Uncertainty isn't bad... not quantifying it is

NASA Airline Operations Workshop

August 2nd, 2016

Overview

Brief introduction to Resilient Ops

Delay prediction using flightsayer

Optimization and metrics under uncertainty using Toolkit for Optimality Metrics Overlay (TOMO)

Uncertainty is not the enemy… not quantifying and hedging against it is

The future is uncertain, even in the short term

- Weather forecasts are probabilistic
- Human actions (FAA, airlines) aren't deterministic
- Conformance to plans isn't perfect

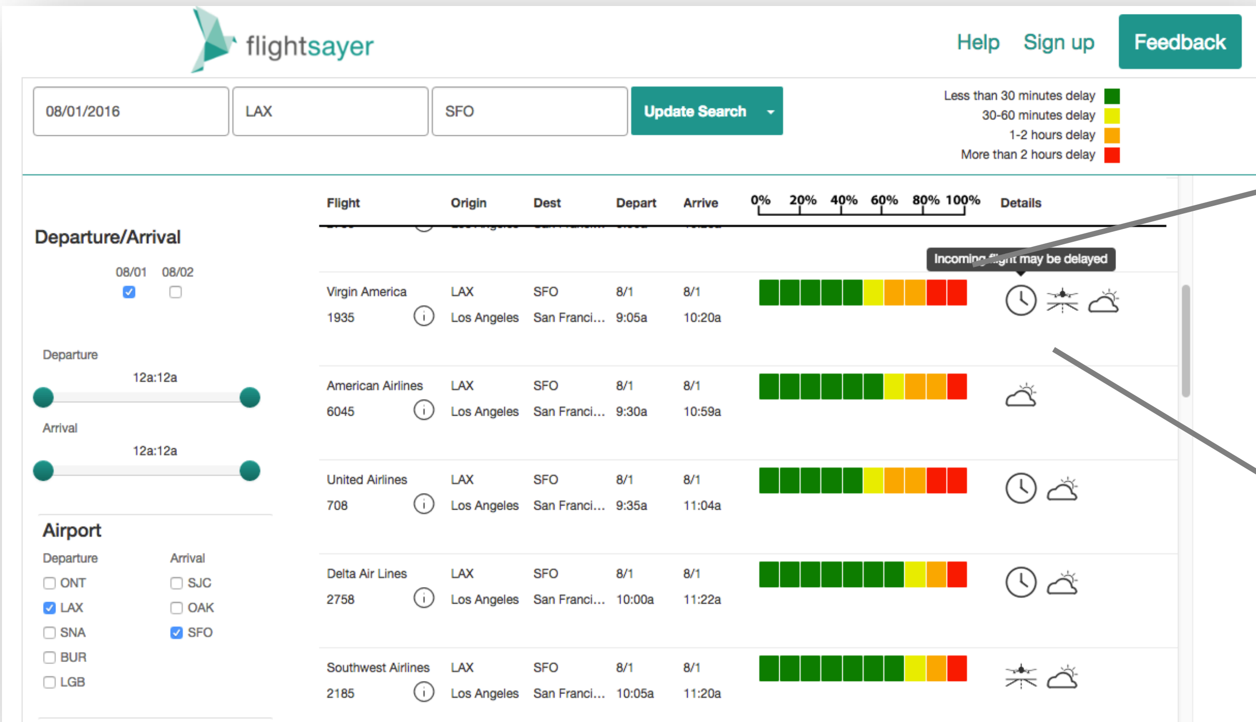
There are two complementary approaches to dealing with uncertainty

- Try and reduce uncertainty through better technology and processes
- Measure, quantify, and predict uncertainty to hedge against it
  - Develop methods to predict randomness
  - Build algorithms that explicitly account for uncertainty

Flightsayer: Probabilistic flight delay predictions

Predicting flight delays using flightsayer

Flightsayer initially developed as a passenger-facing tool



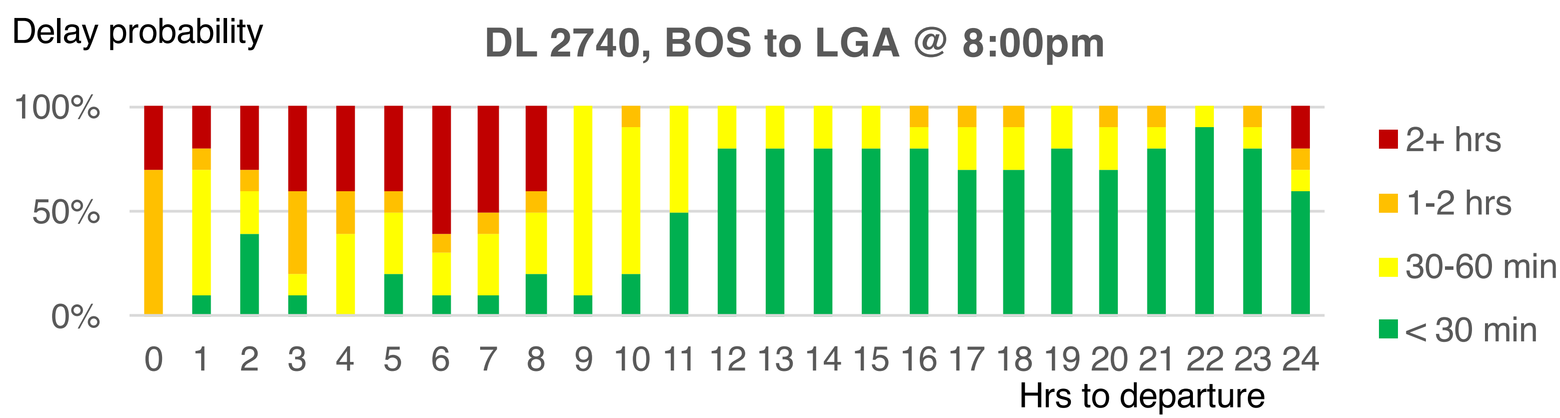
Detailed delay predictions by flight, up to 24 hours out; likelihood of 30-minute delay vs 1 hour vs 2 hours

Delay causes, e.g., capacity constraints, late inbound flight

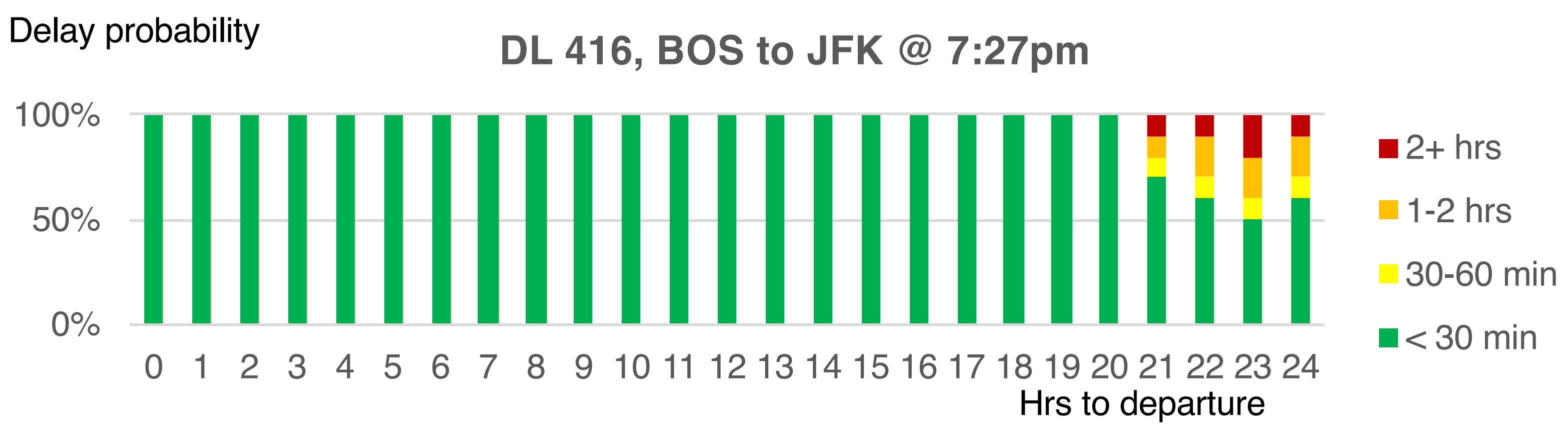
Flightsayer generates probabilistic forecasts of delay

An example of a probabilistic delay forecast

Arrived 213 minutes late

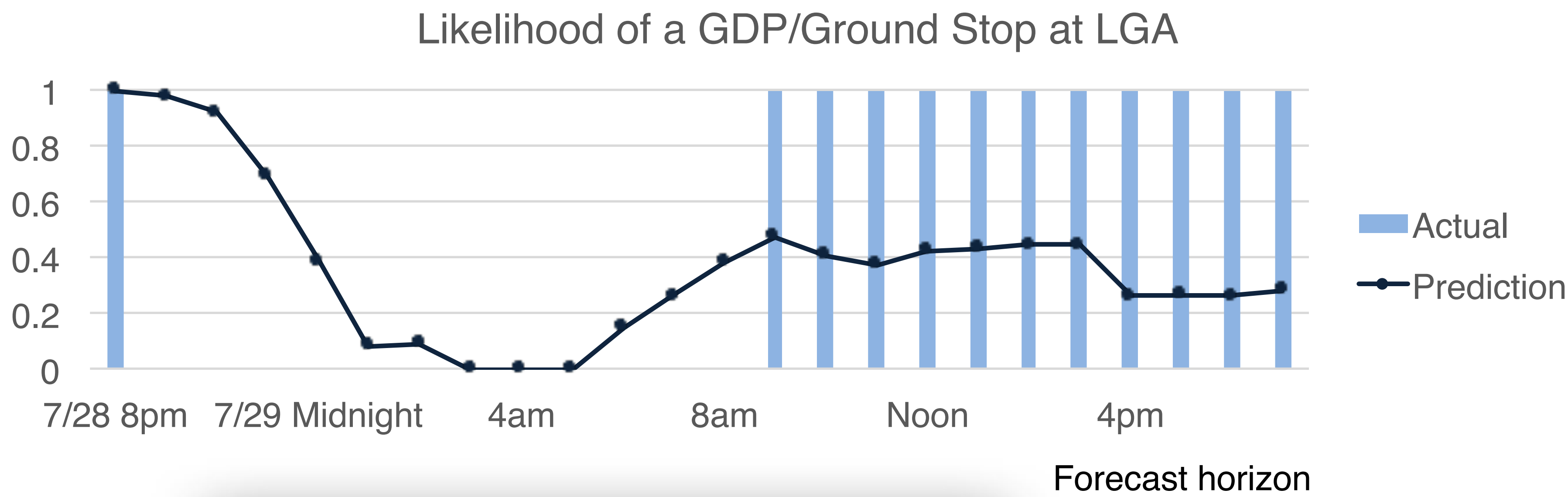


Arrived on time



It is possible to make sound decisions even with imperfect information

Flight forecasts are driven off probabilistic capacity forecasts



ATCSCC Advisory

ATCSCC ADVZY 050 LGA/ZNY 07/29/2016 CDM GROUND DELAY PROGRAM

MESSAGE:
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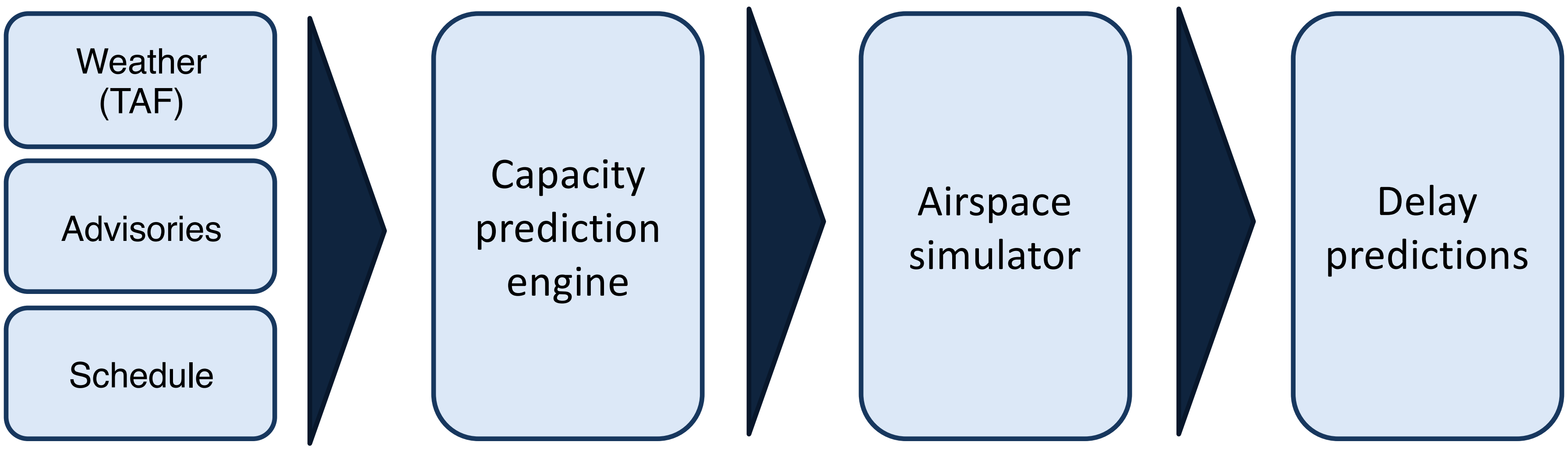
CTL ELEMENT: LGA
ELEMENT TYPE: APT
ADL TIME: 1501Z
DELAY ASSIGNMENT MODE: UDP
ARRIVALS ESTIMATED FOR: 29/1501Z - 30/0359Z
CUMULATIVE PROGRAM PERIOD: 29/1501Z - 30/0359Z
PROGRAM RATE: 34/34/36/36/36/36/36/36/36/36/36/36/36
FLT INCL: ALL CONTIGUOUS US DEP
DEP SCOPE: 1425
CANADIAN DEP ARPTS INCLUDED: CYHZ CYOW CYUL CYYZ CYTZ CYQB
DELAY ASSIGNMENT TABLE APPLIES TO: ZNY
MAXIMUM DELAY: 116
AVERAGE DELAY: 62
IMPACTING CONDITION: WEATHER / WIND
COMMENTS: LGA ARR RWY 4, DEPT RWY 13, LOW POP UP.
```
EFFECTIVE TIME: 291504 - 300459

SIGNATURE: 16/07/29 15:04

GDP called at ~11am

Under the hood: Flight delay forecasts are generated from airport capacity forecasts



All flight and capacity predictions are accessed via a simple API

TOMO: Measuring and optimizing under uncertainty

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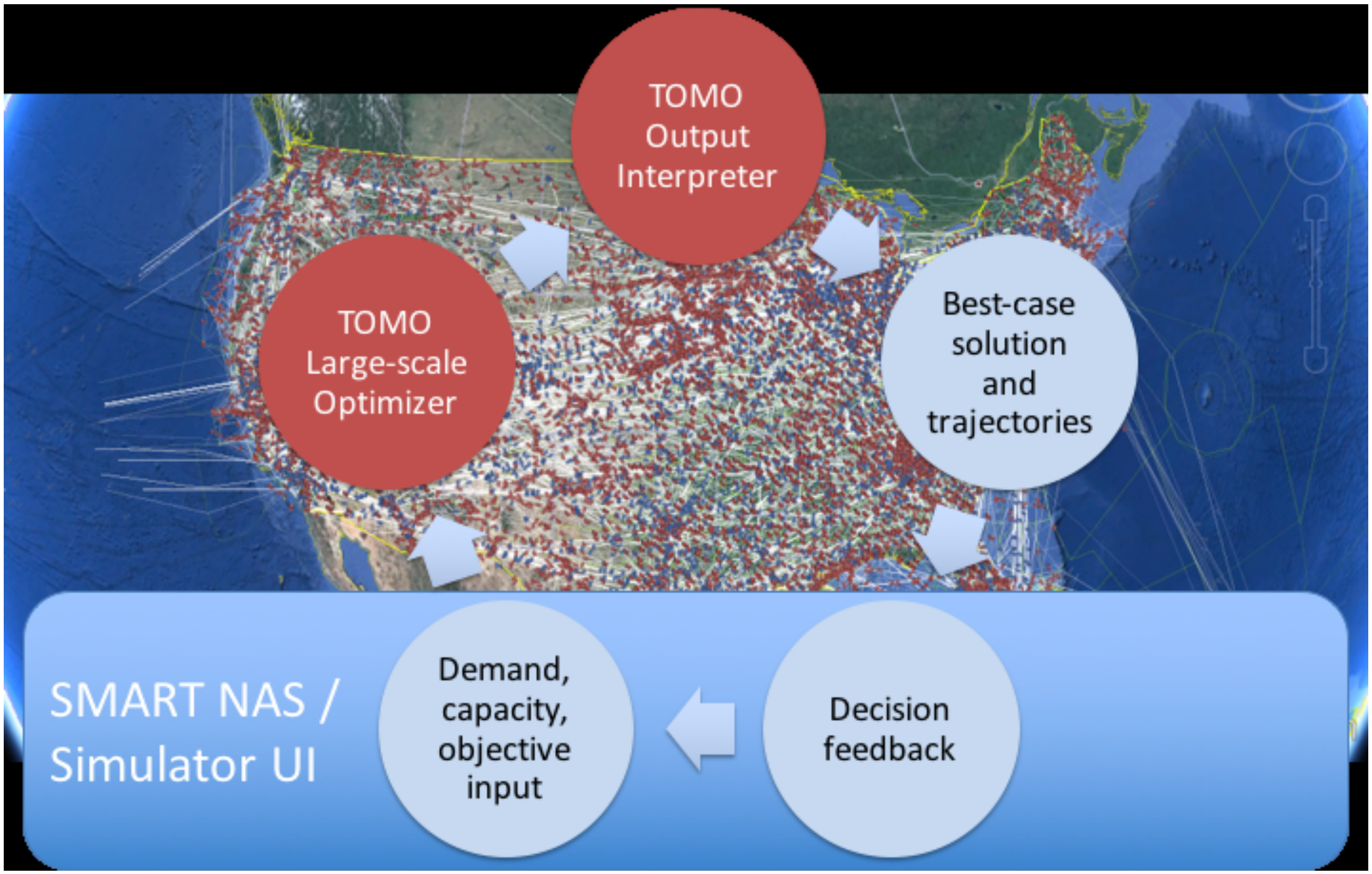
TOMO is a large-scale optimization model that computes optimal trajectories of aircraft under various objectives such as delays, fuel burn, and environmental impact

- Allows a simulated scenario to be compared to a baseline
- Facilitates an apples-to-apples comparison of two scenarios by normalizing the performance of each to the "best achievable" case

Traditionally, there have been two challenges to using an optimization-based baseline

- Computational difficulty in calculating optimal solutions to large-scale problems
- Calculating optimal solutions under uncertainty (need to determine the optimal decisions given that there was uncertainty in the inputs when the decision was made)

TOMO is designed to provide optimal metrics as well as actionable decision feedback



Key is being able to optimize under uncertainty

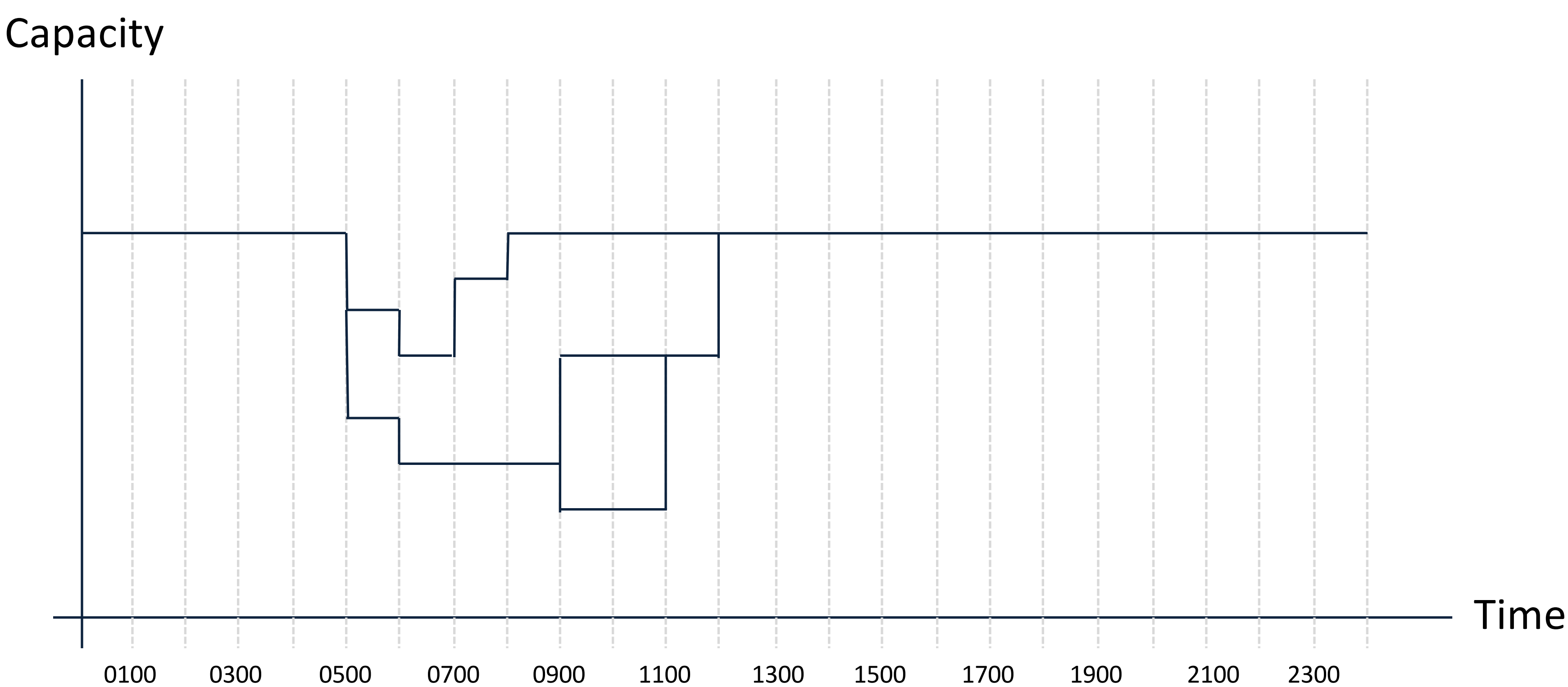
Large-scale optimization of trajectories given schedules and capacities has been studied by various groups (including NASA)

However, optimizing under uncertainty has been overlooked, typically for being ”too hard”

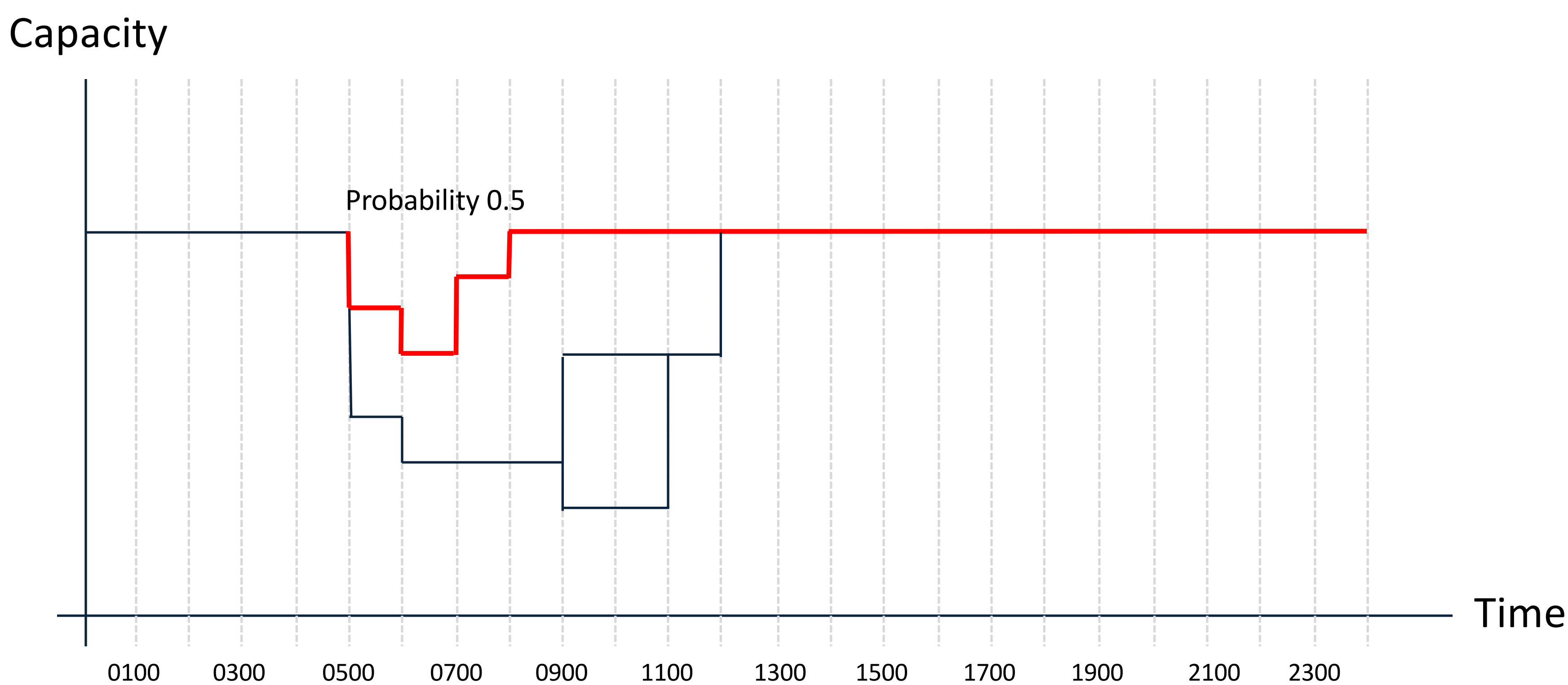
Key to optimizing under uncertainty is to provide trajectories with recourse

- If scenario X happens, fly this this trajectory; if not, fly this other trajectory
- Output needs to explicitly state decisions that need to be made under all scenarios (effectively generating a detailed playbook for each flight)

TOMO generates routes with recourse when given a probabilistic scenario tree capacity forecast



Model generates routes with recourse when given a probabilistic scenario tree capacity forecast



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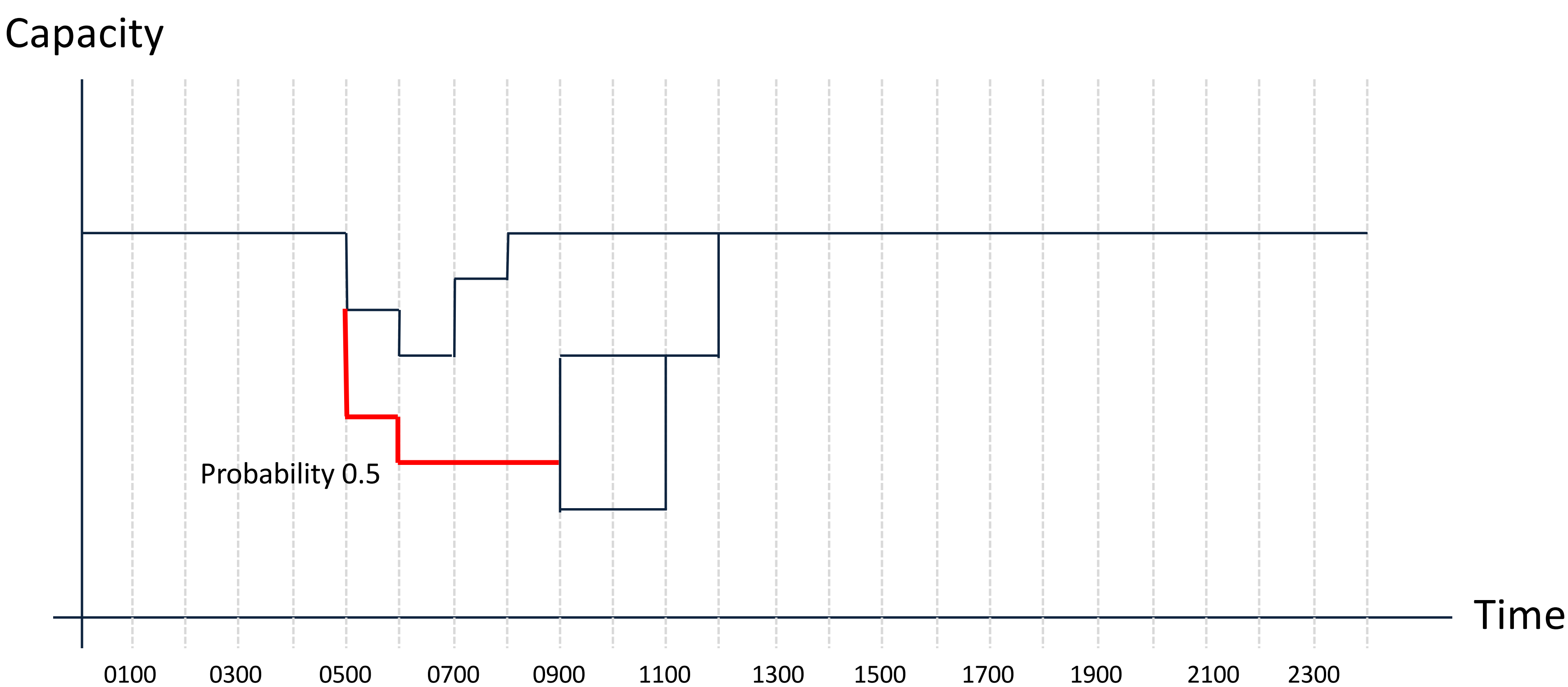

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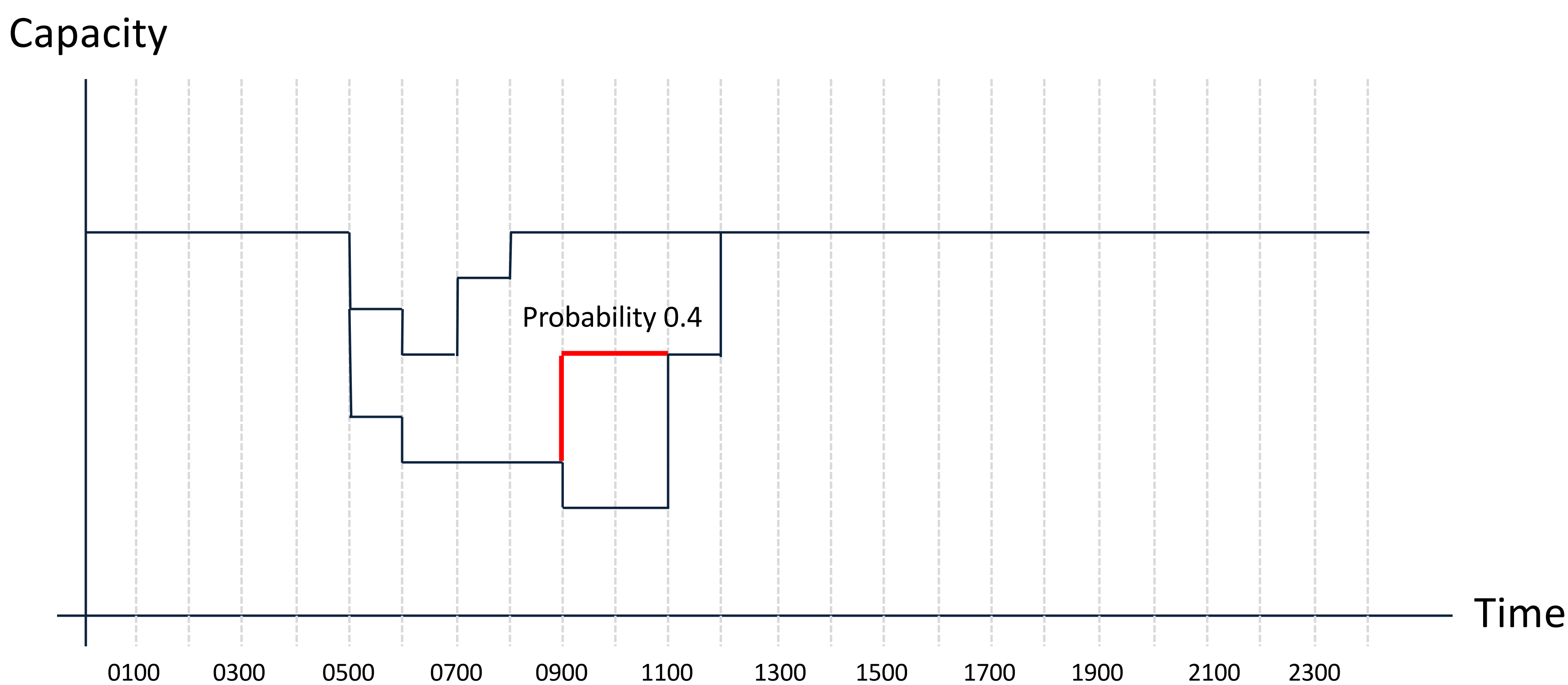

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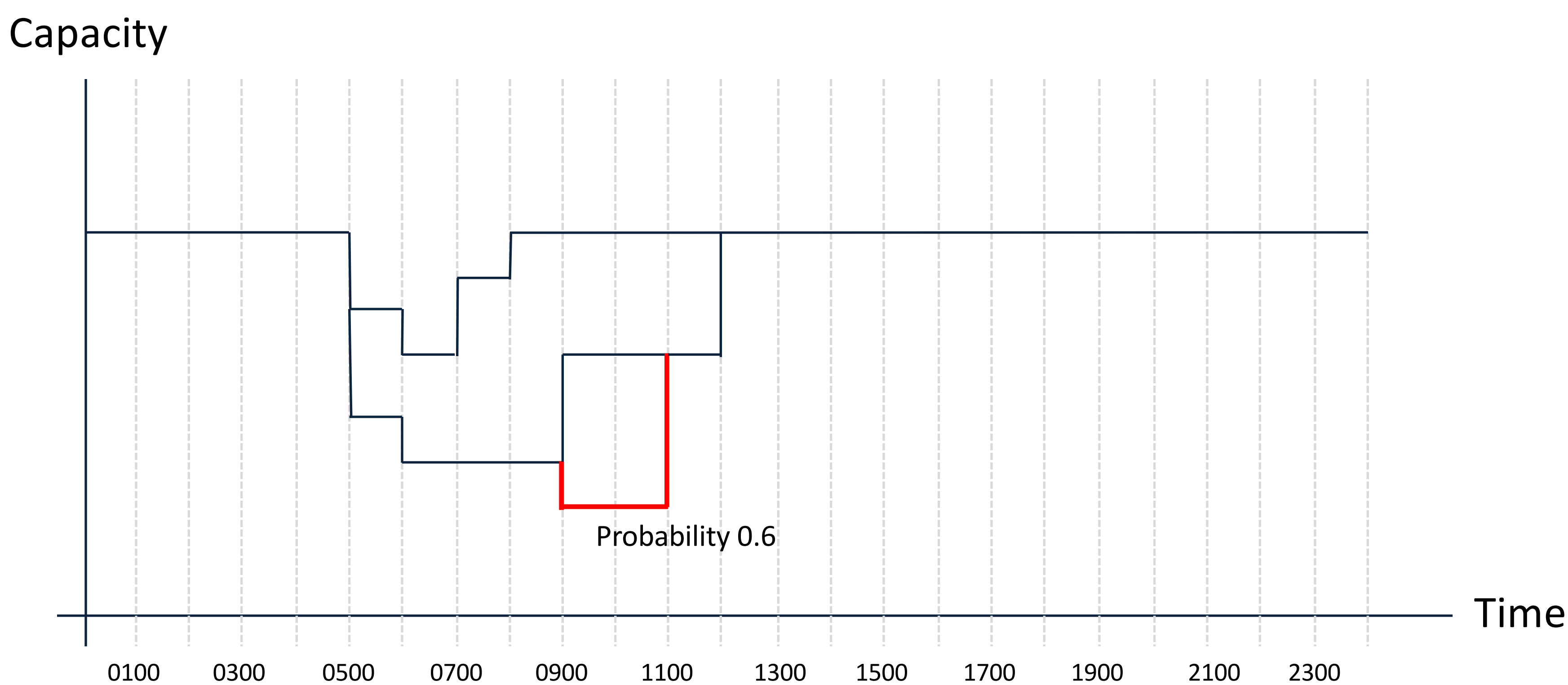
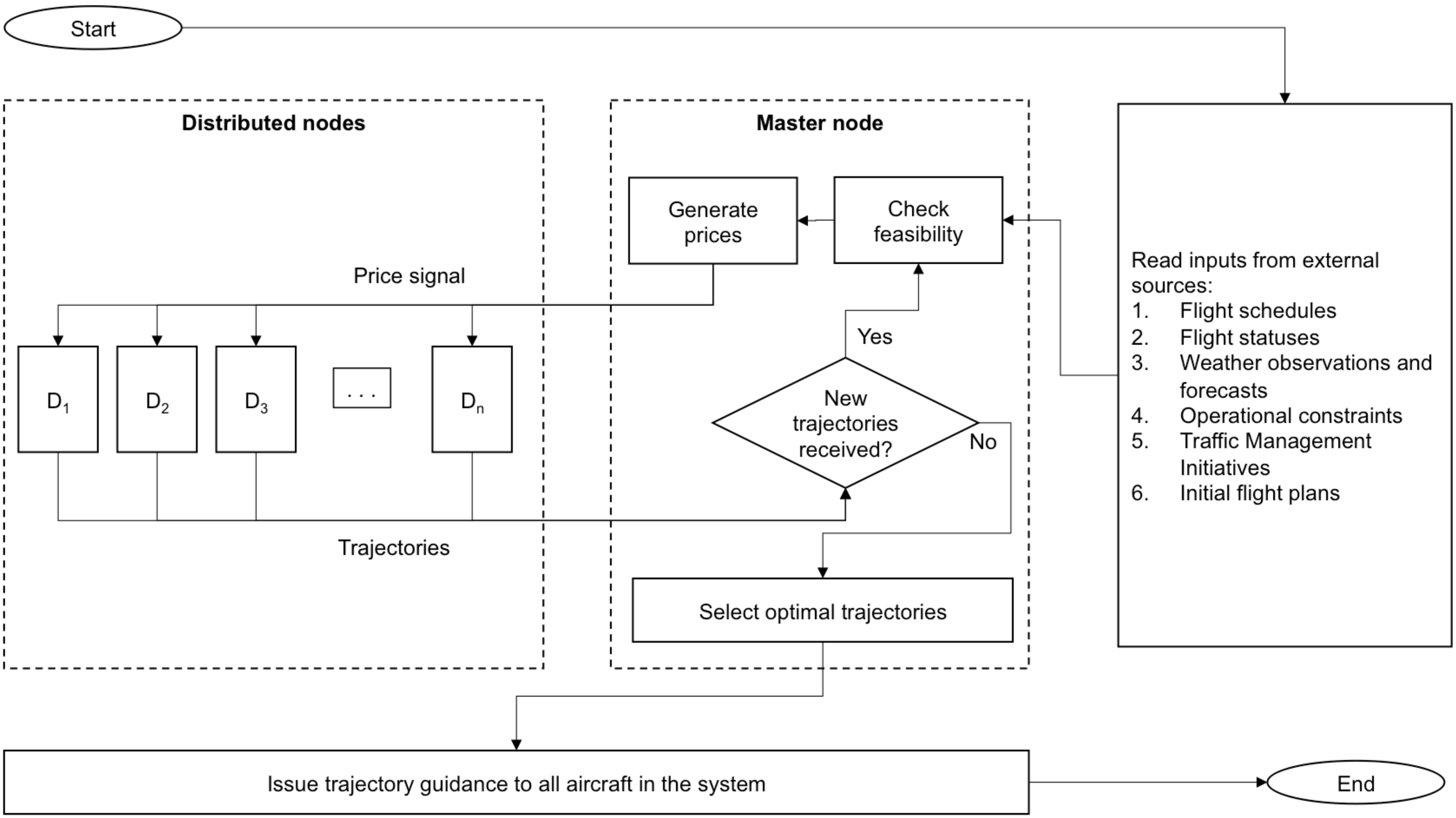


Probability trees of airport capacity can be generated using flightsayer's probabilistic capacity forecasts

Solved by column generation (decomposition of a large problem into multiple parallel sub-problems)



A day in the life of the NAS (2030)

Optimization under uncertainty is key to greater autonomy and better understanding of decisions

Being able to optimize under uncertainty will be key to realizing greater autonomy in planning and execution

- Beyond human capacity to envision all possible scenarios that could play out and develop a plan for each scenario
- Will lead to greater efficiency through better hedging strategies

Being able to "retroactively" optimize under uncertainty will lead to a better understanding of past decisions

- Were decisions on 7/29 better than on 7/28 *given the information that was available*?
- Was Delta more efficient than American *given the operating constraints and best available information*?

Takeaways

For Airline Operations Center

- Uncertainty *can* be quantified, and lead to meaningful decisions
- IROPS, dispatch may find probabilistic predictions useful, *as long as they are interpreted consistently and rigorously*

For NASA

- Developing *predictive* algorithms that are rigorous and robust is important
- **Models that explicitly deal with uncertainty will be key to achieving autonomy for planning and optimization**