Automated Scenario Generation for Human-in-the-Loop Simulations

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Motivation

• **Need for realistic scenarios to study diverse operations**
  – Unmanned Aerial Vehicles
  – Urban Air Mobility
  – Supersonic aircraft

• **Manual creation of realistic scenarios for generating traffic for Human-in-the-Loop simulation is difficult**
  – Missing and erroneous data
  – Repeated creation of scenario and testing in simulation is time consuming
  – Difficulties cause studies to be limited to few scenarios

• **Automated scenario generation has potential for overcoming limitations**
  – Use real air traffic data to create scenario
  – Remove flights with erroneous data
  – Mix data from different days to achieve desired traffic volume
Research Questions

- Can initial traffic scenario be generated using an automated process that runs in Multi-Aircraft Control System (MACS)?
- Can this initial traffic scenario be used as a starting point for building a Human-in-the-Loop (HITL) scenario?
- How does one compare the initial traffic scenario created using the automated process with the manually altered HITL-scenario?
- Can an automated process be used to directly create a HITL-scenario?
Outline

• Air Traffic Management (ATM) Testbed

• Automated scenario generation using ATM Testbed

• Approach

• Results

• Conclusions
Air Traffic Management Testbed

Data Distribution Service

Test Bed Visualization Services

Real Aircraft

High-fidelity Simulator

ATM Simulation

Stakeholder Tools

Traffic Generators

Trajectory Generator

Scheduler

Conflict Detection

Conflict Resolution

Component A

Component N

GovCloud

Test Bed Support Services Including Housekeeping
Creation of Seed-scenario

Input Data for Scenario Generation
Automated Scenario Generation
Seed-scenario
Input Data for Scenario Generation

• Reduced Record (RD)
  – Single record for each flight
    • Beacon-code, flight-plan, takeoff/landing runway, departure/arrival time, sector/center transition list

• Event Data (EV)
  – Multiple records related to events for each flight
    • Event time and type- landing, crossing
    • Example: center crossing from ZOA to ZLA

• Integrated Flight Format (IFF)
  – Multiple records for each flight
    • All flight plans including amended flight plans
    • Position data

• EV and RD useful for filtering and IFF for data augmentation
Simulation Architect View for Composing MACS Traffic Scenario

Data Loader

Airport Arrival Filter: KEWR

Landing Runway Filter: 22L

Airport Arrival Filter: KLGA

Airline Filter: AAL, DAL

Landing Time Filter: start-time, end-time

MACS Traffic Scenario Builder

Other inputs

EV Filter

RD Filters
MACS Scenario Generation Steps

Load & filter input data
MACS Scenario Generation Steps

1. Load & filter input data
2. Preprocess flight data
MACS Scenario Generation Steps

1. Load & filter input data
2. Preprocess flight data
3. Flights remaining?
   - Yes
MACS Scenario Generation Steps

1. Load & filter input data
2. Preprocess flight data
3. Flights remaining?
   - Yes
     - Find entry track data
MACS Scenario Generation Steps

1. Load & filter input data
2. Preprocess flight data
3. Flights remaining?
   - Yes
     1. Find entry track data
     2. Find last flight-plan prior to entry track time
MACS Scenario Generation Steps

1. Load & filter input data
2. Preprocess flight data
3. Flights remaining?
   - Yes: Find entry track data
     - Find last flight-plan prior to entry track time
     - Process flight-plan data
MACS Scenario Generation Steps

1. Load & filter input data
2. Preprocess flight data
3. Flights remaining?
   - Yes
     4. Find entry track data
     5. Find last flight-plan prior to entry track time
     6. Process flight plan data
     7. Compute entry state data

MACS Scenario Generation Steps

1. Load & filter input data
2. Preprocess flight data
3. Flights remaining?
   - Yes
     4. Find entry track data
     5. Find last flight-plan prior to entry track time
     6. Process flight plan data
     7. Compute entry state data
8. Update comment fields
MACS Scenario Generation Steps

1. Load & filter input data
2. Preprocess flight data
3. Flights remaining?
   - Yes
     - Find entry track data
     - Find last flight-plan prior to entry track time
     - Compute entry state data
     - Process flight plan data
     - Update comment fields
     - Assign values to data fields
MACS Scenario Generation Steps

1. Load & filter input data
2. Preprocess flight data
3. Flights remaining?
   - Yes
     - Find entry track data
     - Find last flight-plan prior to entry track time
     - Process flight plan data
     - Compute entry state data
4. Assign values to data fields
5. Update comment fields
MACS Scenario Generation Steps

1. Load & filter input data
2. Preprocess flight data
3. Flights remaining?
   - Yes: Find entry track data
     - Find last flight-plan prior to entry track time
       - Process flight plan data
         - Compute entry state data
         - Update comment fields
   - No: Assignment values to data fields
      - Output scenario data
MACS Scenario Generation Steps

1. Load & filter input data
2. Preprocess flight data
3. Flights remaining?
   - Yes: Find entry track data
   - Yes: Find last flight-plan prior to entry track time
   - Yes: Process flight plan data
   - Yes: Compute entry state data
   - No: Assign values to data fields
4. Update comment fields
5. Output scenario data
6. Stop
Approach: Seed-scenario versus HITL-scenario

- Input Data for Scenario Generation
- Automated Scenario Generation
- Seed-scenario
Approach: Seed-scenario versus HITL-scenario

Input Data for Scenario Generation

Automated Scenario Generation

Seed-scenario

Manual Refinement
Approach: Seed-scenario versus HITL-scenario

- Input Data for Scenario Generation
- Automated Scenario Generation
- Seed-scenario
- Manual Refinement
- HITL-scenario
Traffic Scenarios

• Seed-scenario generated using automated process
  – June 6, 2016 RD, EV and IFF files
  – Arrivals to Newark, New Jersey
  – Six-hours traffic starting at 17:00 UTC
  – 299 flights; 274 landing on 22L, six on 22R, one on 29 and 18 not assigned

• Manually altered HITL-scenario
  – Entry times altered to squeeze six-hours of traffic to five-hours to exceed arrival capacity of 40 aircraft/hour
  – Flights within 40 nautical miles surrounding airport removed
  – Some flights at the beginning of scenario removed
  – Flights removed to maintain ratio of internal (400 nautical miles) to total number of flights
  – 191 flights, all landing on 22L
# Data Analysis I: Number of Flights with Same Parameter Value

<table>
<thead>
<tr>
<th>#</th>
<th>Parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Call-sign</td>
</tr>
<tr>
<td>2.</td>
<td>Aircraft-type</td>
</tr>
<tr>
<td>3.</td>
<td>Destination airport</td>
</tr>
<tr>
<td>4.</td>
<td>Landing runway</td>
</tr>
<tr>
<td>5.</td>
<td>MACS flight-plan</td>
</tr>
<tr>
<td>6.</td>
<td>ATC flight-plan</td>
</tr>
<tr>
<td>7.</td>
<td>Beacon-code</td>
</tr>
<tr>
<td>8.</td>
<td>Departure airports</td>
</tr>
<tr>
<td>9.</td>
<td>Entry point altitude</td>
</tr>
<tr>
<td>10.</td>
<td>Entry point airspeed</td>
</tr>
<tr>
<td>11.</td>
<td>Entry point sector-ID</td>
</tr>
<tr>
<td>12.</td>
<td>Aircraft weight</td>
</tr>
</tbody>
</table>

The image shows a graph with the x-axis labeled "Aircraft-type" and the y-axis labeled "Number of flights." The graph plots the number of flights against different aircraft types.
## Seed-scenario Results

<table>
<thead>
<tr>
<th>#</th>
<th>Parameter</th>
<th>Once</th>
<th>Repeated</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Call-sign</td>
<td>281</td>
<td>9</td>
<td>290</td>
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<tr>
<td>2.</td>
<td>Aircraft-type</td>
<td>11</td>
<td>24</td>
<td>35</td>
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<tr>
<td>3.</td>
<td>Destination airport</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>4.</td>
<td>Landing runway</td>
<td>1</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>5.</td>
<td>MACS flight-plan</td>
<td>148</td>
<td>47</td>
<td>195</td>
</tr>
<tr>
<td>6.</td>
<td>ATC flight-plan</td>
<td>174</td>
<td>41</td>
<td>215</td>
</tr>
<tr>
<td>7.</td>
<td>Beacon-code</td>
<td>256</td>
<td>21</td>
<td>277</td>
</tr>
<tr>
<td>8.</td>
<td>Departure airports</td>
<td>50</td>
<td>68</td>
<td>118</td>
</tr>
<tr>
<td>9.</td>
<td>Entry point altitude</td>
<td>73</td>
<td>61</td>
<td>134</td>
</tr>
<tr>
<td>10.</td>
<td>Entry point airspeed</td>
<td>77</td>
<td>58</td>
<td>135</td>
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<tr>
<td>11.</td>
<td>Entry point sector-ID</td>
<td>47</td>
<td>23</td>
<td>70</td>
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<tr>
<td>12.</td>
<td>Aircraft weight</td>
<td>5</td>
<td>24</td>
<td>29</td>
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</table>
## HITL-scenario Results

<table>
<thead>
<tr>
<th>#</th>
<th>Parameter</th>
<th>Once</th>
<th>Repeated</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Call-sign</td>
<td>191</td>
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<td>Aircraft-type</td>
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<td>30</td>
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<td>3.</td>
<td>Destination airport</td>
<td>0</td>
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<td>1</td>
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<tr>
<td>4.</td>
<td>Landing runway</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>5.</td>
<td>MACS flight-plan</td>
<td>64</td>
<td>41</td>
<td>105</td>
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<tr>
<td>6.</td>
<td>ATC flight-plan</td>
<td>80</td>
<td>40</td>
<td>120</td>
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<tr>
<td>7.</td>
<td>Beacon-code</td>
<td>181</td>
<td>5</td>
<td>186</td>
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<tr>
<td>8.</td>
<td>Departure airports</td>
<td>41</td>
<td>50</td>
<td>91</td>
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<tr>
<td>9.</td>
<td>Entry point altitude</td>
<td>35</td>
<td>46</td>
<td>81</td>
</tr>
<tr>
<td>10.</td>
<td>Entry point airspeed</td>
<td>23</td>
<td>14</td>
<td>37</td>
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<tr>
<td>11.</td>
<td>Entry point sector-ID</td>
<td>0</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>12.</td>
<td>Aircraft weight</td>
<td>3</td>
<td>16</td>
<td>19</td>
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</tbody>
</table>
# Seed-scenario versus HITL-scenario

<table>
<thead>
<tr>
<th>#</th>
<th>Parameter</th>
<th>Seed-scenario</th>
<th>HITL-scenario</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Once/Total (%)</td>
<td>Repeated/Total (%)</td>
<td>Once/Total (%)</td>
</tr>
<tr>
<td>1.</td>
<td>Call-sign</td>
<td>97</td>
<td>3</td>
</tr>
<tr>
<td>2.</td>
<td>Aircraft-type</td>
<td>31</td>
<td>69</td>
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<tr>
<td>3.</td>
<td>Destination airport</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>4.</td>
<td>Landing runway</td>
<td>25</td>
<td>75</td>
</tr>
<tr>
<td>5.</td>
<td>MACS flight-plan</td>
<td>76</td>
<td>24</td>
</tr>
<tr>
<td>6.</td>
<td>ATC flight-plan</td>
<td>81</td>
<td>19</td>
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<td>7.</td>
<td>Beacon-code</td>
<td>92</td>
<td>8</td>
</tr>
<tr>
<td>8.</td>
<td>Departure airports</td>
<td>42</td>
<td>58</td>
</tr>
<tr>
<td>9.</td>
<td>Entry point altitude</td>
<td>54</td>
<td>46</td>
</tr>
<tr>
<td>10.</td>
<td>Entry point airspeed</td>
<td>57</td>
<td>43</td>
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<tr>
<td>11.</td>
<td>Entry point sector-ID</td>
<td>67</td>
<td>33</td>
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<tr>
<td>12.</td>
<td>Aircraft weight</td>
<td>17</td>
<td>83</td>
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</table>
## Data Analysis II: Distribution

<table>
<thead>
<tr>
<th>#</th>
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<tr>
<td>1</td>
<td>Route length</td>
</tr>
<tr>
<td>2</td>
<td>Cruise speed</td>
</tr>
<tr>
<td>3</td>
<td>Cruise altitude</td>
</tr>
<tr>
<td>4</td>
<td>Actual landing time</td>
</tr>
<tr>
<td>5</td>
<td>Predicted landing time</td>
</tr>
<tr>
<td>6</td>
<td>Aircraft weight</td>
</tr>
<tr>
<td>7</td>
<td>Entry time</td>
</tr>
<tr>
<td>8</td>
<td>Entry point airspeed</td>
</tr>
<tr>
<td>9</td>
<td>Entry point altitude</td>
</tr>
</tbody>
</table>

![Histogram of Entry Point Airspeed](image)

- Number of flights: 80
- Entry point airspeed (knots): 712 knots
Data Analysis III: Seed-scenario Landing Rate

\[ t_L = t_E + \frac{l_R}{\overline{V}_{CR}} \]

- \( t_L \) – Expected landing time
- \( t_E \) – Entry time
- \( l_R \) – Route length
- \( \overline{V}_{CR} \) – Average cruise speed
Seed-scenario v/s HITL-scenario
Landing Rate Results

Landing time (hours past 17 UTC)

Landing rate (flights/hour)

Seed-scenario actual

HITL-scenario expected

Landing rate (flights/hour)

274 flights

191 flights
Approach: HITL-scenario versus MACS Output

Input Data for Scenario Generation

Automated Scenario Generation

Seed-scenario

Manual Refinement

HITL-scenario
Approach: HITL-scenario versus MACS Output

1. Input Data for Scenario Generation
2. Automated Scenario Generation
3. Seed-scenario
4. Manual Refinement
5. HITL-scenario
6. MACS Simulation
Approach: HITL-scenario versus MACS Output

- Input Data for Scenario Generation
- Automated Scenario Generation
- Seed-scenario
- Manual Refinement
- HITL-scenario
- MACS Simulation
- MACS Simulation Output
HITL-scenario v/s MACS Output

Landing Rate Results

- Expected landing rate graph is sensitive to cruise speed
  - Faster shifts left
  - Slower shifts right

- Errors due to
  - 18 aircraft did not land in MACS
  - Aircraft performance models in MACS
  - Conversion of Mach to cruise speed using standard atmosphere
Conclusions

- MACS simulations can be run with seed-scenario created using the ATM Testbed

- Seed-scenario was found to be a good starting point for creating HITL-scenario

- Duplicate flight and distribution analysis useful for data quality and eliminating flights with unreasonable parameter values

- Analysis showed that many of the manual adjustments can also be included in the automated process to directly create the HITL-scenario
Extra Slides
Future Work

Enhance Scenario Generation to create Human-in-the-Loop scenarios

• Eliminate flights with erroneous parameter values
• Select flights to achieve the internal to total ratio
• Alter the landing times to achieve the desired landing rate