Integrating optimization and simulation to gain more efficient airport logistics

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Background

- The air transportation system
  - large and complex
  - time critical processes
  - different actors with contradicting objectives
- The airport is a bottleneck in the air transportation system
- Collaborative decisions making (CDM) creates a common ground for the actors
- CDM gives a growing amount of information that leads to mounting complexity in the decision making process
- Additional support is needed for decision making
Airport Logistics

- The vision with airport logistics is to develop a complete picture of all processes and activities at and around the airport.
  - Interaction and impact

- Analyze the usage of all resources at the airport to find solutions optimal for the entire airport, rather than solutions optimized for an individual actor.
The air transportation system

- **Value Flows**
  - Passengers and baggage
  - Cargo

- **Major support flows**
  - Aircraft
  - Crew

- **Minor support flows**
  - Fuel trucks
  - De-icing trucks
  - Cleaning crews
  - Catering
  - Etc.
The turn-around process

Turn-around services

A network flow problem
Integrating optimization and simulation

- A first step to prove the concept
- Simulation model of the turnaround process
- Optimization algorithm for scheduling de-icing trucks
Conceptual simulation model

- TA-resources in service pools
- Simplifications
  - Cleaning and catering can always be performed simultaneously
  - Fuelling can always be performed after boarding
  - Fuelling can not be performed simultaneously as baggage handling
  - Water is not always performed before sanitation in the simulation
De-icing

- At Stockholm Arlanda, between October and April
- Step 1: De-ice with Type 1 fluid
- Step 2: Anti-ice with Type 2 fluid
- Hold-over time: from anti-ice to take-off
  - Gives a tight time window for service
- Planning today
  - Tactical based on weather and flight schedule
  - Operational based on pilot request
Scheduling de-icing trucks

- A schedule is constructed before the day of operations
  - Truck schedule based on a flight schedule
  - Each truck will get a number of departing flights to serve

- Multiobjective
  - Minimize the departure \textit{delay} that the de-icing trucks are causing
  - Minimize the \textit{distance} travelled by the de-icing trucks
Min \[ \sum_{i=0}^{N} \sum_{j=0, j \neq i}^{N} \sum_{k=1}^{K} \sum_{r=1}^{R} (a \cdot l_i + b \cdot w_{ij} x_{ij}^{kr}) \] \[ a = 1, b = 0.5 \]

s.t. \[ \sum_{i=1}^{N} x_{ih}^{kr} - \sum_{j=1}^{N} x_{hj}^{kr} = 0 \]
\[ \sum_{j=0}^{N} \sum_{k=1}^{K} \sum_{r=1}^{R} x_{ij}^{kr} = 1 \]
\[ \sum_{i=1}^{N} \sum_{j=1}^{N} d_{ij} x_{ij}^{kr} \leq q_k \]
\[ t_{i} + s + f_{i} + w_{j} - M \cdot (1 - x_{ij}^{kr}) \leq t_{j} \]
\[ p_{i} \geq t_{i} + s + f_{i} \]
\[ p_{i} \geq STD_{i} \]
\[ l_{i} \geq t_{i} + s + f_{i} - STD_{i} \]

\[ h \in \{0,...,N\}, \quad k \in \{1,...,K\}, \quad r \in \{1,...,R\} \]
\[ t_{m}^{stop} + f_{0} - M \cdot (1 - z_{mn}^{k}) \leq t_{n}^{start} \]
\[ z_{mn}^{k} \geq x_{i0}^{kn} + x_{0j}^{kn} - 1 \]
\[ t_{r}^{stop} \geq p_{j} + w_{j0} - M \cdot (1 - x_{j0}^{kr}) \]
\[ 0 \leq t_{r}^{start} \leq t_{j} - w_{0i} + M \cdot (1 - x_{0i}^{kr}) \]
\[ t_{i} \geq 0, \quad p_{i} \geq 0, \quad l_{i} \geq 0 \]

\[ m, n \in \{1,...,R\}, \quad k \in \{1,...,K\}, \quad n \geq m, \quad k \in \{1,...,K\} \]
\[ i, j \in \{0,...,N\} \]
\[ j \in \{1,...,N\}, \quad k \in \{1,...,K\}, \quad r \in \{1,...,R\} \]
\[ i \in \{1,...,N\}, \quad k \in \{1,...,K\}, \quad r \in \{1,...,R\} \]
\[ i \in \{1,...,N\} \]

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Computational results

- The de-icing scheduling problem is solved using a GRASP heuristic

<table>
<thead>
<tr>
<th>Solution</th>
<th>Traveling time [minutes]</th>
<th>Delay [minutes]</th>
</tr>
</thead>
<tbody>
<tr>
<td>GWOAC</td>
<td>842</td>
<td>340 270</td>
</tr>
<tr>
<td>GRASP 1</td>
<td>1020</td>
<td>295</td>
</tr>
<tr>
<td>GRASP 2</td>
<td>1066</td>
<td>207</td>
</tr>
</tbody>
</table>
Integrating de-icing schedules in the turn-around simulation model

- Schedule conditions
  - Additional delays due to other services, arrival time delay etc.
  - Other process times and fluid requirements
- Simulation scenarios
  1. No de-icing
  2. De-icing based on first-go-first-served
  3. De-icing based on GRASP1
  4. De-icing based on GRASP2
## Computational results

| Scenario | Touch down | | | | | | Stand | | | | | | Off block | | | | | |
|---------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
|         | Percentage delay | Max delay | Average delay | Percentage delay | Max delay | Average delay | Percentage delay | Max delay | Average delay | Percentage delay | Max delay | Average delay |
| Scenario 1 | 19% | 3 min | 44 sec | 1% | 7 min | 4 min | 8% | 14 min | 5 min |
| Scenario 2 | 19% | 3 min | 42 sec | 2% | 10 min | 5 min | 27% | 32 min | 8 min |
| Scenario 3 | 19% | 3 min | 42 sec | 1% | 7 min | 3 min | 26% | 43 min | 7 min |
| Scenario 4 | 19% | 3 min | 42 sec | 1% | 7 min | 3 min | 24% | 20 min | 6 min |

### De-icing

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Percentage waiting</th>
<th>Max waiting time</th>
<th>Average waiting time</th>
<th>Total waiting time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scenario 1</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Scenario 2</td>
<td>23%</td>
<td>40 min</td>
<td>13 min</td>
<td>1181 min</td>
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<tr>
<td>Scenario 3</td>
<td>21%</td>
<td>47 min</td>
<td>10 min</td>
<td>808 min</td>
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<tr>
<td>Scenario 4</td>
<td>18%</td>
<td>33 min</td>
<td>9 min</td>
<td>646 min</td>
</tr>
</tbody>
</table>
Future Research

- Optimization and integration of other turn-around services
- Extend and refine the simulation model
  - Final approach, taxiing and take-off
- Make the decision support tools useful for operational planning and control