Assessing Delay Propagation in Airline Plans: An Update

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Review

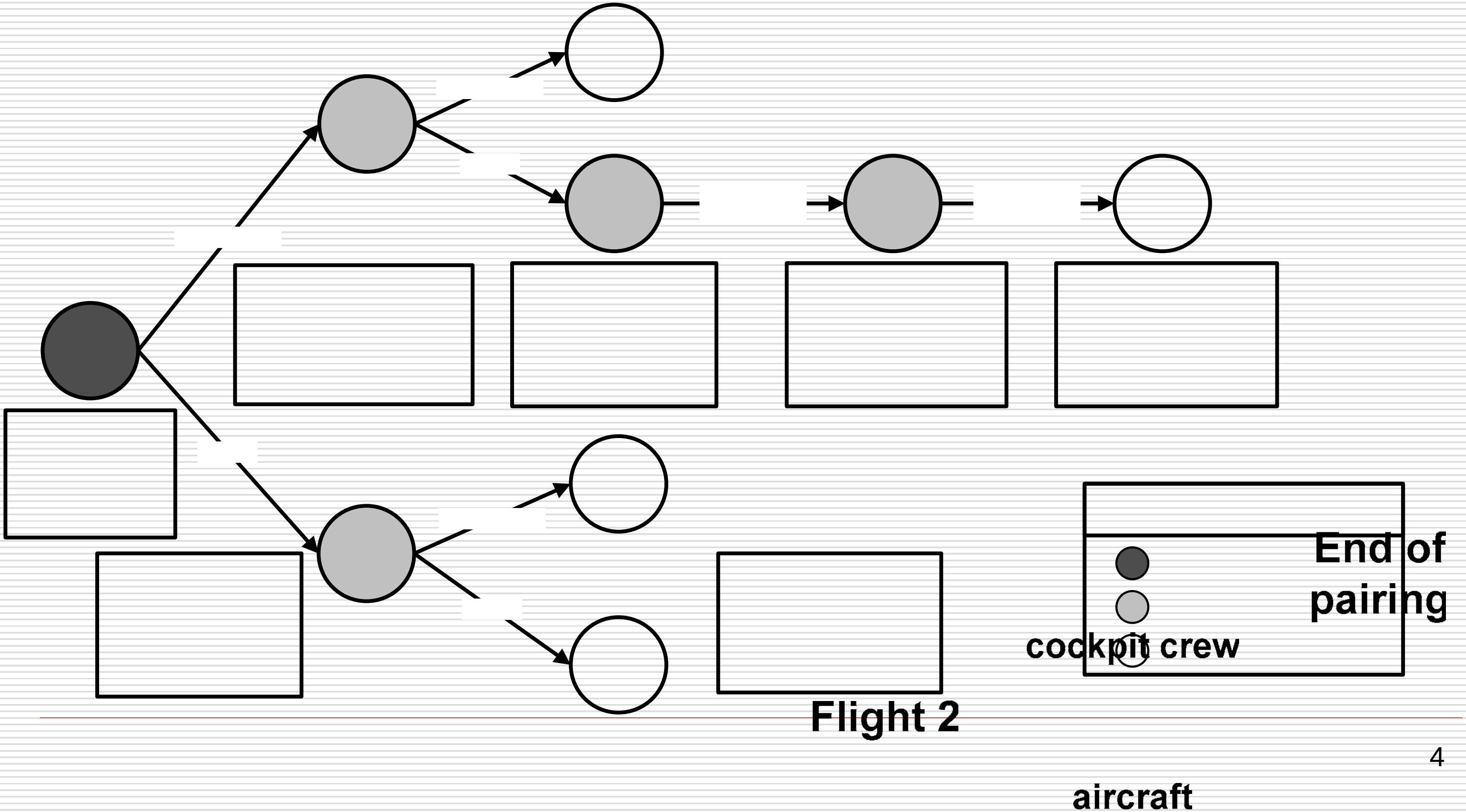
- Our goal is to better understand the relationship between planned and actual operations
- How can changes in the plan improve operational performance?
- Two stages of project:
  - *Analyze* potential for delay propagation
  - *Decrease* potential for delay propagation

Review of Analysis

- Build *propagation trees* to evaluate how an individual *root delay* might propagate through the network
- Construct trees for each flight, each delay interval
- Summarize metrics

Propagation Tree: Example

Nodes: flights **Arcs**: connections due to transfer of resources



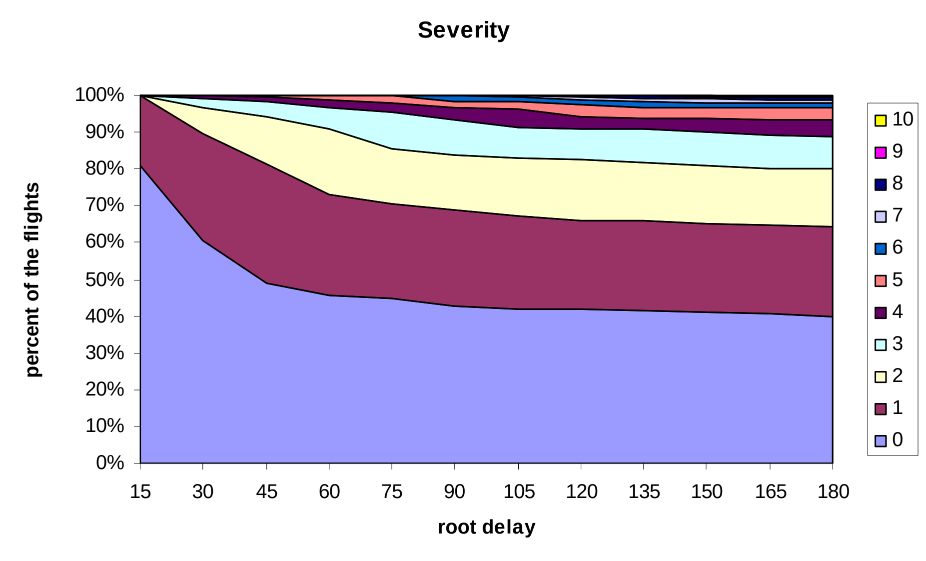
Defining Metrics

- Propagation magnitude
  - Total minutes of delay propagated in the flight network divided by the original delay

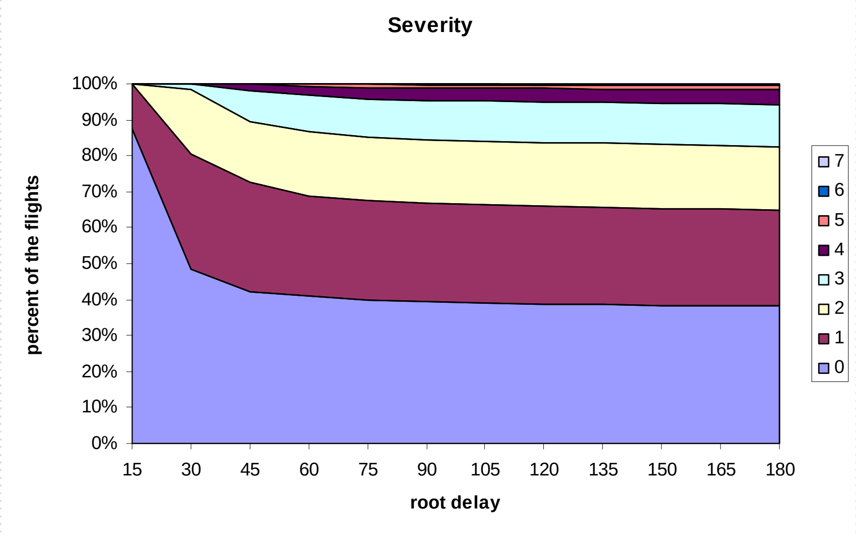
$$\text{propagation magnitude} = \frac{\text{total propagated delays}}{\text{original delay}}$$

- Propagation severity
  - Total number of disrupted flights

Severity Across All Delay Lengths



Carrier 1



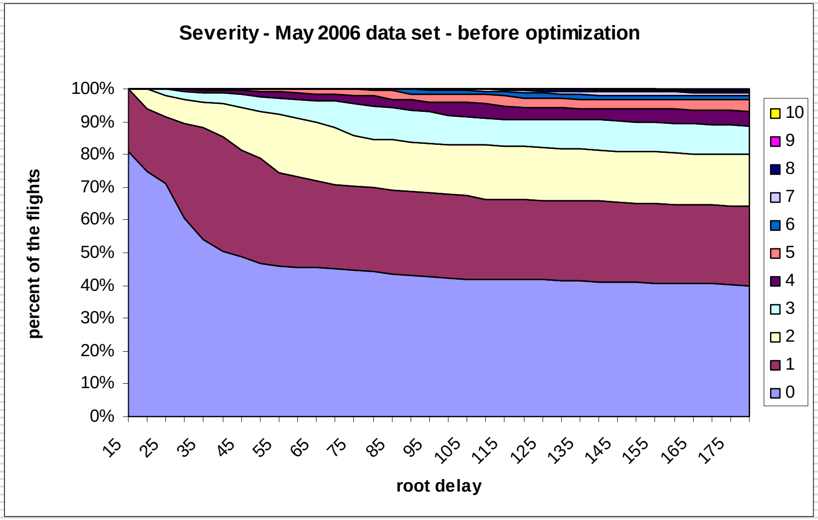
Carrier 2

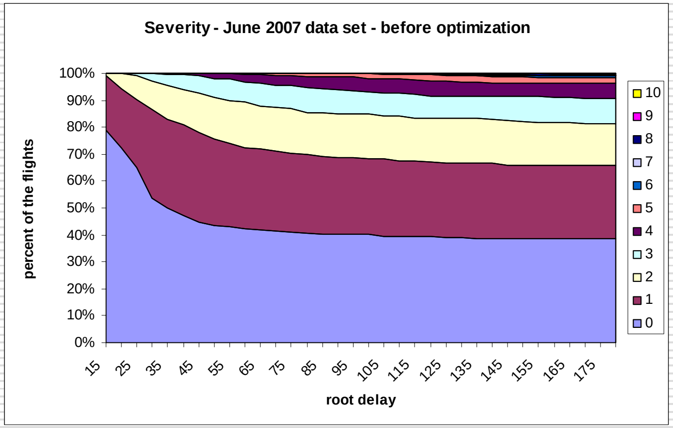
Cohn, Belobaba, Ahmadbeygi, and Guan, 2007

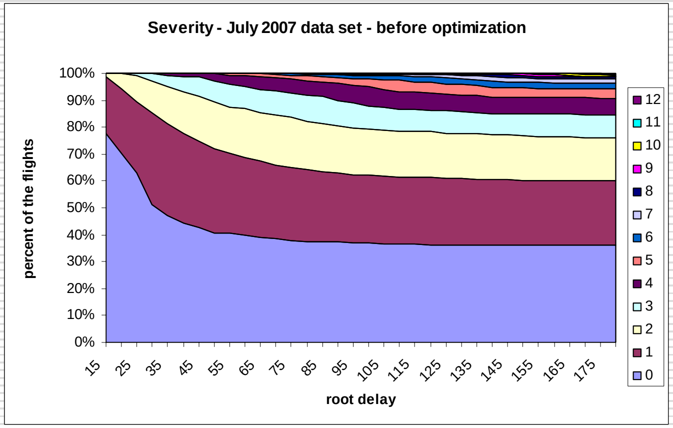
What's New in Analysis

- For first carrier, evaluated two more data sets
  - Both after sizeable change in fleet composition
  - Two different dates (different demand levels, schedules, weather patterns)

Severity Across All Delay Lengths







What's Next in Analysis

- Cabin crews
- Critical passenger itineraries
- Recovery

Review of Optimization

- Can we improve robustness by changing flight times slightly, in order to better utilize the slack?
  - Don't change crew assignments, fleeting, or routing
  - Only changes are to re-allocate slack where it is most needed
- Does not capture all the opportunities to improve robustness
- A starting point that does not require explicit assignment of costs or values to delay

Linear Programming Formulation I

- Minimize the expected value of **one-layer** delay propagation while keeping the connections feasible

$$\text{Min} \quad \sum_{m \in \mathrm{M}} \sum_{(f_1, f_2) \in \mathrm{F}} p_{f_1}^{m} d_{f_1, f_2}^{m}$$

$$y_{f_1, f_2} = s_{f_1, f_2} + x_{f_1} + x_{f_2} \qquad \forall (f_1, f_2) \in \mathrm{A}$$

$$d_{f_1, f_2}^{m} \geq m - y_{f_1, f_2} \qquad \forall (f_1, f_2) \in \mathrm{A} \quad \forall m \in \mathrm{M}$$

$$d_{f_1, f_2}^{m} \geq 0 \qquad \forall (f_1, f_2) \in \mathrm{F} \quad \forall m \in \mathrm{M}$$

$$d_{f_1, f_2}^{m} = \max\{0, m - y_{f_1, f_2}\}$$

$$k_f^- \leq x_f \leq k_f^+ \quad \forall f \in \mathrm{F} \qquad y_{f_1, f_2} \geq 0 \quad \forall (f_1, f_2) \in \mathrm{A}$$

What's New in Optimization

- First approach only looked at one layer of delay
- New approach allows delay to propagate until fully absorb
- Little change on performance (run time)
- Still a linear program
- Some difference in outcome

Linear Programming Formulation II

- Minimize the expected value of **all-layers** delay propagation while keeping the connections feasible

$$\text{Min} \quad \sum_{m \in \mathrm{M}} \sum_{f_0 \in \mathrm{F}} \sum_{f_i \in \mathrm{T}_{f_0}^m} p_{f_0}^m d_{f_0,f_i}^m$$

$$y_{f_1,f_2} = s_{f_1,f_2} + x_{f_1} + x_{f_2} \qquad \forall (f_1, f_2) \in \mathrm{A}$$

$$d_{f_0,f_i}^m \geq m - y_{f_0,f_i} \qquad \forall f_i \in \mathrm{T}_{f_0}^m \text{ s.t. } r_{f_0}^m(f_i) = f_0 \quad \forall m \in \mathrm{M}$$

$$d_{f_0,f_i}^m \geq d_{f_0, r_{f_0}^m(f_i)}^m - y_{r_{f_0}^m(f_i), f_i} \qquad \forall f_i \in \mathrm{T}_{f_0}^m \text{ s.t. } r_{f_0}^m(f_i) \neq f_0 \quad \forall m \in \mathrm{M}$$

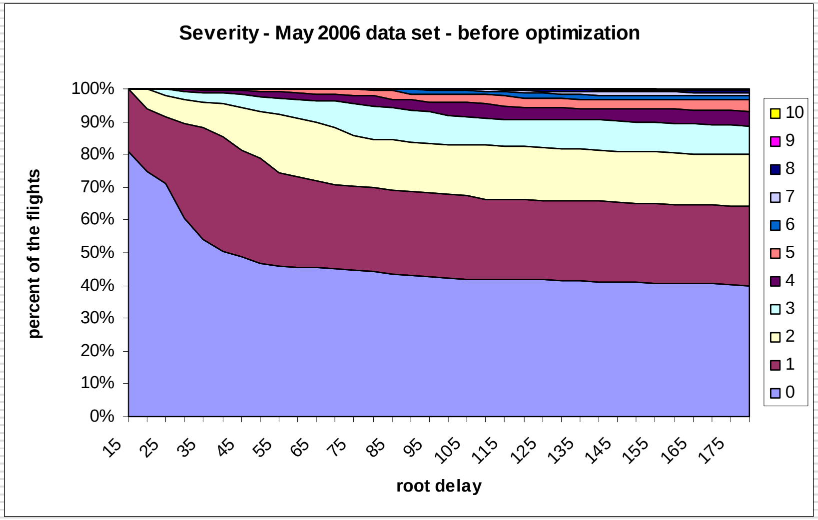
$$d_{f_0,f_i}^m \geq 0 \qquad \forall f_0 \in \mathrm{F}, \; f_i \in \mathrm{T}_{f_0}^m \quad \forall m \in \mathrm{M}$$

$$k_f^- \leq x_f \leq k_f^+ \quad \forall f \in \mathrm{F} \qquad y_{f_1,f_2} \geq 0 \quad \forall (f_1, f_2) \in \mathrm{A}$$

Implementation

- Implemented the model using CPLEX10.0/C++
- Used historical data in order to compute the probability of departure delays (p_f^m)
- Assumptions:
  - Equal time windows $k_f^+ = k_f^- = 15$
  - For the flights that start a duty period $k_f^+ = 15, \quad k_f^- = 0$
  - For the flights that end a duty period $k_f^+ = 0, \quad k_f^- = 15$

Results


Severity - May 2006 data set - before optimization
percent of the flights
root delay
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
15
25
35
45
55
65
75
85
95
105
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135
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175
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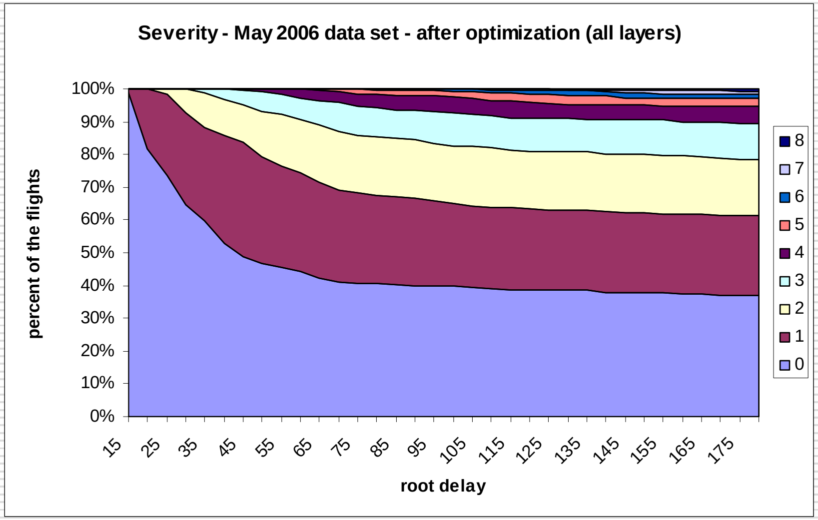
2
1
0


Severity - May 2006 data set - after optimization (all layers)
percent of the flights
root delay
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
15
25
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45
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165
175
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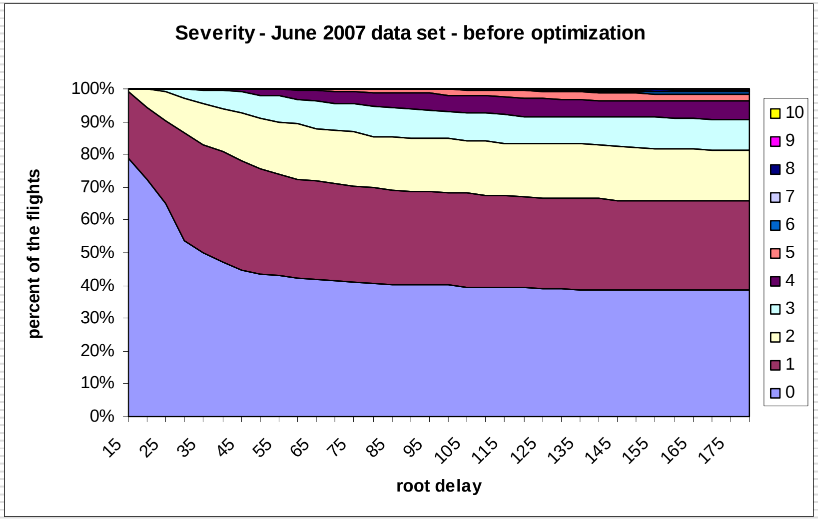
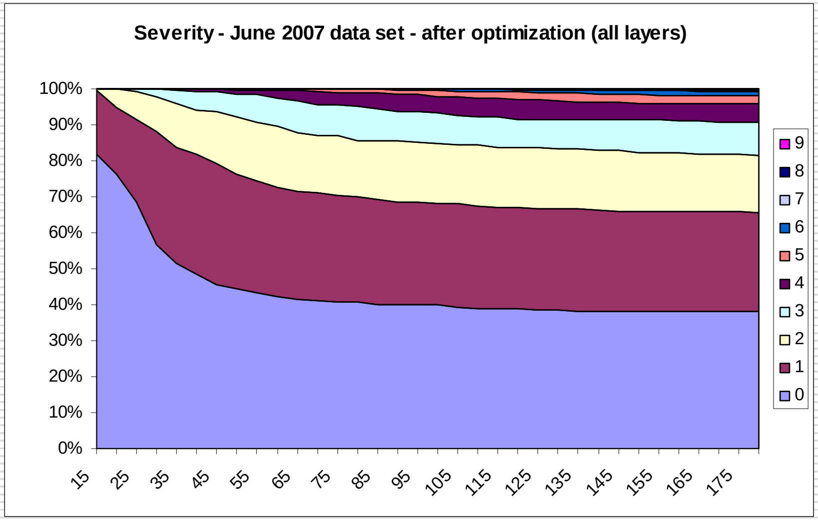
0

Results



Severity - June 2007 data set - before optimization
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
percent of the flights
15 25 35 45 55 65 75 85 95 105 115 125 135 145 155 165 175
root delay
10
9
8
7
6
5
4
3
2
1
0



Severity - June 2007 data set - after optimization (all layers)
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
15 25 35 45 55 65 75 85 95 105 115 125 135 145 155 165 175
9
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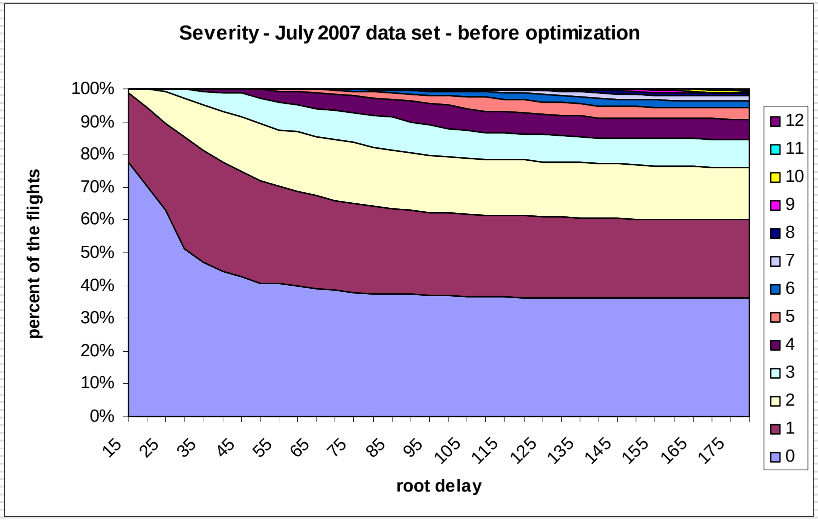
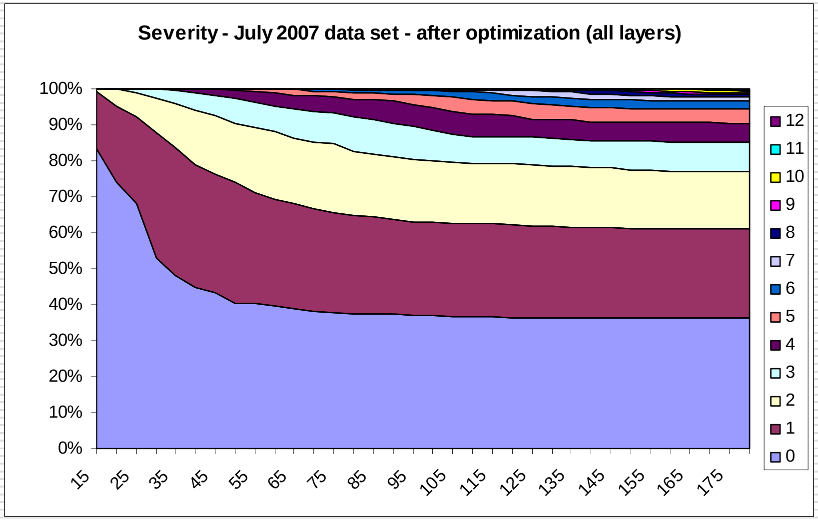
1
0

Results


Severity - July 2007 data set - before optimization
percent of the flights
root delay
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
15 25 35 45 55 65 75 85 95 105 115 125 135 145 155 165 175
12
11
10
9
8
7
6
5
4
3
2
1
0


Severity - July 2007 data set - after optimization (all layers)
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
15 25 35 45 55 65 75 85 95 105 115 125 135 145 155 165 175
12
11
10
9
8
7
6
5
4
3
2
1
0

Results, cont.

May 2006

Model I : One-layer propagation model	Model II : All-layers propagation model
obj. fun. value before opt = 789.22 obj. fun. value after opt = 519.103 reduction% = 34.2% running time = 1 sec	obj. fun. value before opt = 1187.76 obj. fun. value after opt = 768.949 reduction% = 35.3% running time = 1 sec obj. fun. based on model I = 787.989 reduction% = 33.6%

Results, cont.

June 2007

Model I : One-layer propagation model	Model II : All-layers propagation model
obj. fun. value before opt = 543.895 obj. fun. value after opt = 441.049 reduction% = 18.9% running time = 1 sec	obj. fun. value before opt = 637.878 obj. fun. value after opt = 519.523 reduction% = 18.5% running time = 2 sec obj. fun. based on model I = 526.812 reduction% = 17.4%

Results, cont.

July 2007

Model I : One-layer propagation model	Model II : All-layers propagation model
obj. fun. value before opt = 652.408 obj. fun. value after opt = 551.009 reduction% = 15.5% running time = 1 sec	obj. fun. value before opt = 758.635 obj. fun. value after opt = 636.817 reduction% = 16.05% running time = 3 sec obj. fun. based on model I = 641.107 reduction% = 15.4%

What’s Next in Optimization

- Implementing a simulation to evaluate our surrogate objective function
- In the future, need to better incorporate recovery decisions

Conclusions

- Standard plea for data
- Standard plea for feedback
- Special plea for guidance about modeling recovery