Generating Diverse Reroutes for Tactical Constraint Avoidance

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The Tactical Rerouting Problem

Automation support for tactical rerouting

1. Provides an alert when flight(s) are affected by weather, sector congestion, SAA(s), equipment outages or delay saving opportunity

2. Develops trajectories which factor in aircraft equipage, NAS performance objectives, and operator preferences

3. Facilitates collaboration to refine and approve trajectory modifications

4. Disseminates approved trajectory modifications leveraging XFS/ABRR and Data Comm
Challenges for Algorithmic Development

Problem Set
[set of flights needing reroutes]

Advisory Set
[constraint-avoiding reroutes for each flight]

Acceptability Metrics
Weather Avoidance
Airspace Conformance
Congestion Reduction
Maintain Schedules
Limited Coordination
Capacity Utilization

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**Approach**

- **Problem Set**: [set of flights needing reroutes]
- **Generate Candidate Reroutes**
  - Construct Networks
  - Optimize Reroutes
- **Advisory Set**: [constraint-avoiding reroutes for each flight]
- **Optimize Advisory Sets**
  - Select Advisory Set reroutes
  - Evaluate Acceptability Metrics
  - Do until Termination criteria is reached
- **Acceptability Metrics**
  - Identify Representative Advisory Sets
  - Cluster and Select Representative
  - Identify Principal Components
Generate Candidate Reroutes

- Generate flight-specific reroutes using network optimization
  - Network constructed from fix-pair segments derived from historical routes
  - Arc costs capture desirable behavior
  - Leverage efficiency of Dijkstra’s shortest path to generate reroutes

- Multiple candidates produced using DSP variant
  - DSP-M produces the shortest path through a specified intermediate node “M”
  - Forces diversity in the reroutes
  - Encourages “flows” in multi-flight examples
Metrics of Acceptability

Individual Flight Metrics
- Design Acceptability
  - Distance
  - Flow conformance
- Management Acceptability
  - Coordination
  - Return to original route
  - Number of segments
- Constraint Avoidance
  - Route blockage
  - Blockage probability
  - Congestion
- Flight Operator Acceptability
  - Schedule integrity

Advisory Set Metric
- Flights in Flow
  - Computes the maximum number of *consecutive fixes* common between 2 reroutes
  - Longest Common Substring (LCS), where each fix is considered a character

![Advisory Set Metric Diagram]

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Optimize Advisory Sets

- **Genetic Algorithms (GAs)** are a class of heuristic search methods
  - Mimic biological evolution to identify good solutions
  - No guarantee of optimality
- Multi-objective GAs (MOGAs) generate the Pareto front of solutions
  - Each solution defines an Advisory Set
  - Returns all non-dominated Advisory Sets

**Advisory Set chromosome**

<table>
<thead>
<tr>
<th>Flight A</th>
<th>Flight B</th>
<th>Flight C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metrics Flight A</td>
<td>Metrics Flight B</td>
<td>Metrics Flight C</td>
</tr>
</tbody>
</table>

- Maximize Metric B
- Minimize Metric A
- Utopia Point
- Pareto Front
- Dominated Solutions
Identify Representative Advisory Sets

- MOGA generates a large number of solutions
  - High-dimensional (10-D) Pareto Front
  - Clustering in 10-D can obscure key trade-offs
- Cluster using Principal Components Analysis
  - PCA identifies the primary correlations between metrics

Source: http://www.joyofdata.de/public/pca-3d/
Identify Representative Advisory Sets

- MOGA generates a large number of solutions
  - High-dimensional (10-D) Pareto Front
  - Clustering in 10-D can obscure key trade-offs
- Cluster using Principal Components Analysis
  - PCA identifies the primary correlations between metrics
- Select representative from each PCA-derived cluster
  - Compute the “central design”
  - Select solution with minimum “distance” to central design
### Multi-flight Example

**MOGA generates 5000 unique Pareto-optimal Advisory Sets**

[out of $1.8 \times 10^{17}$ possible options]

<table>
<thead>
<tr>
<th>Flight</th>
<th>Origin</th>
<th>Destination</th>
<th>#</th>
<th>Color</th>
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<td>Orange Red</td>
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<td>Charleston (CHS)</td>
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<td>Royal Blue</td>
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</table>
PCA Analysis

Flight Operator Acceptability

Design Acceptability

Management Acceptability

Constraint Avoidance

Flights in Flow
Pareto Clustering

Improved metrics:
- Distance
- Flow Conformance
- Coordination
- Return to Route
- Sector Congestion
- Blockage Probability & # of Segments

Improved metric:
- Flights in Flow

Better solutions
Pareto Clustering

Improved metrics:
- Distance, Flow Conformance, Coordination, Return to Route, Sector Congestion, Blockage Probability & # of Segments
- Flights in Flow
- Route Blockage
- Schedule Disruption
- Better solutions

Pareto Clustering
Comparison of Clustering Approaches
Advisory Set Reroutes

Advisory Set 1

Advisory Set 2

Advisory Set 3
Contributions

- The goal of this project is to reliably generate diverse, operationally acceptable route alternatives to traffic managers
  - The multi-flight context results in coordinated solutions
  - The algorithm generates flows as viable, not enforced
  - Multiple Advisory sets provide distinct choices to traffic managers
- For high-dimensional multi-objective optimization, PCA provides a critical analysis of data correlation
  - Highlights key trade-offs, otherwise lost in the volume of data