Assessing Delay Propagation in Airline Plans

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Motivation

- Operations research tools have been used for decades to develop airline plans that maximize utilization of costly, constrained resources such as crews and aircraft
  - Assume deterministic flight times, etc.

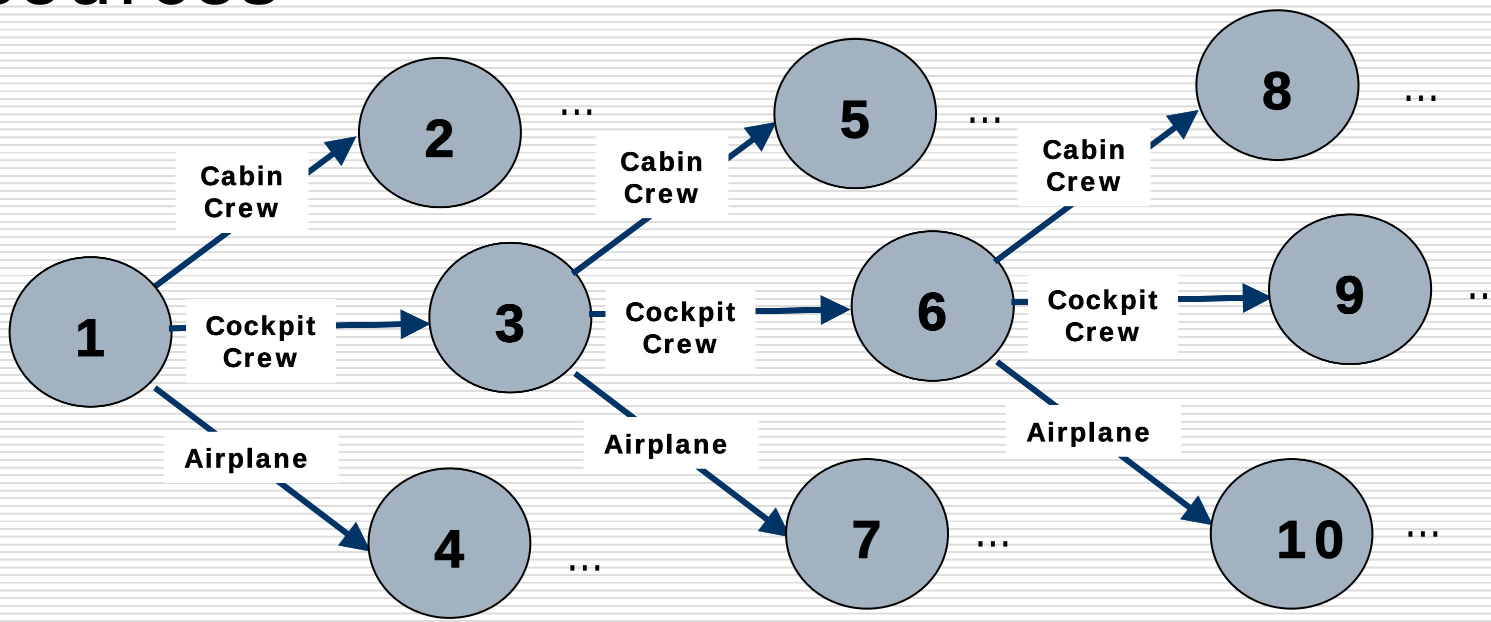
- As a result, many airline plans have very limited slack

Motivation

- It is theorized that such schedules may be far from optimal in practice
  - Limited buffer allows delays to propagate (depth)
  - Splitting of resources (aircraft, cockpit crews, cabin crews, connecting passengers, etc.) can further increase propagation (breadth)

Propagation Tree

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



Our Goal

- Better understand delay propagation
- Use the results to develop better planning tools

Analysis Procedure

- Considered data from one legacy and one low-fare carrier

- For each flight and each possible value of the initial delay (15 minutes, 20 minutes, 25 minutes, ... 60 minutes), we constructed the corresponding propagation tree and kept track of two analysis metrics

Analysis Metrics

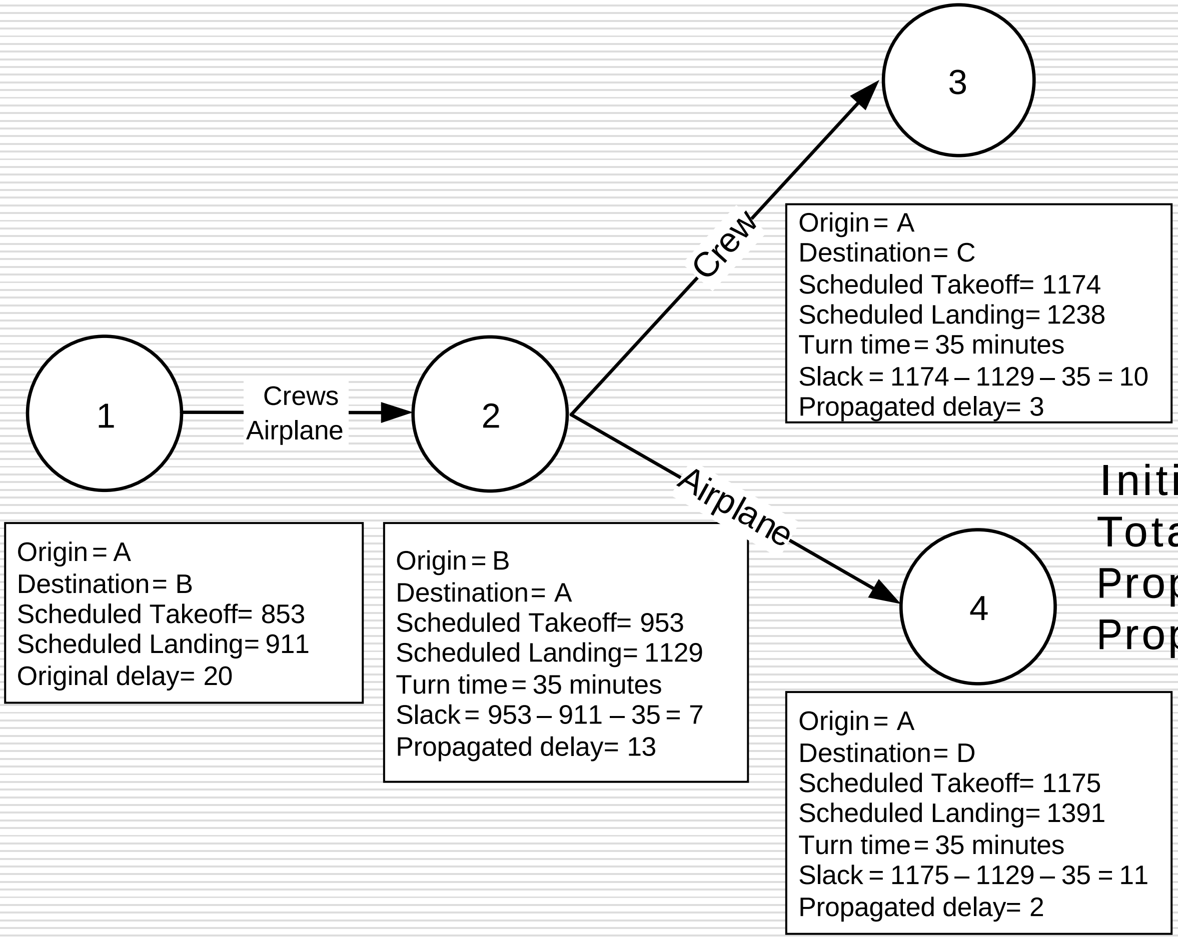
- Propagation magnitude
  - Total minutes of delay propagated in the flight network divided by the original delay

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

- Propagation severity
  - Total number of disrupted flights

- Note: Both metrics are a function of a root flight and an initial delay value

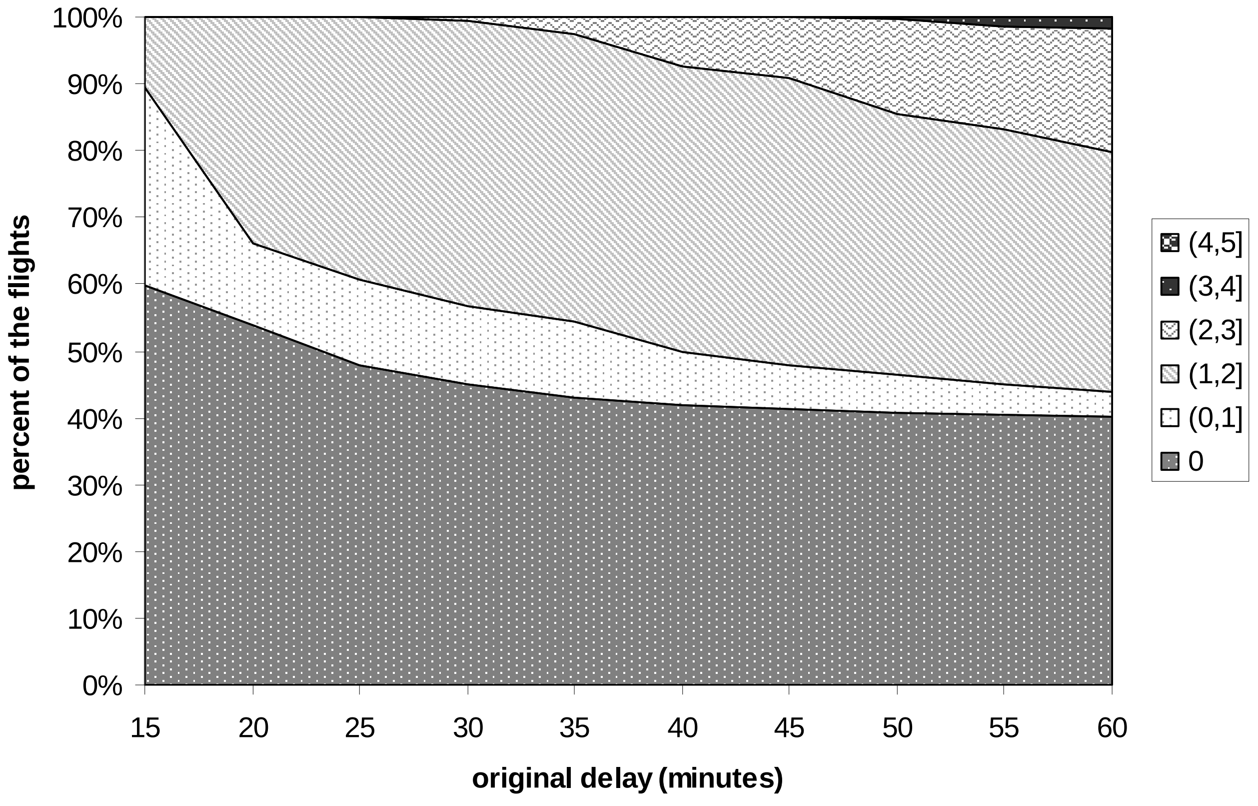
Example



Initial delay = 20 min
Total delay = 38 min
Propagation magnitude = 0.95
Propagation severity = 3

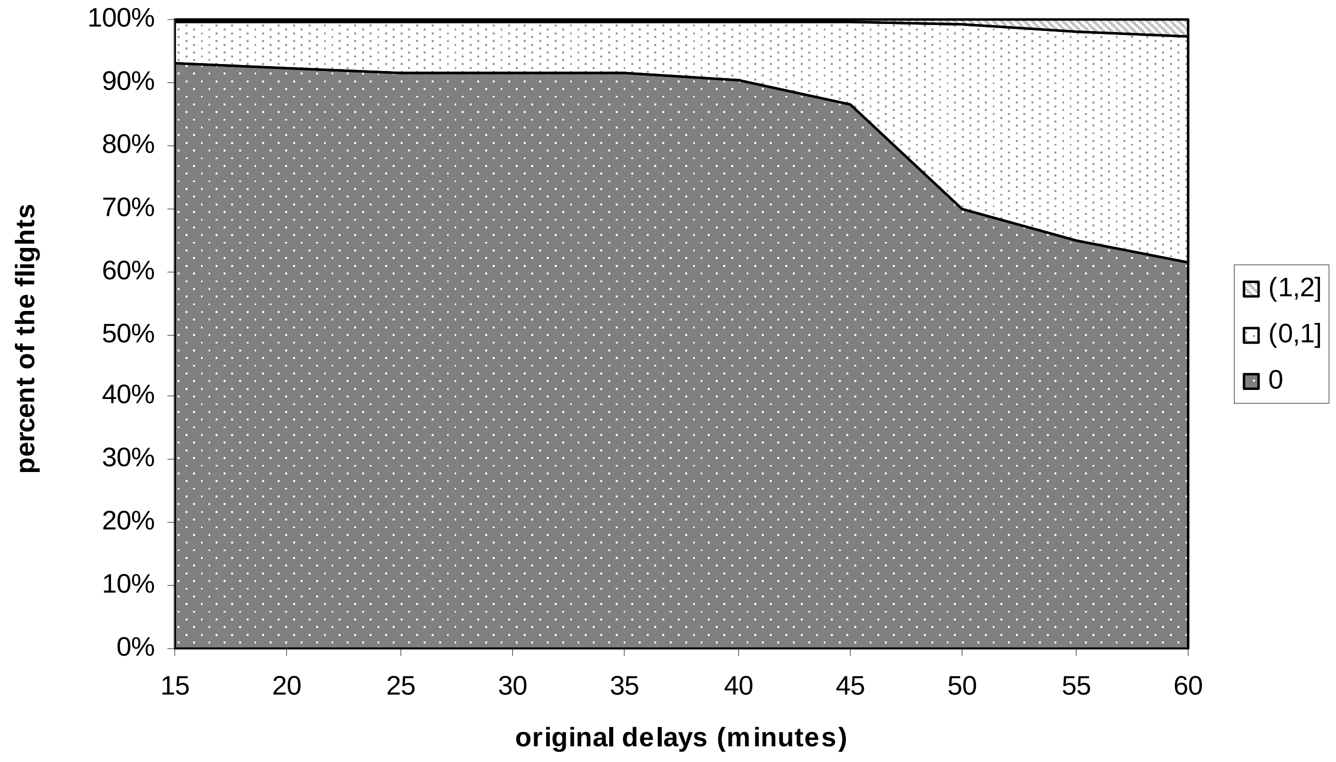
Preliminary Results – Carrier 1

- Propagation magnitude



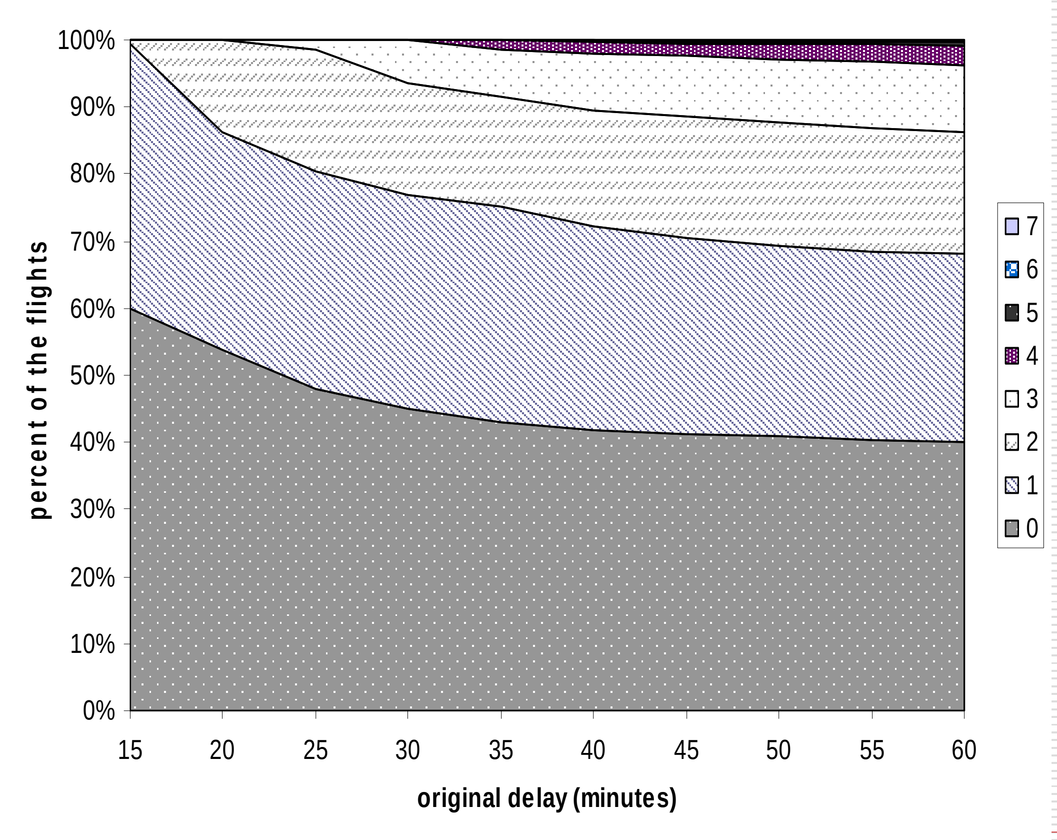
Preliminary Results – Carrier 2

- Propagation magnitude



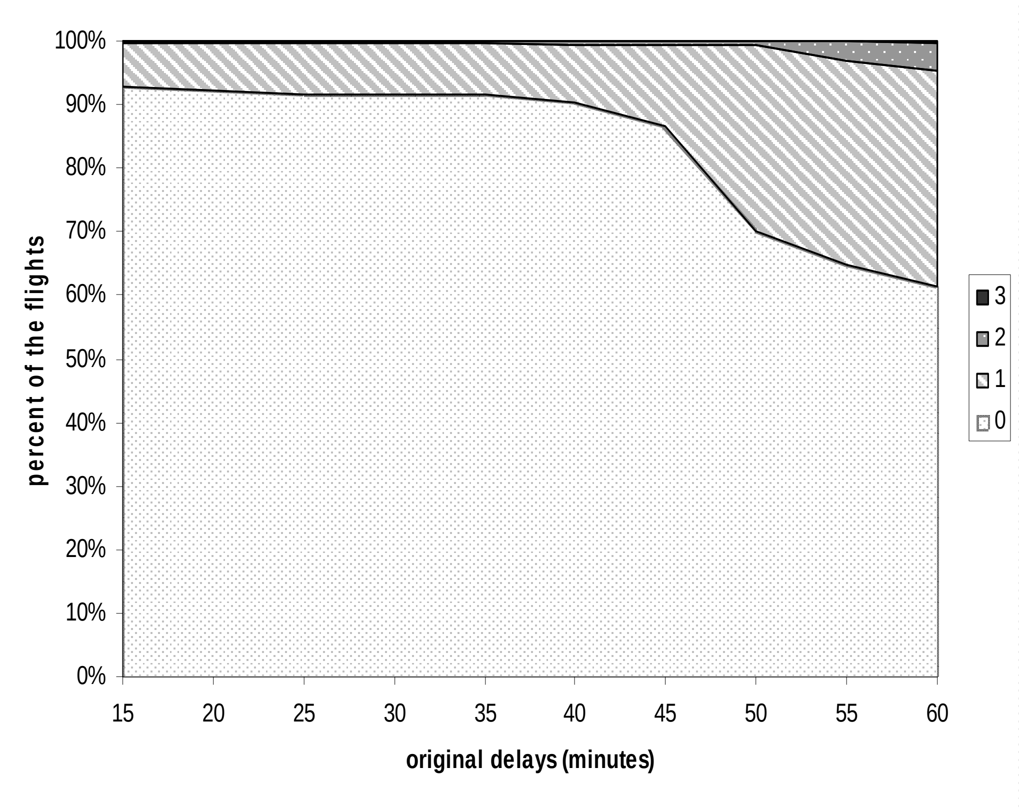
Preliminary Results – Carrier 1

- Propagation severity



Preliminary Results – Carrier 2

- Propagation severity



Preliminary Results – Carrier 1

- Sorted by origin or destination airport

	Origin Airport	Total Delay		Delay Per Flt.	Dev.
Top 5	AAA	505		100.6	-9.6%
	BBB	240		100.6	-9.6%
	CCC	74		87.8	-21.1%
	DDD	72		87.3	-21.5%
	EEE	70		101.1	-9.1%
Bottom 5	VVV	2		110.0	-1.1%
	WWW	2		109.0	-2.0%
	XXX	2		79.0	-29.0%
	YYY	1		110.0	-1.1%
	ZZZ	1		94.0	-15.5%
	Average			111.26	

Initial delay = 60 mins

Preliminary Results – Carrier 2

- Sorted by origin or destination airport

	Origin Airport	Total Delay		Delay Per Flt.	Dev.
Top 5	aaa	151		70.63	4.9%
	bbb	48		72.63	5.3%
	ccc	28		65.00	-3.5%
	ddd	28		72.17	7.2%
	eee	24		66.59	-1.1%
Bottom 5	vvv	2		60.00	-10.9%
	www	1		60.00	-10.9%
	xxx	1		60.00	-10.9%
	yyy	1		60.00	-10.9%
	zzz	1		60.00	-10.9%
	Average			67.34	

Initial delay = 60 mins

Improvements

- Probability of initial delay
- Correlations
- Passenger itinerary, cabin crew connections
- Recovery considerations
- More data!!!

High-Level Insights

- In many cases, delay *doesn't* propagate
- But when it does, it can significantly increase system delay
- Most propagation seems to be broad rather than deep

Robust Scheduling

- 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

LP Formulation

- Sets:
  - Set of flights F
  - Set of connections A
    - Union of four other sets: cockpit crew (P), cabin crew (C), equipment (E) and itinerary (I) connections
    - A = P ∩ C ∩ E ∩ I
  - Set of possible delay values (minutes) M

- Parameters:

$$k_f^+ \geq 0 \qquad \forall f \in \mathrm{F}$$

$$k_f^- \geq 0 \qquad \forall f \in \mathrm{F}$$

$$0 \leq p_f^m \leq 1 \qquad \forall f \in \mathrm{F}, \forall m \in \mathrm{M}$$

  - $s_{f_1,f_2} \geq 0 \qquad \forall (f_1, f_2) \in \mathrm{A}$

Linear programming formulation

- Decision variables:

- $k_f^- \le x_f \le k_f^+ \quad \forall f \in \mathrm{F}$
  - $0 \le x_f^+ \le k_f^+ \quad \forall f \in \mathrm{F}$
  - $0 \le x_f^- \le k_f^- \quad \forall f \in \mathrm{F}$

- $d_{f_1,f_2}^m \ge 0 \quad \forall (f_1, f_2) \in \mathrm{A}\ , \quad \forall m \in \mathrm{M}$
- $y_{f_1,f_2} \ge 0 \quad \forall (f_1, f_2) \in \mathrm{A}$

Linear programming formulation

- Objective function:

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

  - Minimize the expected value of delay propagation

Constraints

- Keep the connections feasible:

$$y_{f_1,f_2} = s_{f_1,f_2} + x^-_{f_1} + x^+_{f_2} - x^+_{f_1} - x^-_{f_2} \quad \forall (f_1, f_2) \in \mathrm{A}$$

- Calculate the delay propagation:

$$d^m_{f_1,f_2} \geq 0 \quad \forall (f_1, f_2) \in \mathrm{A}, \quad \forall m \in \mathrm{M}$$

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

Current Status

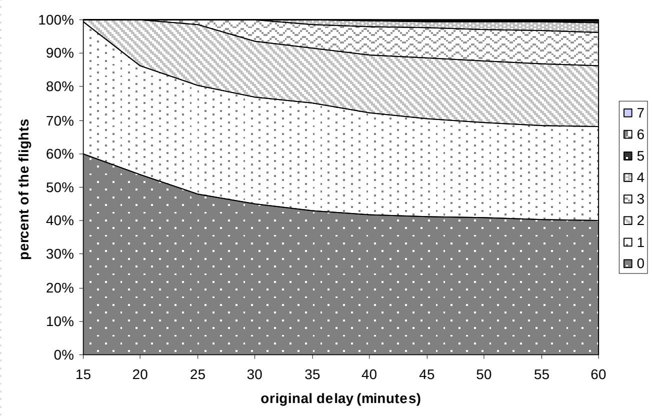
- Basic approach implemented, undergoing testing
- Many features yet to be added
- Current results are promising
- Need more data!

Results –Carrier 1

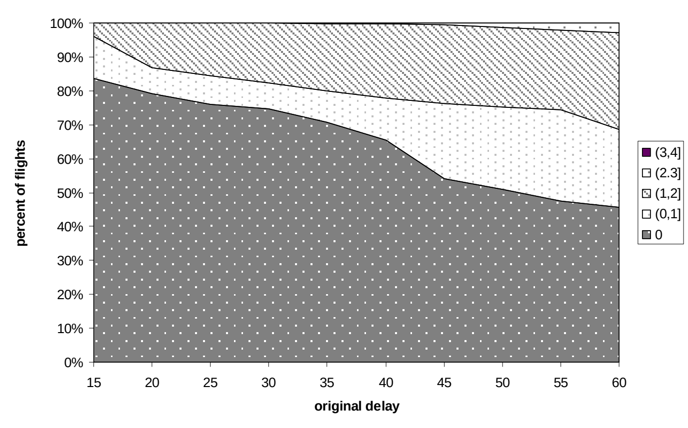
magnitude

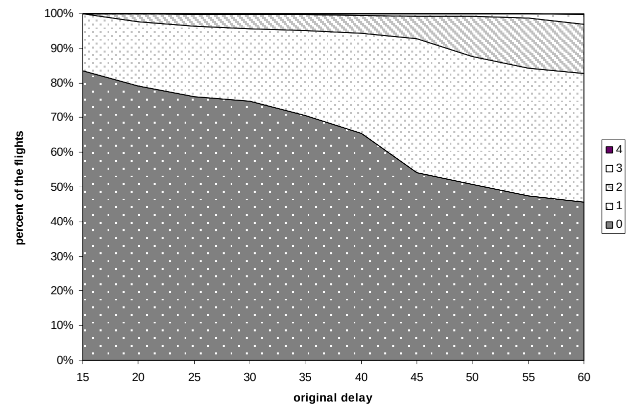
severity

before



after





Future Research

- More analysis
  - More data sets
  - Including cabin crews and passengers, weighted delays, recovery, correlations…
- Planning tool
  - More data sets
  - More analysis
  - Operational considerations
  - Recovery, correlation
  - Cost impact of potential propagation reduction