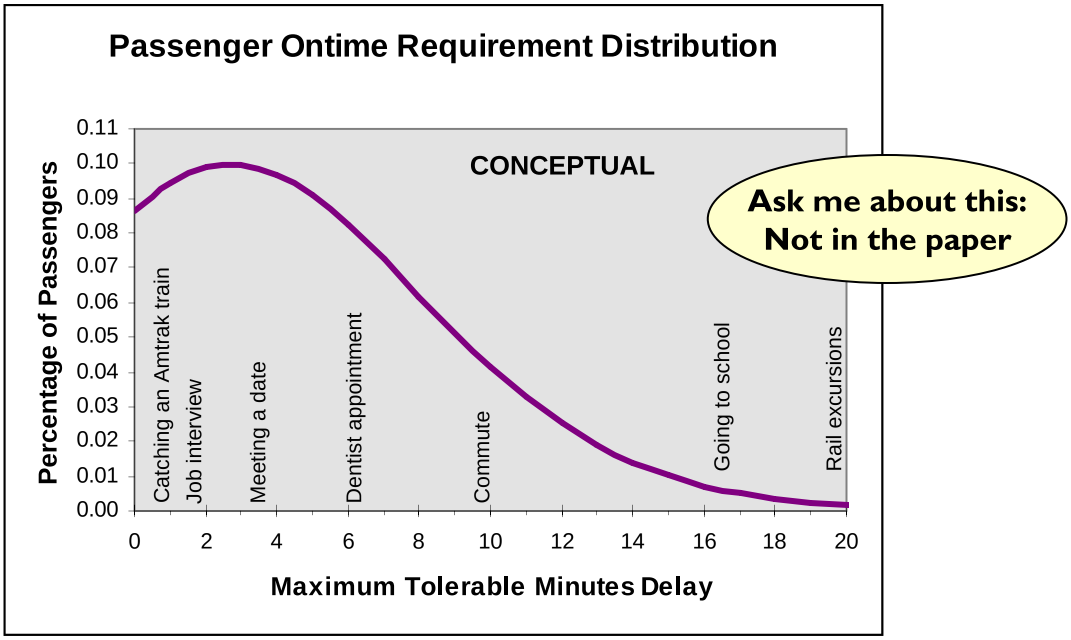
# Consumer Perception of Service Failures

- Correct measure is:
  - "How long did I wait until the train came?" (% of passengers waiting more than 1 hdwy)
  - "Did Transit make me late for my meeting?" (% of passengers arriving within their own "comfort buffer")
- Not:
  - Average wait time
  - MDBF
  - Schedule adherence
  - # of dropped trips

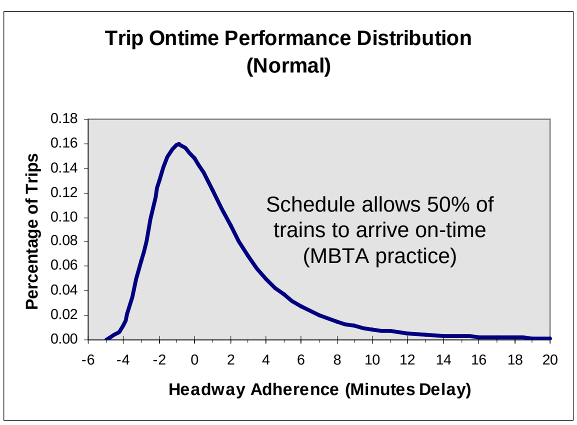
Is there an *inherent* disutility of failure (i.e. *image* problem), or do riders understand that failures are inevitable?

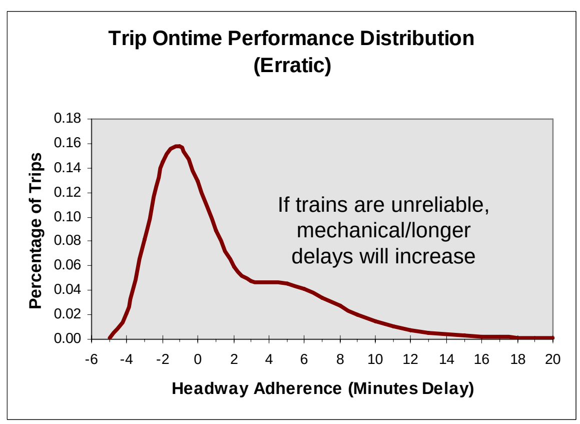
# Customer Requirement/ Performance Interaction

- Passengers will tolerate different amounts of delay, depending on trip purpose



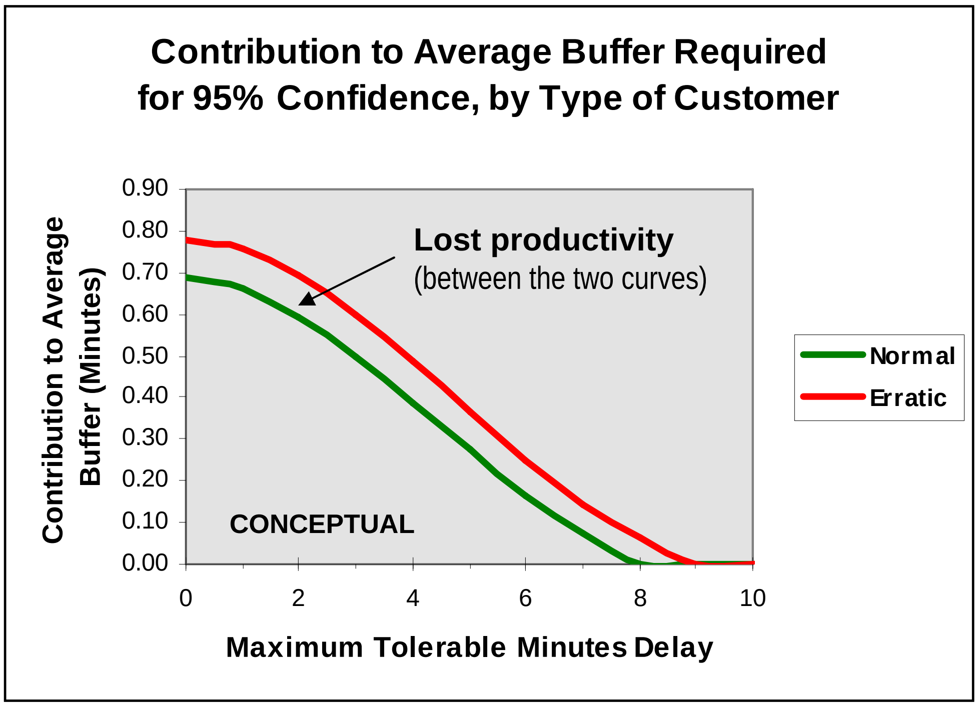

- On-time performance distribution will vary, depending on railcar reliability (& other things)



# Lost Productivity Associated with Mechanical Delays

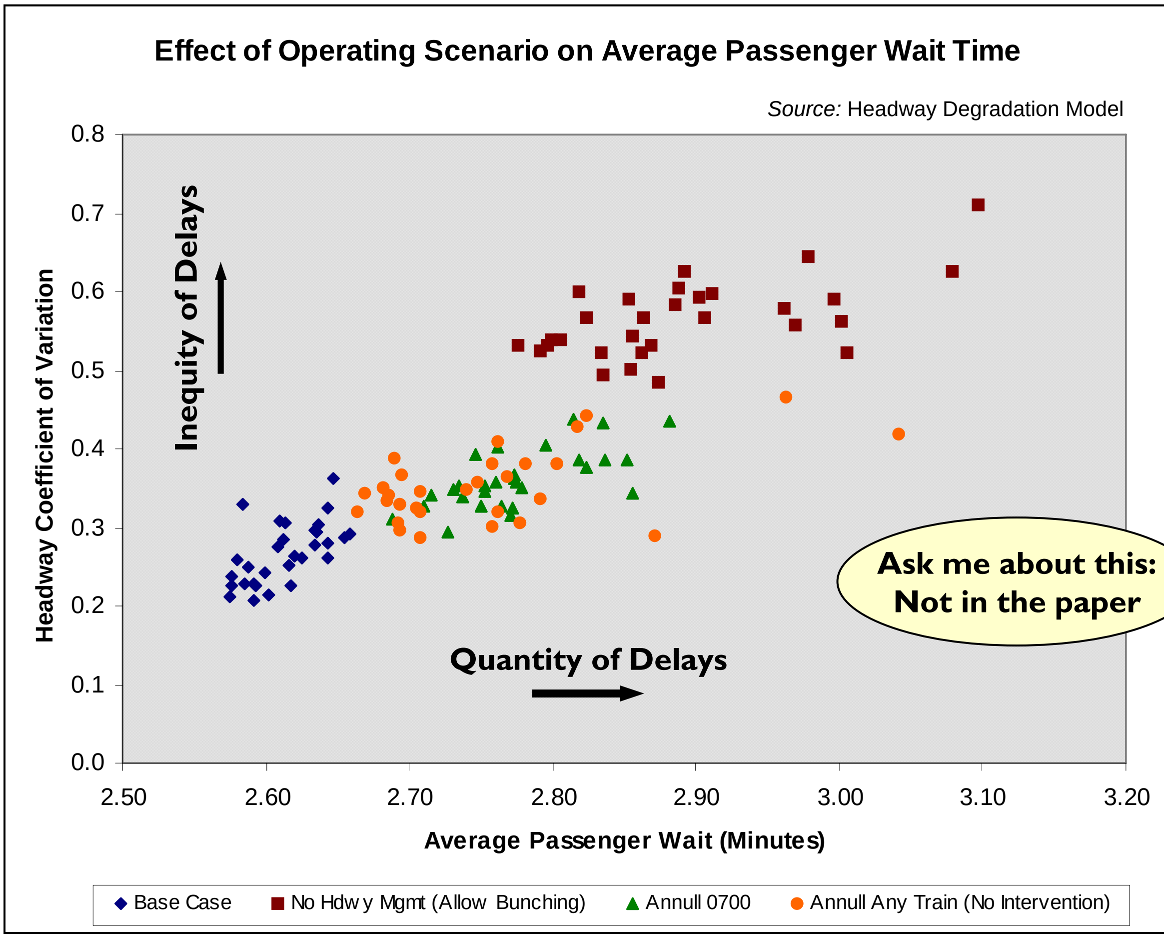
- If customers have to leave earlier for the same appointment to have 95% confidence of arriving on-time, precious time is lost.




- To calculate the social disbenefit of reliability loss, the correct measure is "increase in average buffer time"
- Decrease in on-time performance (to within four minutes) from 85% to 78% increased average buffer by… 47 seconds!

# Stochasticity of Transit Operations

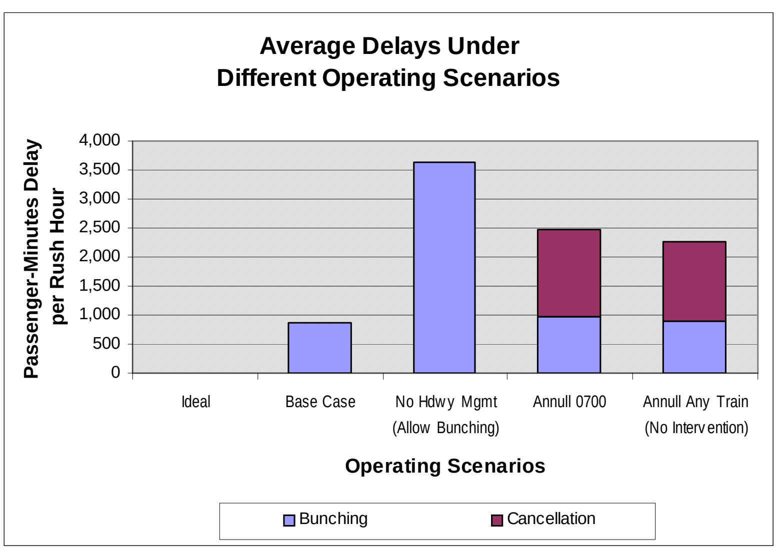
- What's really causing the delays?




- Cancelling one train due to maintenance difficulties is better than sloppy headways
  - Except for people on that train, and one after
  - 'Spreading out' will further reduce delays

# Transit Headway Degradation Model

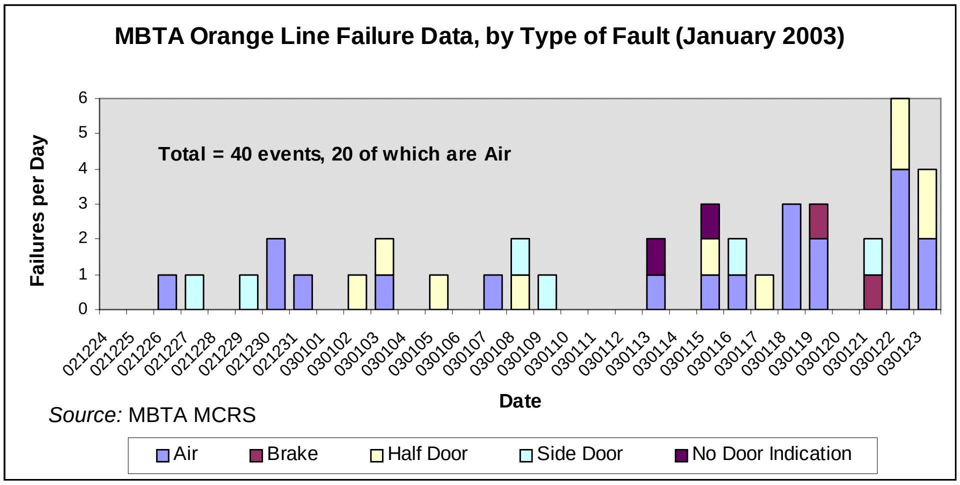
- Straightforward 4 steps (30 run average)
  - Sectional Runtime → Schedule
  - Perturbations (Normally Distributed)
    - Simulated 'Bunching' (later trains run later)
  - Schedule + Perturbations + Constraints = Schedule Adherence & Headway Data
    - e.g Train Blocking, Minimum Separation
  - Demand + Headway = Passenger Wait Times
- Determine the sources of delays
  - Forced cancellation much more manageable than general headway degradation




  - How to *distribute* delays equitably?
  - *Average* delay the correct measure?
  - How do riders plan trips?

# Effect of Weather on Failures

- Does maintenance really reduce failures?

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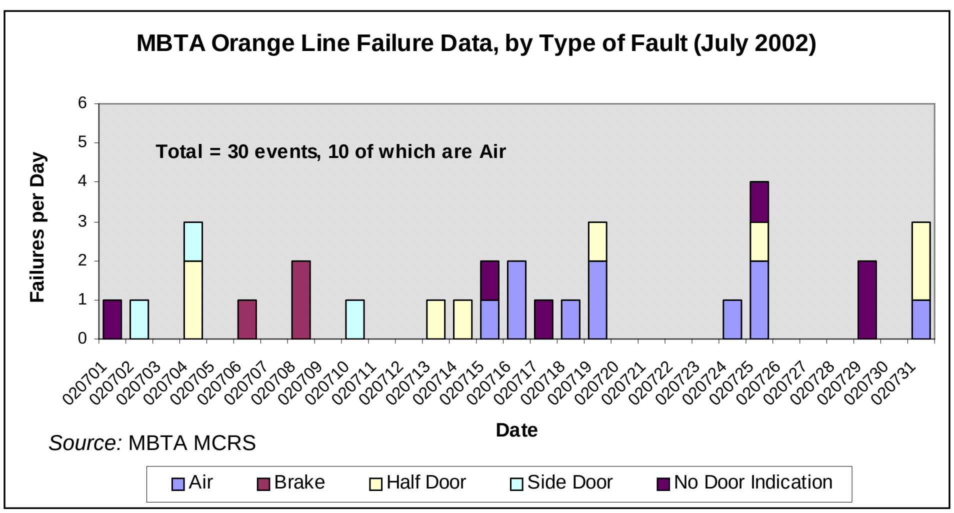
… or does warmer weather?

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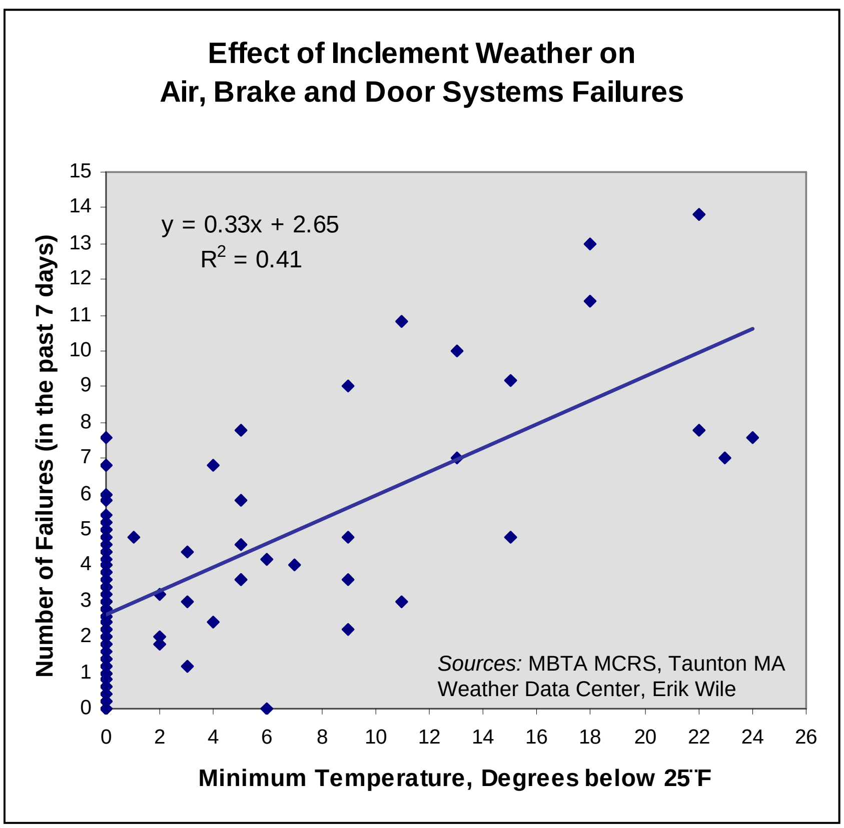
- Can you do anything about this?
  - Correl(*MinTemp*<25°F, *Failures*) > 0.6

# Inclement Weather

- 3 interpretations for cold weather
  - Unpreventable failures?
  - Preventable by inspection?
  - Requires operating & design precautions to mitigate its effects


- Research needed to determine % of failures actually preventable through maintenance
- Failure mode data required

**Read about this in the paper**

# Conclusions & Recommendations

- Light Maintenance Standards: The Old Way
  - Valve rebuild every $x$ days;
    Bearings greased every $y$ miles
- Fault Management: The New Way
  - Opportunistic inspection (preventative)
  - Measure maintenance effectiveness through railcar-related passenger minutes lost
- Some Standards Should Remain: Safety
  - Articulated joints on MBTA Type 7 cars, dismantled, cleaned and greased every 6 years
- Maintenance Scheduling: Service Impacts
  - Maint. not 'constraint' – consumer of asset time
  - Scheduling to evaluate impact on service levels
  - Determine serv. & maint. schedule concurrently
- Engineering Research: Test, Get Data
  - Collect failure mode data accurately
  - Do post-mortems for in-service failures
  - Test things; test it again; test it different ways

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*Lexcie Lu, Transit Analyst,* (lexcie@alum.mit.edu)
*P.O. Box 406, Islip. N.Y. 11751-0406*