Incorporating Robustness in Passenger Aviation Planning Models

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Motivation

- Airline scheduling is complex due to lots of interdependent expensive resources
- To fully utilize resources such as crews and aircraft, airlines develop schedules with minimal slack
- Plans that are efficient on paper may not be robust in practice
- Delays can propagate downstream from one flight to another, assuming there is limited buffer between the flights

Challenging Questions

- How do we assess the robustness of a schedule?
- How do we compute the value of robustness within a schedule?
- How do we incorporate robustness in the planning process?

Our Goals

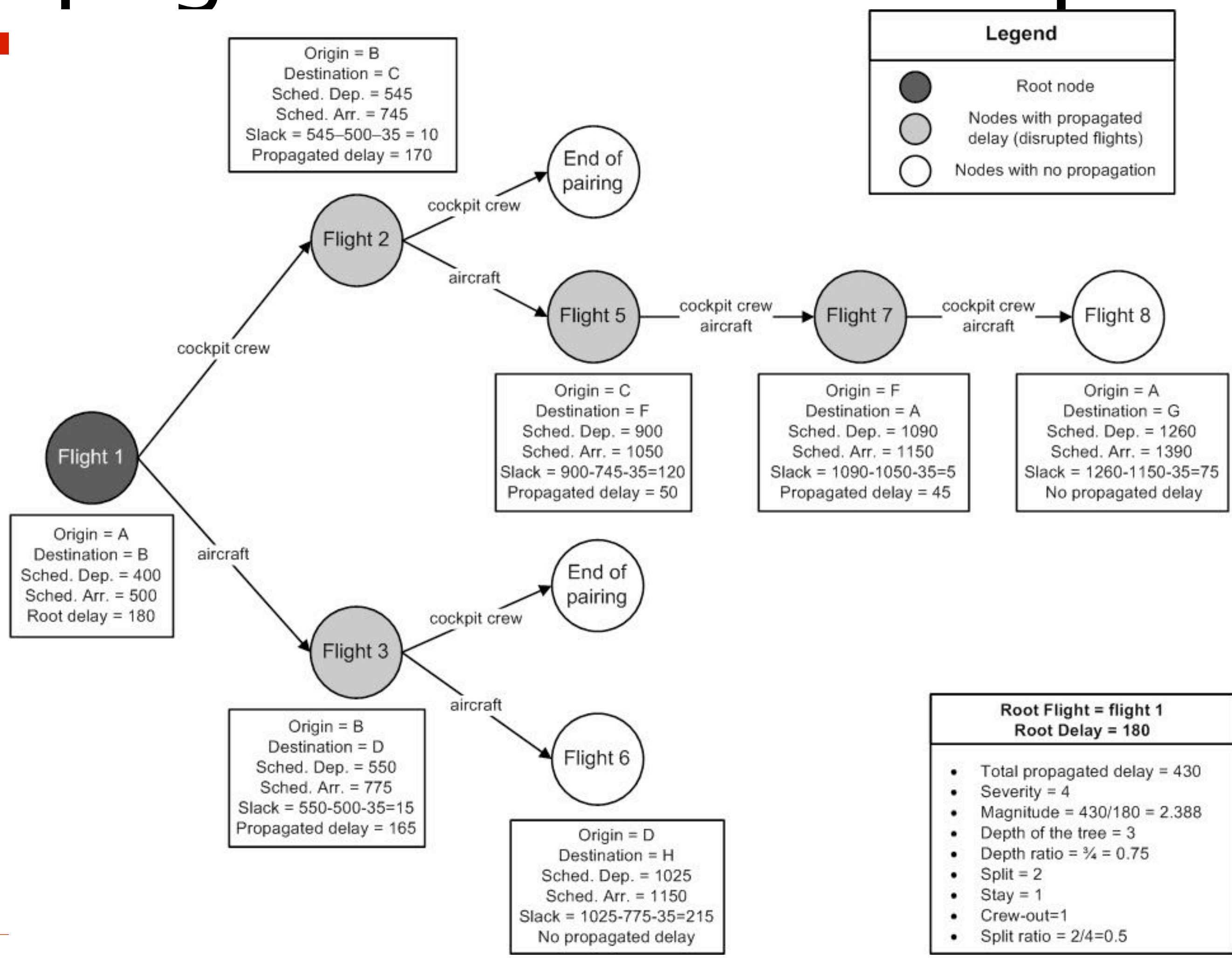
- Develop metrics for assessing robustness
- Understand the relationship between the structure of a network schedule and the potential for delay propagation
  - Not simulating operational performance
  - Not reviewing historical data
  - Instead, focus on inter-connections between resources in the network plan

Propagation Trees

- Consider the impact of a "root delay"
  - Mechanical failure
  - Ground hold

- How much can an isolated delay impact the rest of the system?
  - Not considering correlations
  - Not considering recovery options (swaps, cancellations…)
  - Focus is on network structure, relationship between plan and potential for propagation

Propagation Tree: Example

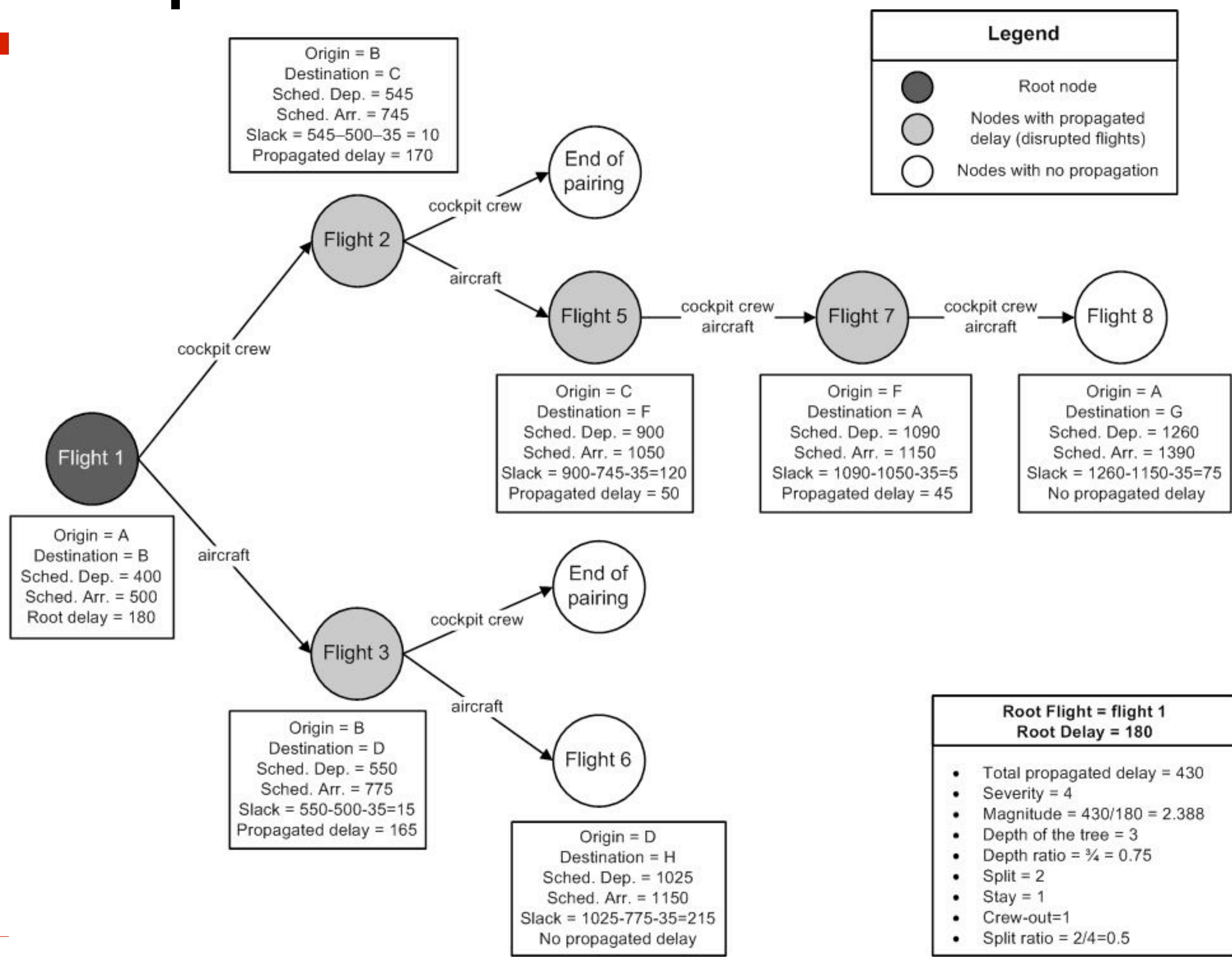


Analysis Metrics

- Magnitude – ratio of total propagated delay to original root delay
- Severity – Total number of disrupted flights
- Depth – Length of longest path

- Note: Metrics are functions of the root flight delay and its length

Example Revisited



Analysis Procedure

- For each flight and each value of the initial delay (15, 30, … 180) minutes
  - Construct the propagation tree
  - Keep track of the analysis metrics

- Two carriers
  - One traditional hub-and-spoke carrier
  - One niche “low-fare” carrier
  - Single snapshot in time

Worst-Case Scenarios

- How significant can propagation be?
  - Worst-case severities of 7, 10
  - Worst-case depths of 6, 10
  - Worst-case magnitude 5.78, 6.16
- Observations
  - All associated with 180-minute root delay
  - All are extreme (only 4 flights with severity of 7, one with severity of 10)
  - Very little impact of branching!

Severity with 180 Minute Root Delay

Severity	# Flights	% Flights		# Flights	% Flights
10	1	0.24		0	0.00
9	1	0.24		0	0.00
8	3	0.73		0	0.00
7	4	0.98		4	0.23
6	5	1.22		6	0.35
5	14	3.41		20	1.16
4	18	4.39		68	3.96
3	36	8.78		201	11.69
2	65	15.85		303	17.63
1	99	24.15		460	26.76
0	164	40.00		657	38.22
Sum	410	100.00		1719	100.00

* 180 minute root delay

Depth with 180 Minute Root Delay

Depth	# Flights	% Flights		# Flights	% Flights
10	1	0.24		0	0.00
9	1	0.24		0	0.00
8	2	0.49		0	0.00
7	3	0.73		0	0.00
6	4	0.98		2	0.12
5	13	3.17		20	1.16
4	19	4.63		68	3.96
3	37	9.02		202	11.75
2	64	15.61		302	17.57
1	102	24.88		468	27.23
0	164	40.00		657	38.22
Sum	410	100.00		1719	100.00

* 180 minute root delay

Depth Ratio with 180 Minute Root Delay

Depth Ratio	# Flights	% Flights		# Flights	% Flights
1	235	57.32		1033	60.09
(0, 1)	11	2.68		29	1.69
0	164	40.00		657	38.22
Sum	410	100.00		1719	100.00

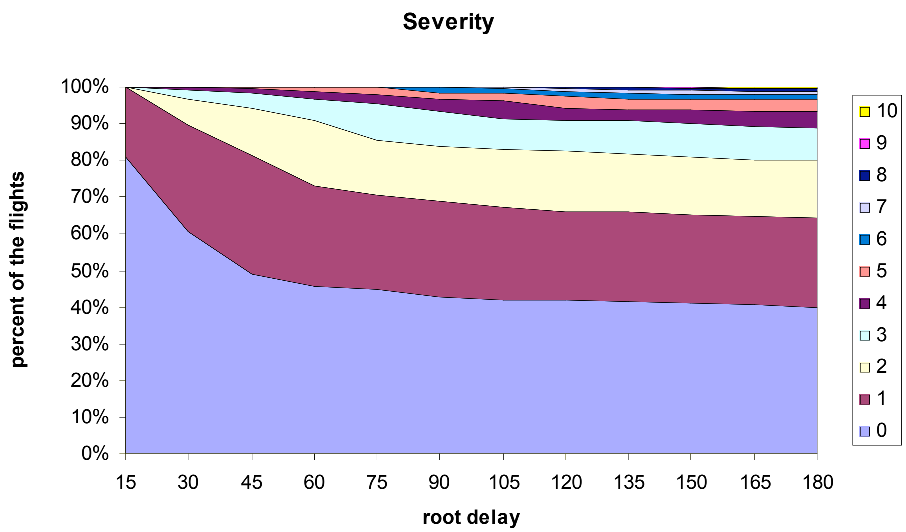
* 180 minute root delay

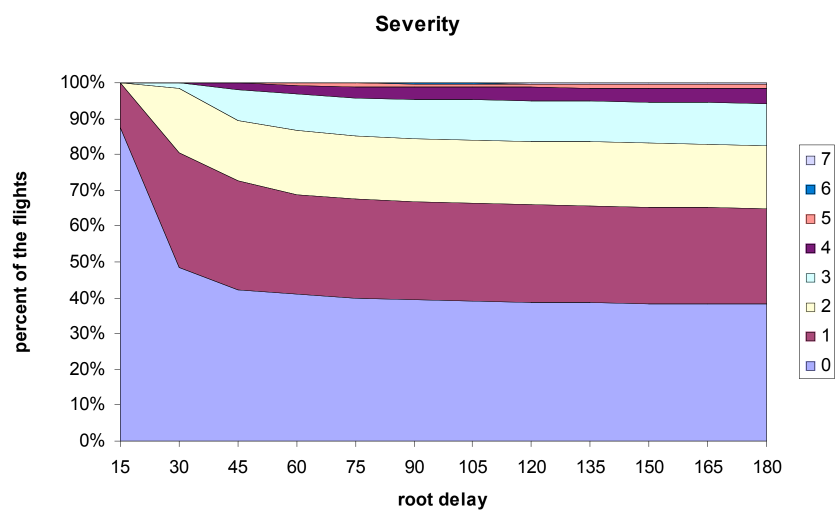
Magnitude with 180 Minute Root Delay

Magnitude	# Flights	% Flights		# Flights	% Flights
(6, 7]	2	0.49		0	0.00
(5, 6]	3	0.73		3	0.17
(4, 5]	9	2.20		12	0.70
(3, 4]	14	3.41		62	3.61
(2, 3]	42	10.24		198	11.52
(1, 2]	73	17.80		316	18.38
(0, 1]	103	25.12		471	27.40
0	164	40.00		657	38.22
Sum	410	100.00		1719	100.00

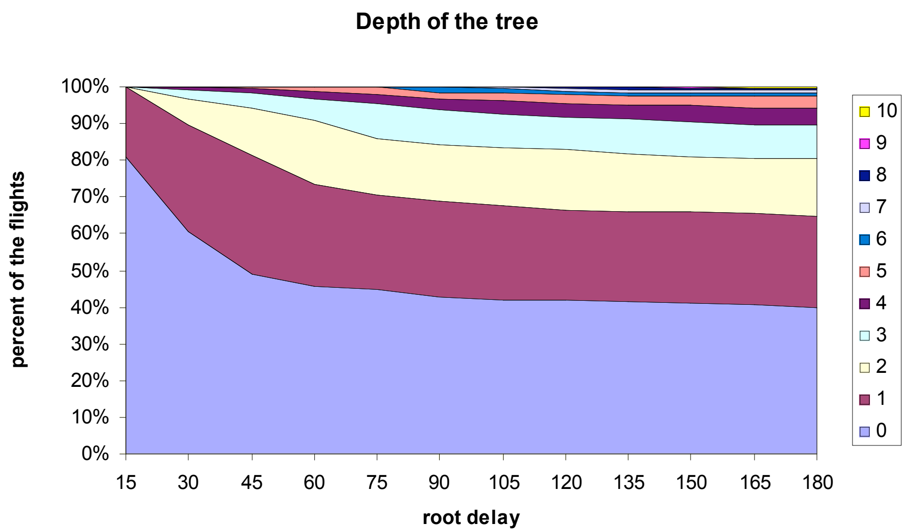
* 180 minute root delay

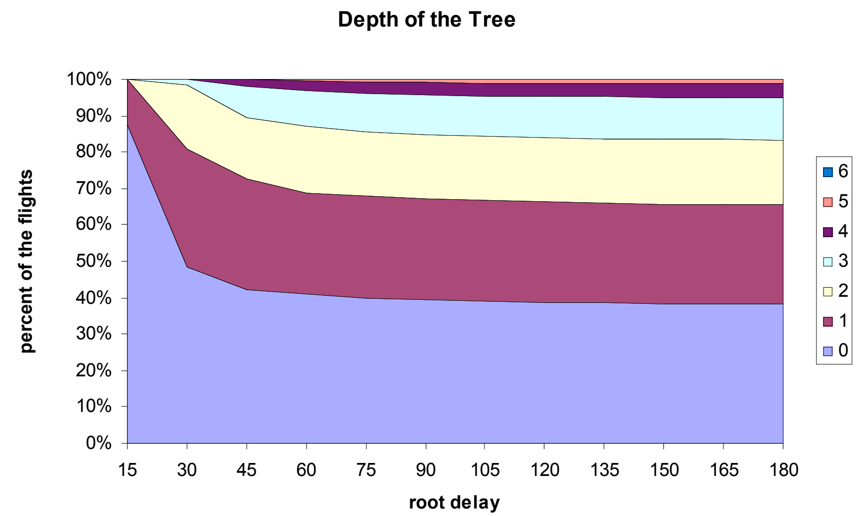
Severity Across All Delay Lengths



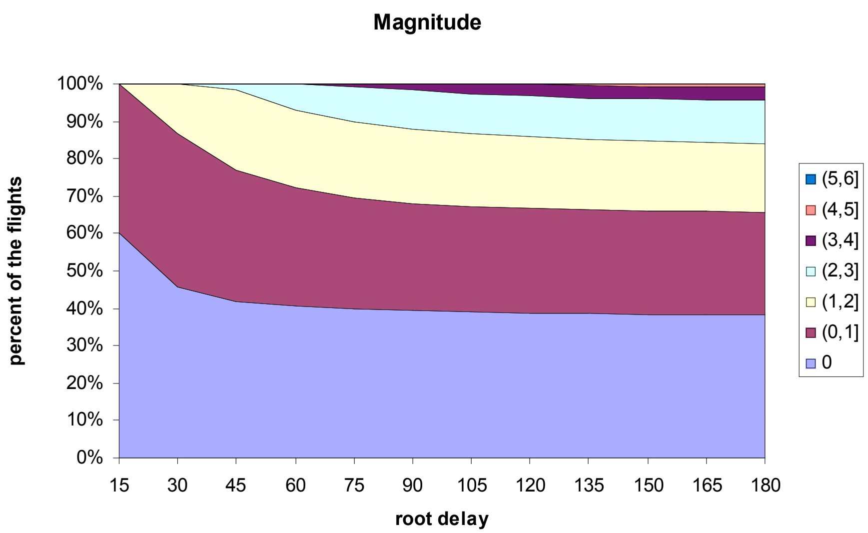


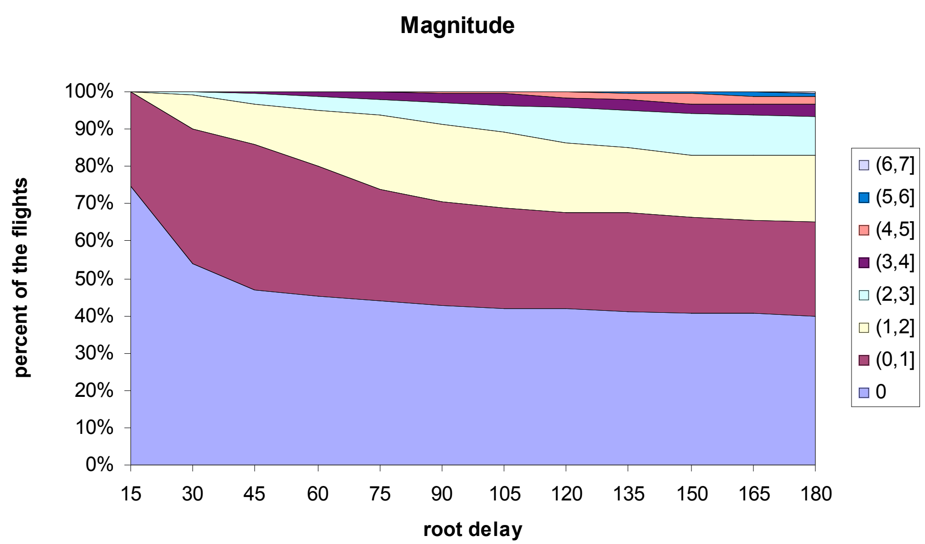
Depth Across All Delay Lengths





Magnitude Across All Delay Lengths

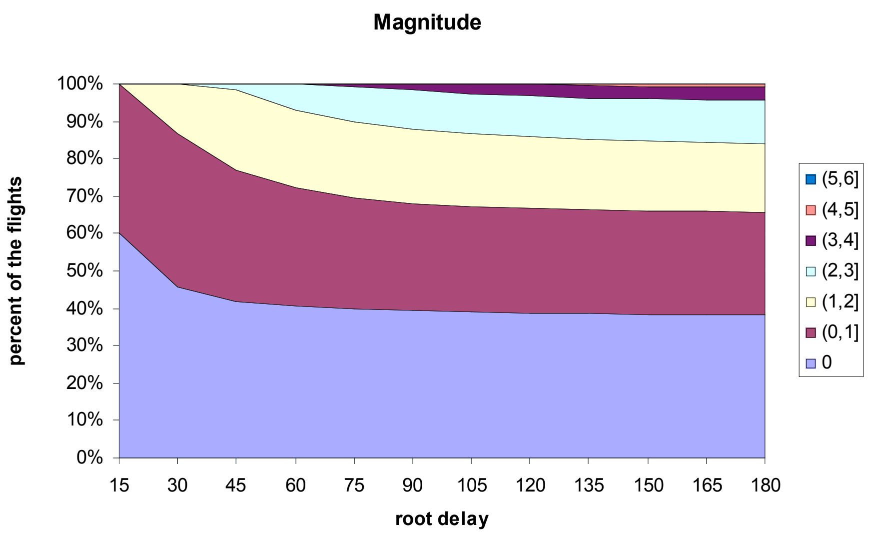


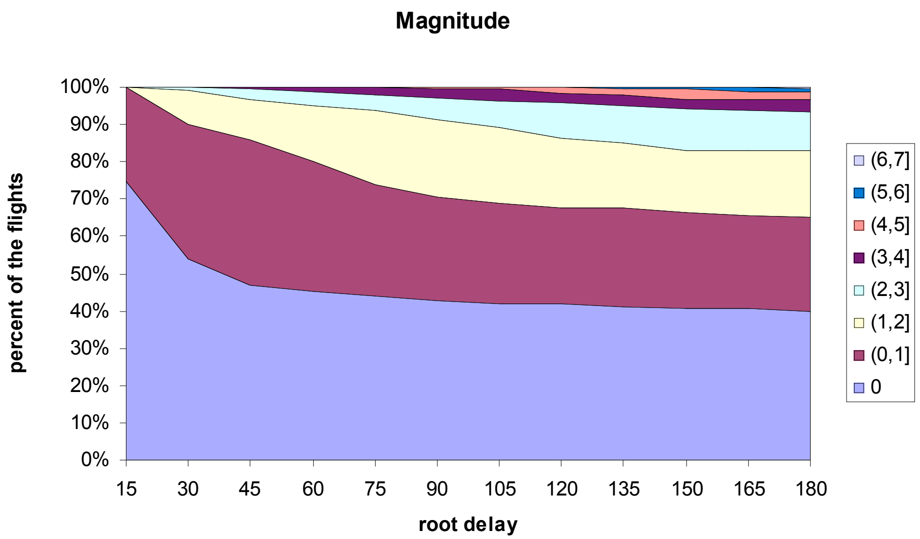


Conventional Wisdom 1

- CW: “Propagated delays are more significant than the original delays themselves.”
- True or false?
- Both!
  - When delays propagate, the propagated delay can be significantly larger than the initial root delay…
  - …but lots of delays don’t propagate at all.
    - Off-peak times
    - Crews going off-duty
    - Aircraft going off-rotation
    - End-of-day effects

Magnitude Across All Delay Lengths





Conventional Wisdom 2

- CW: “A single delay can “snowball” through the entire network.”
- True or false?
- False
  - Buffers keep delays from propagating extensively (i.e. number of impacted flights is contained)
    - Down periods
    - Crews going off-duty
    - Aircraft going off-rotation
    - Crews and aircraft staying together
    - Propagation trees tend to only have one branch
  - Limited numbers of down-stream delays still has significant cost impact

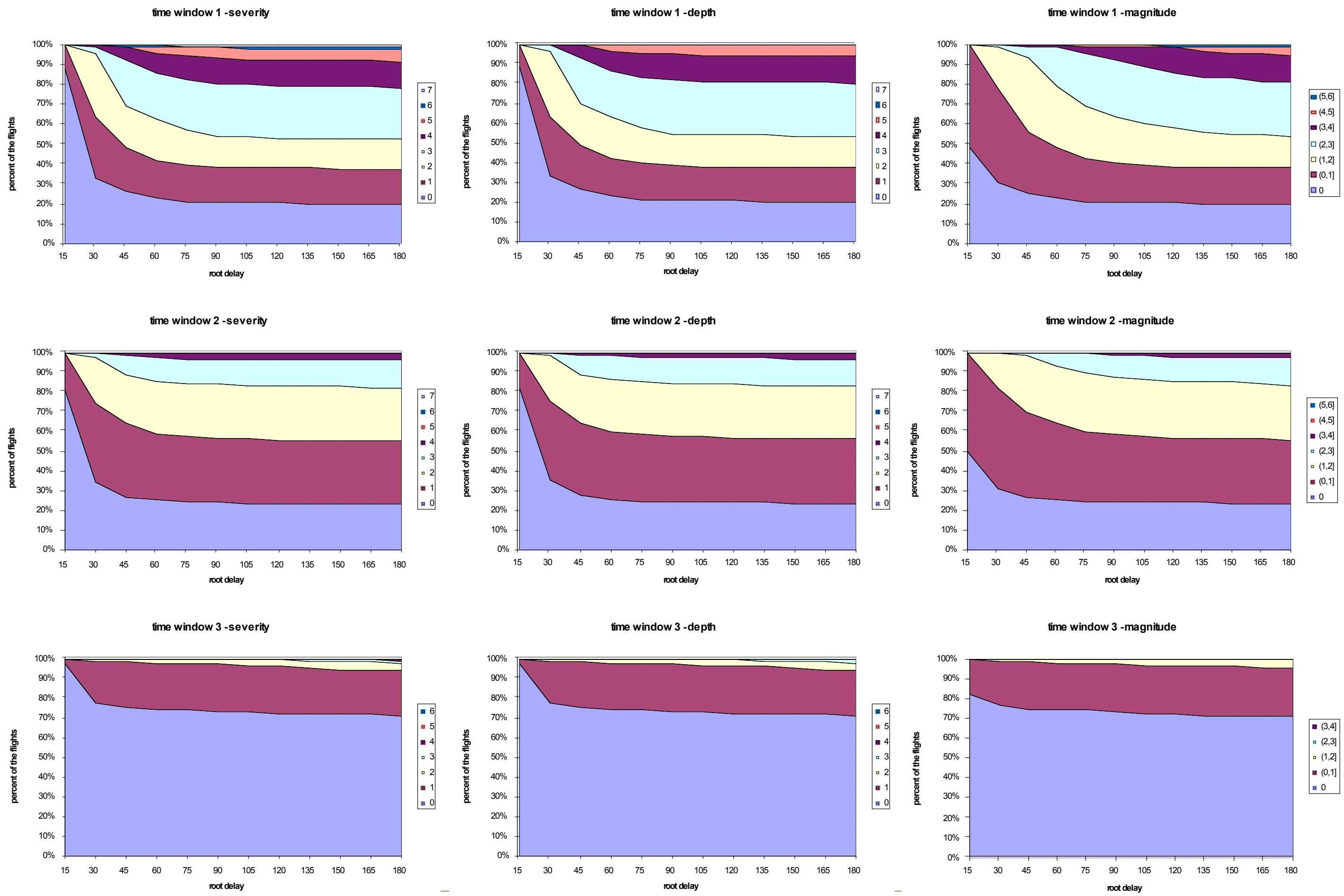
Conventional Wisdom 3

- CW: “Keeping crews and aircraft together can mitigate the impact of disruption.”
- True or false?
- True
  - Most of the “trees” we saw did not actually branch at all
  - Nonetheless there can be significant propagation (e.g. 8 – 10 flights deep in the tree)
  - Can keeping crews and aircraft together ever *increase* propagation?

Conventional Wisdom 4

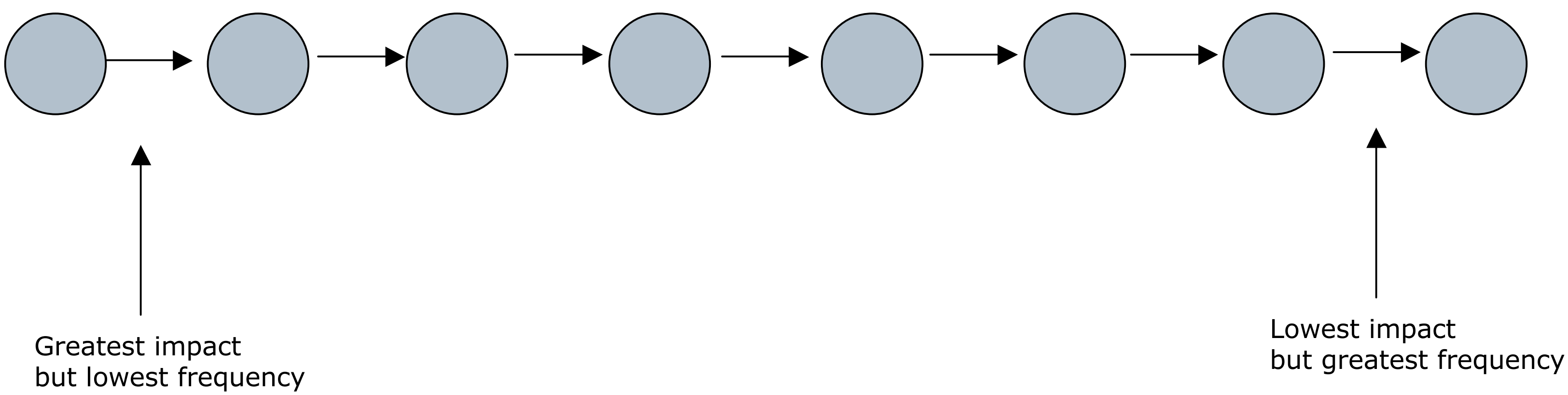
- CW: "Delays that occur early in the day can cause greater propagation than delays later in the day."
- True or false?
- True (on average)

Conventional Wisdom 4



Conventional Wisdom 5

- CW: “It is most important to prevent delays early in the day.”
- True or false?
- False



What’s Missing

- Cabin crews
- Passenger itineraries
- International flights
- Correlations
- Recovery operations
- Weighted probabilities of root delays

What Comes Next

- Continue analysis
  - Additional carriers
  - Expand scope
- Assessing value of robustness
- Incorporation in schedule planning
  - Current work in schedule design