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)

\[ \alpha_2 = 0.3 \]

does not intersect

impassable (high intensity)

\[ \alpha_2 = 0.3 \]
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

\[ P = \frac{1}{1 - \sum \alpha_i} \]

\[ P = \frac{1}{1 - 0.1} \]
\[ \alpha_2 = 0.1 \]

\[ P = \frac{1}{1 - 0.6} \]
\[ \alpha_1 = 0.6 \]

\[ P = \frac{1}{1 - (0.6 + 0.3)} \]
\[ \alpha_3 = 0.3 \]
Risk-Adjusted Field

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

current op. proxy

x-distance (nmi)
Metrics for Example #1

- **Nominal Risk**
- **Risk-Hedged**
- **Shorter Path**
- **Deterministically Safe**

![Graph showing metrics](image)
Re-routing Options – Example #2

y-distance (nmi)

x-distance (nmi)

0 20 40 60 80 100

0 20 40 60

-20 -40 -60

0.6 0.3 0.1

from to
Metrics for Example #2

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

Path risk (nondim.) vs. excess path length (nondim.)

- More Path Risk
- Shorter Path

Current op. (proxy)
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.