Strategies to Mitigate Off-Nominal Events in Super Dense Operations

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Outline

• Definitions
• Brief Overview of Super Dense Operations (SDO)
• Failure Modes
• Route Flexibility
• Mitigation Strategies
• Conclusion
Definition of Operational Conditions

• Nominal Condition – All elements of the system are operating as designed, and operational and environmental factors are as planned and as forecast.

• Off-Nominal Condition – All elements of the system are operating as designed, but operational or environmental factors are not as planned or as forecast.

• Emergency Condition – Most elements of the system are operating as designed, but one or more of them are in a condition that requires special handling.

• Failure Condition – One or more components cease to perform as designed, planned, or expected, resulting in significant impact to one or more elements of the system.
Definition of Planning Functions

- **Mitigation Strategy** – A strategy by which the SDO system adapts to an off-nominal, emergency, or failure condition and returns in a safe and efficient manner back to nominal conditions.

- **Nominal Plans** – A nominal plan determines the roles, responsibilities, and actions expected for SDO, given a weather forecast, airspace boundaries, and additional constraints and parameters.
  - Nominal Plan for a Controller
  - Nominal Plan for a Pilots

- **Contingency Plans** – Pre-computing a series of contingency plans establishes mitigation strategies for off-nominal, emergency, and failure conditions.
  - Contingency Plans for a Controller
  - Contingency Plans for a Pilot
Super Dense Operations (SDO)

• NextGen Operational Concept
• Maximize throughput in Terminal Area
  - 4D Trajectory Based Operations (TBO) exploiting Required Navigation Performance (RNP) and Area Navigation (RNAV)
  - Structured and Unstructured Routing solutions given weather constraints
  - Flexible Airspace Boundaries
  - Dynamically Adjusted Plans with Data Link Communications for 4DTs
RNP Examples

Before RNAV Routing
RNP Examples

After RNAV Routing
Transition Airspace Routing

Metroplex

Departures

Arrivals

Chicago Metroplex
Routing Problems Solved on a 2D Manifold

3D solution is defined on a 2D Manifold

Tree-Based Routing

En Route Weather Avoidance Route creates a “poke through” constraint on the 2D Descent Manifold

3D Weather Hazard Constraint intersecting with 2D Descent Manifold
Routing Problems Solved on a 2D Manifold

3D solution is defined on a 2D Manifold

Free Flight Routing
Example Tree-based Routing Solutions for SDO
Investigate Human Factors in HITL Simulation

Courtesy: Walt Johnson, NASA Ames Research Center
Failure Modes and Effects Analysis (FMEA)

- See Ganji and Krozel (this conference)*
- Focus on Tactical Failures in SDO Functionality
- Failure Modes Categories:
  - Modes that Require an Aircraft Diversion
  - Modes that Address an Emergency Landing
  - Modes that Involve Non-Cooperative Aircraft
  - Modes with a temporary loss of Communication
  - Modes with Human Errors in Communication
  - Modes with a Temporary Loss of an Airspace Resource
  - Modes with a Temporary Loss of an Airport Resource

General Problem Statement

- Begin in a Nominal SDO Condition
- System is subject to:
  - Failure Condition,
  - Emergency Condition, or
  - Off-nominal Condition
- Using a Mitigation Strategy, the system is returned to a Nominal SDO Condition
Mitigation Strategies - Diversions

Route to Alternate Airport may have hazardous weather constraints

Alternate airports may be in the same sector or a neighboring sector
Mitigation Strategies – Emergency Landing

- Alternate Airport
- Route 1
- Route 2
- Route 3
- SDO Airport

Diagram showing different routes and airports for emergency landing strategies.
Mitigation Strategies – Non-Cooperative Aircraft

Preference is to solve the problem internal to sector boundaries

SDO Airport
Mitigation Strategies – Route Flexibility
Voronoi Diagram Geometry

Voronoi Diagram of set of Weather Constraints
Voronoi Diagram of set of Weather Constraints
Path within Voronoi Diagram that has the same routing among constraints as the flow/route
Constrained Airspace

Purple region defines the volume of unconstrained airspace in vicinity of routing structure.

Locus of maximal disks (purple) centered along Voronoi path.
Constrained Airspace Metric within a Sector
Mitigation Strategies – Tree Flexibility
Mitigation Strategies

• Use of Flexible Airspace:
  - Temporary Holding
  - Reroutes of Individual Aircraft
  - Locally Redefining the SDO Routing Tree Structure

• Speed Control to Open up Gaps in a Traffic Stream
Mitigation Strategies – Contingency Path Maps

8 Contingency Plans identified in the OPM. Plans 1-6 are FMS-compatible for Aircraft 3. Plans 3-6 are FMS-compatible for Aircraft 2.
Conclusion

• We discuss strategies for addressing off-nominal conditions in SDO
• FMEA is useful in establishing the range of failure conditions, off-nominal conditions, and emergency conditions that must be considered
• We investigated contingency plans associated with particular failure modes
• Useful tools for contingency planning include:
  - Defining the flexible airspace around a route or tree where holding, rerouting, or tree adjustment can occur
  - Speed control strategies to open up gaps in traffic streams
  - Contingency Path Maps for routing to alternate destinations