Aircraft Boarding

Data, Validation, Analysis

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Introduction

aerican trajectory, ground operations, boarding

- Aviation System Block Upgrades (ASBU)
  - timeline to implement efficient flight paths

- Trajectory Based Operations (TBO)
  - Global ATM Operational Concept (Doc. 9854)
  - Flight & Flow Information for a Collaborative Environment (FF-ICE Concept, Doc. 9965)
  - need for a System Wide Information Management (SWIM, Doc. 10039)

- Aircraft trajectory (Air-to-Air vs. Gate-to-Gate)
  - A-CDM - milestone concept
  - 4D ground trajectory - turnaround management
  - critical path → Boarding (± 3 min)
Boarding Time

- Boarding time measured in the field
  - 282 events, single aisle aircraft (B737, A320)
  - boarding with 29 - 190 passengers

- Analysis of boarding rate (passenger per time)
  - assumption of slow, medium, fast progress
  - Q-Q plot to differentiate measurements and expected distribution

- Classification of boarding rates
  - linear progress \( y = mx + n \)
    - average \( m = 4.5 \text{ pax/s}, n = 2.3 \text{ min} \)
    - slow \( m = 1.0 \text{ pax/s}, n = 12.3 \text{ min} \)
    - medium \( m = 1.2 \text{ pax/s}, n = 8.2 \text{ min} \)
    - fast \( m = 2.2 \text{ pax/s}, n = 3.5 \text{ min} \)
Aircraft Boarding Model

- Approach (Airbus 320, 29 rows, 174 seats)

- Simulation environment

- ASEP: stochastic approach, grid-based
- operational aspects, e.g. seat load, arrival rates, boarding strategy
- individual passenger behavior
Model Assumptions

- **Problem**: Boarding is owned by the passenger

- Boarding model covers operational reality of airline boarding strategy by:
  - seat load factor of current flight
  - passenger arrival rate at the aircraft
  - one door/ two doors configuration
  - amount of hand luggage
  - passenger conformance to boarding strategy
  - individual passenger behavior (speed, seat shuffle, time to store luggage)
  - passenger group constellation
Boarding Strategies

major boarding strategies
- random
- block
- outside-in

derivative strategies
- reverse pyramid
- optimized block

operational constraints
- 1st class
- conformance rate
- seat load factor
- groups
Validation
arrival rate

• Initial assumption of 14 passengers per minute arrival, equally distributed

• Measurement indicates exponential distribution of inter-arrival times between passengers ($\mu_{\text{time}} = 3.7s$)

• Deboarding is 50% faster than boarding
Validation

hand luggage storage

• Initial assumption: triangular distribution

\[ F(t) = \begin{cases} 
\frac{(t-min)^2}{(max-min)(mode-min)}, & \text{if } min \leq t \leq mode \\
1 - \frac{(max-t)^2}{(max-min)(max-mode)}, & \text{if } mode < t \leq max. 
\end{cases} \]

• 323 values from field trials, Weibull distribution

\[ F(x; \alpha, \beta, x_{\text{min}}) = 1 - e^{-\left(\frac{x-x_{\text{min}}}{\beta}\right)^\alpha} \]

• With \( \alpha = 1.7, \beta = 16.0s, x_{\text{min}} = 0s \)

• Comparison of assumption and field measurements
Validation passenger seat shuffle

• Different kind of seat occupation pattern demands for a specific amount of individual movements

• Assumption: Triangular distribution for single movement (min = 1.8 s, mode = 2.4 s, max = 3.0 s)

• Comparison of assumption and field measurements

  But: only 10 - 15 measurements per category
## Validation

**comparison to prior results**

<table>
<thead>
<tr>
<th>Boarding Strategies</th>
<th>boarding time (%)</th>
<th>standard deviation (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>random</td>
<td>outside-in</td>
</tr>
<tr>
<td>1 door</td>
<td>100.0</td>
<td>80.9</td>
</tr>
<tr>
<td>calibrated</td>
<td>100.0</td>
<td>79.5</td>
</tr>
<tr>
<td>2 doors</td>
<td>74.2</td>
<td>63.8</td>
</tr>
<tr>
<td>calibrated</td>
<td>74.1</td>
<td>62.5</td>
</tr>
<tr>
<td></td>
<td>7.1</td>
<td>5.5</td>
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<tr>
<td>calibrated</td>
<td>7.3</td>
<td>5.7</td>
</tr>
<tr>
<td></td>
<td>4.6</td>
<td>2.9</td>
</tr>
<tr>
<td>calibrated</td>
<td>5.9</td>
<td>5.5</td>
</tr>
</tbody>
</table>
Field Trials (I)

specific boarding strategies

• Field trials with two different scenarios (13 flights)
  • A320/B738 aircraft
  • standard gate position
  • families are not separated

• Comparison of simulation and field measurements

<table>
<thead>
<tr>
<th>Boarding Strategies</th>
<th>Boarding time (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>data</td>
</tr>
<tr>
<td>random</td>
<td>102.6</td>
</tr>
<tr>
<td>airline - S1</td>
<td>94.8</td>
</tr>
<tr>
<td>airline - S2</td>
<td>88.0</td>
</tr>
<tr>
<td>*airline - S2</td>
<td></td>
</tr>
</tbody>
</table>

• Accuracy of the boarding model: ± 5%
Field Trials (II)

**specific boarding strategies**

- Field measurements with 64 trials
  - A320/B738 aircraft
  - one door and two doors configuration
  - seat load factor in three groups:
    - A with 60%-80% (27 flights),
    - B with 80%-90% (20 flights), and
    - C with more than 90% (17 flights)
  - remote, gate, and apron positions
  - passenger classification: tourist, EU, Germany
  - amount of pre-boarding passengers

- **Problem**: too many variations

- Comparison of simulation and field measurements

<table>
<thead>
<tr>
<th>SLF</th>
<th>60% - 80%</th>
<th>80% - 90%</th>
<th>90% - 100%</th>
</tr>
</thead>
<tbody>
<tr>
<td>1door</td>
<td>2doors</td>
<td>1door</td>
<td>2doors</td>
</tr>
</tbody>
</table>

- Diagram showing boarding time regarding to random reference.
Infrastructural Changes

*side-slip seat*

- Staggered seat approach
- Wider aisle enables passengers to pass each other
- Development of appropriate boarding strategy
- Up to 20% savings in boarding time (one door)
New Technology and Procedure – Side-Slip Seat

head-to-head simulation
Summary / Outlook

- Stochastic model covers all **operationally relevant** aspects of aircraft boarding
- Field trials and measurements provide a **solid database for validation**
- Measurements in the field indicate both reliable set of input parameters and **valid simulation approach** (± 5%)

Next steps
- **design of reliable, fast turnaround** for short-haul flights
  - first approach drafted
- **online prediction** of boarding progress for 4D ground trajectory
  - model developed and used as input for deep learning approach
- **dynamic seat allocation** to regain control of the boarding sequence
  - concept developed and already tested at Cologne-Bonn airport
Aircraft Boarding

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