An Enhanced Autonomy Approach to Automated Trajectory Negotiation

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- Overview
  - Motivation and problem statement
  - Automated trajectory negotiation concept introduction
  - Conclusions and next steps

Problem Statement – Trajectory Negotiation

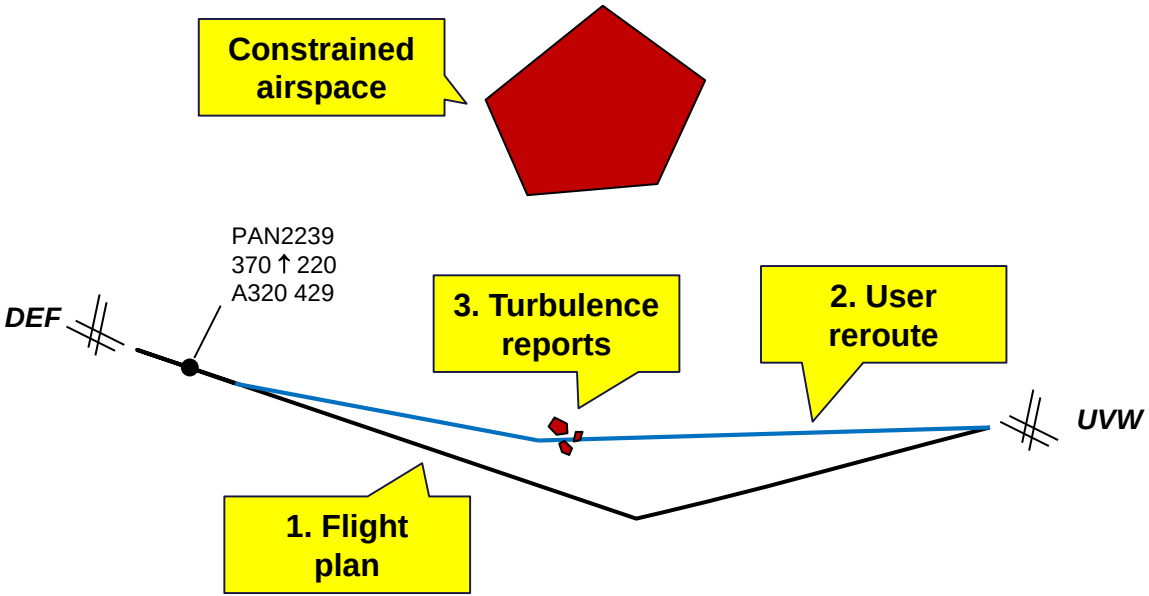
- Trajectory Based Operations (TBO) will require frequent, fast trajectory negotiations to account for operational uncertainty
- Due to current time-consuming and workload-intensive process:
  - Airspace users (AUs) self-filter requests to avoid rejection and overloading FAA personnel
  - FAA personnel implement conservative reroutes to avoid modifying the plan later
- AUs may not receive detailed reasons for rejected requests
- Widespread use of flight deck optimization capabilities likely to overwhelm FAA infrastructure with amendment requests
  - Emerging users will increase volume of requests

Current manual process is not scalable to TBO, or to a NAS that accommodates emerging airspace users

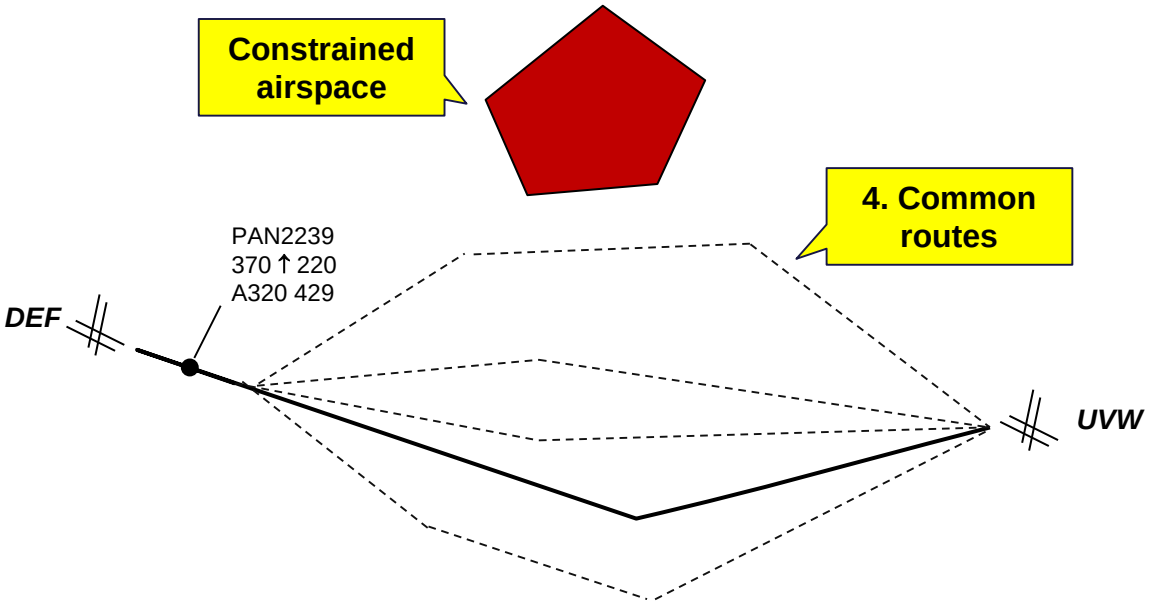
Automated Trajectory Negotiation Service

- Eliminates trial and error
  - (Propose trajectory, wait to learn whether it is rejected, propose another trajectory)
- Considers constraints and preferences of negotiation participants
  - Airspace users and traffic managers
- Could be deployed in many ways:
  - Within Traffic Flow Management Service (TFMS)
  - Separate System Wide Information Management (SWIM) service
  - External to FAA as third party service or part of airspace user flight planning systems
- Scales to accommodate increases in trajectory amendment requests
  - As airspace users adopt continuous flight deck optimization and air/ground connectivity
- Applicable to emerging users as well as legacy aviation

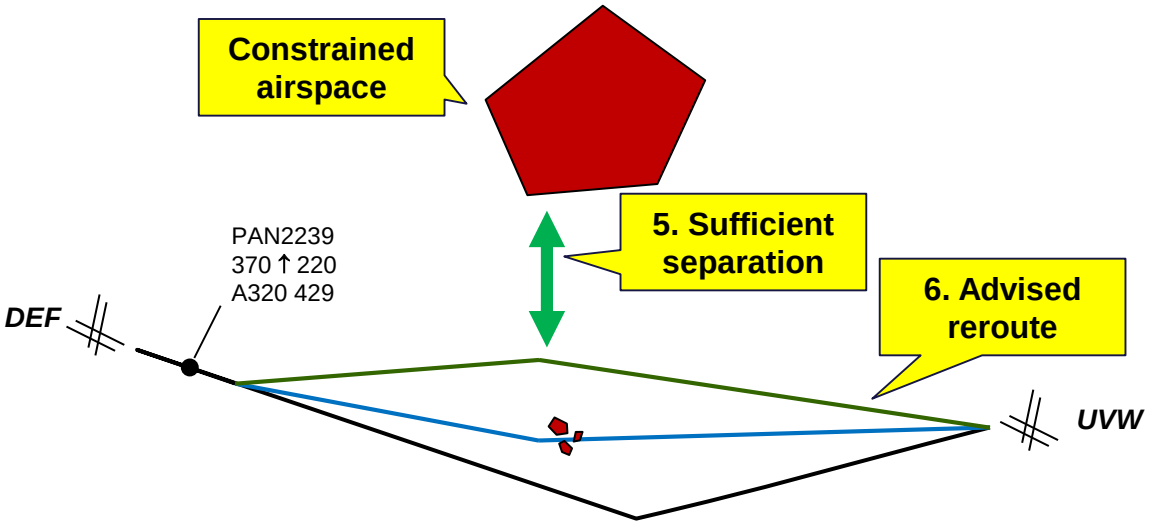
Use Case 1: Evaluate AU-Proposed Reroute (1/4)



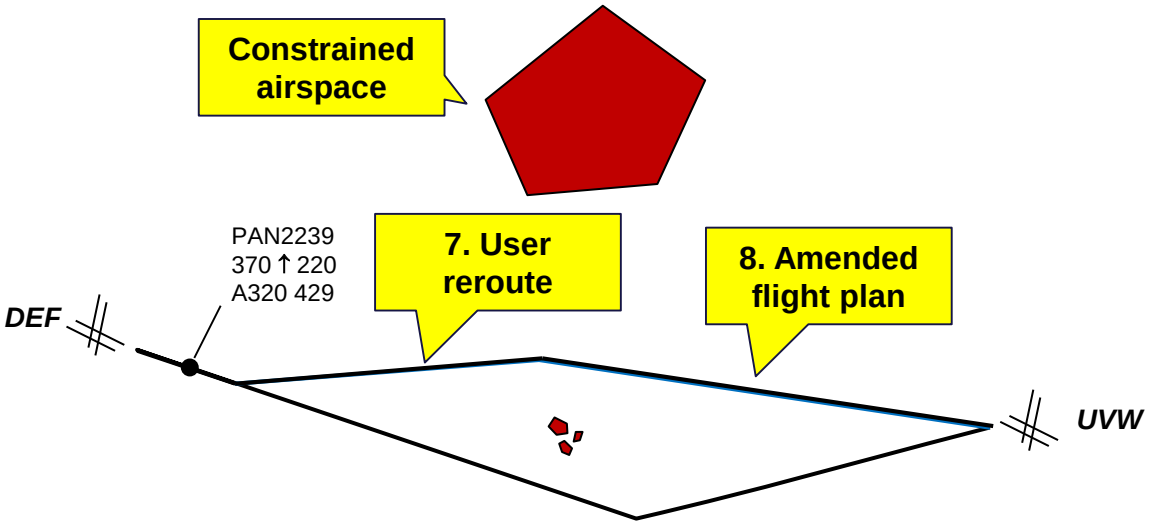
Use Case 1: Evaluate AU-Proposed Reroute (2/4)



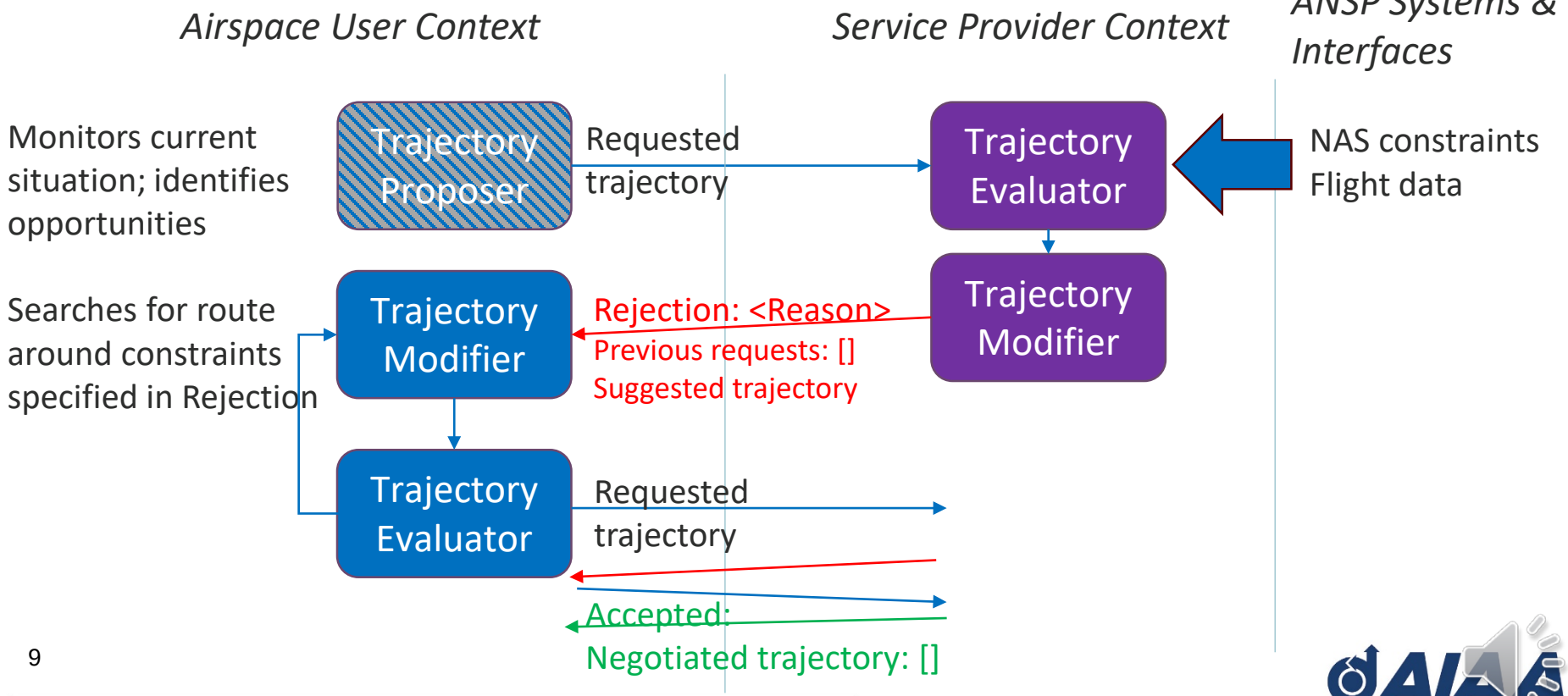
Use Case 1: Evaluate AU-Proposed Reroute (3/4)



Use Case 1: Evaluate AU-Proposed Reroute (4/4)

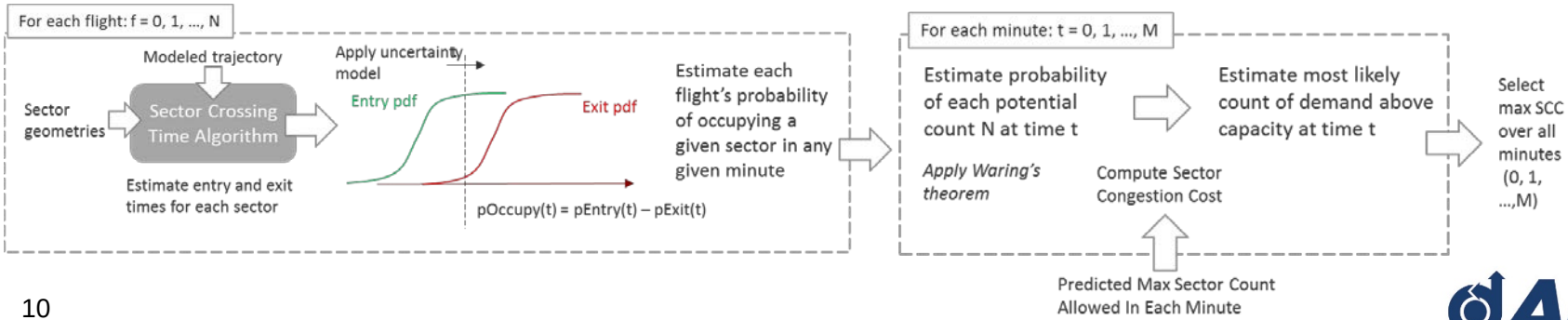


Automated Trajectory Negotiation Data Flows



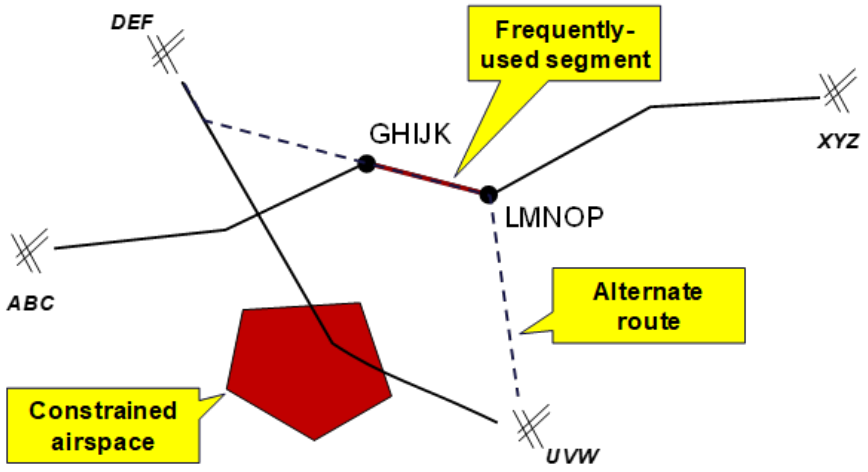
Calculating Sector Congestion Cost

- Automated Trajectory Negotiation best suited to amendments starting at least 15 minutes into the future
  - Avoid trajectory modifications that will impact a controller's plan
  - Accurate trajectory conflict detection uncertain at long lookaheads
- Use *sector congestion* forecast as key trajectory acceptability metric

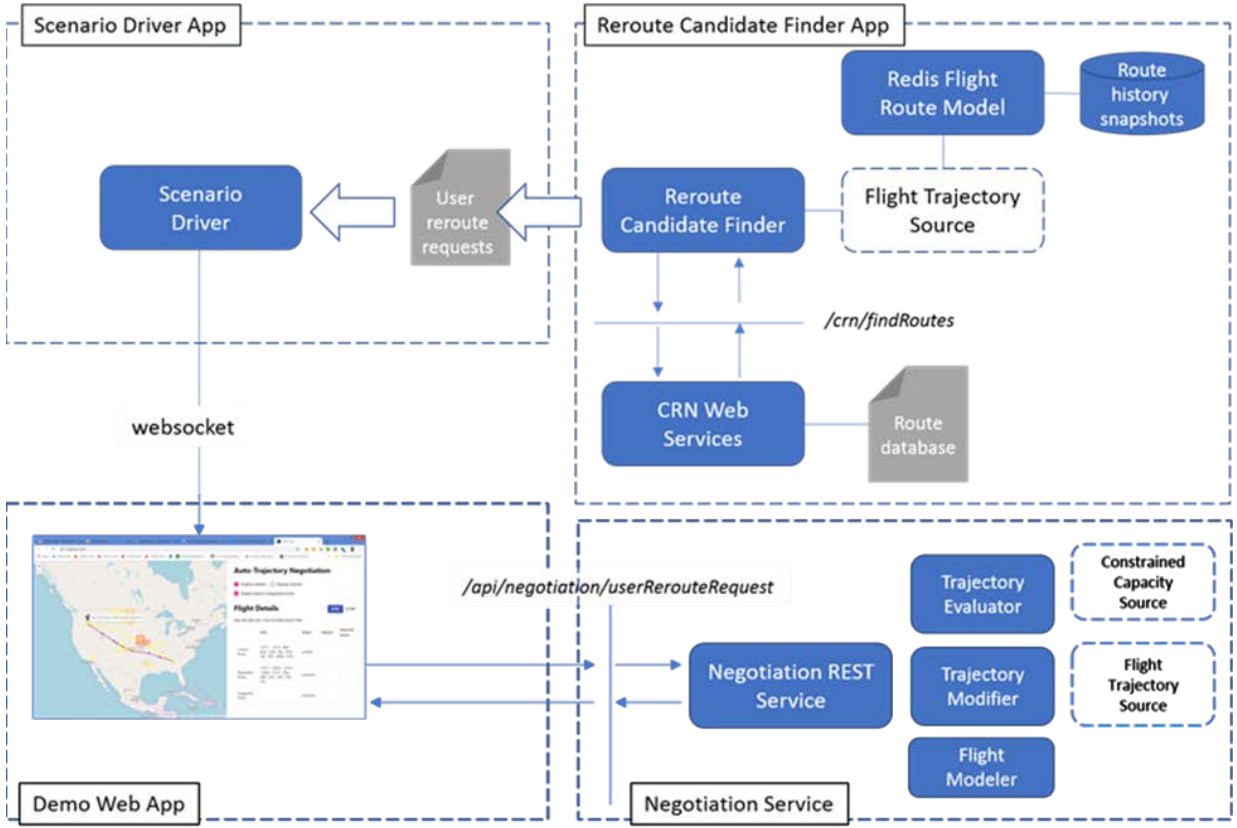


Trajectory Proposal: Clearable Routes Network

- Trajectory Proposer function finds alternatives to trajectories with unacceptable sector congestion cost
  - Searches *Clearable Routes Network* to identify paths around constraining sectors
- Empirically derived database of commonly used routes provides a large set of feasible route options

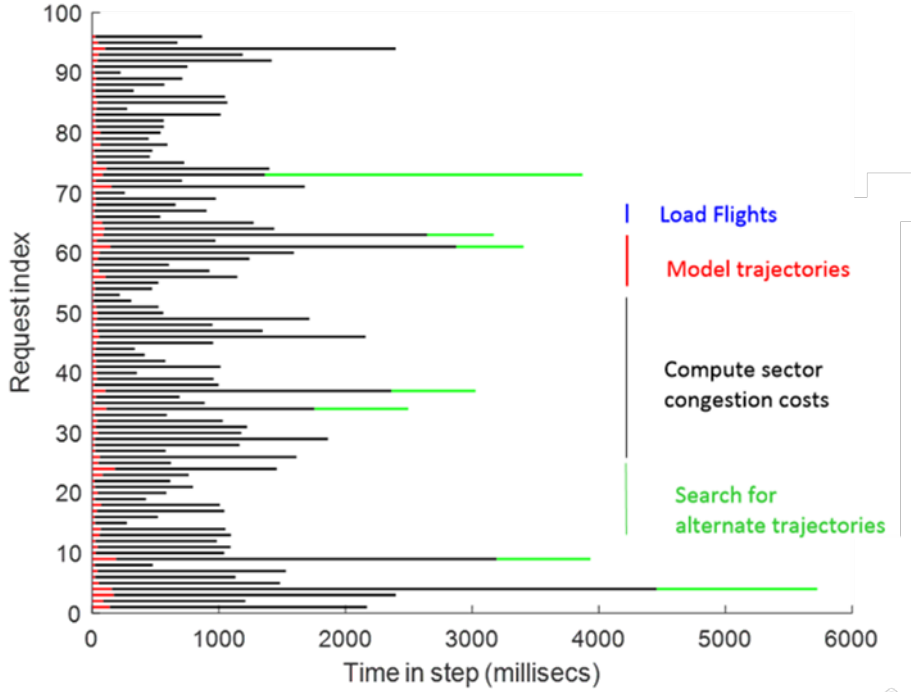


Automated Trajectory Negotiation Service Prototype



Response Time Analysis

- CPU time associated with key functional areas
  - Focus on end-to-end processing of a single request
- Sector Congestion Cost most expensive calculation
  - Scales linearly with the number of sectors traversed
  - 90% require ≤ 2 seconds



Human-*driven* (not Human-*centric*) Negotiation

- Human-autonomy teaming principles ensure negotiation is *efficient*, *reliable*, and *safe*
  - Changeable distribution of responsibilities between humans and automated systems based on context that provides *authority* along with *responsibility*
  - Service operation must be *transparent* and facilitate *appropriate calibration of trust*
  - Allow humans to direct exploration of the solution space
  - Expression of constraints and preferences that is *straightforward* for human users and *fits into their workflows*
- Address information requirements, especially when human evaluation is deemed ***not*** required
  - Allow humans to maintain understanding of flights' routes, negotiation status, performance of existing trajectories relative to the solution space and user preferences
- Support human-automation and human-human coordination and communication of constraints and preferences

Conclusions and Next Steps

- Developed and evaluated algorithms and prototype framework to support automated trajectory negotiation
  - Enhanced autonomy is needed to support the necessary speed and volume of negotiations to complete the transition to TBO
- Further evaluation needed:
  - Specific parameters for determining operational acceptability
    - For example, CRN currently does not guarantee that route segments are easily recognizable
    - Sector demand relative to capacity is not the only measure of operational acceptability and should be fortified with other considerations
  - Requirements and interaction design for human evaluation of proposed reroutes
    - Expressing constraints and preferences in a manner that is straightforward for human users and that fits into workflows
    - Directing the Automated Trajectory Negotiation Service to explore the solution space for new trajectory options
    - Communicating negotiation status and “performance” of existing trajectories relative to the solution space and user preferences

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