Using Agent-Based Modelling to Determine Collision Risk in Complex TMA Environments

ICRAT 2018, Castelldefels, 27.06.2018
Motivation - PBN-supported Parallel Approaches

The CRM research project is part of the SESAR Solution PJ.01-03 Thread 1

*Improved parallel approach operations supported by PBN*
Context - Parallel Approaches

- regulated by ICAO Doc. 9643: *Manual on Simultaneous Operations on Parallel or Near-Parallel Instrument Runways (SOIR)*
- parallel dependent or independent operations
- radar vectoring onto straight-in approaches only
- lateral / vertical separation on intercept
**Context** - The CRM Project

- Current regulations are based on risk assessment methods from 1960s
- New concepts require for extended methodologies to assess
  - Safety: Probability of Separation Infringements and Collisions
  - Capacity: Nuisance Breakout Rate
- Baseline Scenario - Final Approach
  - separation constraints on intercept
  - allows for validation via rebuilding of historic scenarios
- Extensions - Complex Operations
  - intercept area and upstream (vectors or PBN to final)
  - more heterogeneous traffic constellations (e.g. RECAT-EU)
  - loosened separation requirements (esp. vertical, e.g. allow efficient CDAs)
Hazard Identification - Final Approach Segment

- Example: The historic *Blunder on Final Approach* Hazard
- Metrics: Rate of TCVs (safety), Nuisance Breakout Rate (capacity)

![Diagram showing deviation from navigation tolerances and examples of correction and worst-case scenarios involving blunders, evaders, wandering aircraft, and NTZ.]
Hazard Identification - Intercept Area

- Extend area under investigation upstream to include intercept of final approach
- Safety Cases:
  - Separation Infringement during Intercept
  - Blunder on Intercept
Agent-Based Monte-Carlo Simulation

- Air Traffic Controller
- Radio
- Surveillance System
- Pilot
- FMS
- Autopilot
- Physical Aircraft Body
- Error Rate
- Stochastic Parameter
- Navigation Tolerances
- Agent
- Reaction Time
- Accuracy

Using Agent-Based Modelling to Determine Collision Risk in Complex TMA Environments
Chair of Air Transport Technology and Logistics // Stanley Förster, Hartmut Fricke, and Markus Vogel
ICRAT 2018, Castelldefels, 27.06.2018
in case slant range falls below threshold (Test Criterion), record a TCV (Test Criterion Violation)

\[ P(TCV) = \frac{N_{TCV}}{2N_{Events}} \cdot P(Blunder) \]

- \( N_{Events} \) - Total number of simulated blunder events
- \( P(Blunder) \) - Probability of a Blunder to occur
**ABMS - Separation Infringement Probability I**

- Combine Agent Simulation with probabilistic risk assessment method
- ABMS generates nominal (ideal) flight paths
- Track deviations are described by probability distributions from statistical analyses of radar data
- Alternatively, use of design criteria, such as RNP-0.3 or RNP-0.1

Source: Thiel C. und H. Fricke, Collision risk on final approach - a radar data based evaluation method to assess safety, ICRAT 2010
**ABMS - Separation Infringement Probability II**

Apply cross-correlation (difference between two random variables) to obtain probability of separation infringement

\[
\forall (m, n) : P_{m,n} = \prod_{d \in x,y,z} P(s_{m,n,d} \leq S_d)
\]

\[
P(s_{m,n,d} \leq S_d) = \int_{-S_d}^{+S_d} \int_{-\infty}^{+\infty} g_{m,d}(u) \cdot g_{m,d}(u + v) \, du \, dv
\]

- **P** - Probability of Separation infringement
- **(m, n)** - aircraft pair on adjacent approach tracks
- **d \in x, y, z** - dimension
- **g_{k,d}** - track deviation distribution of aircraft k in dimension d
- **S_d** - required separation
- **s_{m,n,d}** - distance between aircraft in dimension d
- **u, v** - integration variable, along dimension's axis
Results - The Classic Blunder Scenario I

- Parameter setting extracted from ICAO SOIR document:
  - reduced scenario to 2-dimensional configuration (no information about vertical components)
  - test criterion: 500 ft slant range
  - e.g. speed = 150 kts, overall reaction time = 8s, 1% worst case blunder, etc.
  - some parameters are unknown (e.g. radar position, threshold displacement, final length, etc.)

- ICAO target: 1 TCV per 56 Million approaches \( \approx 1.8 \cdot 10^{-8} \)

- our results: \( \sim 8 \cdot 10^{-9} \)
Results - The Classic Blunder Scenario II

Probability of a TCV per approach vs. number of simulated blunder events
Results - The Classic Blunder Scenario III
Results - The Classic Blunder Scenario IV
**Results - Novel Scenario: Blunder on Intercept I**

Rate of Test Criterion Violations per Approach:

- **vector:** \(< 4.165 \cdot 10^{-12}\)
- **RNP-0.3:** \(< 4.165 \cdot 10^{-12}\)
- **RNP-0.1:** \(< 4.165 \cdot 10^{-12}\)
Results - Novel Scenario: Blunder on Intercept II
Results - Novel Scenario: Separation Infringement I
**Results - Novel Scenario: Separation Infringement II**

![Graphs showing separation infringement probability](../Output/Log/PBN01_ILS_ICPT_NORMOPS_si_prob_last.csv)

![Graphs showing separation infringement probability](../Output/Log/PBN03_ILS_ICPT_NORMOPS_si_prob_last.csv)

![Graphs showing separation infringement probability](../Output/Log/VECT_ILS_ICPT_NORMOPS_si_prob_last.csv)

---

Using Agent-Based Modelling to Determine Collision Risk in Complex TMA Environments
Chair of Air Transport Technology and Logistics // Stanley Förster, Hartmut Fricke, and Markus Vogel
ICRAT 2018, Castelldefels, 27.06.2018

---

**Technische Universität Dresden**

**Dresden Concept**
Conclusion

- Motivation: PBN-supported Parallel Approaches
- Extend historic risk-assessment methodologies for independent parallel approach operations
- Identified Hazards
  - Blundering Aircraft
  - Separation Infringement
- adopt Agent-Based Monte-Carlo Simulation Framework
- investigated exemplary scenarios
Contact

Dipl.-Inf. Stanley Förster
stanley.foerster@tu-dresden.de

TU Dresden
Faculty of Transportation and Traffic Science
“Friedrich List”
Institute of Logistics and Aviation
Chair of Air Transport Technology and Logistics

The CRM project is financed by

Eurocontrol Experimental Centre
c/o Karim Zeghal, Bruno Rabiller