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

Alexander V. Sadovsky
Karl D. Bilimoria

NASA Ames Research Center

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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)

\[ \alpha_2 = 0.3 \]

impassable

\[ \alpha_2 = 0.3 \]

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Re-routing for Weather Avoidance

“deterministically safe”: re-routes around all weather

(our proxy for) current operational practice
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
Risk-Adjusted Field

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

\[ \alpha_1 = 0.6 \]

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

\[ \alpha_2 = 0.1 \]

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

\[ \alpha_3 = 0.3 \]

\[ P = \frac{1}{1 - 0.3} \]
Risk-Adjusted Field

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

\( P = 1.0 \)

\( P = 2.5 \)
\( \alpha_1 = 0.6 \)

\( P = 3.3 \)

\( P = 1.4 \)
\( \alpha_3 = 0.3 \)

\( P = 1.1 \)
\( \alpha_2 = 0.1 \)
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

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

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
deterministically safe

y-distance (nmi)

x-distance (nmi)
Metrics for Example #1

Path risk (nondim.)

0.20
0.15
0.10
0.05
0.
0.
0.
0.
0.0
0.05
0.10
0.15
0.20

nominal

current op. (proxy)

risk-hedged

Less Path Risk

Shorter Path

deterministically safe
Re-routing Options – Example #2
Metrics for Example #2

- **nominal**
- **risk-hedged**
- **deterministically safe**

More Path Risk → Shorter Path

Current op. (proxy)

Excess path length (nondim.)

Path risk (nondim.)
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

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