How do you board a 150 seat airplane in less than 15 minutes?

Group boarding helps speed up the boarding process

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Outline

1. Motivation
2. Airplane boarding
3. Modeling airplane boarding
4. Simulating airplane boarding
5. Implementation
6. Conclusions
What is the turn time of an airplane?

- **Turn time**
  - Usually measured by the time between two consecutive flights that an airplane spends on the ground
  - One of the metrics used by commercial airlines to measure efficiency of their operations
How faster turn time improves profits

Faster turn time

More flights annually

More paying passengers annually

More profit for the airline
Factors that affect turn time

- Turn time includes
  - Passenger boarding and debarking
  - Cargo loading and unloading
  - Airplane fueling
  - Cabin cleaning and galley servicing

- “One of the key elements of turn time: passenger boarding”
  - S. Marelli, G. Mattocks, R. Merry, The Boeing Company
  - Source: http://www.boeing.com/commercial/aeromagazine/aero_01/textonly/t01txt.html
Reducing passenger boarding time

- **Expected improvements for the airline**
  - Faster turn time
  - Better aircraft/crew utilization
  - Higher revenues

- **Expected improvements for the passengers**
  - Faster boarding times
  - Better on-time performance
  - Higher customer satisfaction
Examples of boarding strategies

- **Traditional boarding strategies**
  - Passengers are assigned to seats
  - Board all passengers together or board by calling out row numbers

- **Group boarding strategies**
  - Seats (passengers) are assigned to groups
  - Board passengers by calling out group numbers

- **Unassigned seating boarding strategies**
  - Passengers are not assigned to a seat and can choose a seat whenever they board the airplane
Model objectives

- **Objective**
  - Minimizing average total boarding time
- **But...**
  - How to determine the number of groups?
  - How to determine group size?
  - How to determine group composition?
Modeling airplane boarding

- Considerations
  - A320 layout (3 seats on each side of the aisle)
  - Economy class (23 rows)

- Assumptions
  - Maximum passenger load
  - Single parties only
  - All passengers board in their assigned group
Model issues

- Explicitly including time related parameters tends to increase the complexity of the model
  - Surrogate metric for time: expected passenger interference

- Passenger interference
  - Event where a passenger blocks the free flow of another passenger moving from the boarding gate to their seat

Minimizing total expected interferences =? Minimizing total boarding time
Passenger interference

Seat interference
A passenger (1A) tries to get to a seat near the window (1B) but is obstructed by another passenger already seated near the aisle.

Aisle interference
A passenger (2A) tries to reach his seat further down the aisle (2B) but is obstructed by other passengers trying to find their seats or stow their luggage.
Seat interferences (known)
Seat interferences (probabilistic)
Aisle interferences
Notation

- $x_{ijk} = \begin{cases} 1 & \text{if seat } (i,j) \text{ is assigned to group } k \\ 0 & \text{otherwise} \end{cases}$

- $N = \{1,2,\ldots, n\}$ Set of rows

- $M = \{A, B, C, D, E, F\}$ Set of seats

- $G = \{1,2,\ldots, g\}$ Set of groups

- $\lambda^s$ Penalty for seat interferences

- $\lambda^a$ Penalty for aisle interferences
Model objective (seat interferences)

- **Objective**

\[
\begin{align*}
\lambda^s_1 \sum_{i \in N} \sum_{k \geq G} x_{iAk} x_{iBk} x_{iCl} + \lambda^s_1 \sum_{i \in N} \sum_{k \geq G} x_{iFk} x_{iEk} x_{iDk} + \\
\lambda^s_2 \sum_{i \in N} \sum_{k \leq G < k} x_{iAk} x_{iBk} x_{iCl} + \lambda^s_3 \sum_{i \in N} \sum_{k \leq G < k} x_{iAk} x_{iBk} x_{iCk} + \lambda^s_4 \sum_{i \in N} \sum_{k \leq G < k} x_{iAk} x_{iBk} x_{iDk} + \\
\lambda^s_5 \sum_{i \in N} \sum_{k \leq G < k} x_{iFk} x_{iEk} x_{iDl} + \lambda^s_6 \sum_{i \in N} \sum_{k \leq G < k} x_{iFk} x_{iEk} x_{iCk} + \lambda^s_7 \sum_{i \in N} \sum_{k \leq G < k} x_{iFk} x_{iEk} x_{iDk} + \\
\lambda^s_8 \sum_{i \in N} \sum_{k \leq G < k} x_{iAk} x_{iBk} x_{iCm} + \lambda^s_9 \sum_{i \in N} \sum_{k \leq G < k} x_{iAk} x_{iBk} x_{iCk} + \lambda^s_{10} \sum_{i \in N} \sum_{k \leq G < k} x_{iAm} x_{iBk} x_{iCk} + \\
\lambda^s_{11} \sum_{i \in N} \sum_{k \leq G < k} x_{iAk} x_{iBk} x_{iCl} + \lambda^s_{12} \sum_{i \in N} \sum_{k \leq G < k} x_{iAk} x_{iBk} x_{iCl} + \\
\lambda^s_{13} \sum_{i \in N} \sum_{k \leq G < k} x_{iFk} x_{iEk} x_{iDl} + \lambda^s_{14} \sum_{i \in N} \sum_{k \leq G < k} x_{iFk} x_{iEk} x_{iDl} + \lambda^s_{15} \sum_{i \in N} \sum_{k \leq G < k} x_{iFk} x_{iEk} x_{iDl} + \\
\lambda^s_{16} \sum_{i \in N} \sum_{k \leq G < k} x_{iFk} x_{iEk} x_{iDl} + \lambda^s_{17} \sum_{i \in N} \sum_{k \leq G < k} x_{iFk} x_{iEk} x_{iDl} + \lambda^s_{18} \sum_{i \in N} \sum_{k \leq G < k} x_{iFk} x_{iEk} x_{iDl}.
\end{align*}
\]
## Expected seat interference

<table>
<thead>
<tr>
<th>Passenger order</th>
<th>E(SI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st window</td>
<td>0</td>
</tr>
<tr>
<td>2nd middle</td>
<td>1</td>
</tr>
<tr>
<td>3rd aisle</td>
<td>2</td>
</tr>
<tr>
<td>window</td>
<td>2</td>
</tr>
<tr>
<td>middle</td>
<td>3</td>
</tr>
</tbody>
</table>

### Penalty

<table>
<thead>
<tr>
<th>Penalty</th>
<th>Passenger order</th>
<th>E(SI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\lambda^s_1$</td>
<td>[window, middle, aisle]</td>
<td>1.5</td>
</tr>
<tr>
<td>$\lambda^s_2$</td>
<td>[window, middle] → [aisle]</td>
<td>0.5</td>
</tr>
<tr>
<td>$\lambda^s_3$</td>
<td>[window, aisle] → [middle]</td>
<td>1.5</td>
</tr>
<tr>
<td>$\lambda^s_4$</td>
<td>[middle, aisle] → [window]</td>
<td>2.5</td>
</tr>
<tr>
<td>$\lambda^s_5$</td>
<td>[window] → [middle, aisle]</td>
<td>0.5</td>
</tr>
<tr>
<td>$\lambda^s_6$</td>
<td>[middle] → [window, aisle]</td>
<td>1.5</td>
</tr>
<tr>
<td>$\lambda^s_7$</td>
<td>[aisle] → [window, middle]</td>
<td>2.5</td>
</tr>
<tr>
<td>$\lambda^s_8$</td>
<td>[window] → [aisle] → [middle]</td>
<td>1</td>
</tr>
<tr>
<td>$\lambda^s_9$</td>
<td>[middle] → [window] → [aisle]</td>
<td>1</td>
</tr>
<tr>
<td>$\lambda^s_{10}$</td>
<td>[middle] → [aisle] → [window]</td>
<td>2</td>
</tr>
<tr>
<td>$\lambda^s_{11}$</td>
<td>[aisle] → [window] → [middle]</td>
<td>2</td>
</tr>
<tr>
<td>$\lambda^s_{12}$</td>
<td>[aisle] → [middle] → [window]</td>
<td>3</td>
</tr>
</tbody>
</table>
Model objective (aisle interferences)

\[ \lambda_1 \sum_{i \in N} \sum_{u,v \in L} \sum_{k \in G} x_{iuk} x_{ivk} + \lambda_4 \sum_{i \in N} \sum_{u,v \in R} \sum_{k \in G} x_{iuk} x_{ivk} + \]

\[ 2\lambda_2 \sum_{i \in N} \sum_{u,v \in M} \sum_{k \in G} x_{iuk} x_{ivk} + \]

\[ \lambda_3 \sum_{a,b \in N; a < b} \sum_{u,v \in M} \sum_{k \in G} x_{aux} x_{bvk} \]

\[ \lambda_4 \sum_{i \in N} \sum_{u,v \in M} \sum_{k \in G; k < l} x_{iuk} x_{ivl} + \lambda_4 \sum_{i \in N} \sum_{u,v \in R} \sum_{k \in G; k < l} x_{iuk} x_{ivl} + \]

\[ \lambda_5 \sum_{i \in N} \sum_{u,v \in M; u \in L} \sum_{k \in G; k < l} x_{iuk} x_{ivl} + \lambda_2 \sum_{i \in N} \sum_{u,v \in M; u \in L} \sum_{k \in G; k < l} x_{iuk} x_{ivl} + \]

\[ \lambda_6 \sum_{a,b \in N; a < b} \sum_{u,v \in M} \sum_{k \in G; k < l} x_{aux} x_{bvl} \]

(2a)  (2b)  (2c)  (2d)  (2e)  (2f)
## Expected aisle interference

<table>
<thead>
<tr>
<th>Penalty</th>
<th>Description</th>
<th>$E(AI)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\lambda_1^a, \lambda_2^a, \lambda_3^a$</td>
<td>Winthin groups</td>
<td>$1/g_i$</td>
</tr>
<tr>
<td>$\lambda_4^a, \lambda_5^a, \lambda_6^a$</td>
<td>Between groups</td>
<td>$1/(g_i g_{i+1})$</td>
</tr>
</tbody>
</table>

Diagram (not provided in text).
Model constraints

- Subject to

\[ \sum_{k \in G} x_{ijk} = 1 \] for all \( i \in N, j \in M \) \hspace{1cm} (3)

\[ \sum_{i \in N} \sum_{j \in M} x_{ijk} = g_k \] for all \( k \in g \) \hspace{1cm} (4)

\[ x_{ijk} \in \{0,1\} \] for all \( i \in N, j \in M, k \in g \) \hspace{1cm} (5)
Boarding strategies

<table>
<thead>
<tr>
<th>BF6</th>
<th>BF5</th>
<th>BF4</th>
<th>BF3</th>
</tr>
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<table>
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Back-to-front

Outside-in
## Computational results

<table>
<thead>
<tr>
<th>Seat Interferences</th>
<th>BF6</th>
<th>BF5</th>
<th>BF4</th>
<th>BF3</th>
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<tr>
<td>OI3</td>
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<table>
<thead>
<tr>
<th>Aisle Interferences</th>
<th>87</th>
<th>85</th>
<th>83</th>
<th>81</th>
<th>78.68</th>
<th>78.41</th>
<th>78.04</th>
<th>78.68</th>
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<tbody>
<tr>
<td>Within groups</td>
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<tr>
<td>Same row same side</td>
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<td>9</td>
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<td>7</td>
<td>6</td>
<td>5</td>
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<tr>
<td>Different rows</td>
<td>58</td>
<td>61</td>
<td>64</td>
<td>67</td>
<td>68</td>
<td>69</td>
<td>70</td>
<td>69.67</td>
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<tr>
<td>Between groups</td>
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<td></td>
</tr>
<tr>
<td>Same row same side</td>
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<td>0</td>
<td>0</td>
<td>0</td>
<td>0.06</td>
<td>0.06</td>
<td>0.04</td>
<td>0.02</td>
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<td>0.06</td>
<td>0.06</td>
<td>0.04</td>
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<td>Different rows</td>
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<td>1</td>
<td>2.56</td>
<td>2.29</td>
<td>1.96</td>
<td>1.31</td>
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<tr>
<td>Total interferences</td>
<td>159</td>
<td>157</td>
<td>155</td>
<td>153</td>
<td>81.68</td>
<td>81.41</td>
<td>81.04</td>
<td>104.7</td>
</tr>
</tbody>
</table>
Simulation of the boarding process

- Data collection at Los Angeles airport
  - Passengers were filmed inside the jet bridge
  - Passengers were filmed inside the airplane

- Data collected
  - Passenger walk speed
  - Passenger luggage speed
  - Passenger interference time
  - Passenger arrival rate
  - Passenger demographics (% parties of one, two, three, ...)
  - Total boarding time
Simulation demo
## Simulation results

<table>
<thead>
<tr>
<th></th>
<th>BF6</th>
<th>BF5</th>
<th>BF4</th>
<th>BF3</th>
<th>OI6</th>
<th>OI5</th>
<th>OI4</th>
<th>OI3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seat interferences</td>
<td>72.22</td>
<td>73.36</td>
<td>72.11</td>
<td>70.76</td>
<td>2.94</td>
<td>2.94</td>
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<td>Aisle interferences</td>
<td>52.27</td>
<td>52.74</td>
<td>53.36</td>
<td>53.41</td>
<td>42.64</td>
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<td>42.02</td>
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<tr>
<td>Total interferences</td>
<td>124.5</td>
<td>126.1</td>
<td>125.5</td>
<td>124.2</td>
<td>45.58</td>
<td>45.86</td>
<td>44.96</td>
<td>73</td>
</tr>
</tbody>
</table>
Simulation results

![Graph showing the relationship between the average time between passengers and total boarding time. The graph includes lines for O16 and BF6.]
Implementation

- America West Airlines (AWA) implemented group boarding system-wide in September 2003
- US Airways is phasing in AWA’s group boarding system over the course of 2006 and 2007
Implementation results

Total departure delays at America West Airlines in hours per month, data does not include LAS

Average decrease of 20%
Implementation results

Total departure delays at America West Airlines in hours per month, data only includes PHX

Average decrease of 59%
Concluding remarks

- “Anthony V. Mulé, senior vice president for customer services, says the system, introduced in 2003, has saved at least two minutes in boarding time. "This is a great illustration of how science helped improve both efficiency and customer service," says Mr. Mulé”
  - Source: The Wall Street Journal, November 2, 2005
Questions?

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Airplane boarding research

Airplane boarding in the news