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

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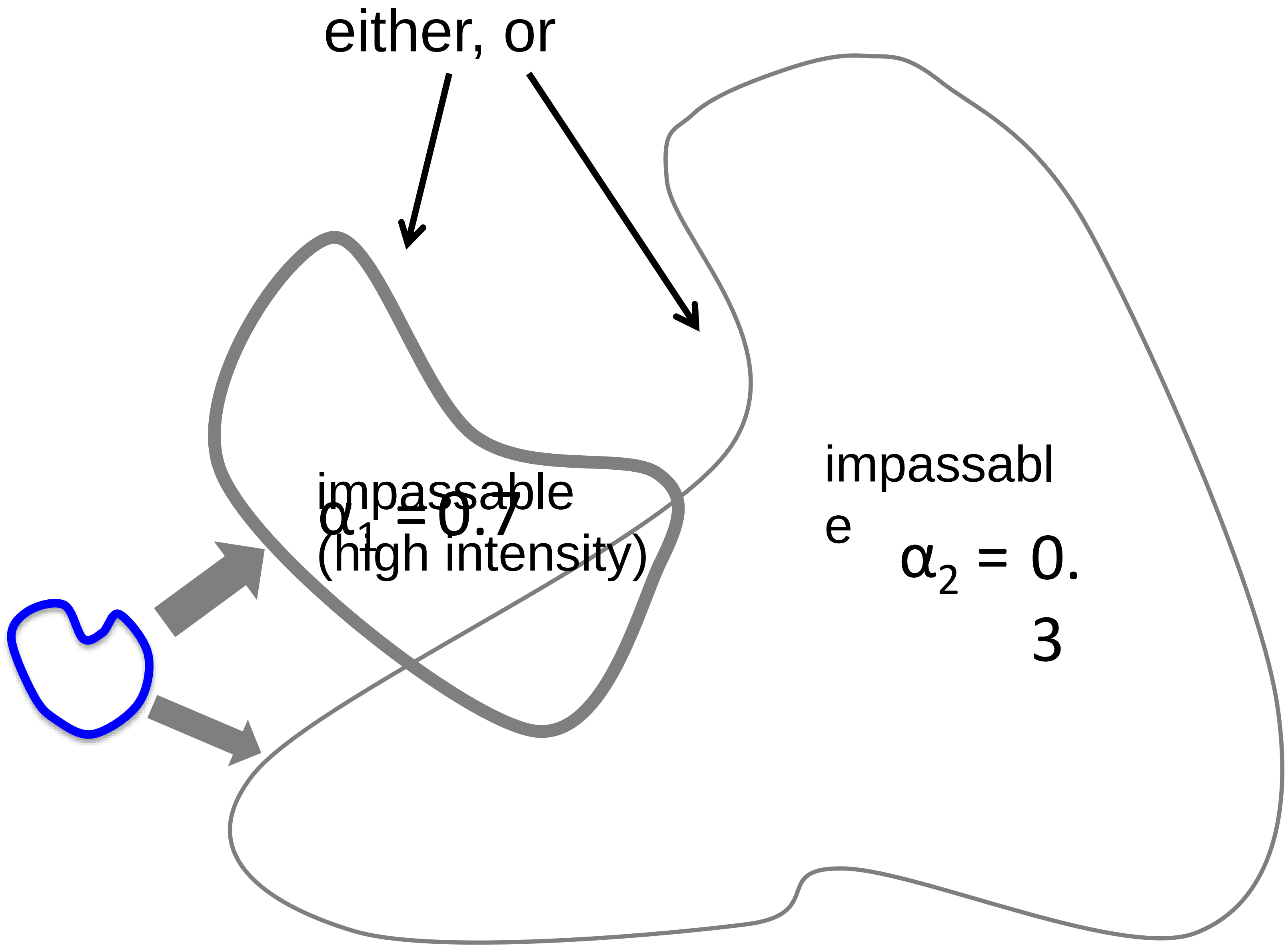
Outline

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

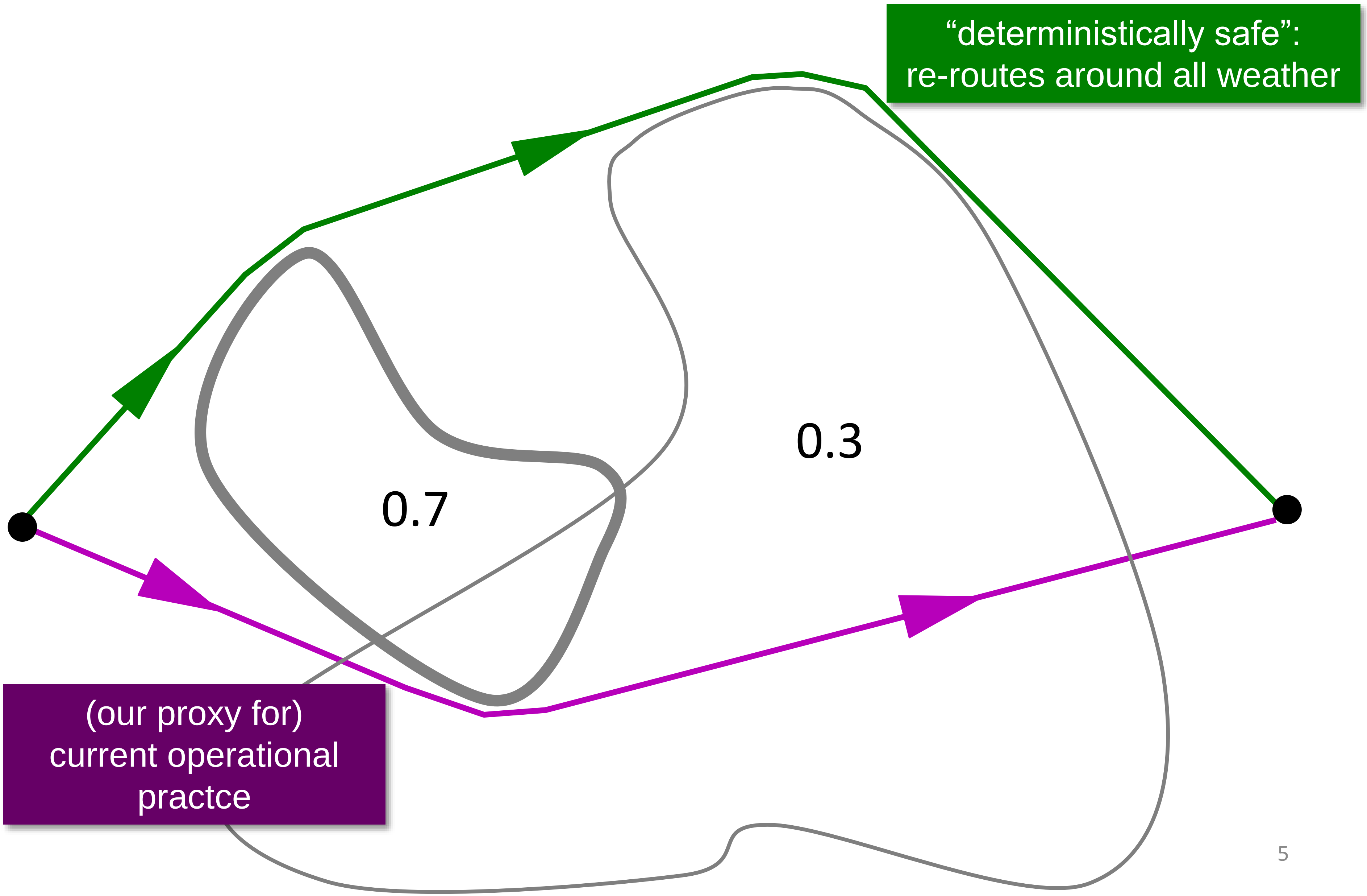
Background

- 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

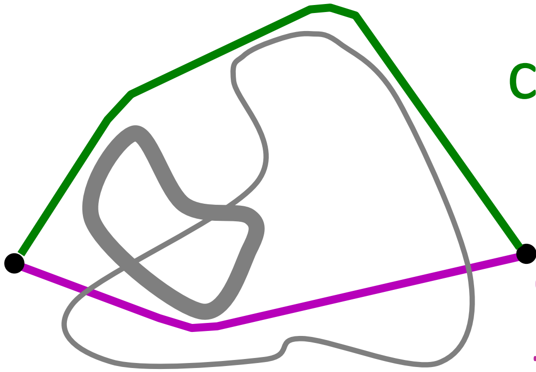
Re-routing for Weather Avoidance



Re-routing for Weather Avoidance



Motivation for Risk-Hedging



can incur high flight operation cost

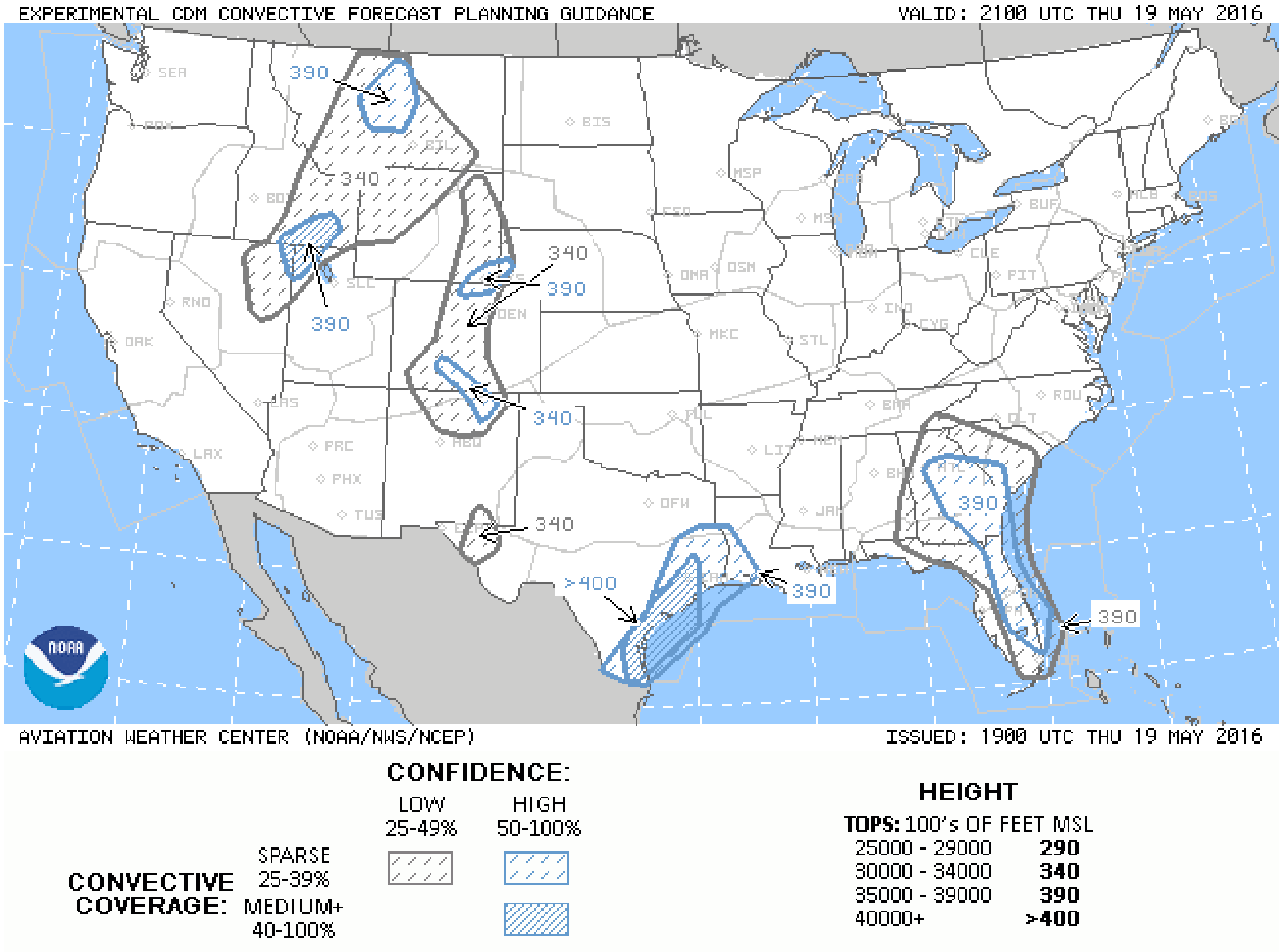
can incur high cost for disruption of traffic operations

Risk-hedged approach:

minimize a combination of these two costs (later slide)

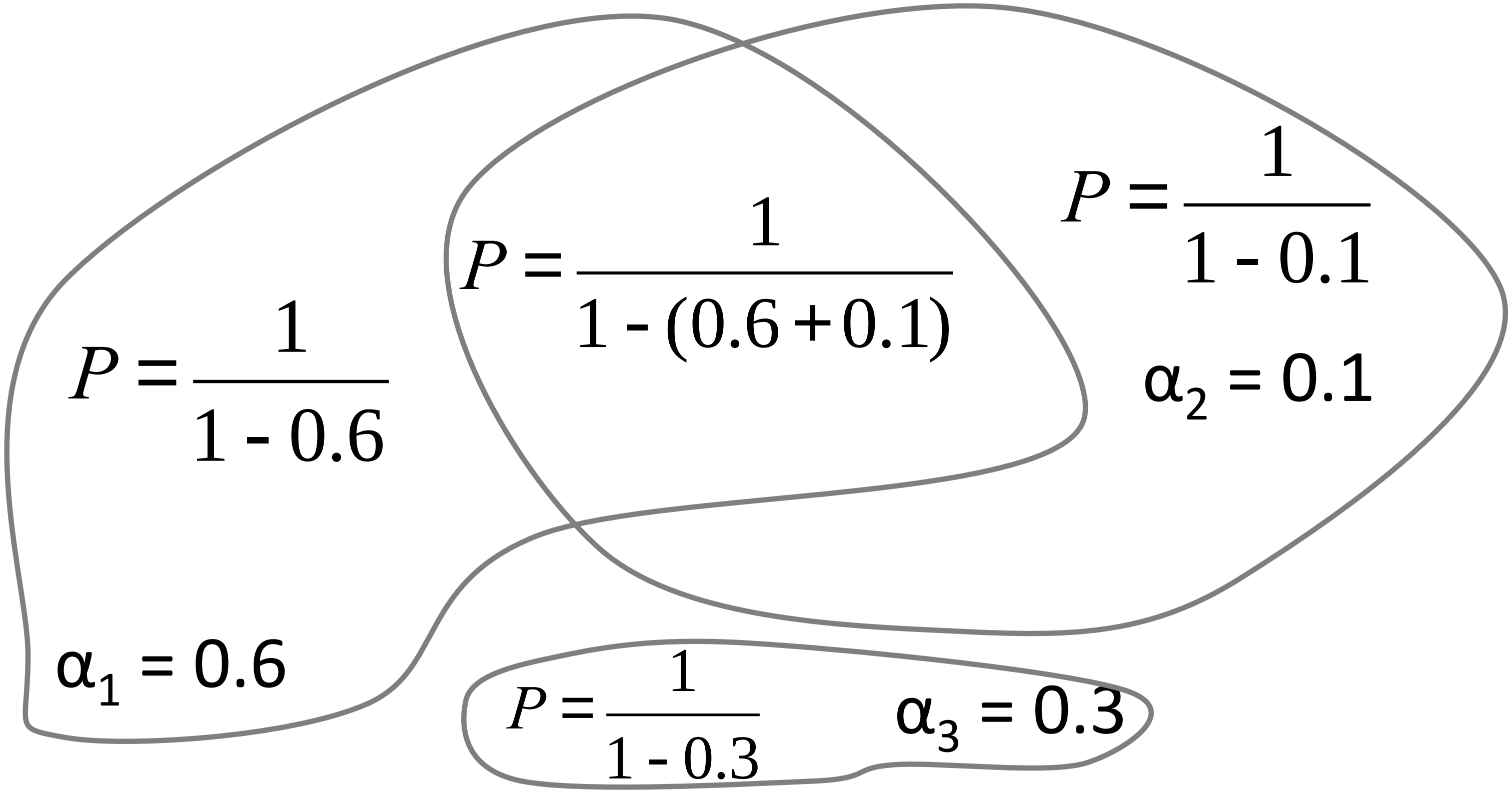
- “Risk” refers to risk of disruption caused by tactical re-routing; hence a path has high risk if a large segment lies within a weather instantiation of high likelihood
- Research is far term: assumes ensemble weather forecast with multiple (instantiations + likelihoods)
- CDM (Collaborative Decision Making) Convective Forecast Planning (CCFP) currently provides a rudimentary version of the desired capability

Example CCFP Advisory



Risk-Adjusted Field

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



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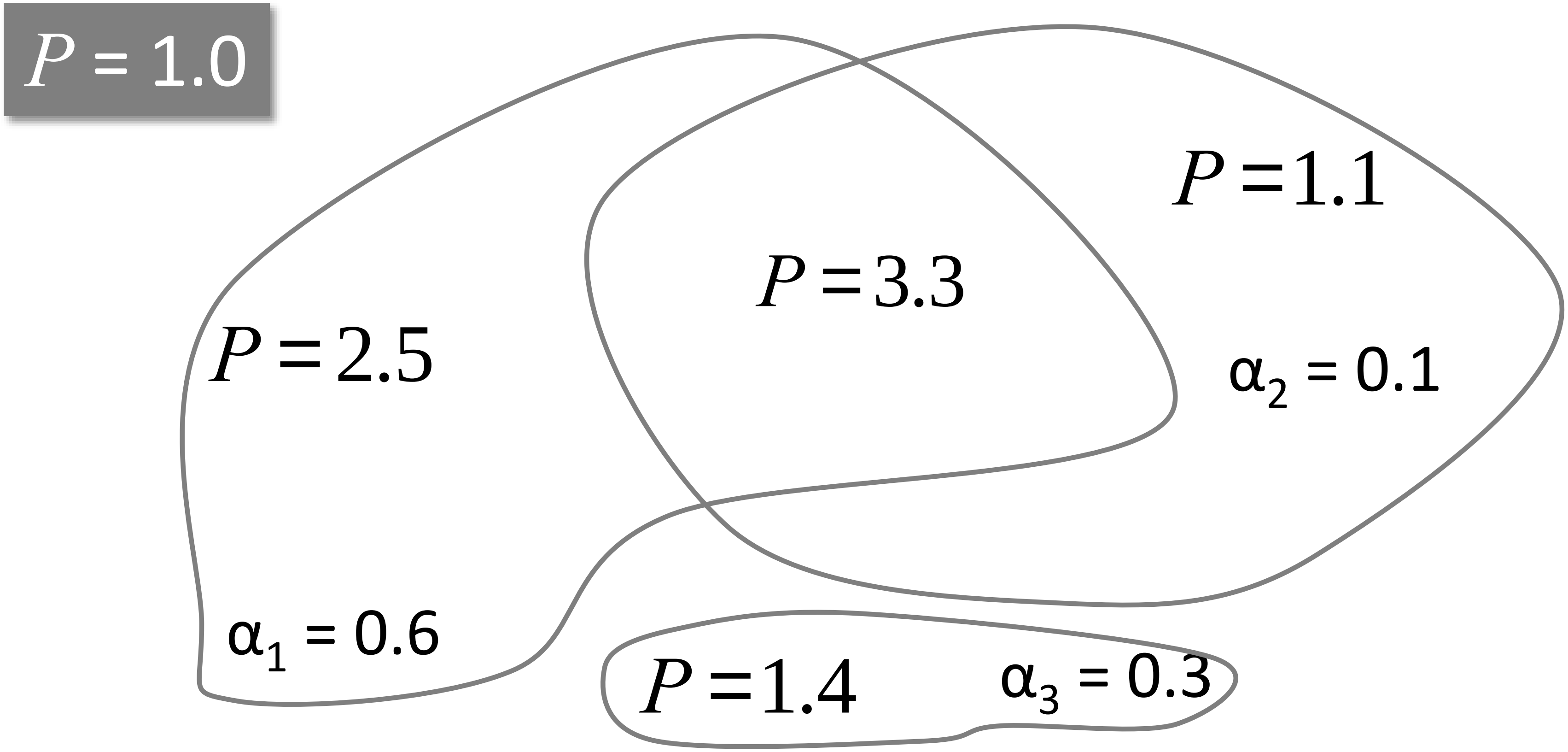
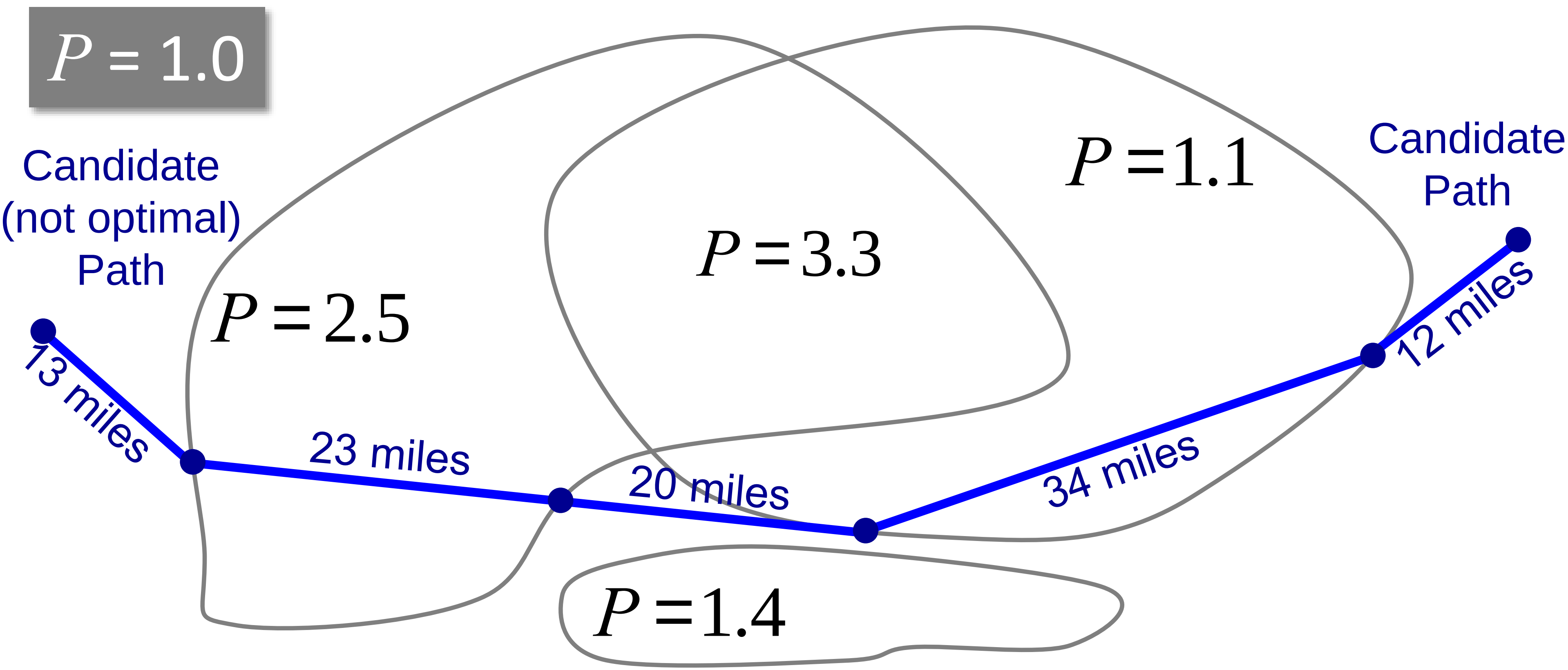


Risk-Adjusted Path Length:
the minimization objective

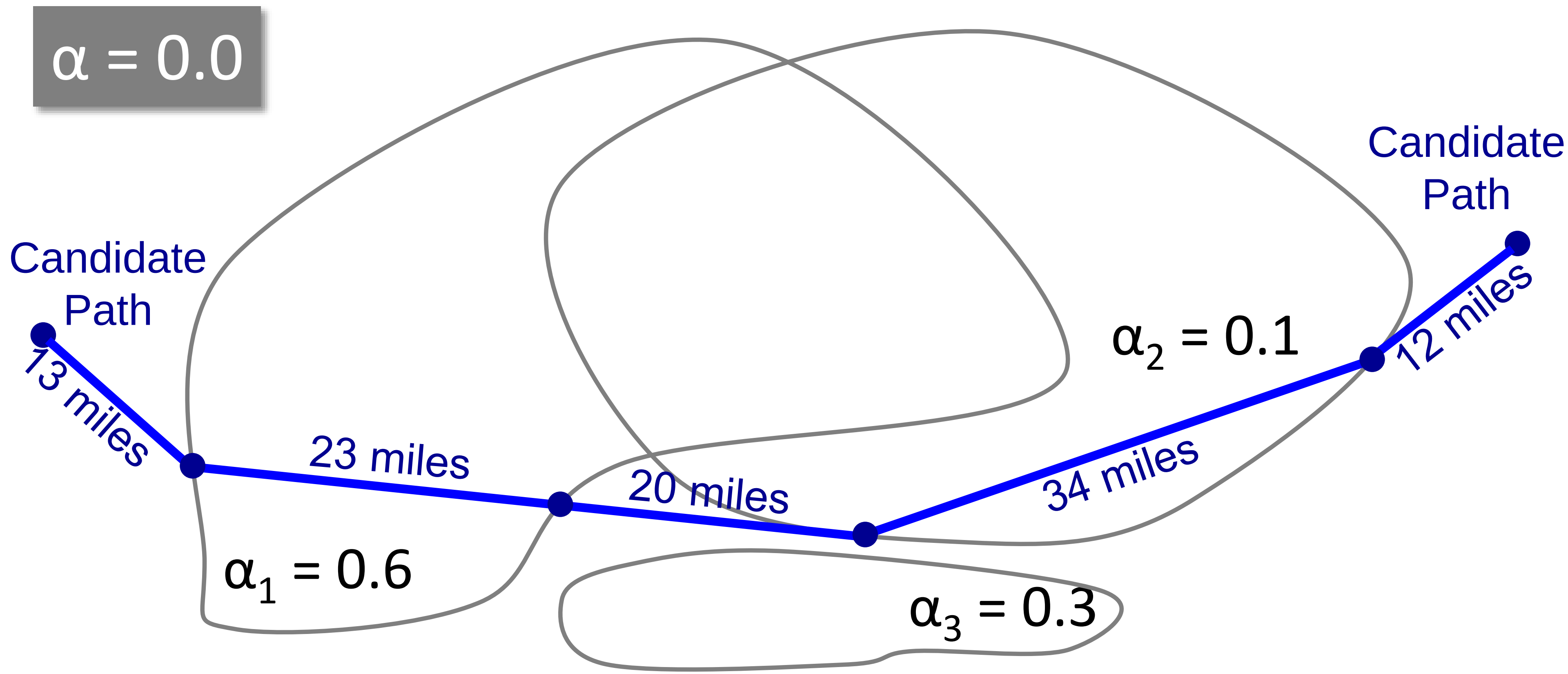


Risk-adjusted path length =
(1 x 13 + 2.5 x 23 + 1 x 20 + 1.1 x 34 + 1 x 12) = 130.9 miles

Risk-Hedged Re-routing

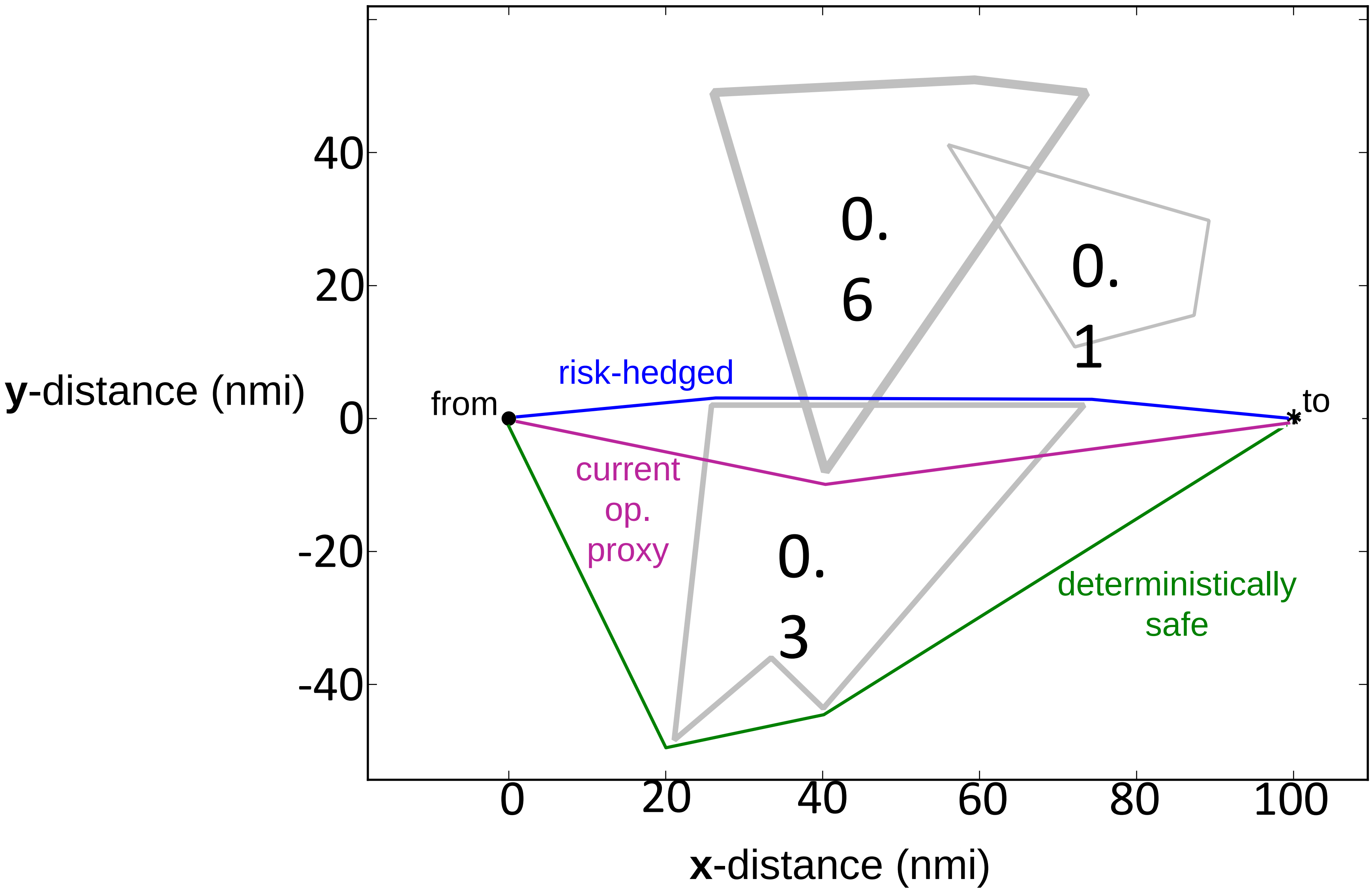
- Compute re-routes by minimizing risk-adjusted path length
- Evaluate the computed re-routing using these metrics:
  - Path length (proxy for flight operation cost)
  - Path risk (defined on next slide)

Path Risk:
an evaluation metric

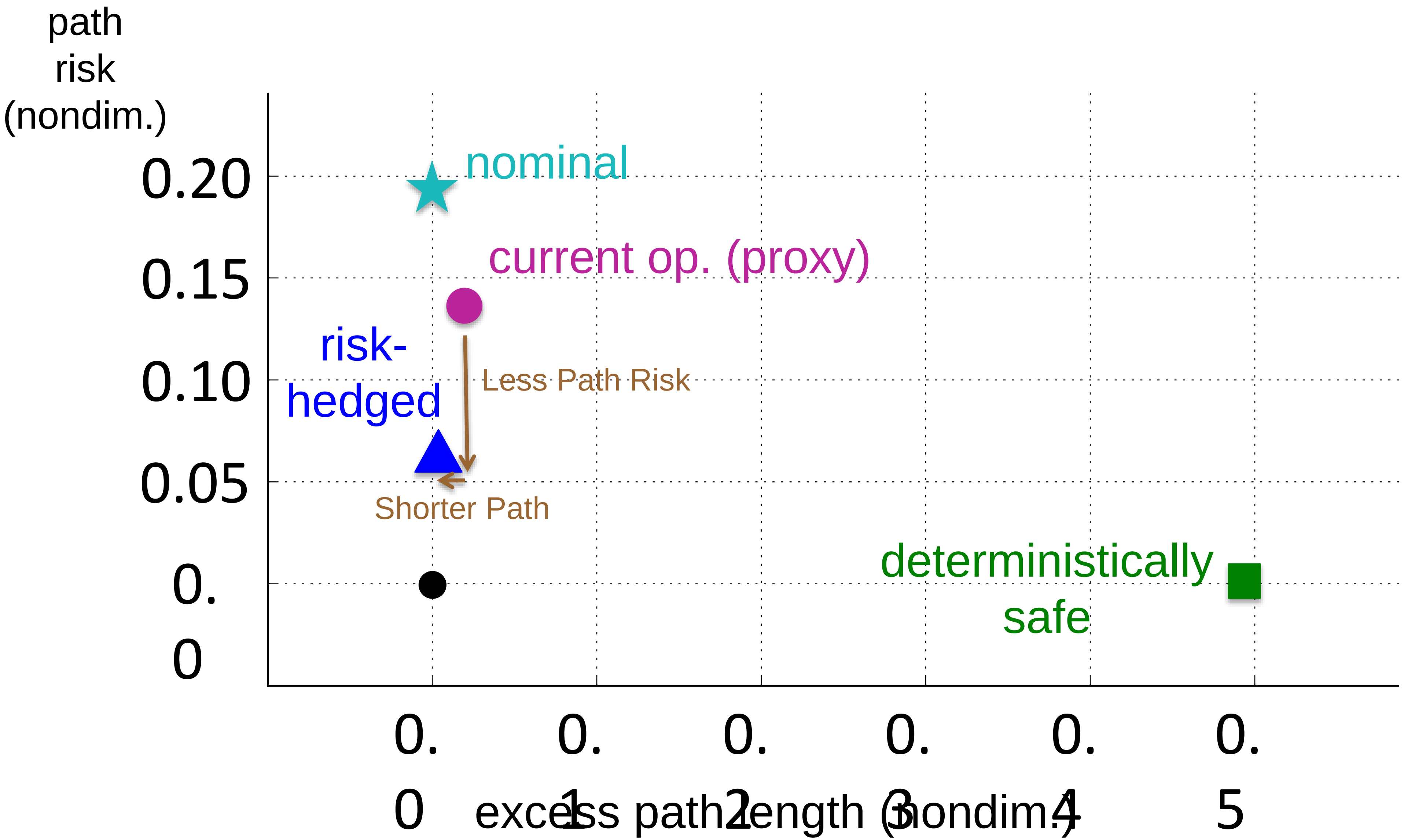


Path Risk =
(0 x 13 + 0.6 x 23 + 0 x 20 + 0.1 x 34 + 0 x 12) / (13 + 23 + 20 + 34 + 12) = 0.17

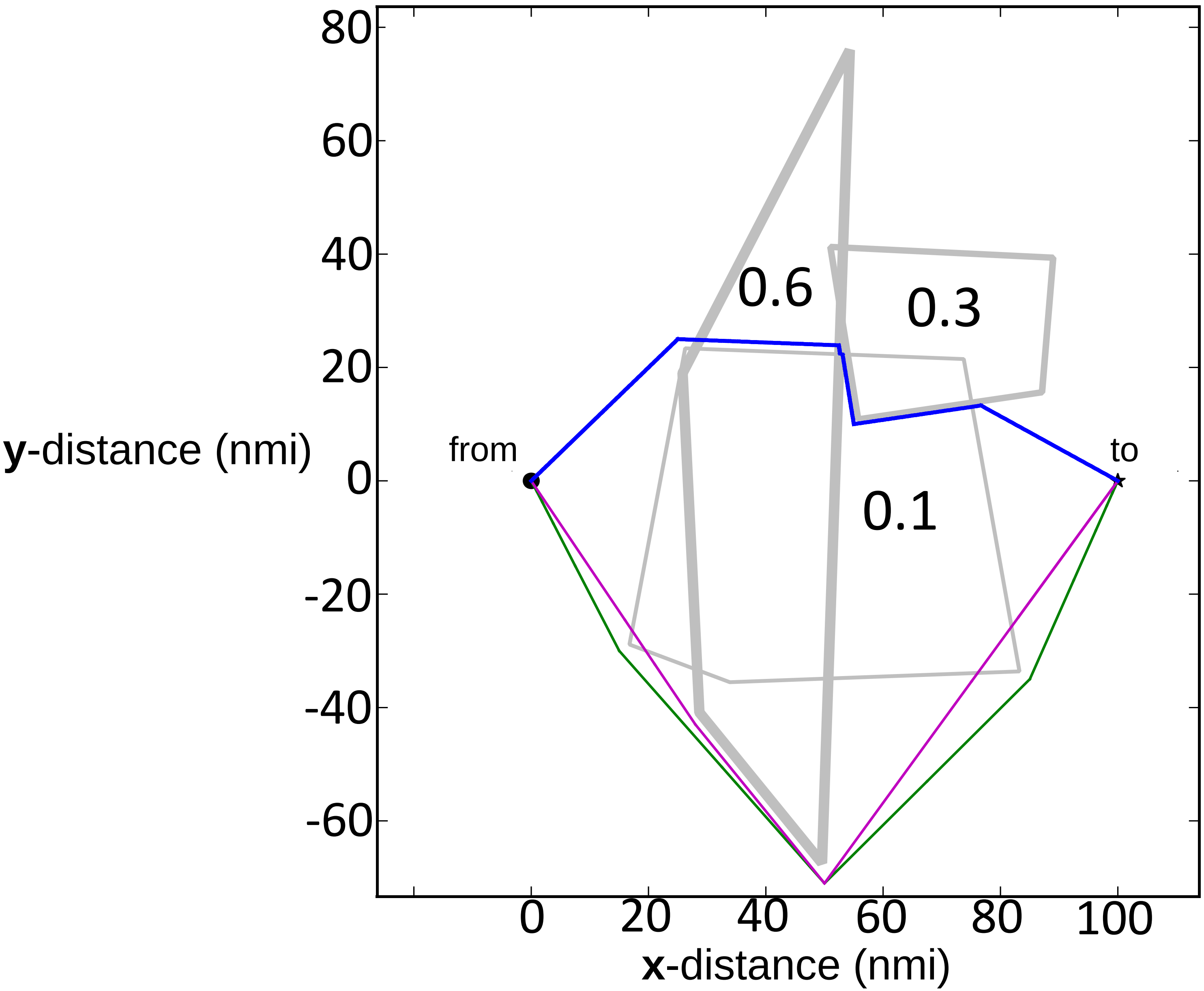
Re-routing Options – Example #1



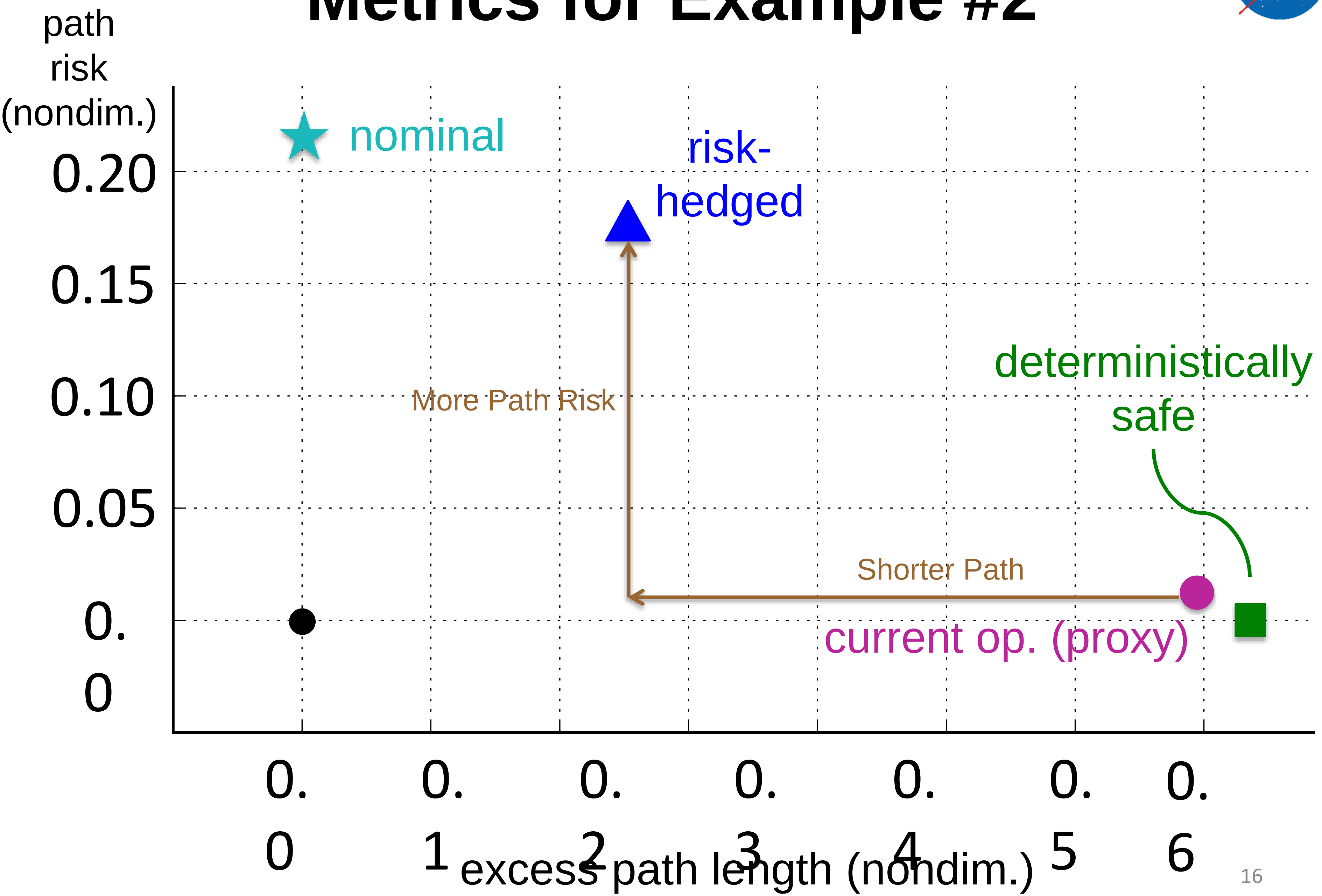
Metrics for Example #1



Re-routing Options – Example #2



Metrics for Example #2



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

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

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