UNCERTAINTY HANDLING AND TRAJECTORY SYNCHRONIZATION FOR THE AUTOMATED ARRIVAL MANAGEMENT

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1. Status quo of the UTOPIA project

2. Simulation environment

3. Scenario setup

4. Implementation and simulation results

5. Outlook
Each UTOPIA member focuses on one of three innovative key elements:

- Study **uncertainty sources** and their propagation in the aircraft n-dimensional trajectories (nDT), considering also system disruptions

- Formal models of trajectory data and **trajectory synchronization** protocols for heterogeneous systems in an automated environment,

- Advanced **trajectory management algorithms** and ground synchronization functions based on the formal n-dimensional trajectory data and uncertainty models substituting today's HMI by **automated functions**
1. Status Quo - Concept Specification

- SESAR Milestone Deliverable 3 “The ATM Target Concept” and European ATM Master Plan as technological baseline of aircraft operations in the year 2020 (ConOps)

- Operational concept description (e.g. SESAR or NextGen) focusing on
  - aircraft and ground automation,
  - trajectory synchronization,
  - technical requirements for airspace users and ground-based systems

- UTOPIA specific ConOps
  - terminal maneuvering area (E-TMA) extended to 500+ NM imposing considerably larger look ahead times (LAT)
  - automated inbound sequencing
  - tailored to Frankfurt Airport (EDDF) environment in 3 RWY configuration
1. Status Quo - Stochastic Modeling, Definitions

- Uncertainty triggered by
  - change of system states
  - availability of data (update rate)
  - (reliable) sources of data

- Disruption
  - uncertain states require high update rates inducing high amount of data to be exchanged to grant synchronization
  - system fails (disrupted) if it cannot satisfy the synchronization demand

- Synchronization (updates) required, if agents (represented by their trajectory) tend to violate pre-defined navigation tolerances
1. Status Quo - Stochastic Modeling, Basics

- Following ICAO's RNP/RNAV concept:
  - uncertain input factors result into along, cross, and/or vertical track tolerances
  - along track tolerance (ATT) significant to target times (e.g. CTO, RTA) as generated through the UTOPIA AMAN

- Uncertainty factors classified into two domains
  - atmospheric conditions
  - navigation performance /operational factors

- Implementation
  - unsteady wind conditions result in increased ATT inducing uncertain target times (AMAN: over FAF)
  - Individual ATT additionally used to optimize the arrival sequence
  - convective weather scenarios covered by no-go-zones, leading to re-routing of individual flight plans
1. Status Quo - Stochastic Modeling, Data

- Atmospheric Conditions

Windfield

Convective Weather (declared No-Go-Zones)

Meteox.com (DWD, KMI, KNMI, MetEireann, MeteoFrance, MetOffice)
1. Status Quo - Design Scheme for Virtual Environment

- Agent-based approach (capability of autonomous acting and decision making)
  - Agents individually plan their trajectory (through dedicated Boeing / Airbus FMS)
  - Agents individually react on AMAN advices
  - Agents communicate their decisions

- Modeling of
  - atmospheric conditions
  - weather patterns
  - corridor of uncertainty (COU)

- Mandatory set of messages for data exchange (AIDL) extended with uncertainty information
2. Simulation Environment

UTOPIA Demonstrator

Trajectory Management

AMAN

FACT

UTOPIA Demonstrator

Control Process

TP Trajectory Predictor

nDT n-dimensional trajectory description data
2. Simulation Environment - BR&TE Tools FACT & APATS
2. Simulation Environment - Receiving UTOPIA Messages

- WX forecast
- Flight plan
- AIP
- TCP IN
- FMS TP
- Guidance Reference (Predicted Trajectory)
- Flight Guidance
- TCI
- Flown Trajectory
- Data Communication
  - Arrival Data
  - Holding Data
  - RTA Data
  - Route translator
  - Holding translator
  - RTA translator
- XML UTOPIA Approach Advice
- XML UTOPIA Holding Advice
- XML UTOPIA RTA Advice
- \( |\text{ETA} - \text{RTA}| > \varepsilon_{\text{funnel}} \)
2. Simulation Environment - Trajectory Data Exchange

- Exchange of trajectory information via **XML** messages
- **Currently** implemented UTOPIA message types
  - Aircraft → Ground (AMAN)
    - Flight Plan (later replaced by FIDL)
    - Track (pseudo message to simulate radar tracking)
    - 4D Trajectory (later replaced by AIDL)
  - Ground (AMAN) → Aircraft
    - administrative purposes (e.g. simulation time)
    - advisories
      - Required Time of Arrival (RTA) at Initial Approach Fix
      - approach transition
      - holding
      - trombone variant and fine tuning
3. Scenario Setup - Control Loop

Air Traffic Simulators: FACT / TABATS

A/C Intent, COU

FPL, Track

Prediction & Monitoring

Spacing, Delay Balance, Stability

Landing Sequence

Advice

Approach, RTA, Holding, Trombone
3. Scenario Setup - Airspace and Traffic

- Frankfurt/Main EDDF
  - ‘Old’ 3 RWY configuration
  - RNAV-Z approaches with ‘trombone’ variations
  - Outer holdings

- Generated traffic is based on CFMU flight data set:
  - EDDF inbound traffic extracted
  - Variations of:
    - Traffic density
    - WTC mix
    - RTA capability
4. Implementation and Simulation Results - Advice Hierarchy

1) Approach and runway
2) RTA if possible
3) Delay absorption in holdings
4) Path stretching with ‘trombones’ and ‘trombone fine tuning’
4. Implementation and Simulation Results - Advice Execution

**Without RTA Advice**

- 07C ACA872 UNON +7 U50 11
- 07C AAL70 UNON +5 09
- 07C DLH1493 KEON +5 07
- 07C DLH3KH PSOS +5 06
- 07C DLH4M PSOS +6 P47 04
- 07C DLH99T PSOS +5 02
- 07C DLH6RW KE1N -- 00
- 07C DLH6MA KE1N +2 59
- 07C BER552P PSOS +1 57
- 07C DLH5P KE2N +1 55
- 07C ALK553 PS1S +2 54
- 07C DLH2UK PSOS 52
- 07C CFG235 UNON +2 50
- 07C DLH2HY KEON 48
- 07C DLH4JH ROON 44
- 07C DLH761 KEON 43
- 07C DLH1461 KEON 41

**With RTA Advice**

- 07C DLH35WV KEON +3 12
- 07C ACA872 UNON +2 10
- 07C AAL70 UNON +2 08
- 07C DLH1493 KEON +1 06
- 07C DLH3KH PSOS +1 05
- 07C DLH4M PSOS 03
- 07C DLH99T PSOS +1 01
- 07C DLH6RW KE1N +1 00
- 07C DLH6MA KEON 58
- 07C BER552P PSOS +2 55
- 07C DLH5P KEON +1 53
- 07C ALK553 PSOS +1 51
- 07C DLH2UK PSOS +2 50
- 07C DLH2HY KEON +1 48
- 07C DLH4JH ROON +2 46
- 07C DLH1461 KE1N +1 45
- 07C DLH761 KEON 43
4. Implementation and Simulation Results - Example Metric

- Scenario: 74 flights
- Flight horizon: 1 hour out
- Simulation time: 4 hours

<table>
<thead>
<tr>
<th>Advice given / Metric</th>
<th>STAR &amp; RWY (reference)</th>
<th>+ Holding &amp; Trombones</th>
<th>+ RTA</th>
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</thead>
<tbody>
<tr>
<td># of Advice</td>
<td>74</td>
<td>360</td>
<td>426</td>
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<tr>
<td>Landings per 15 Minutes</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Average Fuel Usage per Flight</td>
<td>1,84 t</td>
<td>2,37 t</td>
<td>2,30 t</td>
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5. Outlook

- Simulation test bed finished ... Debugging
- Full implementation of wind conditions and evaluation metrics

**Uncertainty** handling:
- Aircraft with reliable (certain) target times get a high priority in arrival sequence
- Aircraft with uncertain target times get a higher degree of freedom in arrival sequence planning
- Introduce flight path adaptations (re-routing) due to convective weather

**Trajectory synchronization:**
- Improve AMAN TP by using aircraft intent information from AIDL messages

**Target:**
- Evaluate effects of weather uncertainty and traffic mixes on the fully automated control loop
Thank you!

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