Merging Flow and Optimizing Aircraft Scheduling in TMA based on GA

*Akinori Murata, **Daniel Delahaye and* Keiki Takadama

*The University of Electro-Communications
**Ecole Nationale de l’Aviation Civile
Background

Air traffic demand is increasing.

Airport is one of bottlenecks of air traffic.

Air traffic controller have high cognitive load.

In Terminal Maneuvering Area (TMA),
• A lot of conflicts occurs in a high possibility.
Route topology

Point Merge topology [Boursier 2008]

Runway

Merge Point

Sequencing legs

Direct-to instruction

[Good]
• Easy to understand for controllers

[Bad]
• Occupying a large space
Objective: effectiveness of sub-route topology in complex env. and order change of aircraft


[Good]
• Easy to design the topology

[Bad]
• No order change of aircraft

Objective: effectiveness of sub-route topology in complex env. and order change of aircraft
Conventional method [Zuniga 2011]

**Optimization**
- **GA** Genetic Algorithm
- Finding aircraft speed and sub-route
- Repeating

**Simulation**
- Evaluation (total conflict)
- Fitness (total delay)
Conventional method: optimization phase

Genetic Algorithm

Population

Individual

Individual

Individual

Individual

Individual

Individual

Genetic operator (Crossover, Mutation)
Selection

Individual

Aircraft_1 | Aircraft_2 | ... | Aircraft_N
\hline
\(\alpha_1\) | \(v_1\) | \(\alpha_2\) | \(v_2\) | ... | ... | \(\alpha_n\) | \(v_n\)

\(\alpha_i\): parameter of sub-route
\(v_i\): speed of aircraft
Conventional method: optimization phase

Population (g)
- Individual
- Individual
- Individual
- Individual
- Individual
- Individual
- Individual
- Individual

Selection
- Individual

Population (g+1)
- Individual
- Individual
- Individual
- Individual
- Individual
- Individual
- Individual

Crossover
- Individual

Mutation
- Individual

New candidate
- Individual
Conventional method: Optimization phase

Individual design
Population

Individual
Individual
Individual
Individual
Individual
Individual

Some candidates including aircraft parameters

<table>
<thead>
<tr>
<th>Individual</th>
<th>Aircraft_1</th>
<th>Aircraft_2</th>
<th>...</th>
<th>Aircraft_N</th>
</tr>
</thead>
</table>

(1) Data of aircraft
- Size_(H,M,S)
- Initial Speed
- Time at entry point

(2) Target of GA
- Sub-route parameter (0-1)
- Regulated speed

(3) Evaluation of aircraft
- Total conflicts
- Schedule delay
Conventional method: Simulation phase

**Input**

\[
\begin{align*}
\alpha_4 & \quad v_4 \\
\alpha_3 & \quad v_3 \\
\alpha_2 & \quad v_2 \\
\alpha_1 & \quad v_1
\end{align*}
\]

**Simulation**

Calculating delay and the total conflicts

Decreasing aircraft speed

\[
\text{Fitness} = \sum_{i=1}^{N} (t_i - ETA_i)
\]
Conventional method: Sub-route design

Individual

<table>
<thead>
<tr>
<th>$\alpha_1$</th>
<th>$v_1$</th>
<th>$\alpha_2$</th>
<th>$v_2$</th>
<th>...</th>
<th>$\alpha_n$</th>
<th>$v_n$</th>
</tr>
</thead>
</table>

$\alpha_i$: parameter of sub-route

$\nu_i$: speed of aircraft

$k$-th sub-route

$\alpha_1 = 1$

$\nu_1$

Aircraft fly along a dotted line
Conventional method: Conflict detection

Conventional method

Checking node and link

Node = waypoint
Link = route

Conventional method cannot position shift from same entry point
Proposed method: Sub-route design

- Limited to shift the position for landing sequence
- Only fixed candidates of sub-route
- More flexible to fly
Proposed method: sub-route selection

Parameter $\alpha$ $[0 \leq \alpha \leq 1]$)

- $\alpha=0$
- $\alpha=1$

Delaying schedule

Parameter $\alpha$: continuous value
- Sub-route makes the schedule more flexible
Proposed method: Conflict detection

Conventional method cannot detect conflict including position shift

Detecting conflicts every time
Experiment

- Environment
  - Charles de Gaulle Airport

- Case (Situation)

<table>
<thead>
<tr>
<th>Total aircraft</th>
<th>29(M,H)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total schedule</td>
<td>60 min</td>
</tr>
</tbody>
</table>

Aircraft speed

\[ v_i' = v_i(1 + \Delta v), \Delta v \in \psi \]
\[ \psi \in [-20\%,5\%] \]

- Evaluation Criteria
  - Total conflicts
  - Total delay
Environment: Overview
Environment: Modeling

Standard terminal arrival route in Charles de Gaulle Airport
Environment: Sub-route

1

2

3

4

5
Experiment setting

Constraints: Minimum separation

<table>
<thead>
<tr>
<th>Trailing aircraft</th>
<th>Heavy</th>
<th>Medium</th>
<th>Light</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heavy</td>
<td>4</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Medium</td>
<td>5</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Light</td>
<td>6</td>
<td>4</td>
<td>3</td>
</tr>
</tbody>
</table>

Parameter Setting

<table>
<thead>
<tr>
<th>parameter</th>
<th>value</th>
</tr>
</thead>
<tbody>
<tr>
<td>population size</td>
<td>100</td>
</tr>
<tr>
<td>generation</td>
<td>500</td>
</tr>
<tr>
<td>crossover rate</td>
<td>1</td>
</tr>
<tr>
<td>mutation rate $P_{Ms}$</td>
<td>0.8</td>
</tr>
<tr>
<td>trial</td>
<td>10</td>
</tr>
</tbody>
</table>

mutation rate $P_{Md}$ 0.3
Experimental result

<table>
<thead>
<tr>
<th>Number of aircraft without detour</th>
<th>14.7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average delay of schedule</td>
<td>79.3 s</td>
</tr>
<tr>
<td>Maximum delay</td>
<td>240 s</td>
</tr>
<tr>
<td>Maximum speed change</td>
<td>23.7 Nt</td>
</tr>
<tr>
<td>Minimum speed change</td>
<td>-93.9 Nt</td>
</tr>
</tbody>
</table>
Experimental result

Without our method

With our method
Conclusion

• Background
  • Importance: Merging aircrafts without conflicts and optimizing their landing sequence
  • Proposed method: flexible sub-route and optimization method based on GA

• Implication
  • Successfully merge all aircrafts without conflicts

• Future work
  • Compared with another method
  • Improving simulation procedure
  • Combination of route topology to increase runway throughput