ASU Arizona State University

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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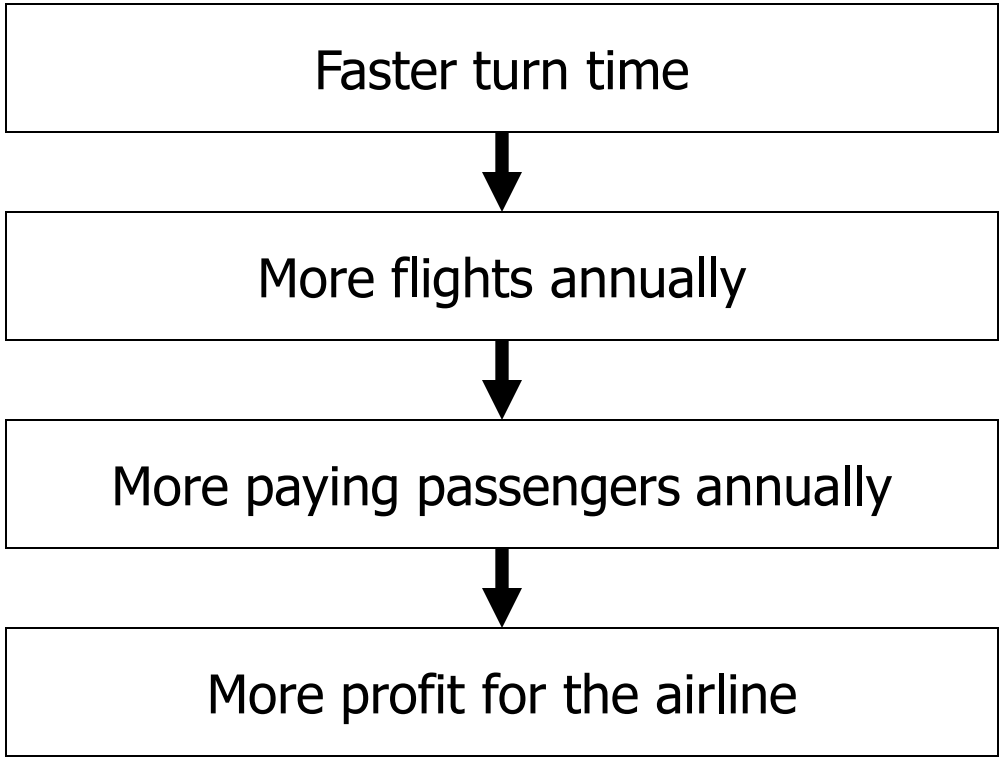
Outline

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



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

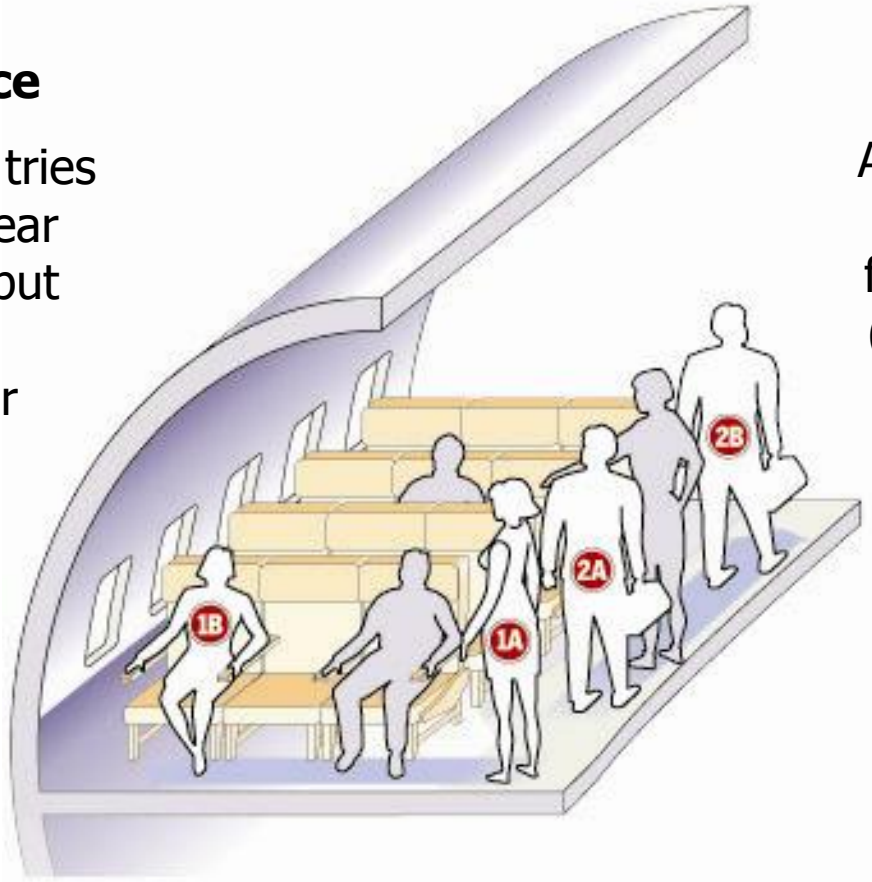
=?

Minimizing total boarding time

Passenger interference

Seat interference

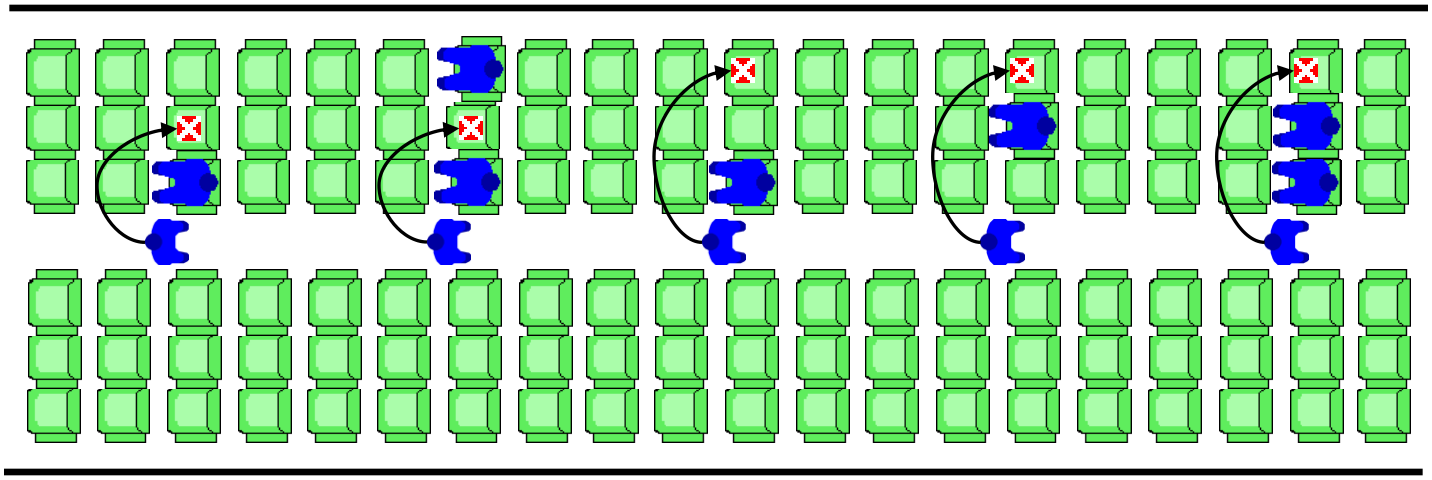
A passenger (1A) tries to get to a seat near the window (1B) but is obstructed by another passenger already seated near the aisle



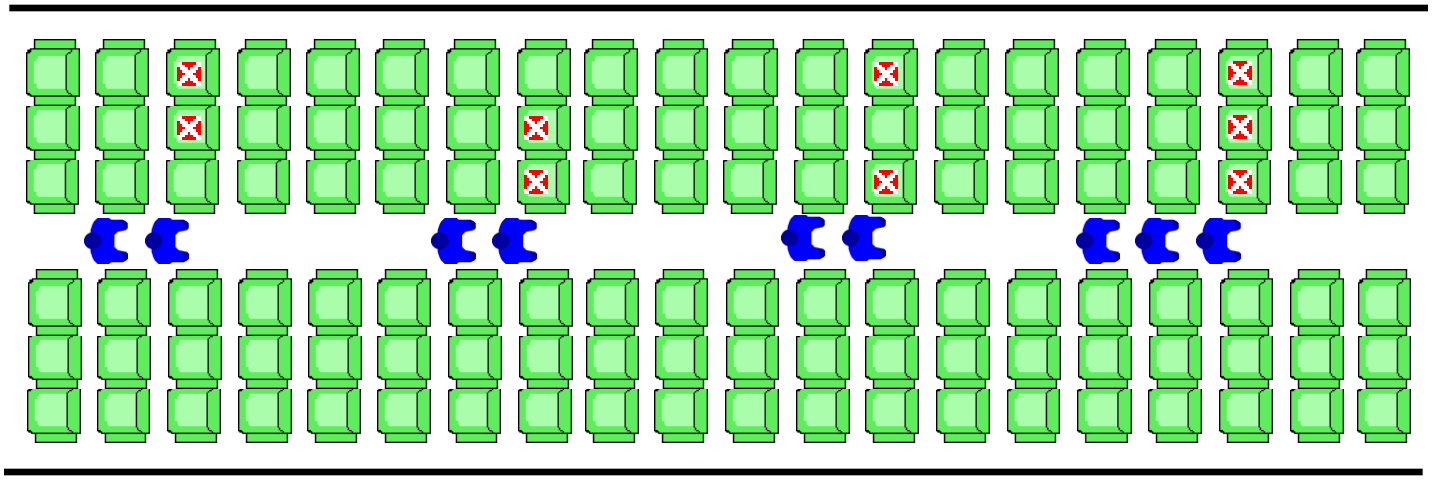
Aisle interference

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

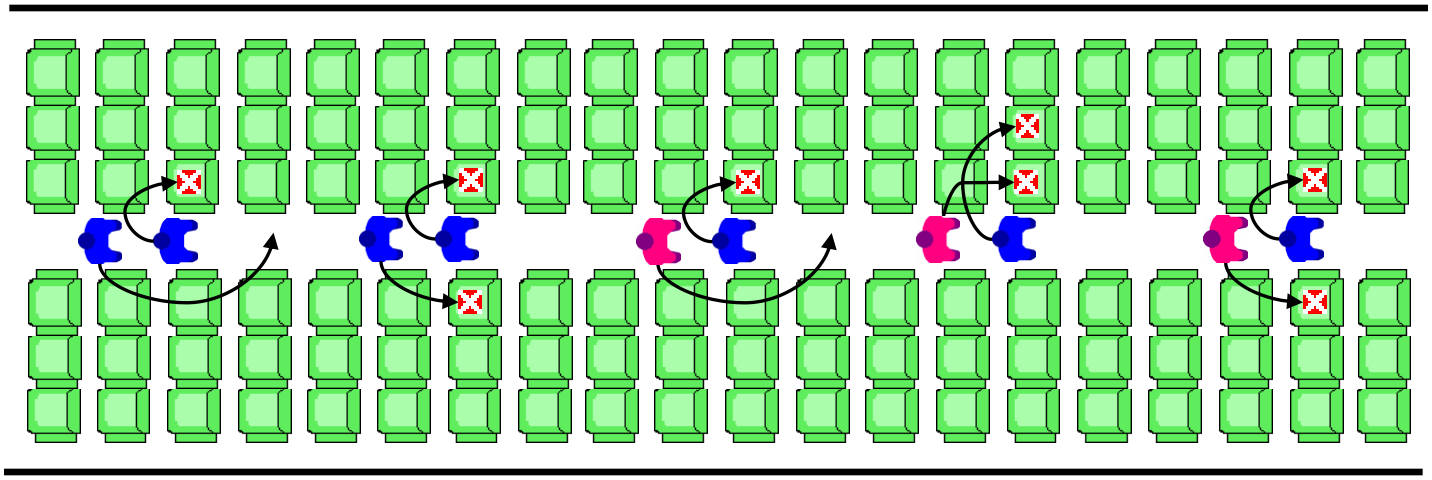
Seat interferences (known)



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
- λ^s Penalty for seat interferences
- λ^a Penalty for aisle interferences

Model objective (seat interferences)

- Objective

$$\lambda_1^s \sum_{i\in N}\sum_{k\in G} x_{iAk}x_{iBk}x_{iCk} + \lambda_1^s \sum_{i\in N}\sum_{k\in G} x_{iFk}x_{iEk}x_{iDk} + \tag{1a}$$

$$\lambda_2^s \sum_{i\in N}\sum_{k,l\in G:k<l} x_{iAk}x_{iBk}x_{iCl} + \lambda_3^s \sum_{i\in N}\sum_{k,l\in G:k<l} x_{iAk}x_{iBl}x_{iCk} + \lambda_4^s \sum_{i\in N}\sum_{k,l\in G:k<l} x_{iAl}x_{iBk}x_{iCk} +$$

$$\lambda_2^s \sum_{i\in N}\sum_{k,l\in G:k<l} x_{iFk}x_{iEk}x_{iDl} + \lambda_3^s \sum_{i\in N}\sum_{k,l\in G:k<l} x_{iFk}x_{iEl}x_{iDk} + \lambda_4^s \sum_{i\in N}\sum_{k,l\in G:k<l} x_{iFl}x_{iEk}x_{iDk} + \tag{1b}$$

$$\lambda_5^s \sum_{i\in N}\sum_{k,l\in G:k<l} x_{iAk}x_{iBl}x_{iCl} + \lambda_6^s \sum_{i\in N}\sum_{k,l\in G:k<l} x_{iAl}x_{iBk}x_{iCl} + \lambda_7^s \sum_{i\in N}\sum_{k,l\in G:k<l} x_{iAl}x_{iBl}x_{iCk} +$$

$$\lambda_5^s \sum_{i\in N}\sum_{k,l\in G:k<l} x_{iFk}x_{iEl}x_{iDl} + \lambda_6^s \sum_{i\in N}\sum_{k,l\in G:k<l} x_{iFl}x_{iEk}x_{iDl} + \lambda_7^s \sum_{i\in N}\sum_{k,l\in G:k<l} x_{iFl}x_{iEl}x_{iDk} + \tag{1c}$$

$$\lambda_8^s \sum_{i\in N}\sum_{k,l,m\in G:k<l<m} x_{iAl}x_{iBm}x_{iCk} + \lambda_9^s \sum_{i\in N}\sum_{k,l\in G:k<l} x_{iAk}x_{iBl}x_{iCm} + \lambda_{10}^s \sum_{i\in N}\sum_{k,l\in G:k<l} x_{iAm}x_{iBl}x_{iCk} +$$

$$\lambda_{11}^s \sum_{i\in N}\sum_{k,l,m\in G:k<l<m} x_{iAk}x_{iBm}x_{iCl} + \lambda_{12}^s \sum_{i\in N}\sum_{k,l\in G:k<l} x_{iAm}x_{iBk}x_{iCl} +$$

$$\lambda_8^s \sum_{i\in N}\sum_{k,l,m\in G:k<l<m} x_{iFl}x_{iEm}x_{iDk} + \lambda_9^s \sum_{i\in N}\sum_{k,l\in G:k<l} x_{iFk}x_{iEl}x_{iDm} + \lambda_{10}^s \sum_{i\in N}\sum_{k,l\in G:k<l} x_{iFm}x_{iEl}x_{iDk} +$$

$$\lambda_{11}^s \sum_{i\in N}\sum_{k,l,m\in G:k<l<m} x_{iFk}x_{iEm}x_{iDl} + \lambda_{12}^s \sum_{i\in N}\sum_{k,l\in G:k<l} x_{iFm}x_{iEk}x_{iDl} + \tag{1d}$$

Expected seat interference

Passenger order			E(SI)
1st	2nd	3rd	
window	middle	aisle	0
window	aisle	middle	1
middle	window	aisle	1
middle	aisle	window	2
aisle	window	middle	2
aisle	middle	window	3

Penalty	Passenger order	E(SI)
λ_1^s	[window, middle, aisle]	1.5
λ_2^s	[window, middle] → [aisle]	0.5
λ_3^s	[window, aisle] → [middle]	1.5
λ_4^s	[middle, aisle] → [window]	2.5
λ_5^s	[window] → [middle, aisle]	0.5
λ_6^s	[middle] → [window, aisle]	1.5
λ_7^s	[aisle] → [window, middle]	2.5
λ_8^s	[window] → [aisle] → [middle]	1
λ_9^s	[middle] → [window] → [aisle]	1
λ_{10}^s	[middle] → [aisle] → [window]	2
λ_{11}^s	[aisle] → [window] → [middle]	2
λ_{12}^s	[aisle] → [middle] → [window]	3

Model objective (aisle interferences)

$$\lambda_1^a \sum_{i\in N}\sum_{u,v\in L:v\neq u}\sum_{k\in G} x_{iuk}x_{ivk} + \lambda_1^a \sum_{i\in N}\sum_{u,v\in R:u\neq v}\sum_{k\in G} x_{iuk}x_{ivk} + \quad (2a)$$

$$2\lambda_2^a \sum_{i\in N}\sum_{u,v\in M:u\in L,v\in R}\sum_{k\in G} x_{iuk}x_{ivk} + \quad (2b)$$

$$\lambda_3^s \sum_{a,b\in N:a<b}\sum_{u,v\in M}\sum_{k\in G} x_{auk}x_{bvk} \quad (2c)$$

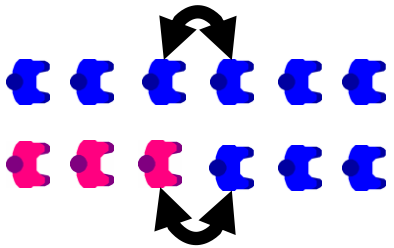
$$\lambda_4^a \sum_{i\in N}\sum_{u,v\in L:v\neq u}\sum_{k,l\in G:k<l} x_{iuk}x_{ivl} + \lambda_4^a \sum_{i\in N}\sum_{u,v\in R:u\neq v}\sum_{k,l\in G:k<l} x_{iuk}x_{ivl} + \quad (2d)$$

$$\lambda_5^a \sum_{i\in N}\sum_{u,v\in M:u\in L,v\in R}\sum_{k,l\in G:k<l} x_{iuk}x_{ivl} + \lambda_2^a \sum_{i\in N}\sum_{u,v\in M:u\in L,v\in R}\sum_{k,l\in G:k<l} x_{iuk}x_{ivl} + \quad (2e)$$

$$\lambda_6^s \sum_{a,b\in N:a<b}\sum_{u,v\in M}\sum_{k,l\in G:k<l} x_{auk}x_{bvl} \quad (2f)$$

Expected aisle interference

Penalty	Description	E(AI)
$\lambda_1^a, \lambda_2^a, \lambda_3^a$	Winthin groups	$1/g_i$
$\lambda_4^a, \lambda_5^a, \lambda_6^a$	Between groups	$1/(g_i g_{i+1})$



Model constraints

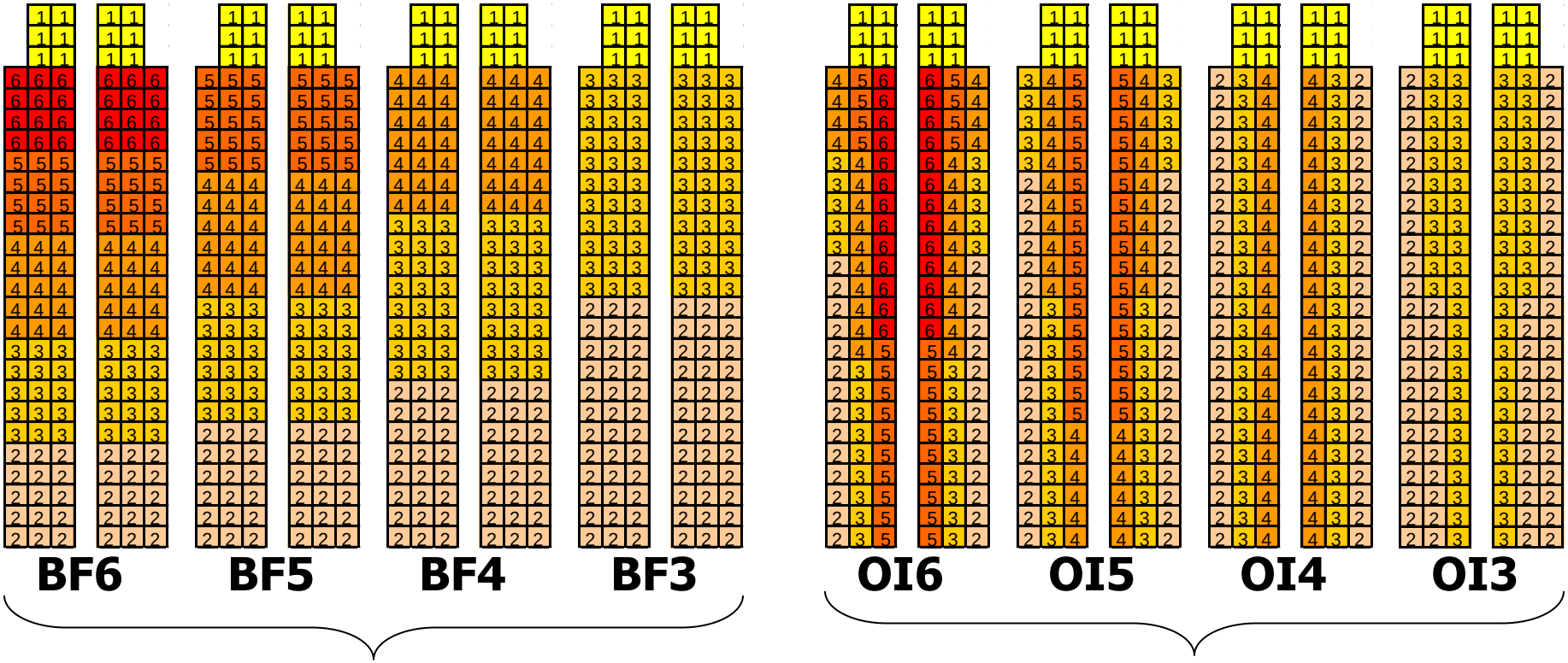
- Subject to

$$\sum_{k \in G} x_{ijk} = 1 \quad \text{for all } i \in N, j \in M \tag{3}$$

$$\sum_{i \in N} \sum_{j \in M} x_{ijk} = g_k \quad \text{for all } k \in g \tag{4}$$

$$x_{ijk} \in \{0,1\} \quad \text{for all } i \in N, j \in M, k \in g \tag{5}$$

Boarding strategies



Computational results

	BF6	BF5	BF4	BF3	OI6	OI5	OI4	OI3
Seat Interferences	**72**	**72**	**72**	**72**	**3**	**3**	**3**	**26**
First class [xx]	3	3	3	3	3	3	3	3
First class [x][x]	0	0	0	0	0	0	0	0
Economy class [xxx]	69	69	69	69	0	0	0	0
Economy class [xx][x]	0	0	0	0	0	0	0	12
Economy class [x][xx]	0	0	0	0	0	0	0	11
Economy class [x][x][x]	0	0	0	0	0	0	0	0
Ailse Interferences	**87**	**85**	**83**	**81**	**78.68**	**78.41**	**78.04**	**78.68**
Within groups								
Same row same side	11	9	7	5	1	1	1	2.33
Same row different side	17	14	11	8	7	6	5	5.33
Different rows	58	61	64	67	68	69	70	69.67
Between groups								
Same row same side	0	0	0	0	0.06	0.06	0.04	0.02
Same row different side	0	0	0	0	0.06	0.06	0.04	0.02
Different rows	1	1	1	1	2.56	2.29	1.96	1.31
Total interferences	**159**	**157**	**155**	**153**	**81.68**	**81.41**	**81.04**	**104.7**

Simulation of the boarding process

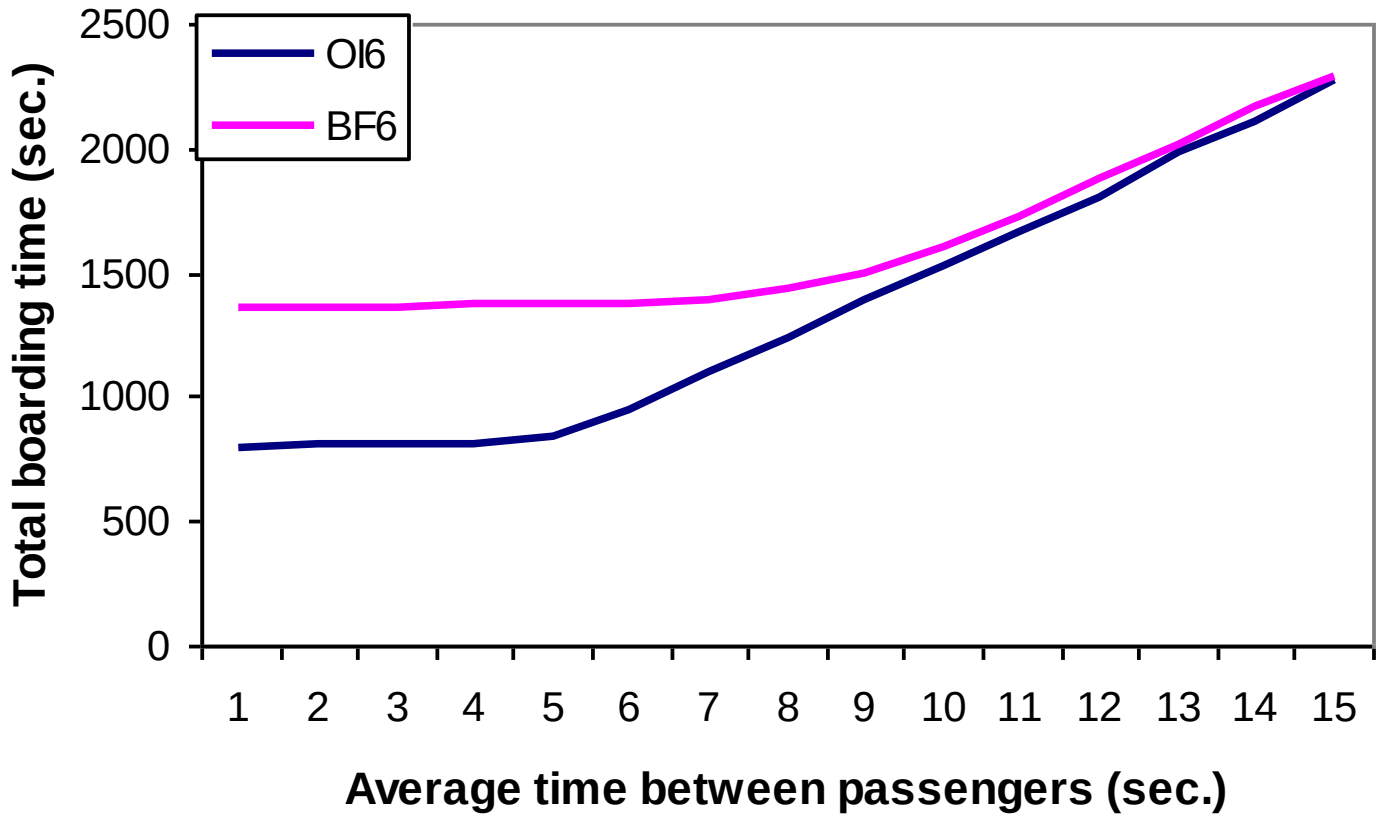
- Data collection at Los Angeles airport
  - Passengers were filmed inside the jet bridge
  - Passengers were filmed inside the airplane
- Data collected
  - Passenger walk speed
  - Passenger luggage speed
  - Passenger interference time
  - Passenger arrival rate
  - Passenger demographics (% parties of one, two, three, …)
  - Total boarding time

Simulation demo

Simulation results

	BF6	BF5	BF4	BF3	OI6	OI5	OI4	OI3
Seat interferences	72.22	73.36	72.11	70.76	2.94	2.94	2.94	26.05
Aisle interferences	52.27	52.74	53.36	53.41	42.64	42.92	42.02	46.95
Total interferences	124.5	126.1	125.5	124.2	45.58	45.86	44.96	73
Boarding time (min:sec)	24:52	24:34	24:21	23:57	23:08	23:03	22:56	23:33

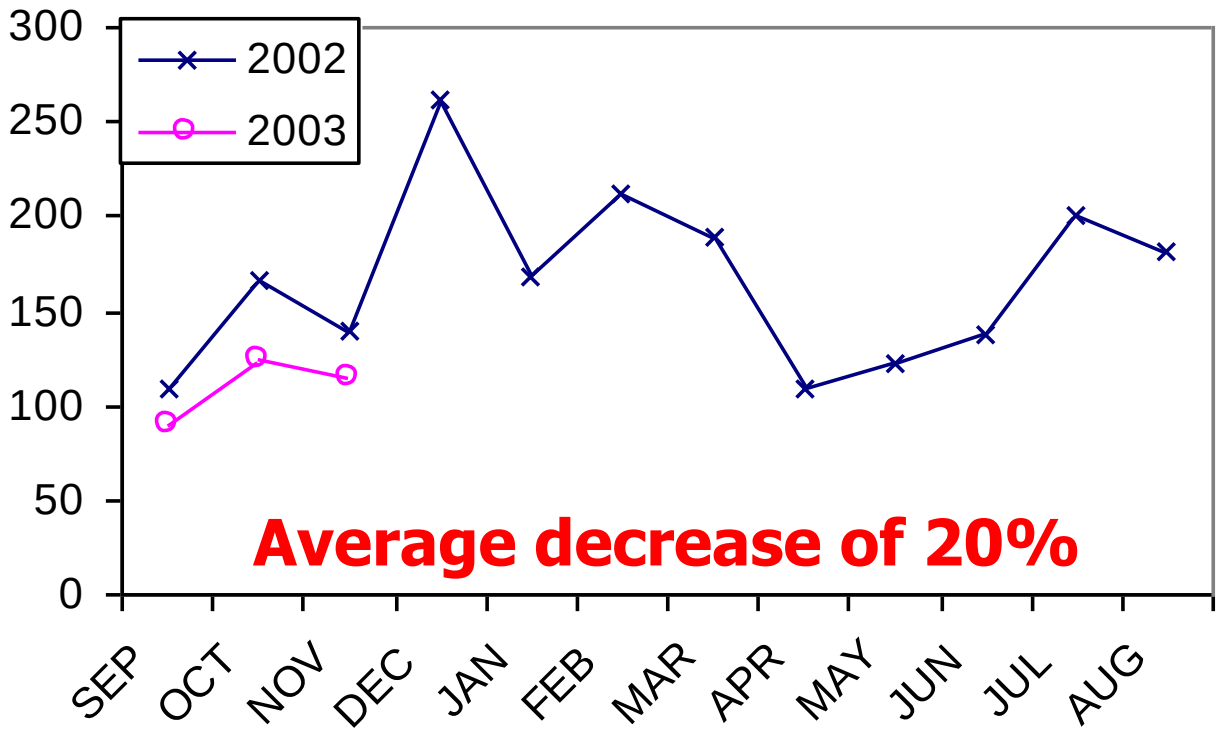
Simulation results



Implementation

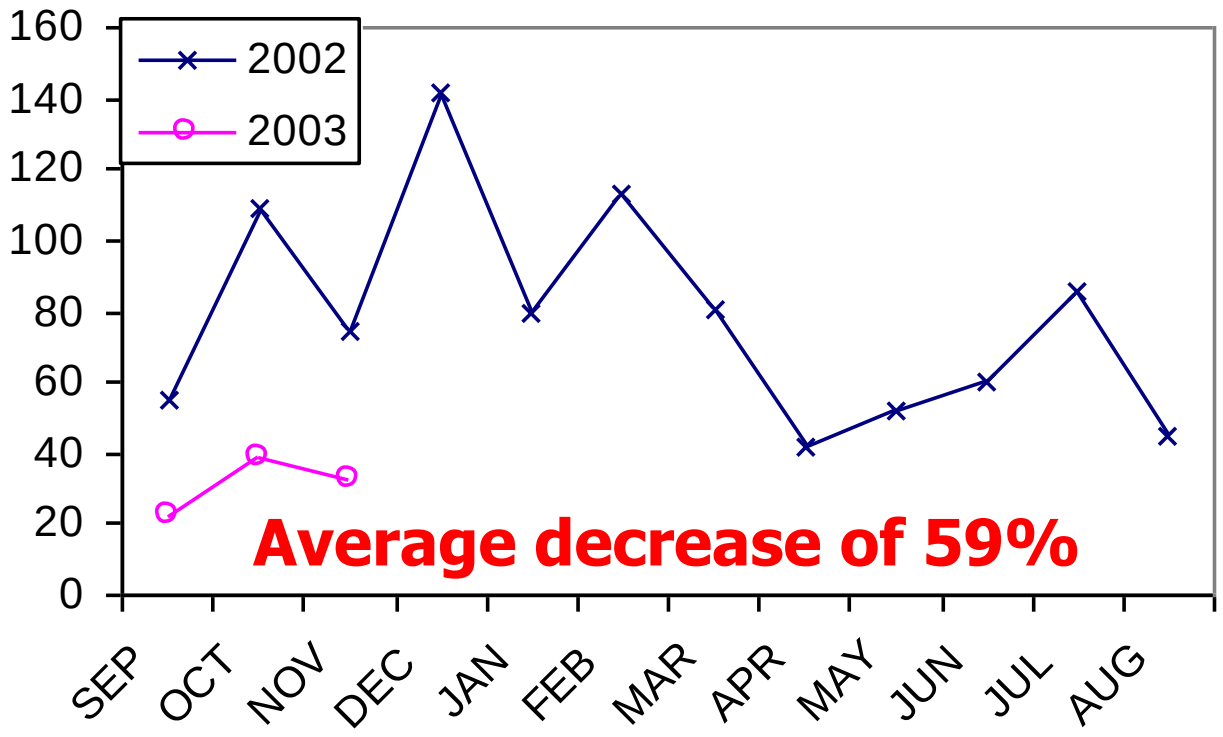
- America West Airlines (AWA) implemented group boarding system-wide in September 2003
- US Airways is phasing in AWA's group boarding system over the course of 2006 and 2007

Implementation results



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

Implementation results



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

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

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