Risk-Hedged Approach for Re-routing Air Traffic Under Weather Uncertainty

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Outline

• Background on route planning
• Re-routing options for weather avoidance
• Risk-hedged approach for re-routing
• Example results
• Conclusion
Background

- Flight operators design the routes they wish to fly
- Air traffic service provider designs and implements re-routing around bad weather
- Strategic planning for re-routes around large weather systems is based on multi-hour weather forecasts
- Multi-hour weather forecasts have high uncertainty, but current products typically provide only the most likely instantiation of future weather
Re-routing for Weather Avoidance

either, or

\[ \alpha_1 = 0.7 \]

impassable (high intensity)

impassable

\[ \alpha_2 = 0.3 \]

3
Re-routing for Weather Avoidance

“deterministically safe”: re-routes around all weather

(our proxy for) current operational practice

0.7

0.3
Motivation for Risk-Hedging

can incur high flight operation cost

can incur high cost for disruption of traffic operations

Risk-hedged approach:
minimize a combination of these two costs (later slide)

• “Risk” refers to risk of disruption caused by tactical re-routing; hence a path has high risk if a large segment lies within a weather instantiation of high likelihood

• Research is far term: assumes ensemble weather forecast with multiple (instantiations + likelihoods)

• CDM (Collaborative Decision Making) Convective Forecast Planning (CCFP) currently provides a rudimentary version of the desired capability
Example CCFP Advisory

EXPERIMENTAL CDM CONVECTIVE FORECAST PLANNING GUIDANCE

VALID: 2100 UTC THU 19 MAY 2016

AVIATION WEATHER CENTER (NOAA/NWS/NCEP) 

ISSUED: 1900 UTC THU 19 MAY 2016

CONFIDENCE:
LOW 25-49%
HIGH 50-100%

CONVECTIVE COVERAGE:
SPARSE 25-39%
MEDIUM+ 40-100%

HEIGHT
TOPS: 100’s OF FEET MSL
25000 - 29000  290
30000 - 34000  340
35000 - 39000  390
40000+    >400

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Risk-Adjusted Field

\[ P = 1 / \left( 1 - \sum \alpha_i \right) \]

\[ P = \frac{1}{1 - 0.6} \]

\[ P = \frac{1}{1 - 0.6 - 0.1} \]

\[ P = \frac{1}{1 - (0.6 + 0.1)} \]

\[ \alpha_1 = 0.6 \]

\[ \alpha_2 = 0.1 \]

\[ \alpha_3 = 0.3 \]
Risk-Adjusted Field

\[ P = 1 / \left( 1 - \Sigma \alpha_i \right) \]

\[ P = 1.0 \]

\[ P = 2.5 \]
\[ \alpha_1 = 0.6 \]

\[ P = 3.3 \]

\[ P = 1.4 \]
\[ \alpha_3 = 0.3 \]

\[ P = 1.1 \]
\[ \alpha_2 = 0.1 \]
Risk-Adjusted Path Length: the minimization objective

Risk-adjusted path length =

\((1 \times 13 + 2.5 \times 23 + 1 \times 20 + 1.1 \times 34 + 1 \times 12) = 130.9 \text{ miles}\)
Risk-Hedged Re-routing

• Compute re-routes by minimizing risk-adjusted path length

• Evaluate the computed re-routing using these metrics:
  – Path length (proxy for flight operation cost)
  – Path risk (defined on next slide)
Path Risk:
an evaluation metric

\[ \alpha_1 = 0.6 \]
\[ \alpha_2 = 0.1 \]
\[ \alpha_3 = 0.3 \]

\[ \text{Path Risk} = \frac{(0 \times 13 + 0.6 \times 23 + 0 \times 20 + 0.1 \times 34 + 0 \times 12)}{(13 + 23 + 20 + 34 + 12)} = 0.17 \]
Re-routing Options – Example #1

deterministically safe
risk-hedged
current op. proxy

to
det risk-hedged

from

current proxy

to

det risk-hedged

x-distance (nmi)

y-distance (nmi)
Metrics for Example #1

- **Path Risk (nondim.)**
  - **Nominal:**
  - **Current Op. (Proxy):**
  - **Risk-Hedged:**
  - **Shorter Path:**
  - **Deterministically Safe:**

- **Excess Path Length (nondim.):**
  - **0.0**
  - **0.05**
  - **0.10**
  - **0.15**
  - **0.20**

The diagram illustrates various path risk scenarios and their corresponding path lengths, indicating a safe zone for deterministic operations.
Re-routing Options – Example #2

The diagram illustrates the x-distance and y-distance (nmi) for a re-routing example. The graph shows various distances, with annotations indicating specific values such as 0.6, 0.3, and 0.1. The diagram includes a path labeled 'from' and 'to', indicating the beginning and end points of the re-routing options.
Metrics for Example #2

- **nominal**
- **risk-hedged**
- **deterministically safe**
- **current op. (proxy)**

Path risk (nondim.)

Excess path length (nondim.)

More Path Risk

Shorter Path
Conclusion

• In some weather avoidance scenarios, the risk-hedged re-routing is shorter and less risky than operational practice

• In other scenarios, risk-hedged re-routing can be:
  – Less risky, but has a longer path
  – More risky, but has a shorter path

• Potential application to re-routing for weather avoidance:
  – Compute risk-hedged path
  – Compare with operational-practice path for risk and path length
  – Choose risk-hedged path if both safer and shorter
Backup Slides
Minimization problem: the Eikonal equation

\[
\frac{1}{P(x)} \| \text{grad} \left( \text{min. cost to endpoint from } x \right) \| = 1
\]
Example Playbook Re-routing

Play: LEV EAST 1

East-bound flows from ZLA, ZAB, ZFW, ZHU are merged and then split into two flows going to DC and NYC airports.