Feasibility Analysis of Aircraft Landing Scheduling for Non-Controlled Airports

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Overview

- Motivations and background

- Research objectives
  - Problem Statement
  - Modeling
  - Methodologies

- Evaluation
  - Flight Simulation
  - Enhancements for this research

- Summary and future work
aircraft scheduling will become the key operational issue at non-controlled airports as the operation volume keeps increasing in the near future. Therefore, the ATC automation system of the non-controlled airport mainly tries to improve the performance of aircraft scheduling.
Small Aircraft Transportation System (SATS)

Expanded Accessibility to several times more destinations

Airports today with “near all weather” availability

Of 5,400 public-use airports, only 715 (13%) have precision instrument approaches (ILS),

5,400 Public Use Airports

Near all-weather accessibility to 5,400 public-use airports?

- 22% within 30 minutes of major/hub airport
- 41% within 30 minutes of any commercial airport
- 93% of population within 30 minutes of SATS-type airport

Ref. SATS program briefing charts
What SATS Does

The SATS concept seeks to achieve:

- *Higher Volume Operations at Non-Controlled Airports*
- Lower Landing Minimums at Minimally Equipped Landing Facilities
- Increased Single-Pilot Crew Safety & Mission Reliability
- En Route Procedures & Systems for Integrated Fleet Operations

Auto Aircraft Landing Scheduling

Aircraft “Highway-in-the-Sky”
Research Overview

Objective:
• Analyze optimal aircraft landing scheduling for non-controlled airports for improved operations

Approach:
• Define aircraft landing scheduling model
  • Constraints
  • Special features of aircraft landing scheduling at non-controlled airports
  • Objective functions
  • Scheduling point

• Compare two aircraft landing scheduling algorithms
• Enhance existing simulation methodologies and run a variety of test scenarios
• Analyze results
Basic Problem Statement

Goal:
- For a sequence of aircraft, determine landing time on a single runway, such that each aircraft lands within its predetermined landing time window, with assured separation criterion between landings.

Issues:
- Incur extra cost penalty if not landing at preferred landing time
- Separation criterion assurance:
  The landing time of an aircraft and each successive aircraft must be greater than a specified minimum, referred as landing separation time

Variation in cost for an aircraft within its landing time window
Aircraft Landing Scheduling Model

Constants:
- \( N = \text{the number of aircraft} \)
- \( E_i = \text{the earliest landing time for aircraft } i \) \( i = 1, \ldots, N \)
- \( L_i = \text{the latest landing time for aircraft } i \) \( i = 1, \ldots, N \)
- \( P_i = \text{the preferred landing time for aircraft } i \) \( i = 1, \ldots, N \)
- \( S_{ij} = \text{the separation time requirement between aircraft } i \text{ and } j \), where aircraft \( i \) lands before aircraft \( j \). \( i = 1, \ldots, N, j = 1, \ldots, N, i \neq j \)
- \( f_i = \text{the penalty cost per unit of time if aircraft } i \text{ lands before the preferred landing time } P_i \) \( i = 1, \ldots, N \)
- \( g_i = \text{the penalty cost per unit of time if aircraft } i \text{ lands after the preferred landing time } P_i \) \( i = 1, \ldots, N \)

Variables:
- \( x_i = \text{the landing time for aircraft } i \) \( i = 1, \ldots, N \)
- \( b_i = \text{how soon aircraft } i \text{ lands before } P_i \) \( i = 1, \ldots, N \)
- \( a_i = \text{how soon aircraft } i \text{ lands after } P_i \) \( i = 1, \ldots, N \)
- \( \delta_i = \begin{cases} 1 & \text{if aircraft } i \text{ lands before aircraft } j \\ \delta_{ij} & \text{if } i = 1, \ldots, N, j = 1, \ldots, N, i \neq j \\ 0 & \text{otherwise} \end{cases} \)

Constraints:

\[ E_i \leq x_i \leq L_i \quad i = 1, \ldots, N \] \hspace{1cm} (1)

\[ \delta_{ij} + \delta_{ji} = 1 \quad i = 1, \ldots, N; j = 1, \ldots, N; i \neq j \] \hspace{1cm} (2)

\[ x_i + S_{ij} \delta_{ij} - (L_i - E_j) \delta_{ji} \leq x_j \]
\[ i = 1, \ldots, N; j = 1, \ldots, N; i \neq j \] \hspace{1cm} (3)

\[ \text{Max}(0, P_i - x_i) \leq b_i \leq P_i - E_i \quad i = 1, \ldots, N \] \hspace{1cm} (4)

\[ \text{Max}(0, x_i - P_i) \leq a_i \leq L_i - P_i \quad i = 1, \ldots, N \] \hspace{1cm} (5)

\[ x_i = P_i - b_i + a_i \quad i = 1, \ldots, N \] \hspace{1cm} (6)
What is a Non-Controlled Airport?

Generally, a non-controlled airport is an airport without an operations tower and terminal radar facilities. It is surrounded by class G airspace.
Aircraft Landing Scheduling Model
SATS is procedure based

Current paradigm:
One-in/One-out

Multiple Operations Procedures

Special approach procedures: vertical entry and lateral entry
Aircraft Landing Scheduling Model

Objective functions:

- Standard objective function: minimize Total Cost of Deviation (TCD) from the preferred landing time.

\[
\text{Minimize } \sum_{i=1}^{N} (f_i b_i + g_i a_i)
\]

- Customized objective function for SATS HVO case: minimize Total Holding Time (THT). The holding time for one aircraft is the time from when it arrives at the IAF until it can begin its approach. The THT is the sum of the holding times for all aircraft in the scenario.

Scheduling point:

- An actual point in time or space. It can be the origination airport from which an aircraft departs, or the boundary of Center airspace.
- In this research project, the time when the first aircraft in each test scenario reaches the waypoint that is 20 nautical miles to its assigned IAF.
Aircraft Landing Scheduling Algorithms

First Come First Served (FCFS) scheduling:
- Baseline algorithm.
- No specified objective function in the FCFS scheduling model.
  1. First aircraft that hits the scheduling point gets the first slot.
  2. Aircraft that is next nearest to the scheduling point gets the second slot.
  3. And so on.

Optimal scheduling:
- Proposed algorithm.
- Uses two specified objective functions (TCD and THT) in the scheduling model.
- In this research, it is solved two different ways:
  - Linear programming problem
  - Job shop problem
Aircraft Landing Scheduling Algorithms
Optimal scheduling algorithms

Problem statement:
• Linear programming problem: Minimize $z(x) = c_1x_1 + ... + c_nx_n$
  subject to
  $a_{11}x_1 + ... + a_{1n}x_n \geq b_1$
  ...
  $a_{m1}x_1 + ... + a_{mn}x_n \geq b_m$
  $x_i \geq 0$ for $i = 1, ..., n.$

• Job shop scheduling problem: $1/E_i/seq - dep/\sum w_i e_i$

Solution methods:
• Simplex algorithm
• Branch-and-bound algorithm
• Tree search algorithm

Intelligently enumerate all the feasible solutions

Flow chart of simplex algorithm
Real-Time Simulation Facility

- Nonlinear, 6-DOF Commander 700; AV-8A Harrier, F-5A Freedom Fighter
  - SGI Onyx Reality II sim engine
  - Networked bank of PC’s
  - Center stick; sidestick
- 155° projected field of view
  - 30 Hz refresh rate
- Programmable Head Up Display
Real-Time Simulation Facility

- **Head Down Displays (HDD)**
  - Reconfigurable
  - CRT; touchscreen LCD

- **Autopilot**
  - Glide slope capture
  - Heading
  - Altitude
  - Pitch attitude

- **Flight Management System (FMS)**
  - Jeppesen data base
  - Pre-flight planning and enroute updating
  - Moving map display
## Experiment Design

### Detailed information of a test scenario

<table>
<thead>
<tr>
<th>Aircraft Type</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
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<td>Flight ID</td>
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<td>N865CP</td>
<td>N700AE</td>
<td>N3998Z</td>
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<td>Latitude</td>
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<td>Altitude</td>
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<td>5000(FT)</td>
<td>6000(FT)</td>
<td>4000(FT)</td>
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<td>107(DEG)</td>
<td>144(DEG)</td>
<td>205(DEG)</td>
<td>225(DEG)</td>
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<td>Planned IAF</td>
<td>RAZVY</td>
<td>RAZVY</td>
<td>LOUIE</td>
<td>LOUIE</td>
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<td>Distance to IAF</td>
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<td>Cruise Airspeed</td>
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<td>125 (KNTS)</td>
<td>150(KNTS)</td>
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<td>Hold Airspeed</td>
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<td>Approach Airspeed</td>
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Numerical Results

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Number of aircraft</th>
<th>FCFS solution TCD</th>
<th>Optimal solution TCD</th>
<th>FCFS solution THT (minutes)</th>
<th>Optimal solution THT (minutes)</th>
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</tbody>
</table>

Compared with FCFS scheduling, optimal scheduling is seen to:

- Decrease TCD by an average of 56.3%
- Decrease THT by an average of 59.3%

FCFS is the optimal solution when FCFS scheduling happens to obtain the optimal sequence (Scenario 6)
Summary and Future Work

Summary:
• Described the basic problem of aircraft landing scheduling
• Established aircraft landing scheduling model for the single runway case at non-controlled airports
• Designed a feasibility analysis using various scheduling algorithms
• Conducted flight simulation and presented numerical results

Results:
• Optimal algorithms show promise, based on measures of merit.

Future Work:
• Developing solution approaches capable of dealing with:
  • Other objective functions
  • Runway throughput
  • Dynamic issues
• Decisions about landing times vary according to situation changes.