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

Real Aircraft
High-fidelity Simulator
ATM Simulation

Data Distribution Service

Test Bed Visualization Services
Stakeholder Tools
Traffic Generators

ATM Services
- Trajectory Generator
- Scheduler
- Conflict Detection
- Conflict Resolution

GovCloud

Component A

Component N

Test Bed Support Services Including Housekeeping
Air Traffic Management Testbed

- Test Bed Visualization Services
- Real Aircraft
- High-fidelity Simulator
- ATM Simulation

Data Distribution Service

- Test Bed Support Services Including Housekeeping
- Stakeholder Tools
- Traffic Generators
- Scenario Generation

ATM Services
- Trajectory Generator
- Scheduler
- Conflict Detection
- Conflict Resolution

GovCloud

Component A
Component N
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
  - Airport Arrival Filter: KLGA
  - Landing Runway Filter: 22L
  - Airline Filter: AAL, DAL
  - Landing Time Filter: start-time, end-time

- EV Filter
- MACS Traffic Scenario Builder
- Other inputs
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

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

1. Load & filter input data
2. Preprocess flight data
3. Find entry track data
4. Find last flight-plan prior to entry track time
5. Assign values to data fields
6. Process flight-plan data
7. Update comment fields
8. Compute entry state data
9. Flights remaining?
   - Yes, repeat steps 2-8

10. No, end process
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
4. Process flight plan data
5. Compute entry state data
6. Update comment fields
7. 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
   - Yes: Find last flight-plan prior to entry track time
   - Yes: Process flight plan data
   - Yes: Compute entry state data
   - No: Output scenario 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
6. Process flight plan data
7. Compute entry state data
8. Assign values to data fields
9. Update comment fields

Next:
- Output scenario data
- 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>

![Graph showing number of flights by aircraft type](image)

**Number of flights**

**Aircraft-type**
# 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>
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<td>9</td>
<td>290</td>
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<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>
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<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>
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<td>5.</td>
<td>MACS flight-plan</td>
<td>148</td>
<td>47</td>
<td>195</td>
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<tr>
<td>6.</td>
<td>ATC flight-plan</td>
<td>174</td>
<td>41</td>
<td>215</td>
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<td>7.</td>
<td>Beacon-code</td>
<td>256</td>
<td>21</td>
<td>277</td>
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<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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<td>11.</td>
<td>Entry point sector-ID</td>
<td>47</td>
<td>23</td>
<td>70</td>
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<td>12.</td>
<td>Aircraft weight</td>
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<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>
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<td>3.</td>
<td>Destination airport</td>
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<td>1</td>
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<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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<td>6.</td>
<td>ATC flight-plan</td>
<td>80</td>
<td>40</td>
<td>120</td>
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<td>7.</td>
<td>Beacon-code</td>
<td>181</td>
<td>5</td>
<td>186</td>
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<td>Departure airports</td>
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<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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</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>
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<td>2.</td>
<td>Aircraft-type</td>
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<td>3.</td>
<td>Destination airport</td>
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<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>
</tr>
<tr>
<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>
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<tr>
<td>10.</td>
<td>Entry point airspeed</td>
<td>57</td>
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<td>Entry point sector-ID</td>
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<td>33</td>
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<td>12.</td>
<td>Aircraft weight</td>
<td>17</td>
<td>83</td>
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</table>
Data Analysis II: Distribution

<table>
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<th>#</th>
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<tr>
<td>1</td>
<td>Route length</td>
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<tr>
<td>2</td>
<td>Cruise speed</td>
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<td>3</td>
<td>Cruise altitude</td>
</tr>
<tr>
<td>4</td>
<td>Actual landing time</td>
</tr>
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<td>5</td>
<td>Predicted landing time</td>
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<tr>
<td>6</td>
<td>Aircraft weight</td>
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<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>

Number of flights

Entry point airspeed (knots)

712 knots
Data Analysis III: Seed-scenario Landing Rate

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

- \( t_L \) – Expected landing time
- \( t_E \) – Entry time
- \( l_R \) – Route length
- \( \bar{V}_{CR} \) – Average cruise speed

Landing rate (flights/hour)

Landing time (hours past 17 UTC)
Seed-scenario v/s HITL-scenario
Landing Rate Results

Landing rate (flights/hour) vs Landing rate (flights/hour)
Landing time (hours past 17 UTC)

Seed-scenario actual

HITL-scenario expected

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