Stochastic Control of Turnarounds at HUB-Airports
A Microscopic Optimization Modell Supporting Recovery Decisions in Day-to-Day Airline Ground Operations

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I. Motivation

- Ground Manager GMAN as an extension of the EUROCONTROL tool chain for collaborative decision making
- Original GMAN concept (Oreschko et al., 2014) considers only single aircraft turnaround and lacks station-wide perspective
- Expansion of the decision support function for multiple parallel turnaround events
- Introduction of control options and scheduling constraints
II. Literature Review

Single Process Modelling through Operational Analyses
- Carr et al. (2005)
- Fricke und Schultz (2009)
- Schlegel (2010)

Stochastic Turnaround Modelling using PERT, Semi-Markov Chains or Monte Carlo Simulation
- Wu and Caves (2004)
- Oreschko et al. (2011-2014)
- Abd Allah Makhloof et al. (2014)
- Antonio et al. (2017)

Modelling of Microscopic Resource Constraints using Scheduling Approaches
- Kuster et al. (2009)
- Norin et al. (2012)
- Padrón et al. (2016)

Pre-tactical Schedule Optimization through Strategic Addition of Buffer Times
- Wu and Caves (2004)
- AhmadBeygi et al. (2010)
- Silverio et al. (2013)
III. Prediction of the Target Off-Block Time

\[ X \sim N(\mu_i, \sigma_i) \]

\[
\begin{align*}
\text{In-Block (IB)} &\quad \text{Acc} \quad \text{N}(2,0.4) \quad \text{Deboarding (DEB)} \quad \text{N}(14,2.8) \quad \text{Unloading (UNL)} \\
\text{Acceptance (ACC)} &\quad \text{PAX Con} \quad \text{N}(2,0.4) \quad \text{Catering (CAT)} \quad \text{N}(10,2.0) \quad \text{Cleaning (CLE)} \\
\text{N}(2,0.4) &\quad \text{Fueling (FUE)} \quad \text{N}(10,2.0) \quad \text{Boarding (BOA)} \quad \text{N}(21,4.2) \quad \text{Finalisation (FIN)} \quad \text{Off-Block (OB)} \\
\end{align*}
\]

\[
\begin{align*}
\text{Water Serv. (WAT)} \\
\text{Toilet Serv. (TOI)}
\end{align*}
\]
III. Prediction of the Target Off-Block Time

1) Analytical Convolution
2) Monte Carlo Simulation

\[ X(\text{TOBT}) \sim ? \]
III. Prediction of the Target Off-Block Time

1) Analytical Convolution

\[ Y_1 = \max(X_{FUE}, X_{CAT}, X_{CLE}) \]

\[ F_{Y_1}(a) = F_{X_{FUE}}(a) \cdot F_{X_{CAT}}(a) \cdot F_{X_{CLE}}(a) \]

\[ f_{Y_1}(a) = F'_{Y_1}(a) = F_{FUE}F_{CAT}F_{CLE} + F_{FUE}f_{CAT}F_{CLE} + F_{FUE}F_{CAT}f_{CLE} \]

\[ F_Z(a) = \int_0^a \int_0^{a-y_1} f_{X_1,Y_1}(x_1,y_1) \, dx_1 \, dy_1 \]

\[ = \int_0^a f_{Y_1}(y_1) \int_0^{a-y_1} f_{X_1}(x_1) \, dx_1 \, dy_1 = \int_0^a f_{Y_1}(y_1) F_{X_1}(a - y_1) \, dy_1 \]

\[ F_M(a) = \int_0^a \int_0^{a-x_3} f_{X_3,Y_2}(x_3,y_2) \, dy_2 \, dx_3 \]

\[ = \int_0^a f_{X_3}(x_3) \int_0^{a-x_3} f_{Y_2}(y_2) \, dy_2 \, dx_3 = \int_0^a f_{X_3}(x_3) F_{Y_2}(a - x_3) \, dx_3 \]
III. Prediction of the Target Off-Block Time

2) Monte Carlo Simulation (10,000 Iterations)

<table>
<thead>
<tr>
<th>Network Path</th>
<th>Mean in min</th>
<th>St.Dev. in min</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 ACC-DEB-FUE-BOA-FIN-OB</td>
<td>46.00</td>
<td>5.12</td>
</tr>
<tr>
<td>2 ACC-DEB-CAT-BOA-FIN-OB</td>
<td>44.00</td>
<td>4.94</td>
</tr>
<tr>
<td>3 ACC-DEB-CLE-BOA-FIN-OB</td>
<td>44.00</td>
<td>4.94</td>
</tr>
<tr>
<td>4 ACC-UNL-LOA-FIN-OB</td>
<td>39.00</td>
<td>4.80</td>
</tr>
<tr>
<td>JP Joint Path Distribution</td>
<td>47.19</td>
<td>4.52</td>
</tr>
</tbody>
</table>

Joint Path Distribution

Graph showing the distribution of time with four paths and a joint path distribution.
IV. Modelling Turnaround Control with RCPSP

Objective Function:

\[ O = D + \sum_{k \in R} R_{D_k} \to m \]

- \( D \): Delay costs
- \( R_{D_k} \): Cost of Recovery Action \( k \)

- Parallelization of Activities
- Process Acceleration through Additional Resources
- Process Acceleration through Reduced Execution
- Acceleration through Link Elimination

\( R_{C_k} \): Cost of Recovery Action \( k \)

Consideration of Resource Sequencing
V. Implementation at a HUB - Airport

<table>
<thead>
<tr>
<th></th>
<th>A320</th>
<th>A320</th>
<th>A320</th>
<th>A320</th>
<th>A330</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ARR</strong></td>
<td>8:15</td>
<td>8:45</td>
<td>9:00</td>
<td>9:25</td>
<td>8:00</td>
</tr>
<tr>
<td><strong>PAX</strong></td>
<td>125</td>
<td>125</td>
<td>125</td>
<td>125</td>
<td>250</td>
</tr>
<tr>
<td>Con PAX</td>
<td>25 to A330</td>
<td>25 to A330</td>
<td>25 to A330</td>
<td>25 to A330</td>
<td>100 (25 to each A320)</td>
</tr>
</tbody>
</table>
V. Implementation at a HUB - Airport

Parameter Definition

- Constant Delay Costs = 100 monetary units (MU) per minute
- Costs for Parallel Fuel-Boarding = 200 MU
- Costs for Quick-Catering = 100 MU
- Costs for Reduced-Cleaning = 100 MU
- Costs per additional Loading Agent = 50 MU
- Costs for Rapid Passenger Transfer = 100 MU
- Costs for Cancelled Connection = 200 MU per Passenger
- Number of Available Catering Vehicles = 8 (5 needed for SOP, 1 per aircraft)
- Number of Available Loading Agents = 20 (15 needed for SOP, 3 per aircraft)
- Number of Available Fire Trucks for Parallel Fuel-Boarding = 1 (Scheduling Constraint)
V. Implementation at a HUB - Airport

Scenario Analysis I

Aircraft 2 (Flight TU003) has (15, 30, 60, 90 min) Arrival Delay – 1000 Iterations uncontrolled and controlled

Off-Block Times Flight TU007 with increasing Arrival Delay

Network Cost with increasing Arrival Delay (Flight TU003)
V. Implementation at a HUB - Airport

Scenario Analysis II

Off-Block Times Flights TU007/010 (90 min Arrival Delay TU003)
VI. Conclusions

- **Stochastic Turnaround Modell** combines stochastic TOBT prediction and deterministic optimization
- Output of **stochastic TOBT** (uncontrolled and controlled), **network cost comparison** (uncontrolled and controlled) and **set of optimal recovery actions** (with probabilities)
- Opportunities to standardize turnaround control and avoid conflicting controller clearances

Further Research

- **Expansion of the Modell Scope**
  - Further Airport Control Options (Gate Dependency, Crew Exch., Delcing Sequence)
  - Further Network Control Options
  - Delay Propagation and Interaction in HUB-Networks

- **Methodological Expansion**
  - Sensitivity Analysis of Process Parameters (Non-Normal Time Distributions)
  - Introduction of Chance Constraints
  - Introduction of Qualitative Measurements for Control Options
Thank you for your attention

Gefördert durch:

aufgrund eines Beschlusses des Deutschen Bundestages
Recap – Time for Questions

- **Stochastic Turnaround Modell** combines stochastic TOBT prediction and deterministic optimization
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