Traffic Flow Management and Uncertainty Mitigation under NEXTGEN

by

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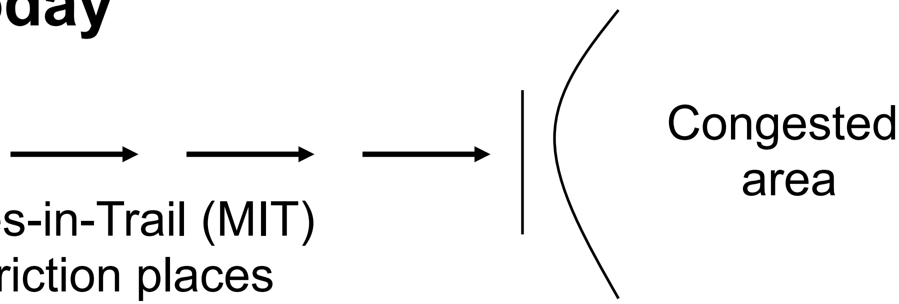
based on work funded under NASA NRA:
"Dynamic, Stochastic Models for Managing Air Traffic Flows"
collaborators on this research: Andy Churchill, Moein Ganji, Mark Hansen, Bob Hoffman, Dave Lovell, Amedeo Odoni, Yoonjin Yoon

NEXTGEN TFM Principles

- Trajectory-Based Ops (TBO)
  - Precision navigation and reduced separation – time-based, highly accurate traffic demand predictions
  - Feedback (on constraints, delays, etc) to user 4-Dimensional Trajectory (4DT) inquiries
- Performance Based Ops
  - Minimum performance levels can be required for certain portions of airspace
  - Priority based on performance characteristics
- Collaborative Air Traffic Mgmt
- Continuous TFM

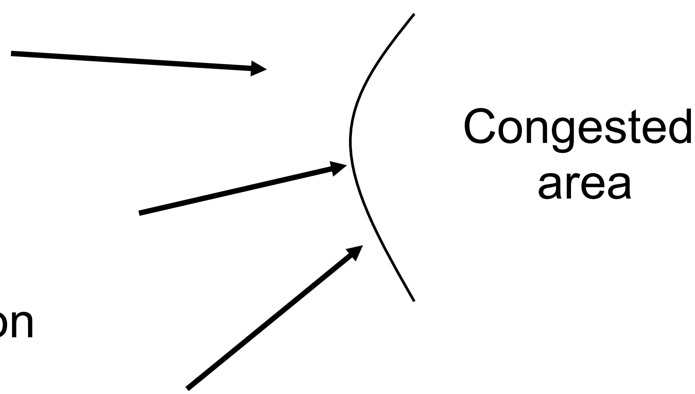
TBO vs MIT

Today



Miles-in-Trail (MIT) restriction places constraint on rate of flow into congested region

NEXTGEN -- TBO



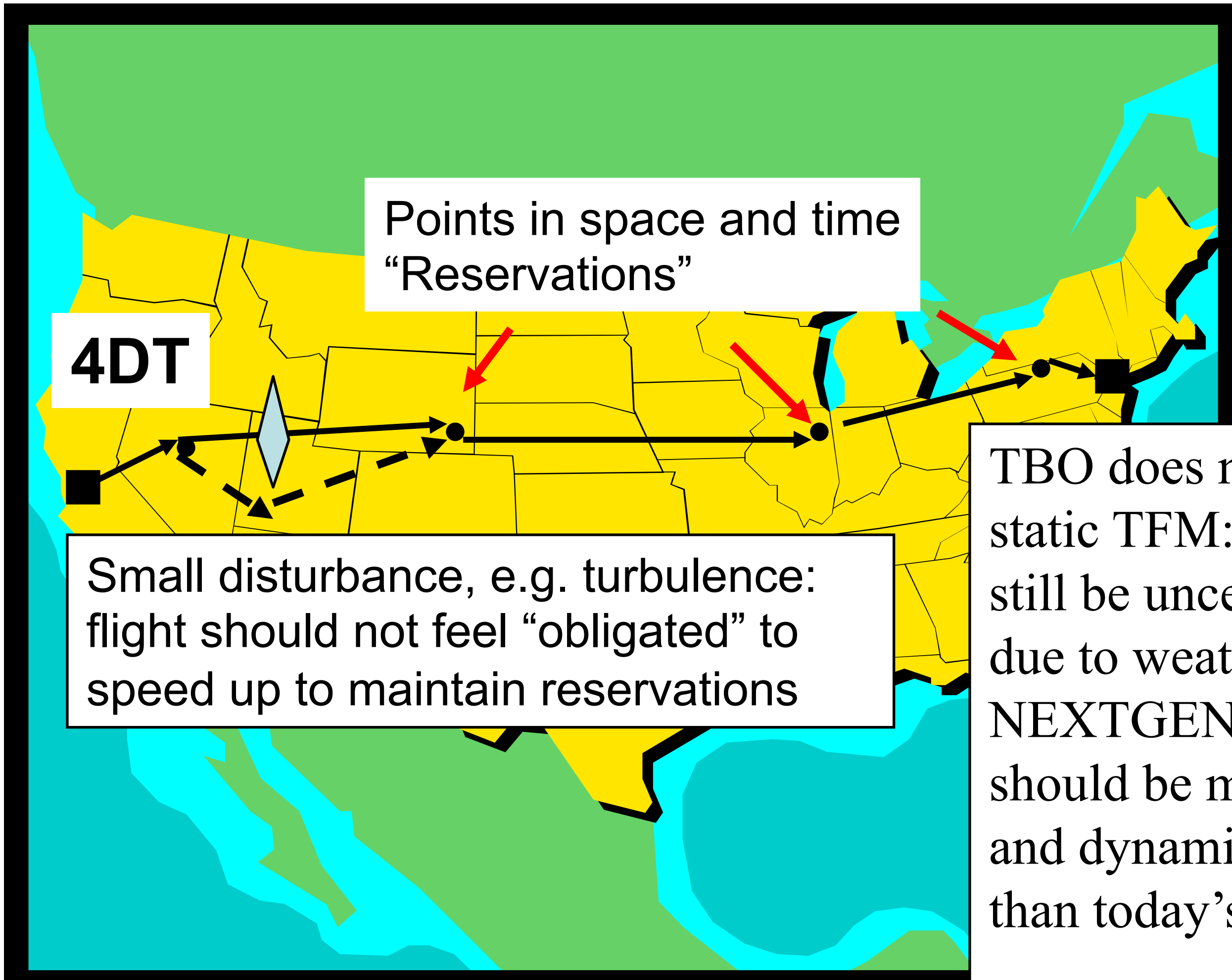
Each flight will have arrival time reservation

Comparison

- While MIT's "protect" congested area, they do not insure full utilization of capacity
- MIT's dynamically (but slowly) to respond to changing conditions
- TBO will allow for much more precise matching of capacity and demand – specific spatial and temporal characteristics of flights can be taken into account

NEXTOR

TBO: what it does not mean



TBO does not mean static TFM: there will still be uncertainty, e.g. due to weather; NEXTGEN TFM should be more flexible and dynamic (not less) than today’s TFM!!

Optimization Models for TFM Planning Under Uncertainty

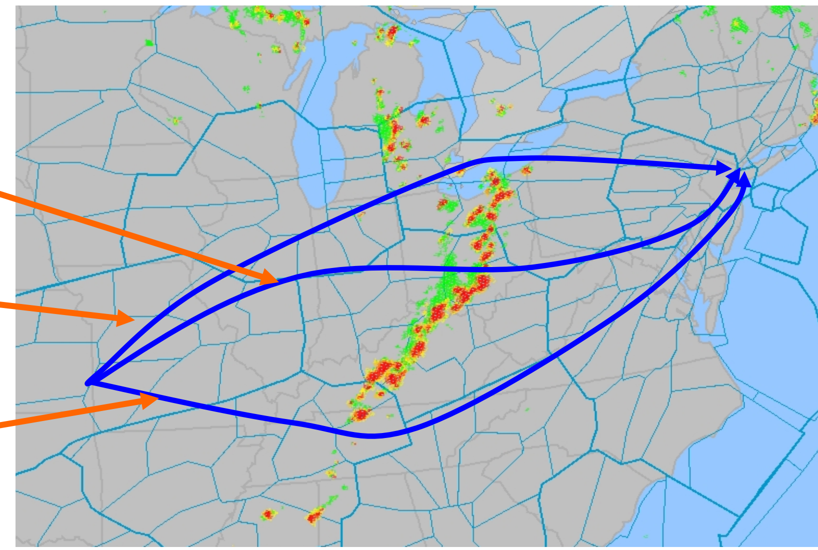
Example: Planning in Presence of Enroute Disturbance

Models 1 (single flight) and 2 (multiple flights)

Option 1: Route through FCA
(If ground delay is not too large)

Option 2: Northern route
(If delay for first choice is large)

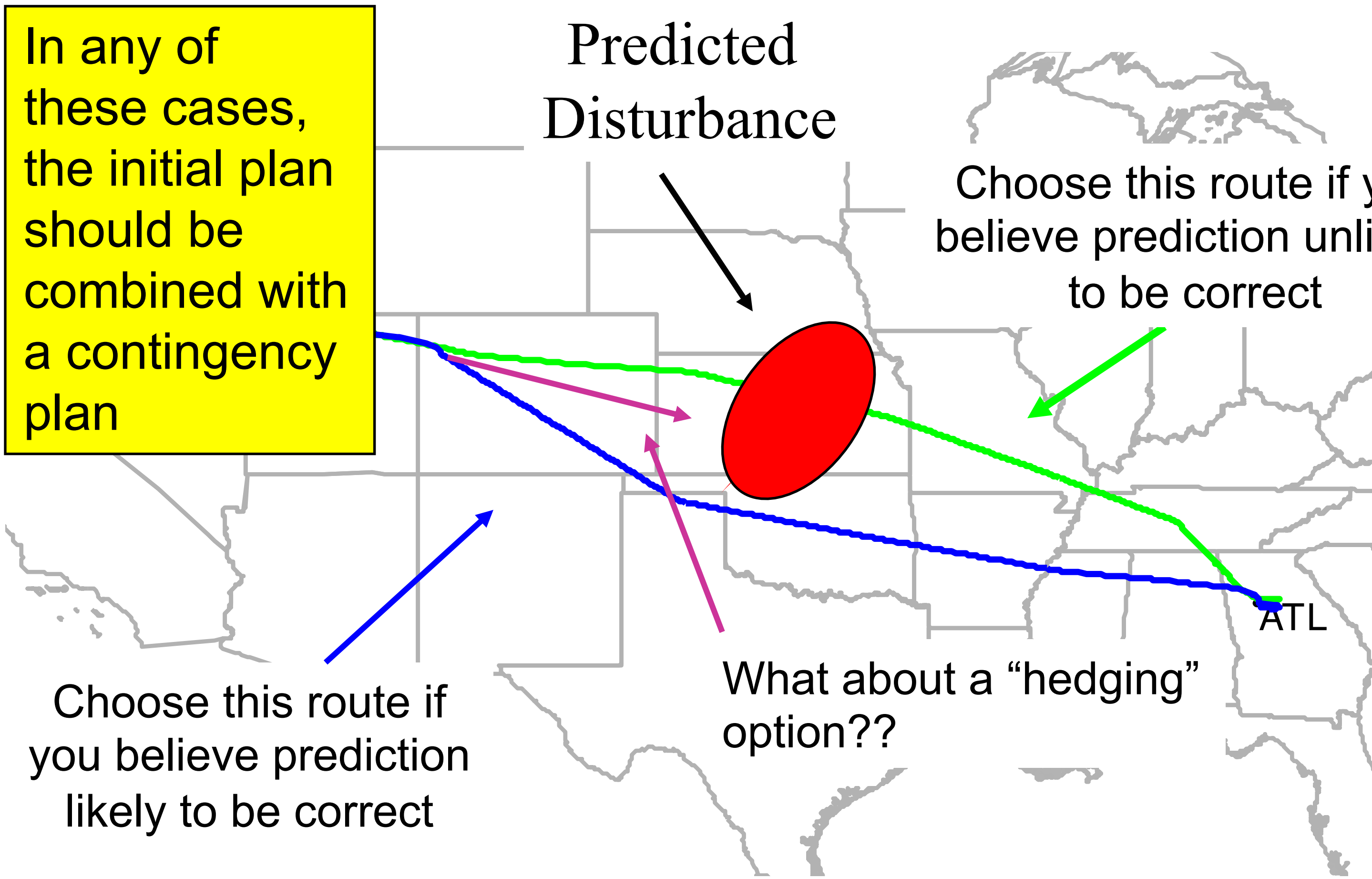
Option 3: Southern route
(If can be done without delay)



Related Research:

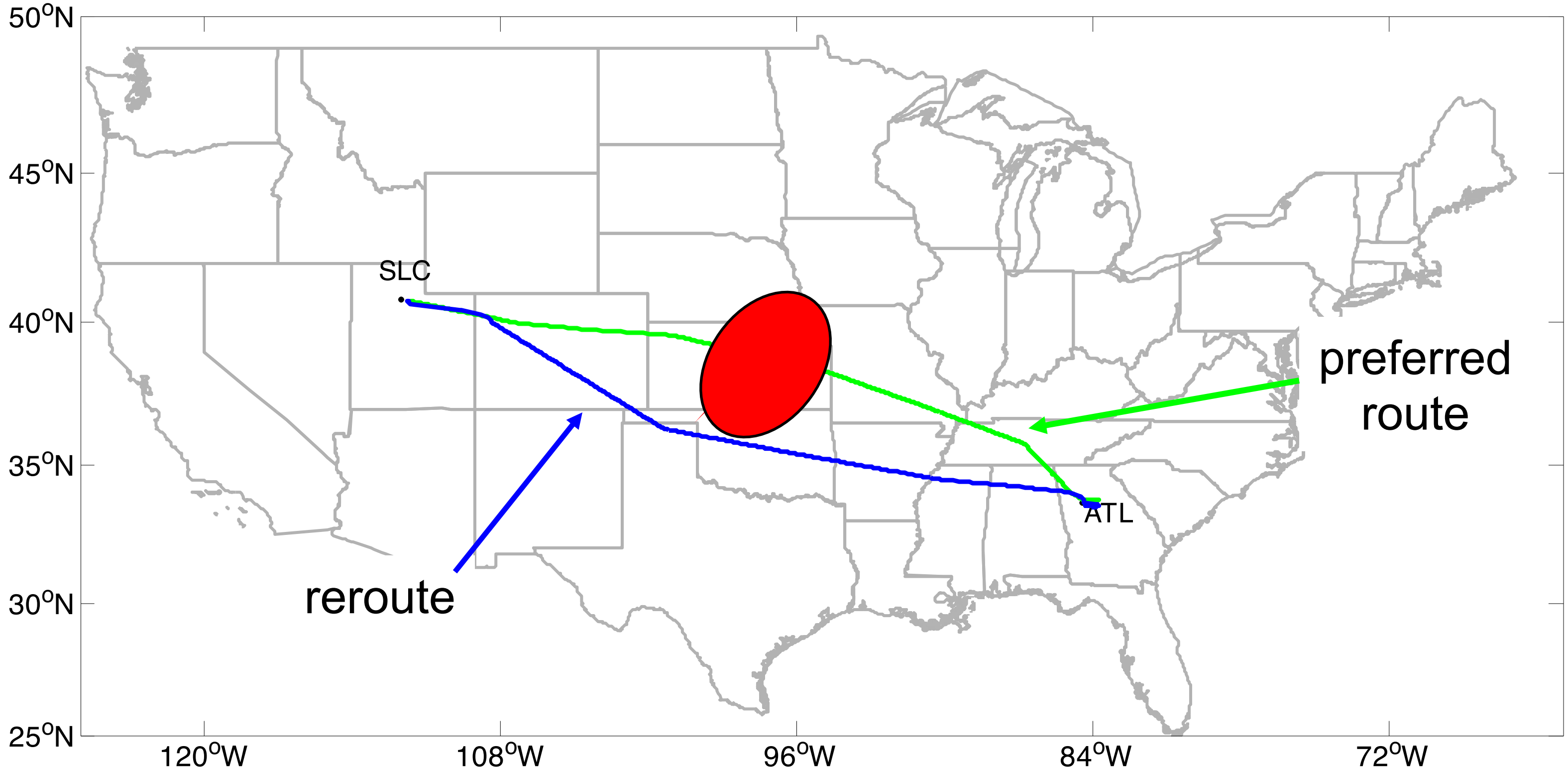
- Hoffman, Krozel, Davidson, Kierstead
- McCrea, Sherali, Trani
- Mukherjee and Hansen
- Nilim and coauthors (several papers)
- Wanke and coauthors (several papers)
- Also literature on stochastic ground holding

Planning Under Uncertainty



Rerouting with Recourse

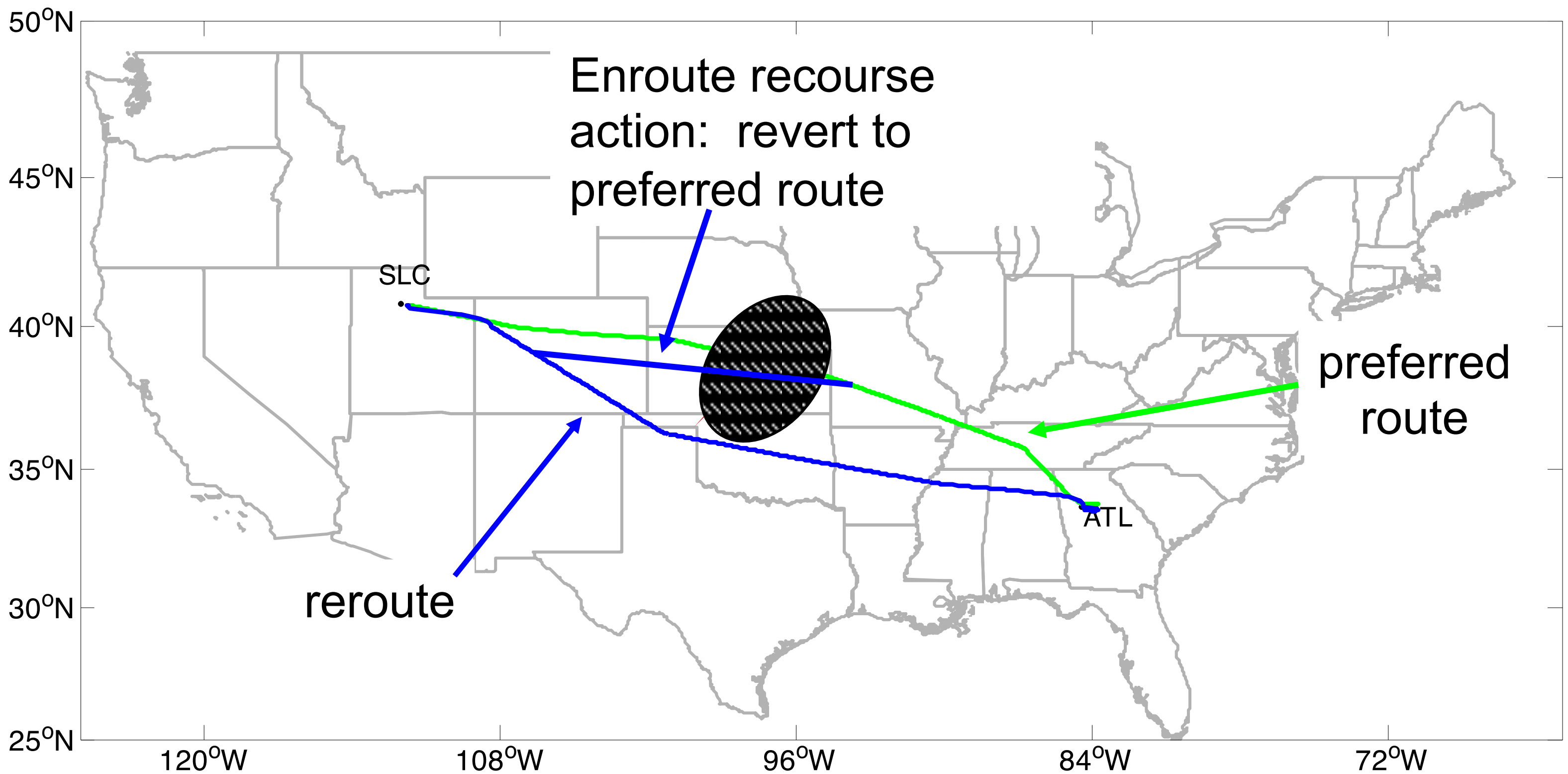
Plan: reroute around disturbance



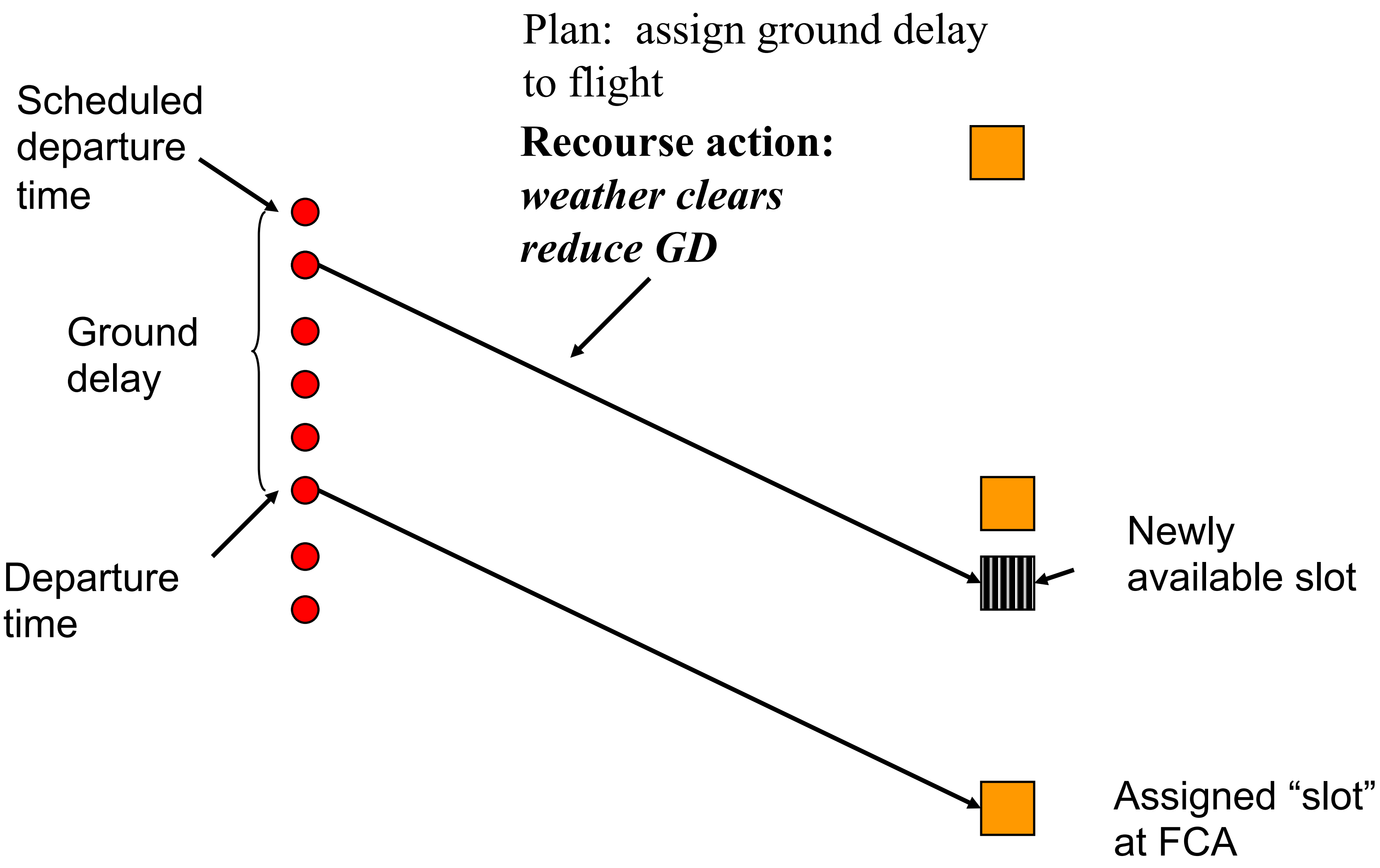
Rerouting with Recourse

Plan: reroute around disturbance;

Recourse action: ***weather clears revert to primary route.***

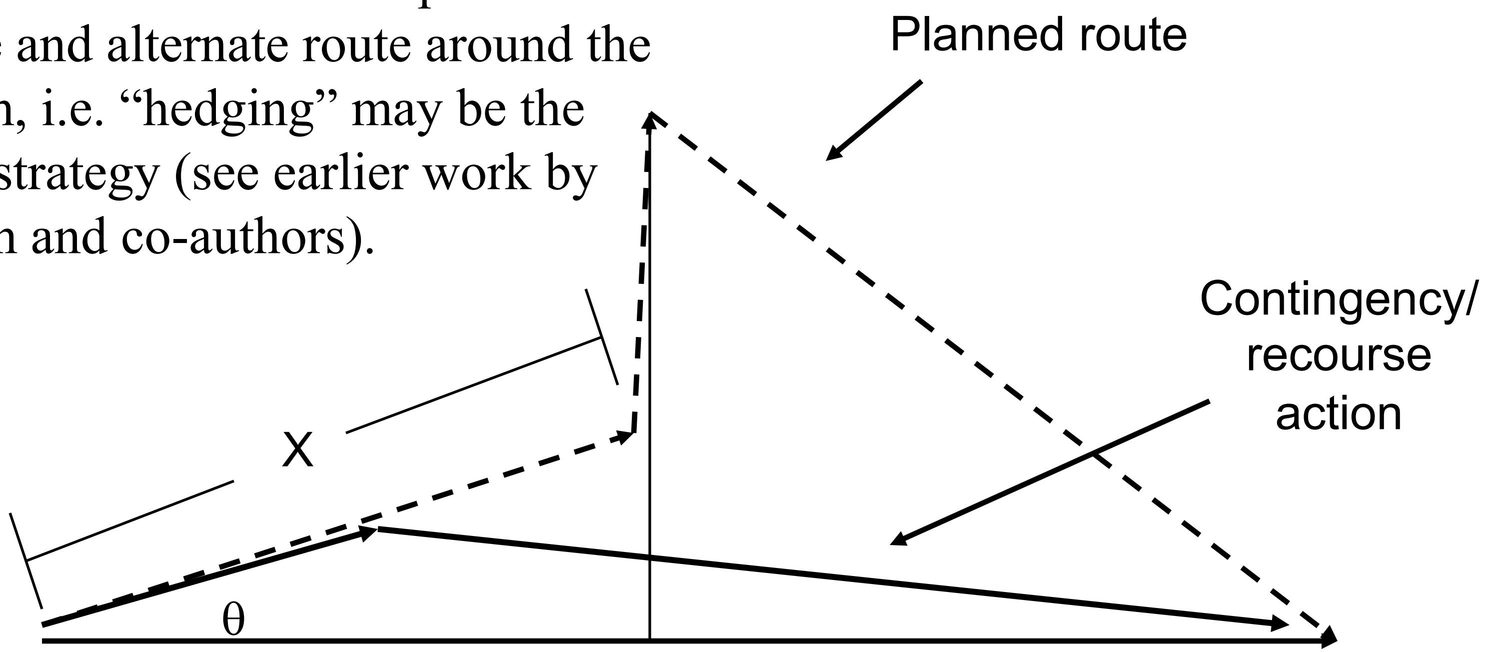


Ground Delay with Recourse

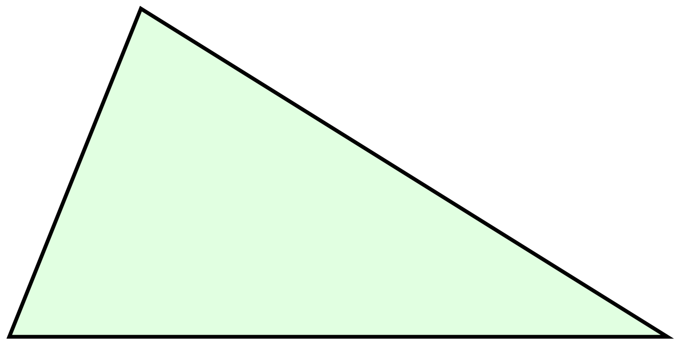


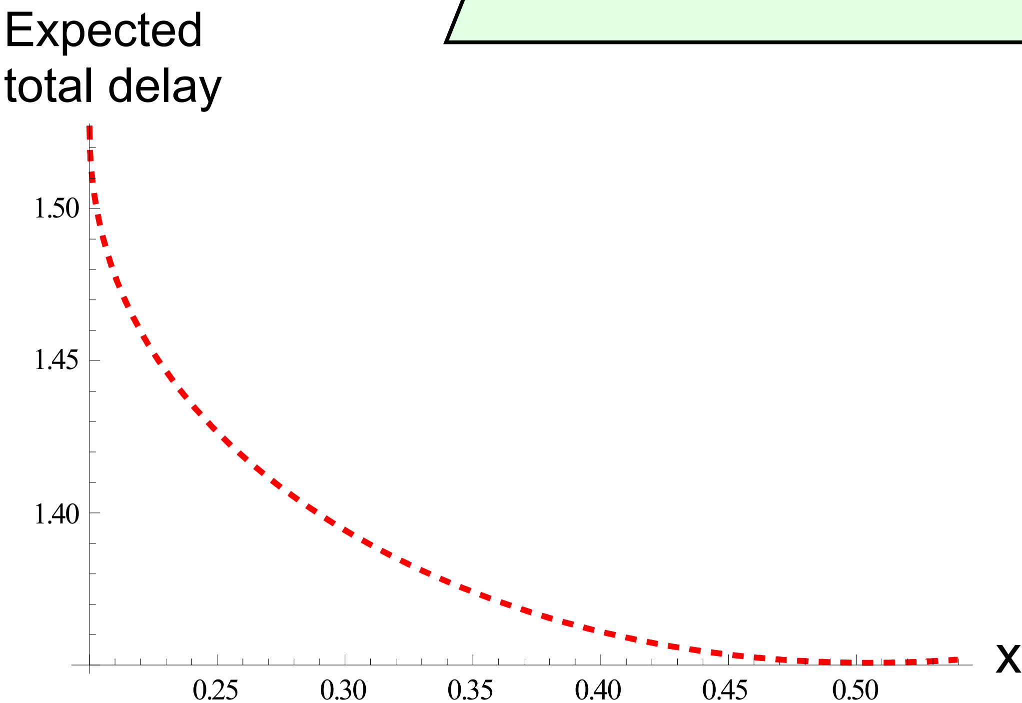
Single Flight Geometric Model

In general, it could be the case that, under uncertainty, the best route is somewhere between the preferred route and alternate route around the storm, i.e. "hedging" may be the best strategy (see earlier work by Nilim and co-authors).



Optimal x depends on geometry



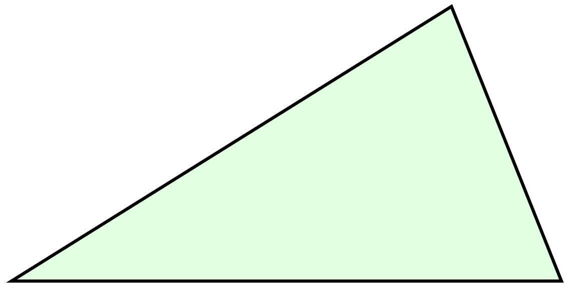


Best x near its maximum value

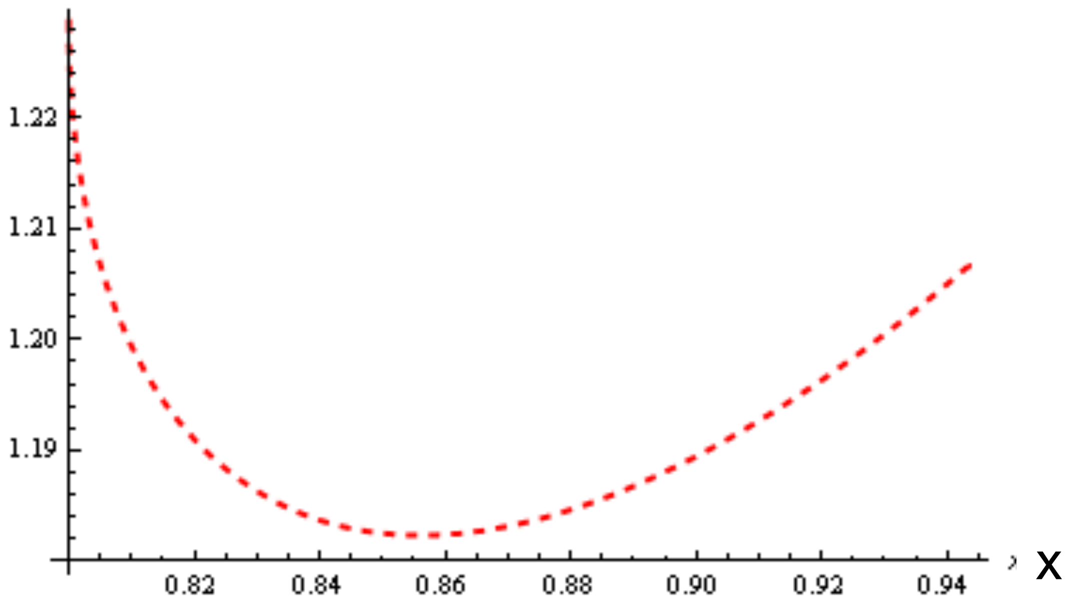
➔

fly around storm

Optimal x depends on geometry



Expected
total delay



Best x near is between min and max

➔

"hedging" is best strategy

Model 1 Conclusions

Model can both provide inputs to system-wide optimization model and provide strategic insight in flight planning

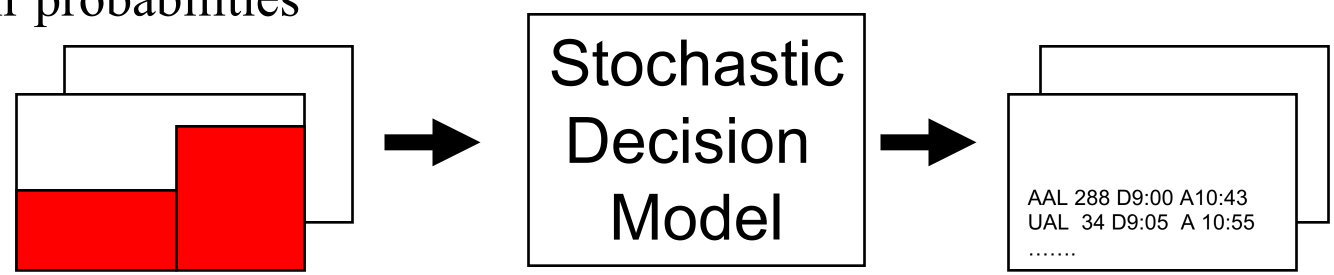
Note: at recent CDM meeting Mike Wambsganss, chief scientist of Flight Explorer, indicated that this class of problem was routinely faced by airlines in context of responding to airspace flow programs (and effective solutions were currently not available).

Model 2: Planning System Response (for **many flights**) to En-route Disturbance

Introduction: Information Requirements for Stochastic Models

Stochastic Model Inputs:
Representation of possible systems states their probabilities

Stochastic Model Outputs:
Plans and contingency plans



OR: plan + recourse actions

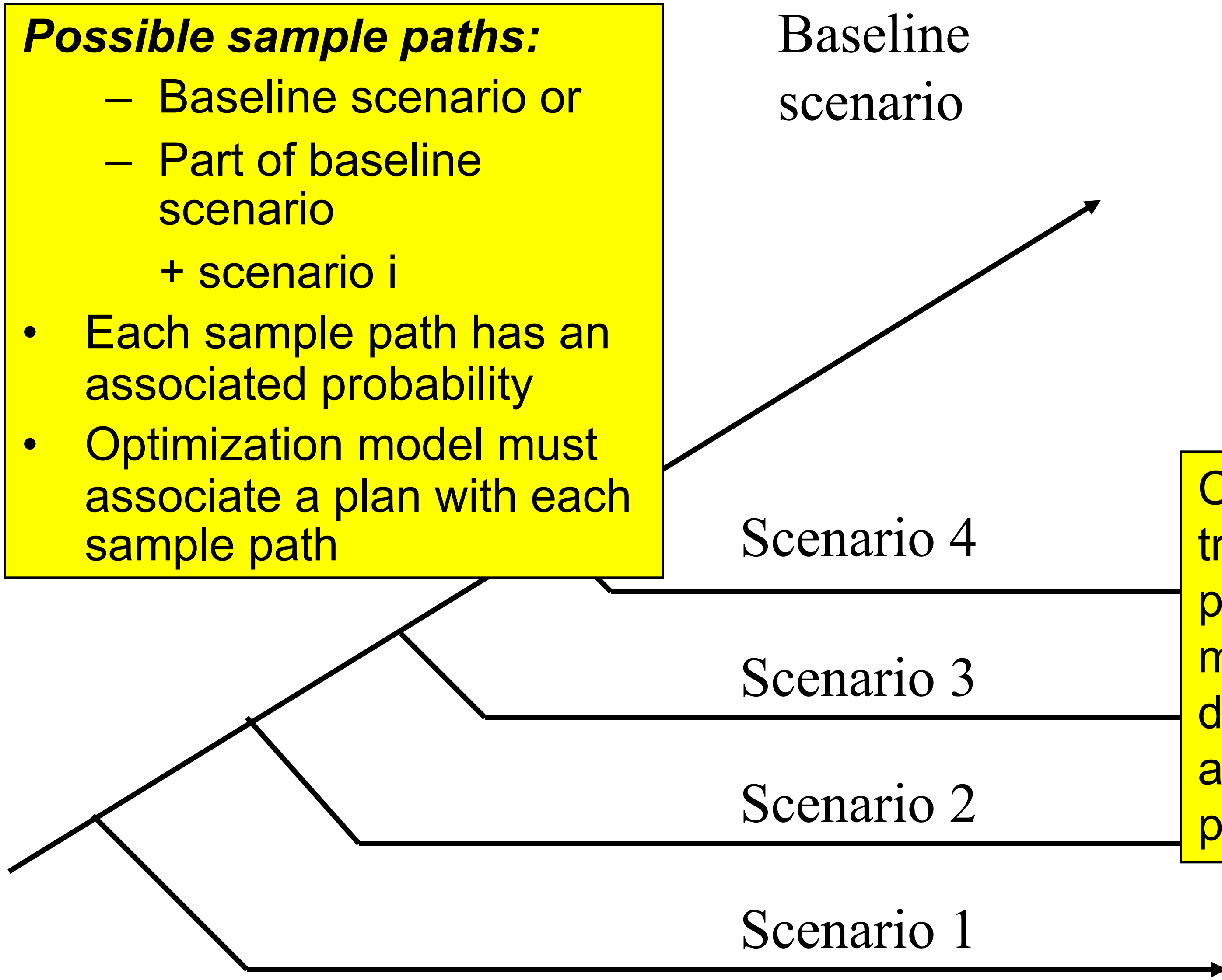
Simplified Model of Uncertainty

Possible sample paths:

- Baseline scenario or
- Part of baseline scenario

  \+ scenario i

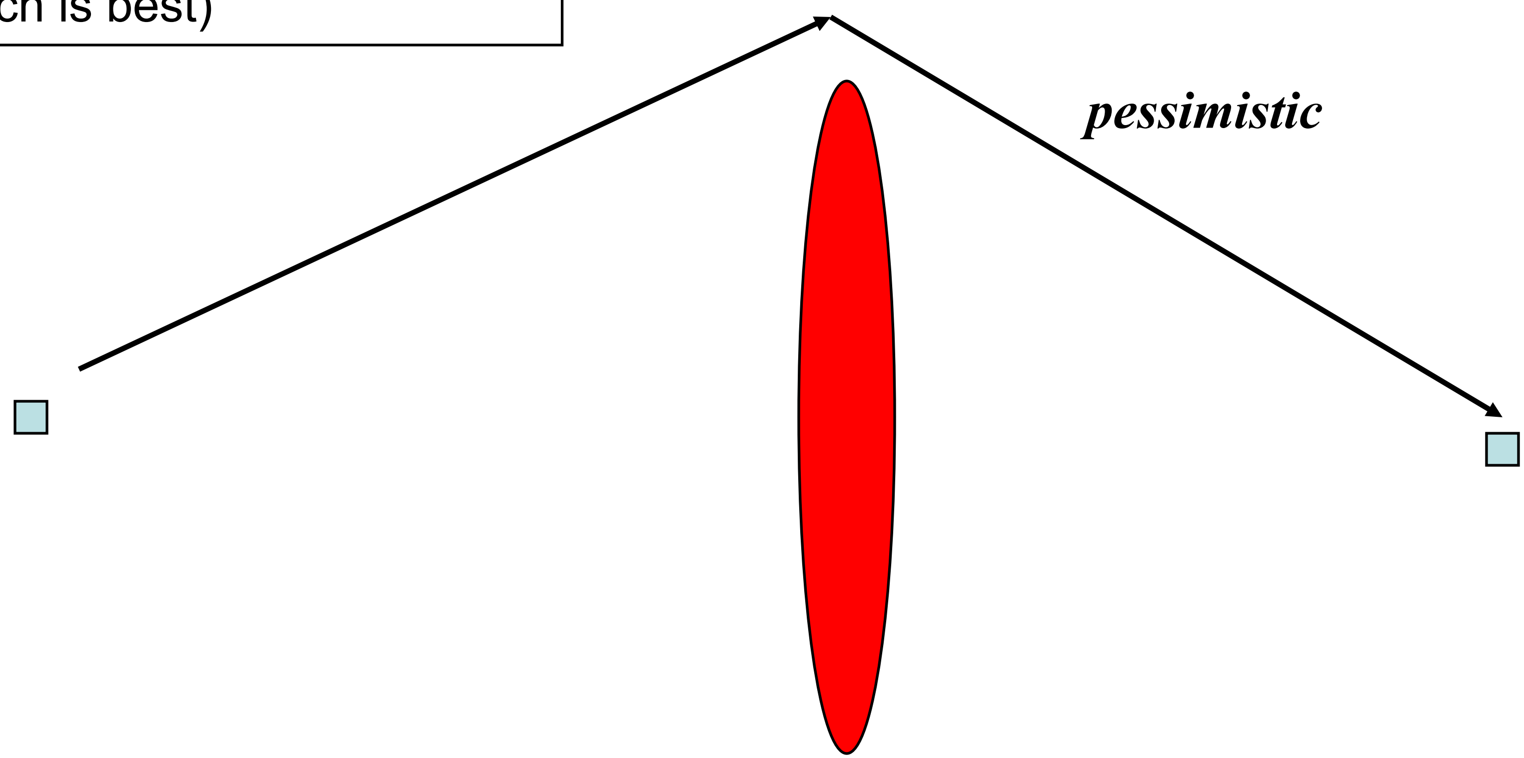
- Each sample path has an associated probability
- Optimization model must associate a plan with each sample path



Computationally tractable integer programming model has been developed to address this problem.

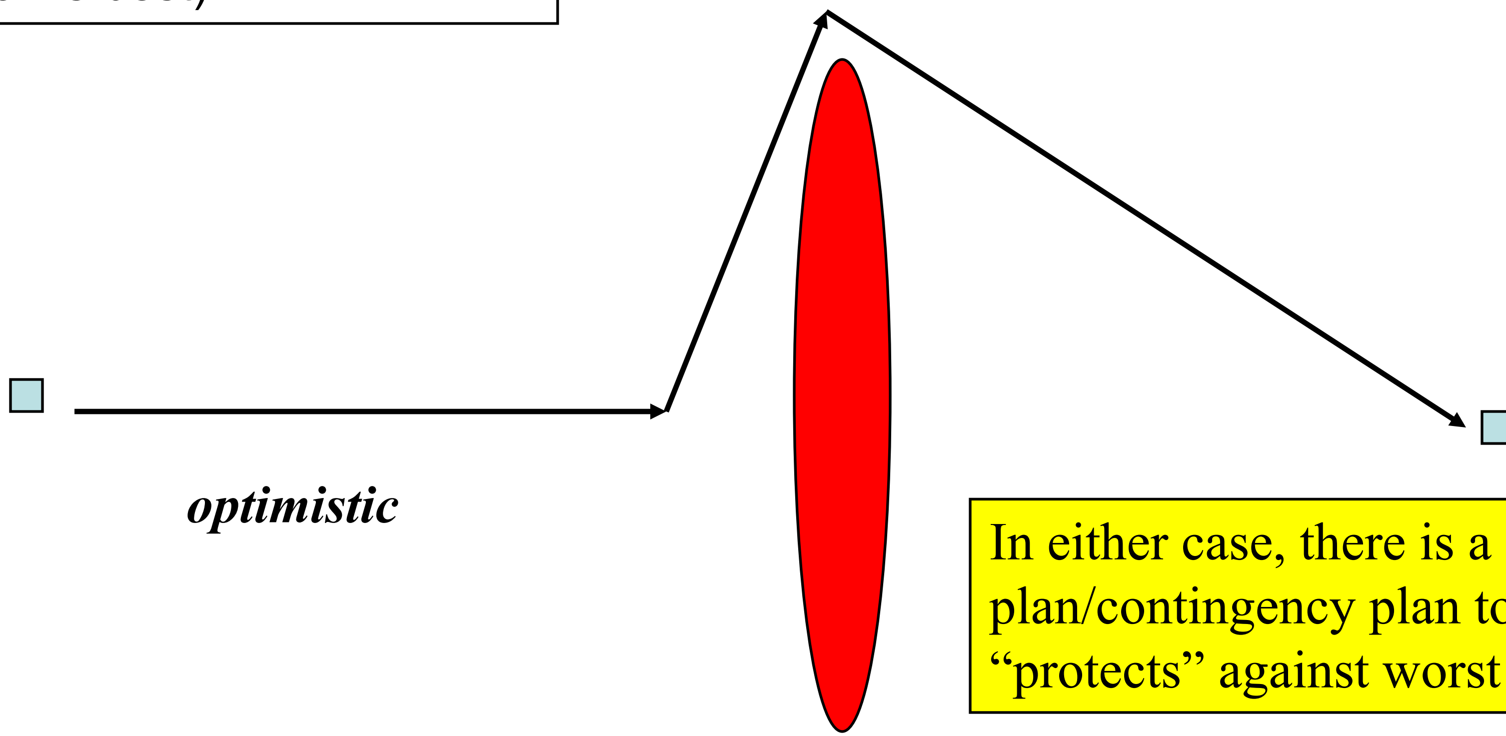
Baseline plan can be pessimistic or optimistic (or hedging) depending on which is best)

Baseline scenario is always worst case scenario (storm lasts longest)



Baseline plan can be pessimistic or optimistic (or hedging) depending on which is best)

Baseline scenario is always worst case scenario (storm lasts longest)



In either case, there is a plan/contingency plan to "protects" against worst case

Model Impact Analysis

OPTIONS:

	Reroute (RR)	Ground Delay (GD)
Plan	*none/static/recourse*	*none/static/recourse*
Execute	*none/static/recourse*	*none/static/recourse*

EXAMPLE:

- static reroute plan – route around storm
- static reroute execution – if storm clears continue on alternate route
- reroute execution with recourse – if storm clears revert to best available route, i.e. direct route

WHAT IS DONE TODAY:

- Generally planning is static but execution has some degree of recourse.

POWER OF MODEL:

- Initial plan takes into account possible recourse actions

  e.g. rerouting may be more aggressive knowing that weather may clear; ground delay may be focused on short haul flights knowing these provide most flexibility with respect to changes in weather.

Model Impact Analysis

OPTIONS:

	Reroute (RR)	Ground Delay (GD)
Plan	*none/static/recourse*	*none/static/recourse*
Execute	*none/static/recourse*	*none/static/recourse*

Four case studies run with 200 flights and varying storm characteristics. (flight and airspace characteristics were generated from geometric model.)

Model Impact Analysis

OPTIONS:

	Reroute (RR)	**Ground Delay (GD)**
Plan	*none/static/recourse*	*none/static/recourse*
Execute	*none/static/recourse*	*none/static/recourse*

Case 1:	**Plan**	**RR:** *recourse*	**GD:** *recourse*
	Execute	**RR:** *recourse*	**GD:** *recourse*

Case 2:	**Plan**	**RR:** *static*	**GD:** *static*
	Execute	**RR:** *static*	**GD:** *static*

Best case vs worst case – this gives bound on potential benefits: savings in total expected delay cost: 73% to 75%

Model Impact Analysis

OPTIONS:

	Reroute (RR)	**Ground Delay (GD)**
Plan	*none/static/recourse*	*none/static/recourse*
Execute	*none/static/recourse*	*none/static/recourse*

Case 5:	**Plan**	**RR:** *static*	**GD:** *recourse*
	Execute	**RR:** *static*	**GD:** *recourse*

Case 6:	**Plan**	**RR:** *static*	**GD:** *static*
	Execute	**RR:** *static*	**GD:** *recourse*

Case 6 is a plausible version of reality; case 5 adds only GD recourse planning to Case 6; savings in total expected delay cost: 20% to 35%

Model Impact Analysis

OPTIONS:

	Reroute (RR)	**Ground Delay (GD)**
Plan	*none/static/recourse*	*none/static/recourse*
Execute	*none/static/recourse*	*none/static/recourse*

Case 1:	**Plan**	**RR:** *recourse*	**GD:** *recourse*
	Execute	**RR:** *recourse*	**GD:** *recourse*

Case 3:	**Plan**	**RR:** *static*	**GD:** *static*
	Execute	**RR:** *recourse*	**GD:** *recourse*

Full power of model vs a fairly optimistic representation of reality: savings in total expected delay cost: 9% to 23%

Model 2 Conclusions and Next Steps

Model is computationally tractable and can have significant positive impact on TFM decisions.

Next Steps:

- Testing using historical traffic and weather patterns.
- Estimate parameters of weather distributions as a function of forecast information (some progress has been made in this direction).
- In recent work, default plan is optimistic route (revert to alternate if weather turns bad).
- Incorporation of “CDM features” into overall model operational concept.

Perspectives for Probabilistic TFM

Probabilistic TFM

Comments from recent CDM meeting:

- Big need for probabilistic TFM
- We do a bad job of “getting out of” TMI’s

Question: How probabilistic TFM is different from deterministic TFM??

Probabilistic TFM: general principle

Every ATM plan should have associated contingency plans

- 4-dimenstional trajectories should come with alternatives.
- Tier 2 plans should have contingency plans, e.g. what to do if weather clears at 1400, 1415, 1430, etc. → these provide roadmaps for “getting out of” TMI’s.
- This concept have implication both for NextGen models and information requirements.

Probabilistic TFM: Specific Mechanisms

- If weather may clear earlier than expected, then tend to focus any ground delays on close in flights.
- If weather may clear earlier than expected, then be more aggressive in getting flights in the air (on alternate routes) if airborne route adjustment is possible.
- Route "hedging" can be the best strategy under certain conditions.

Final Thoughts

Optimization models developed to support both single flight (flight operator focus) and multi-flight (ANSP focus) problem.

Formal modeling of TFM uncertainty can lead to new strategies.

NextGen TFM architecture should be support this perspective.

Extra

Proposed TFM Architecture

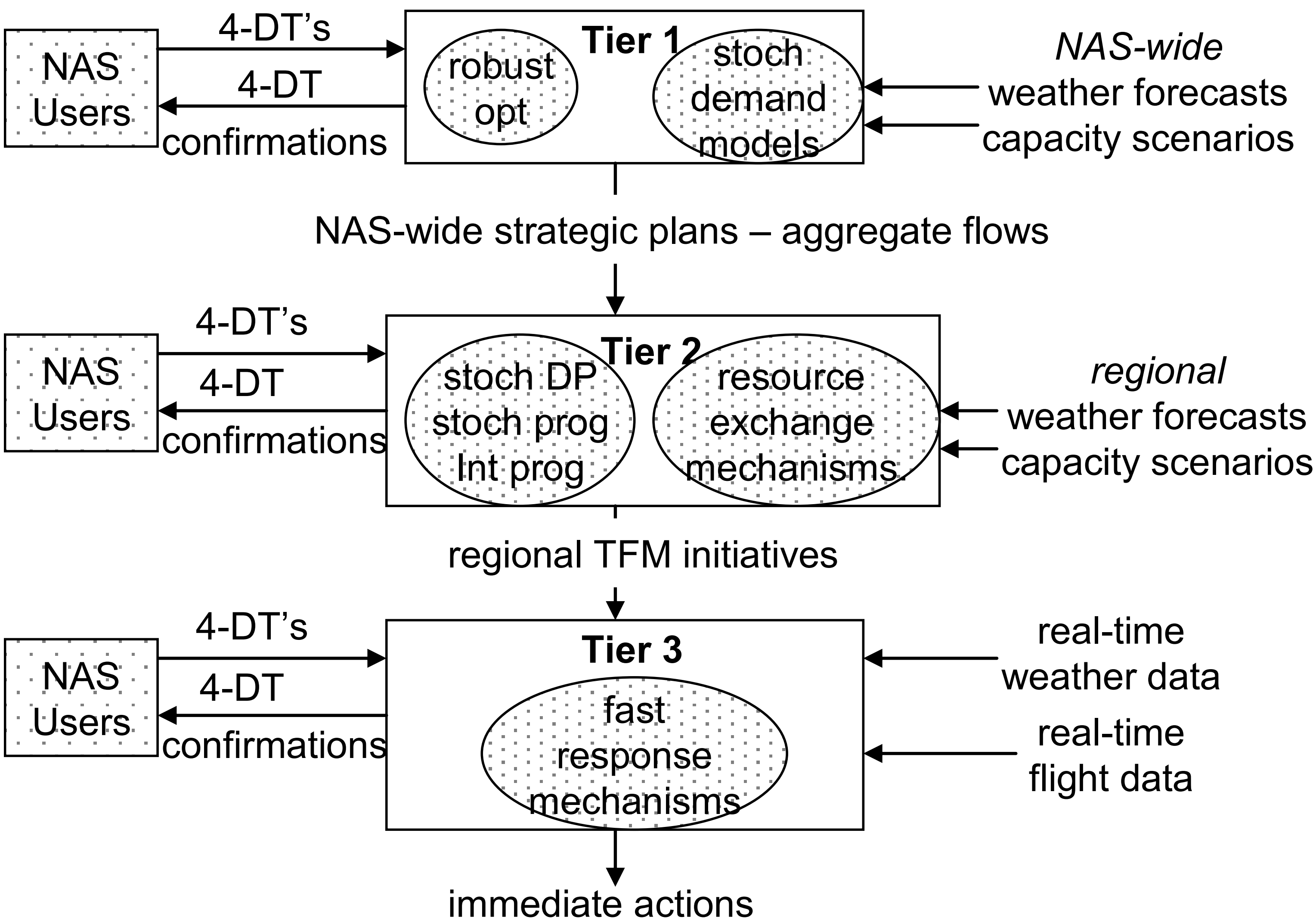


Figure 1: Modeling Approach

Tier 1:

- Aggregate level flows/NAS Wide view
- Congestion prediction and response optimization
- Initiative coordination

Tier 2:

- Flight-level analysis focused on geographic/temporal flight subsets
- Planning and control of traffic flow management initiatives
- Multiple models/problems addressed
- Analogous to ground delay program (GDP) and airspace flow program (AFP) planning models

Tier 3:

- Transaction-oriented control/real-time response

Role/Need for Tier 1 Model

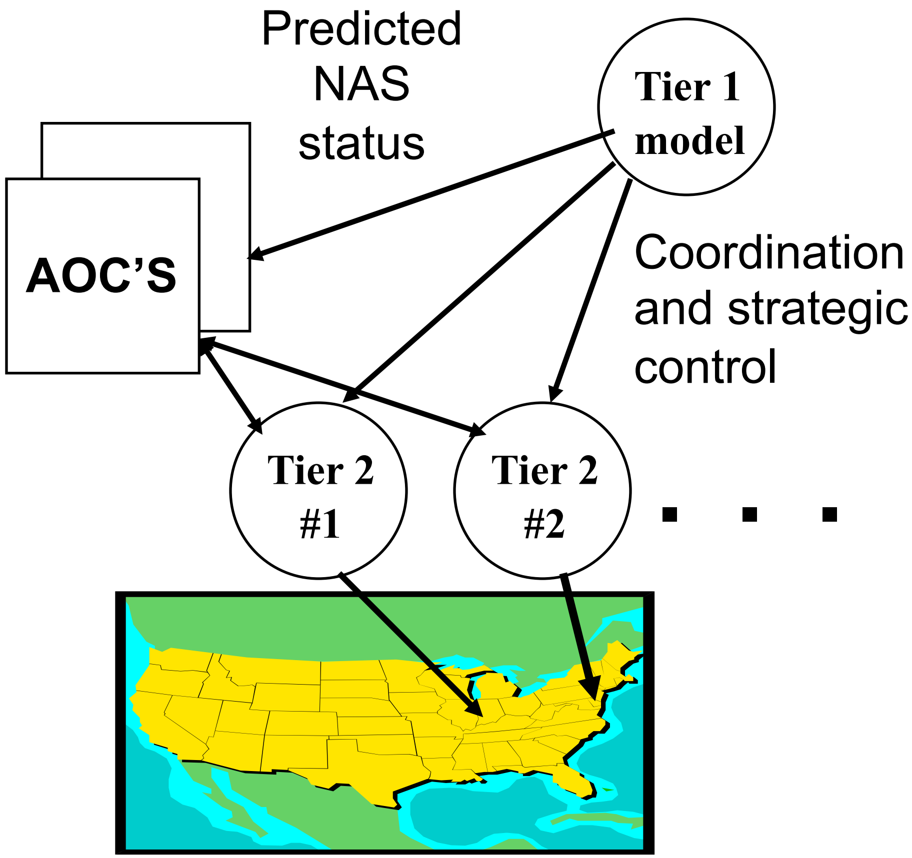
Comments from recent CDM Meeting:

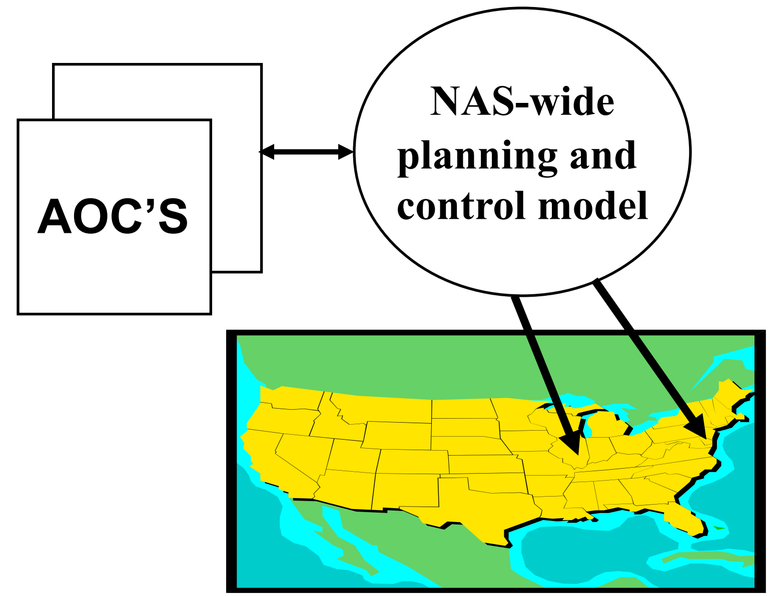
- Strong need to coordinate traffic management initiatives, i.e. multiple ground delay program (GDP's) and airspace flow programs (AFP's).
- Desire to have optimal coordinated plan ("Hal" capability)

Current practice: series of telecon's involving airlines and FAA command center to discuss forecasted weather and anticipated FAA initiatives

- airlines would like to get view (prediction) of state of NAS throughout the day
- from airline perspective there is both uncertainty related to weather and uncertainty related to FAA actions.

Two Approaches to Providing System-Wide Coordination





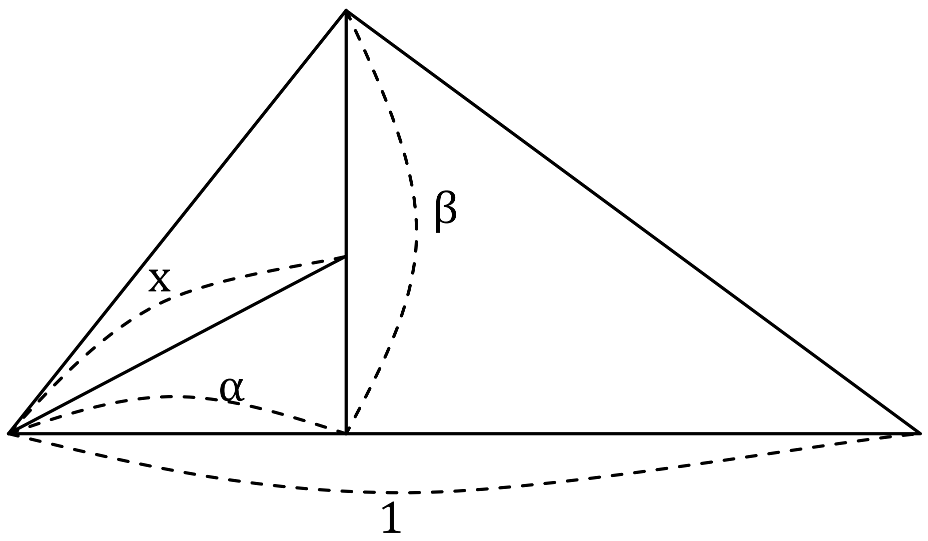
Advantages:

- Computational and operational efficiency
- Fast response to changing conditions
- Natural evolution of today's system

Advantages:

- System-wide optimality
- Streamlined AOC interaction

Ratio Model



Using ratio model, we can show that, if the storm clearance time is uniformly distributed, then expected total delay is a convex function of x
➔ we can closely approximate the optimal solution using Taylor series methods.