

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

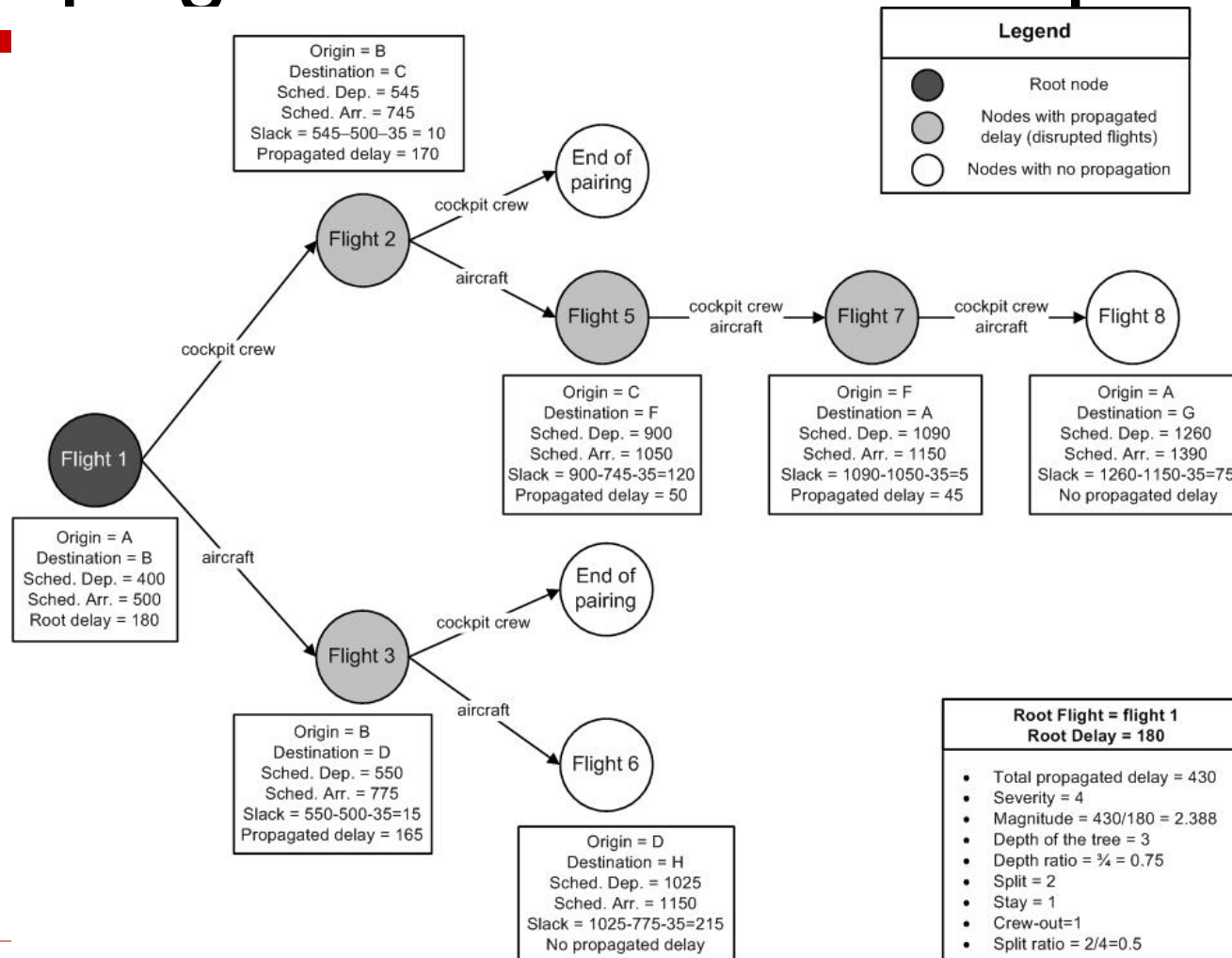
- ❑ Develop metrics for assessing robustness
- ❑ Understand the relationship between the structure of a network schedule and the potential for delay propagation
 - Not simulating operational performance
 - Not reviewing historical data
 - Instead, focus on inter-connections between resources in the network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

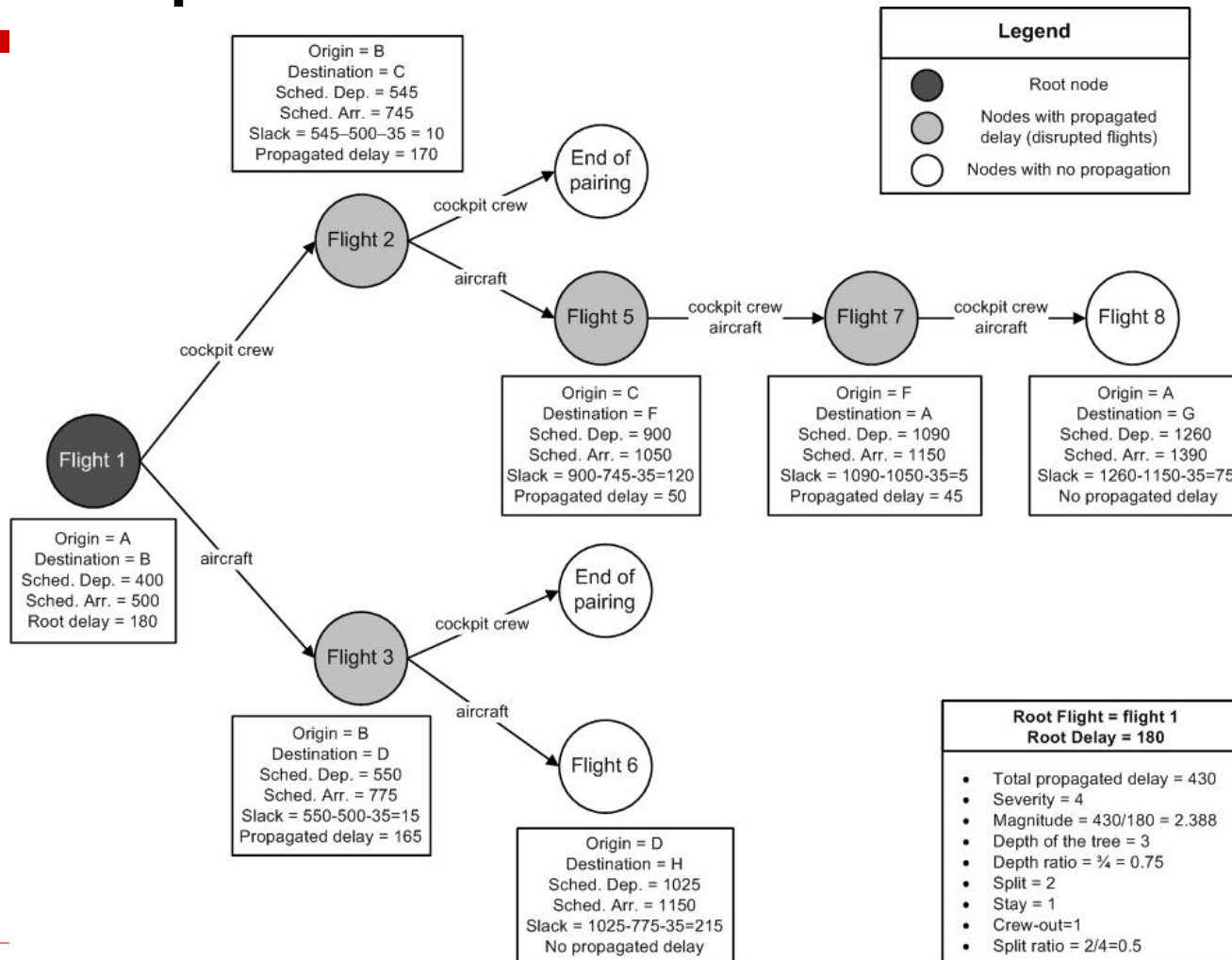
Propagation Tree: Example



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

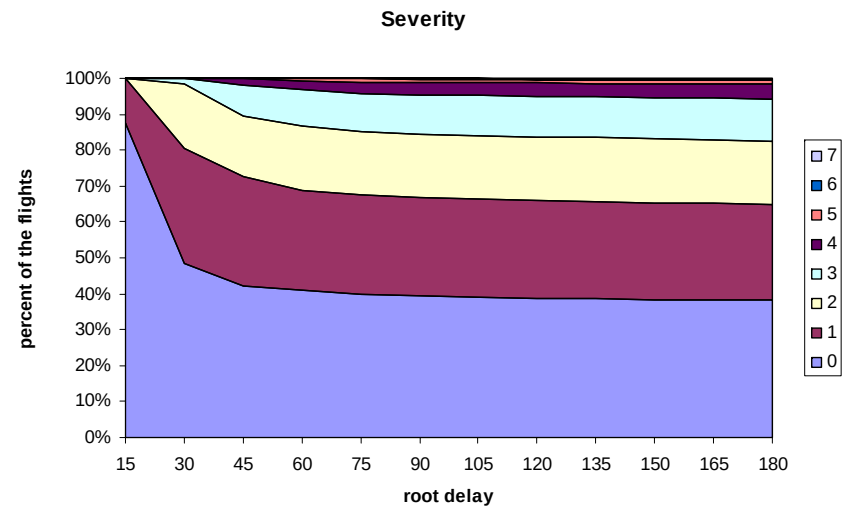
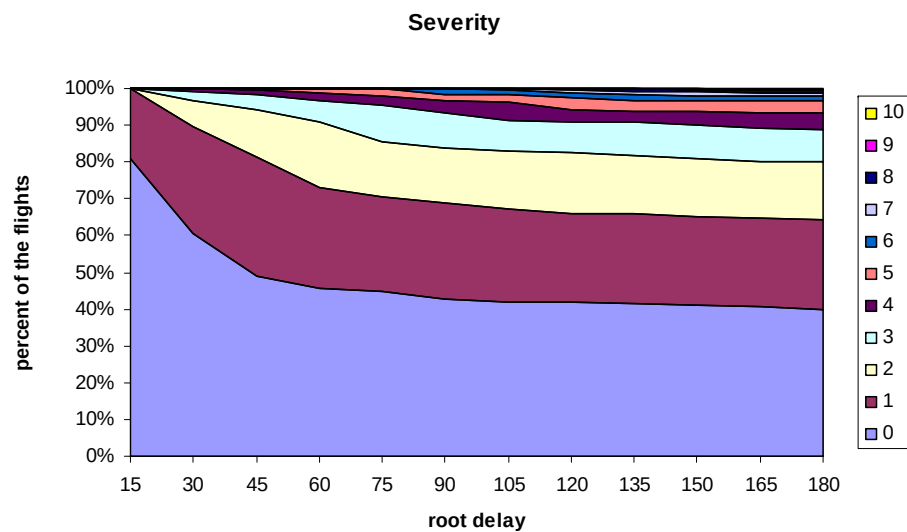
* 180 minute root delay

Magnitude with 180 Minute Root Delay

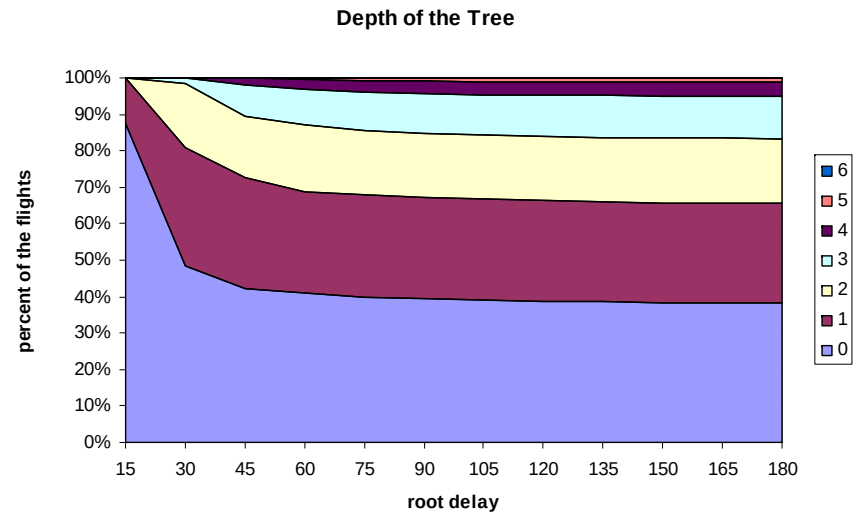
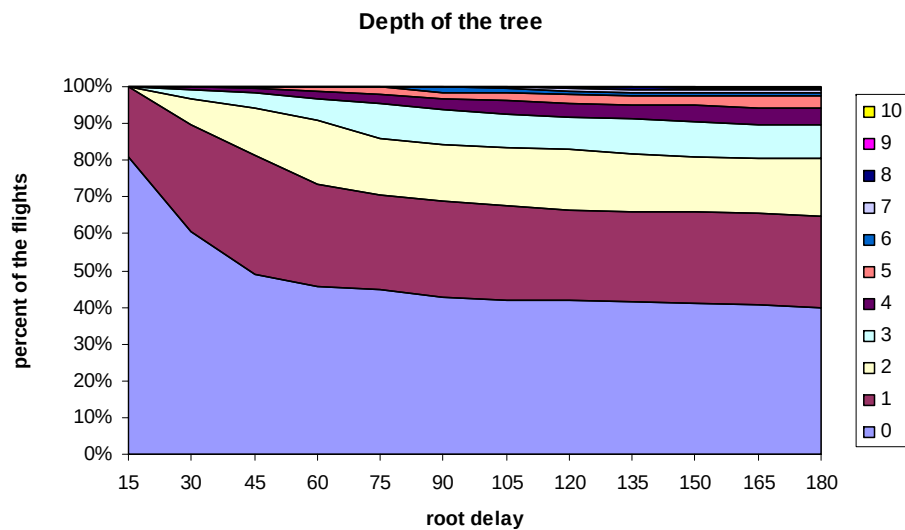
Magnitude	# Flights	% Flights		# Flights	% Flights
(6, 7]	2	0.49		0	0.00
(5, 6]	3	0.73		3	0.17
(4, 5]	9	2.20		12	0.70
(3, 4]	14	3.41		62	3.61
(2, 3]	42	10.24		198	11.52
(1, 2]	73	17.80		316	18.38
(0, 1]	103	25.12		471	27.40
0	164	40.00		657	38.22
Sum	410	100.00		1719	100.00

* 180 minute root delay

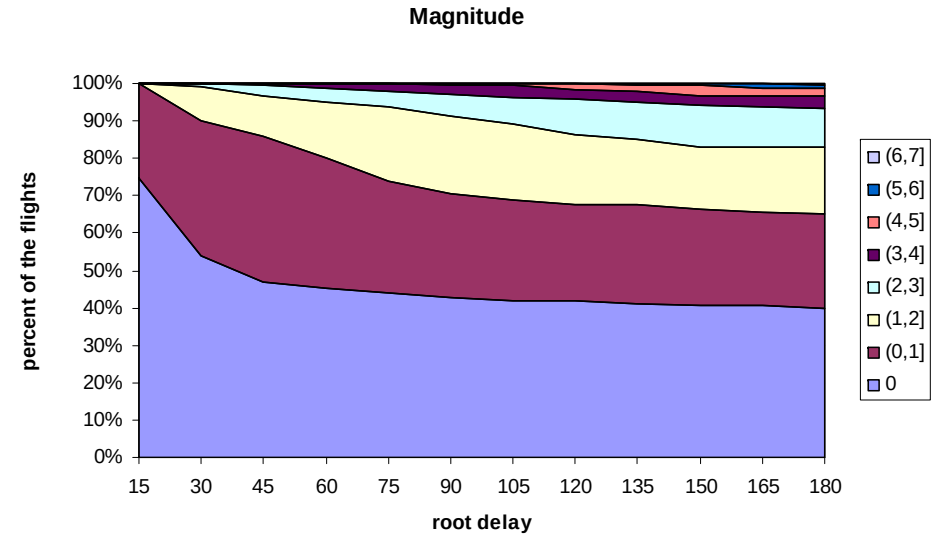
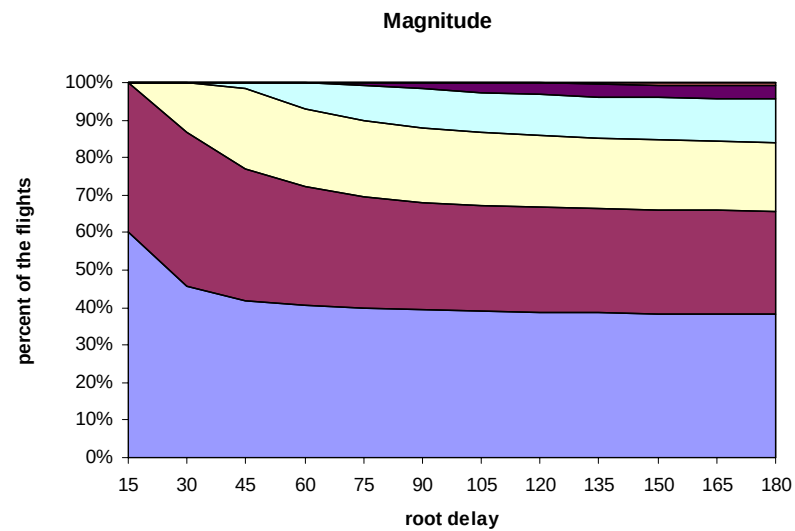
Severity Across All Delay Lengths



Depth Across All Delay Lengths



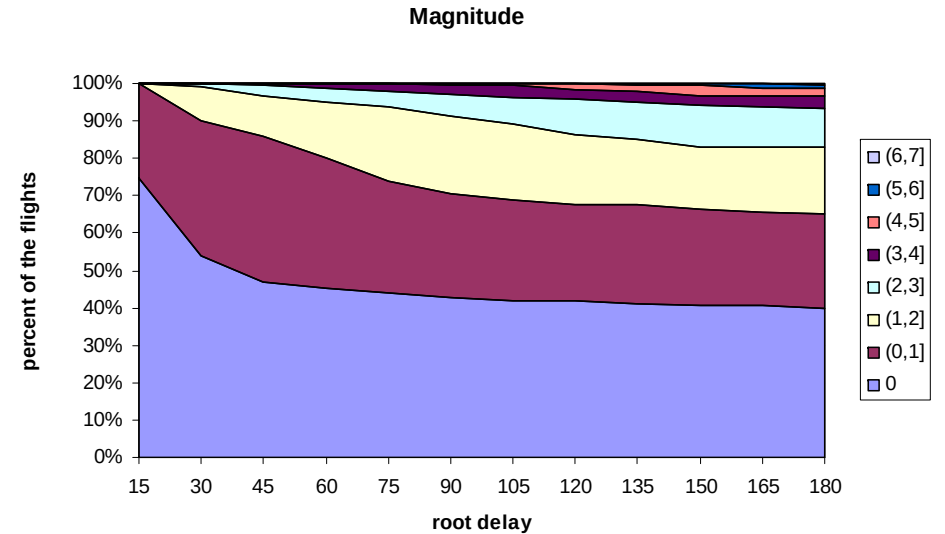
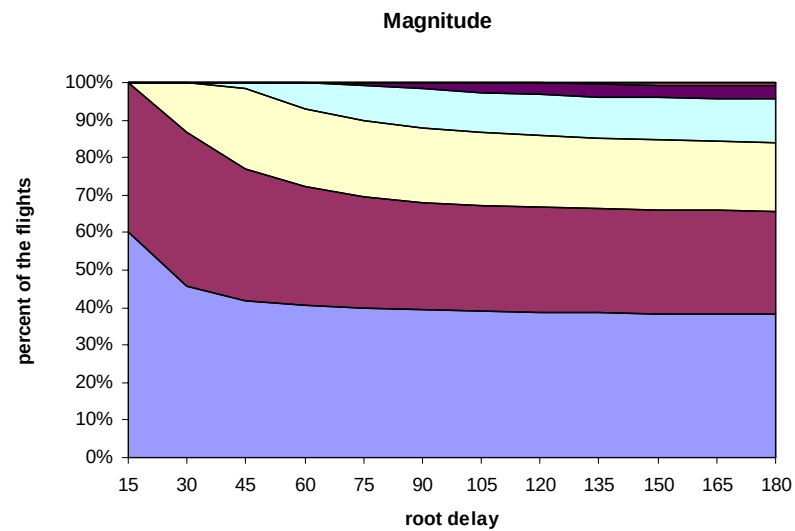
Magnitude Across All Delay Lengths



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

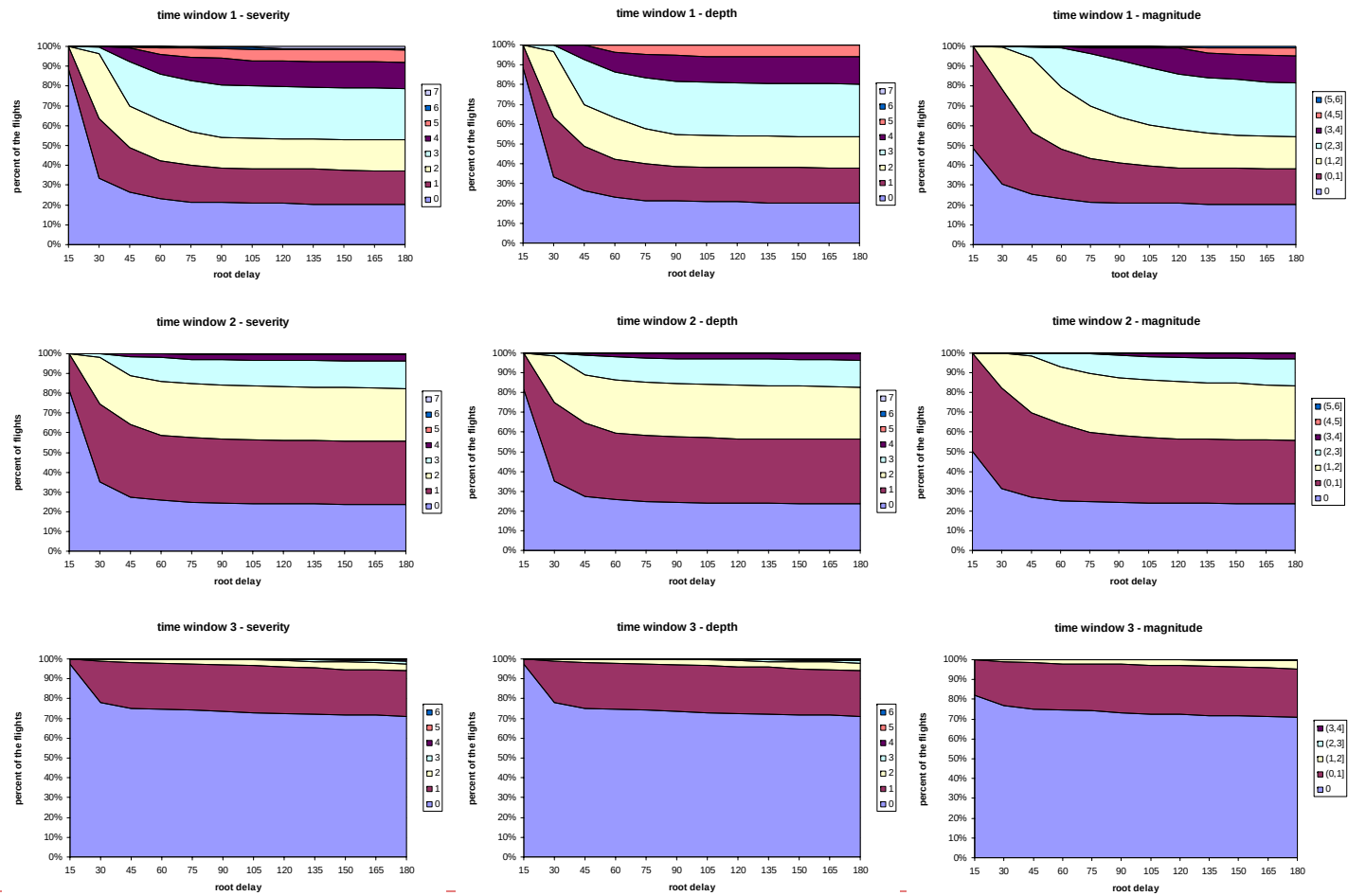
Conventional Wisdom 3

- ☐ 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

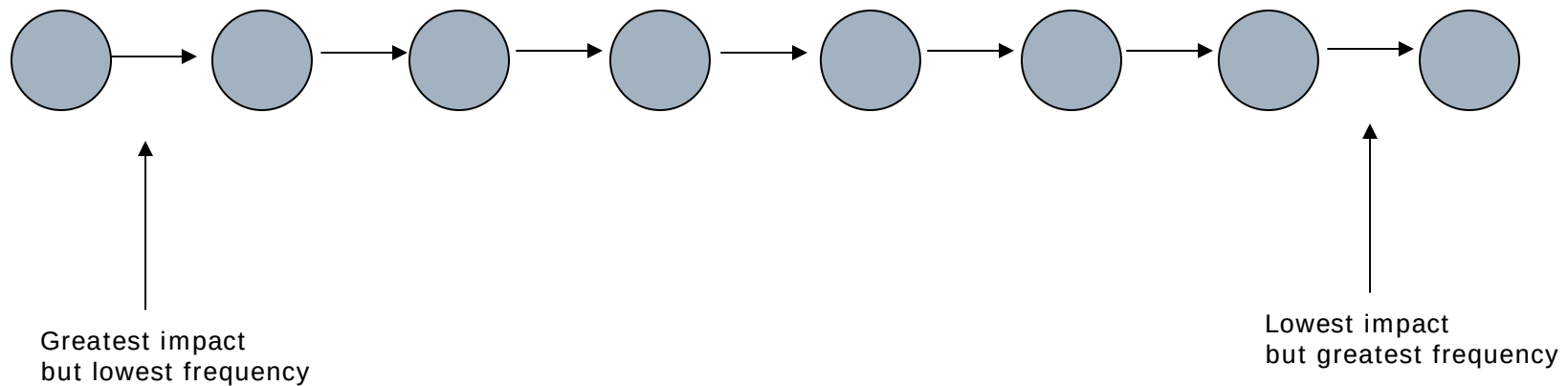
- ☐ CW: “Delays that occur early in the day can cause greater propagation than delays later in the day.”
- ☐ True or false?
- ☐ True (on average)

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