Research in Modeling and Simulation for Airspace Systems Innovation

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Presentation Overview

• Motivation for modeling and simulation (M&S) research
• Long range aspirations for M&S
• Review of some current research efforts
  – Transportation Systems Analysis Model (TSAM)
  – Logic Evolved Decision Making
  – High Fidelity Traffic Ops Simulation
  – Multi-laboratory Simulation
• Future work and opportunities for collaboration
Challenges Facing the U.S. Air Transportation System

A Complex System

- Security
- Capacity
- Demand
- U.S. Economy
- Travel Time
- Safety
- Noise
- Emissions
- Environmental Impacts
Need for System of Systems Approach

- Challenges facing the air transportation system in U.S. are faced by other modes of transportation
- Our existing infrastructures have evolved along different pathways and this has constrained our thinking and exploration of potential solutions
  - Physical infrastructure
  - Governmental infrastructure
  - Economic infrastructure
- Multi-modal transportation (systems of systems) approach using modeling and simulation may open the space of potential solutions and provide new ideas to meet the challenges of our air transportation system
Modeling and Simulation for Systems Innovation - Aspirations

• Be able to model and understand integrated systems using variable fidelity simulation
  – Develop capability to rapidly explore a large solution space at the conceptual level and drill down using higher fidelity simulations to determine the efficacy of concepts

• Model the impacts of human decision making
  – Use interactive and game-based simulation to improve our understanding of human decision making
    • Currently looking at the effect of different information and information delays on decision making and system dynamics
    • Some research has just been initiated to study decision making in competitive environments using multiplayer game-based simulation
Current Research Efforts
Aeronautics Technology Development is Organized Around Three Significant Programs

- Airspace Systems
- Aviation Safety
- Fundamental Aeronautics

Airspace Capability

Future State of Air Travel

Cost
Environment
Safety

Vehicle Capability
Air Transportation Architecture Elements

- Security
- Functional Problems
- Travel Evolution (Business)
- Operational Concepts
- Demographics
- Geography
- Constituent Perspectives
- Nat’l and Regional Economics
- Scenarios
- Business Models

Vehicles

Operations Control (Ground/Airspace)

Take-Off/Landing Facilities

Architecture

SACD Focus
Transportation Systems Analysis Model

- Automobiles
- Commercial Air
- New Mode or Vehicle

Socio-economic Data
Airports and Characteristics
Air Traffic Structure and CONOPS
Multi-modal Travel Time Matrices
Air Transportation Network and Schedules
Aircraft Performance and Cost Characteristics (Airlines, GA and SATS)
Transportation Systems Analysis Model

Attributes of the Transportation Systems Analysis Model

- Computes *National* demand for long distance travel
- Can make projections to 2025
- Uses accepted transportation analysis methods
- Socio-economic based (down to county level detail)
- Demand and supply relationships
- Multi-modal in scope
- Aerospace technology sensitive
- Can be applied to full range of NASA and FAA aviation projects
- Two different program execution environments:
  - Computer platform independent (Matlab version)
  - Platform dependent (Stand-alone PC model with GUI and integrated DLLs)
- Employs Geographic Information Systems (GIS) technology
  - MapObjects
  - VB interface
Selecting a Mode of Travel

Factors considered in selecting a mode:
- Travel time
- Travel cost
- Value of time
- Route convenience
- Trip type
- Reliability of service
- Frequency of service
LED uses formal deductive logic models, approximate reasoning, possibility, probability and graph theory to build robust decision models.

LED models are well-suited for decision problems characterized by little or no quantitative data and the need for extensive expert judgment. The results, including uncertainty are expressed in an easily understandable form.
Methodology of LED Decision Support

- Determine possibilities
- Select metric to rank the possibilities
- Design an inferential model for the metric
- Rank the possibilities
- Express uncertainty in the results
- Make results useful to the customer
Prognostic Risk-based Safety Assessment
For this Year, Model a Subset of the ATS

Today’s National Airspace System (NAS)

MODEL
SUB-SYSTEM ONLY
• IIFD/SA/ASDO/Airport/portal
• M&S

Baseline Risk: Today’s NAS

Technology Gaps

New Risk: Future ATS States

Baseline Risk: Today’s NAS

Technology Gaps

New Risk: Future ATS States

Today’s Hazards

Future Hazards

MODEL
SUB-SYSTEM ONLY
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Baseline Risk: Today’s NAS

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Today’s Hazards

Future Hazards

Today’s Hazards

Future Hazards

TODAY 2025

Limited Automation
Substantial Automation

Fixed Airspace Operations
4-D Trajectories

Limited ATM Info in Cockpit
Net-Enabled Info Access

Etc.
Etc.

R_{Residual} = R_{Future} - R_{Now}

Risk Reduction Potential
• Includes New Technology & Ops
• \Delta R_{Future} = R_{Future} - R_{Tech & Ops Insertion}
• Proactive
• Predictive

13
Merging and Spacing (M&S) Area of Interest

Diagram showing the transition of flight phases and control areas from Crew Dispatch OCC to (ATCT) Tower GRND CLNC and back again, with specific areas of interest defined by TRACON Departure Control, (ARTCC) Center Cruise, and (TRACON) Approach Control.
The Next Generation Air Traffic System (NextGen)

Goals by 2025:
– Scalable system that adapts to increasing traffic demand
– Continually improve safety

Envisioned System Attributes:
– Satellite-based navigation and control
– Digital non-voice communication
– Advanced networking
– A shift of decision making from the ground to the cockpit
– Flight crews will have increased control over their flight trajectories
– Ground controllers will become traffic flow managers

“We need to completely change our approach to the way the system will function in the twenty-first century.”
– Joint Planning and Development Office – JPDO
(www.jpdo.gov)
Some Key NextGen Research Challenges*

• **Meta-level challenge: Accomplishing huge paradigm shifts**
  – From airspace-based operations to *trajectory-based operations*
  – From equipage-based capabilities to *performance-based operations*
  – From human-only control to *automation-dominated trajectory management*
  – From centralized-only architecture to *centralized/distributed hybrid architecture*

  **Metrics of success**
  • Demand-adaptive capacity (“scalability”)
  • Quantifiable safety
  • Behavioral stability and robustness
  • System performance predictability
  • User operational flexibility & equity

• **Micro-level challenge: Traffic complexity control (within new paradigm)**
  – Redefining complexity and preventing automation from exceeding limits
  – Significant challenge: Applying this in a distributed architecture!

* Courtesy of David J. Wing, NASA
## High-Fidelity Traffic Ops Simulation (1/2)

<table>
<thead>
<tr>
<th>Time Horizon</th>
<th>Modeling and Sim Needs</th>
<th>Examples</th>
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<tbody>
<tr>
<td>Years</td>
<td>• Capacity prediction and demand models based on econometrics, population demographics, and future world states</td>
<td>Airspace design; airport expansion</td>
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<td>Days to Months</td>
<td>• Agent-based system models supporting strategic decision-making by airspace operators and service providers</td>
<td>Weather impacts; service provision to airspace users</td>
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<td>• Game-based simulations</td>
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<td>Hours</td>
<td>• Medium-fidelity agent-based wide-area system simulations</td>
<td>Traffic flow management</td>
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<td>• Queuing model based simulation</td>
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<td>• Traffic density prediction simulations</td>
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<tr>
<td>Seconds to Minutes</td>
<td>• High-fidelity local-area traffic simulations incorporating human responses and advanced enabling technologies</td>
<td>Separation assurance</td>
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<td>• High-fidelity flight and ground system component simulations incorporating human responses and advanced enabling technologies</td>
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NASA Airspace and Traffic Operations Simulation (ATOS)

Medium-to-high fidelity, part-task, air traffic simulation environment, developed to explore inter-aircraft, aircraft/airspace, and air/ground interactions

- Designed to take advantage of distributed and networked computation
  - Keep code simple by simulating one aircraft, then connect processes
  - Facilitates specialization

- High-fidelity aircraft and avionics models enable multi-use
  - Multi-aircraft traffic ops sim
  - Single-aircraft crew procedures sim
  - Same automation prototype technology used for both; ensures consistency of results
AviationSimNet Federation

NASA Langley Labs

ASTOR Pilots

HLA G/W

MITRE CAFC2S RCAT Lab

ARINC 429 Bus

Voice: IEEE 1278.1A

Internet

ATOL

TCP

HLA G/W

MITRE VOICE HUB

Voice G/W

MITRE CAASD Integrated ATM Lab

SimPilots

Controllers

Cockpit

Simulation Manager

3-D Viewer

SHA– High Level Architecture

GW - Gateway

Communications Infrastructure
AviationSimNet

A collaboration of US ATM laboratories to create large-scale high-fidelity research simulation capability

• **AviationSimNet Goals:**
  – Enable the faster/cheaper evaluation of new concepts
  – Enable the evaluation of complex concepts that by their nature require large numbers of simulation assets
  – Establish *standards* for linking simulations together in the aviation community

• **Participants:**
  – NASA, FAA
  – MITRE, UPS, ERAU, Rockwell, Lockheed-Martin

*We hope to have European participants in AviationSimNet to facilitate collaborative research*
Summary

• Believe that innovation in M&S methods will enable exploration of more complex systems, including multi-modal passenger transportation, and lead to more innovative air transportation system design

• Aspirations for M&S:
  – To rapidly explore a broad range of potential solutions at the system of systems level and examine with higher fidelity simulation each potential solution.
  – To accurately model human decision making and the effect on system design

• Beginning to look at distributed simulation and other bridging methods to achieve variable fidelity simulation. Researching gaming and interactive simulation to study human decision making.

• Seeking partnerships and opportunities to collaborate on multi-laboratory M&S research - through AviationSimNet and other networks