

# Why Equity is a Pipedream

Analysis of Dynamical Properties of  
Over-scheduled Resources

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CENTER FOR AIR TRANSPORTATION SYSTEMS  
RESEARCH



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# Background

- Government agencies responsible for air transportation have “modernization” plans to invest in:
  - Capacity increases
  - Productivity increases
- Europe – SESAR
- USA - NextGen

# Background

- Modernization plans call for equitable access and use of public resources:
  - “equitable treatments of flight operators” (pg 2-16)
  - “equitable access to NAS resources” (pg 2-29)
  - “equitable management of NAS resources” (pg C-7)
- FAA Policy on Equity
  - “equity is the state in which the welfare of each user of the NAS is increased to the extent possible, given limited resources, after taking proper account of disparate claims and individual circumstances.” RTCA (2002)

# Problems

1. There is no evidence that NextGen will increase capacity sufficiently in all locations to eliminate over-scheduling (Hansman, Donohue, ...)
2. Existing allocation schemes (i.e. GDP, AFP) are perceived to be:
  - economically inefficient
  - inequitable

“We think we have done a good job, when everyone is equally unhappy”  
Senior ANSP manager

# Objective

- Determine the conditions that would have to exist to provide an equitable allocation of overscheduled *resources* amongst *groups of flights*
  - *What is the feasible-space in which equity can occur?*

# Outline

1. Definitions
2. Over-schedule Resources
3. Overview of Equity
4. Dynamical Properties of Overschedule Resources

# Definitions

- Overscheduled Resources:
  - Arrival slot,
  - metering fix
  - Gates
  - comm channels
  - env cap-n-trade.
- Equity for groups of flights
  - Airlines,
  - NAS Users (mil, comm, bizjet, GA)
  - Origin/Destination airport (metro, rural)
  - Pax/Cargo value
  - Emissions/Noises proclivity

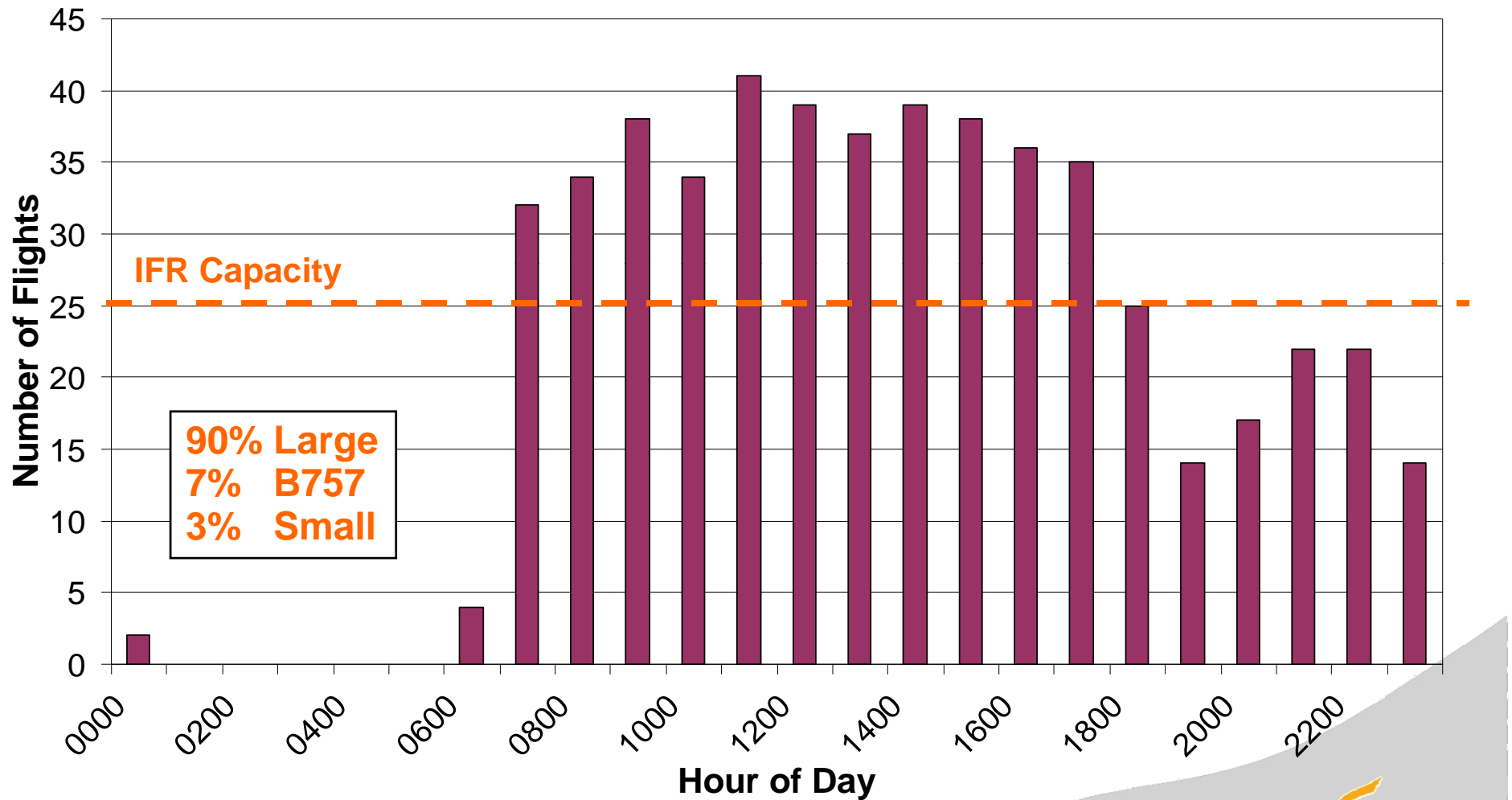
# Overscheduled Resources

FAVORER	FLINCH	ENBEDI	DEPLOD	ARLOD	SONIV
TF	658E170		DWV	LGA	00:04
QQ	308E145		FHL	LGA	00:16
FFT	514A319		DEN	LGA	00:15
DL	1905ND13		ECS	LGA	00:39
CEM	618CF21		DDA	LGA	00:39
LGA	258A319		DDA	LGA	00:39
FET	4110D4B		NFT	LGA	00:00
LGA	215A319		ECS	LGA	00:07
QQ	308E145		BV	LGA	00:12
AV	375CF22		FHL	LGA	00:12
EEF	857E135		BGR	LGA	00:15
CC	460SF31		PH	LGA	00:15
QQ	308E145		FC	LGA	00:17
EEF	857E135		OMH	LGA	00:18
...	...	...	...	...	...

- Competing for same slots
- Resolution causes ripple-effect

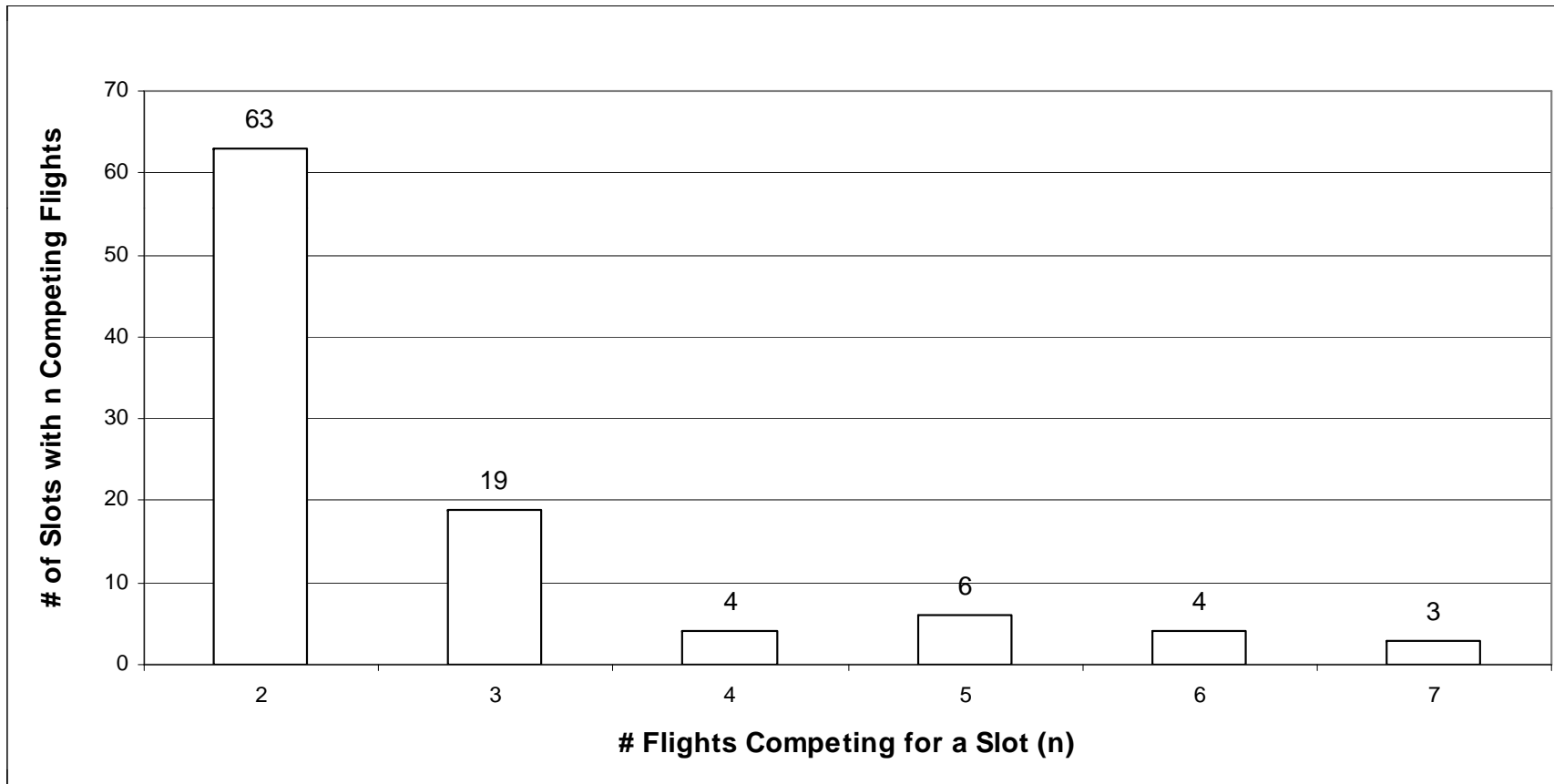
Arrival slots at LGA - ASPM data, June, 1, 2006

# Hourly Arrival Schedule at LGA



Arrival slots at LGA - ASPM data, June, 1, 2006

# Slot Over-subscription



Arrival slots at LGA - ASPM data, June, 1, 2006

# Equity

- Every society has rules for allocating resources amongst members (Young, 1994)
  1. Property rights/Liabilities held and traded according to financial regulations
    - Economically efficient
    - Rapid adjustment to changing environment
    - Subject to socially inequitable allocations
  2. Property rights allocated by governing agency in the interests of societal needs
    - Can be socially equitable
    - Subject to politics

# Equity - Allocation Decisions

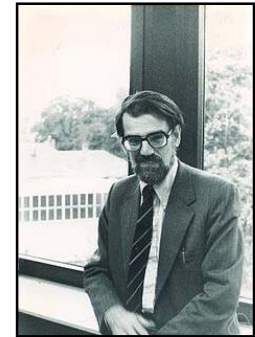
1. Supply decision – determines the amount of resources to be allocated
2. Distributive decision – principle and methods used to allocate
3. Reactive decision – swapping and substitution

# Equity - Distributive Decision

- Distributive mechanism expresses notion of equity by societal norms
- Equity is determined by both principle and precedent
- Distribution “yardstick” difficult to agree on
  - Allocated resources are not equal
  - Claimant parties are not equal

# Equity for Distributive Mechanisms

1. Total Equality
  - One group, one vote
2. Maimonides
  - Constrained optimization (takes into account size of claim)
3. Maimonides Loss
  - Spreading the pain
4. Proportional
  - Larger the claim, the greater the % of allocation
5. Shapely Value
  - coalition supporting power of each individual
  - average outcome for each possible allocation
6. Contested Garment
  - Individual rationality
  - Group rationality = efficiency
  - Core



# Proportional Allocation

- *Proportional Flight Delay Equity* for Group (i) =

$$\frac{\sum \text{Flight Delays Group (i)}}{\text{\# Flights Group (i)}} / \frac{\sum \text{Flight Delays}}{\text{Total Number of Flights}}$$

i = Airline 1 ...n

- *Inter-Airline Proportional Flight Delay Equity* for individual flights is proportional to individual flight delays





# Dynamical Properties of Overscheduled Resources

- Laws of “Conservation of Delays”
- 4 Properties *independent of slot assignment of individual flights in the queue*
  1. Max Users in Queue
  2. Total Time Queue Present
  3. Total Delay Time
  4. Total Users in Queue

Airline actions (e.g. gaming) cannot change these fundamental properties

# Dynamical Properties of Overscheduled Resources

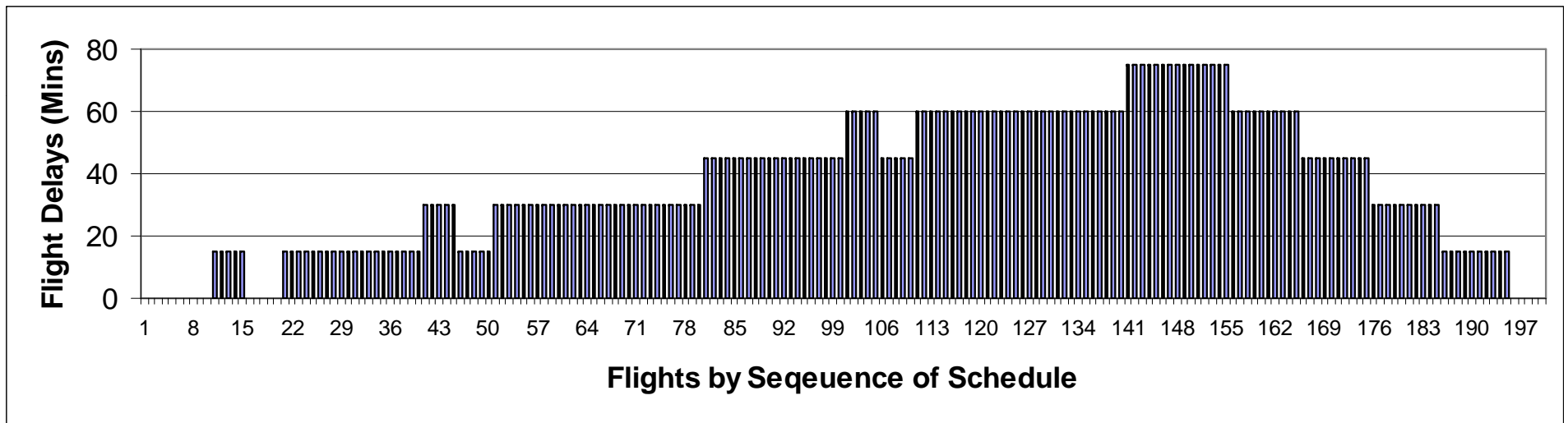
- Total Delay Time =

$$\frac{1}{2} * T_{\text{OverScheduled}}^2 * (\text{DemandHigh} - \text{Capacity}) *$$

$$\left[ 1 + \frac{\text{DemandHigh} - \text{Capacity}}{\text{Capacity} - \text{DemandLow}} \right]$$

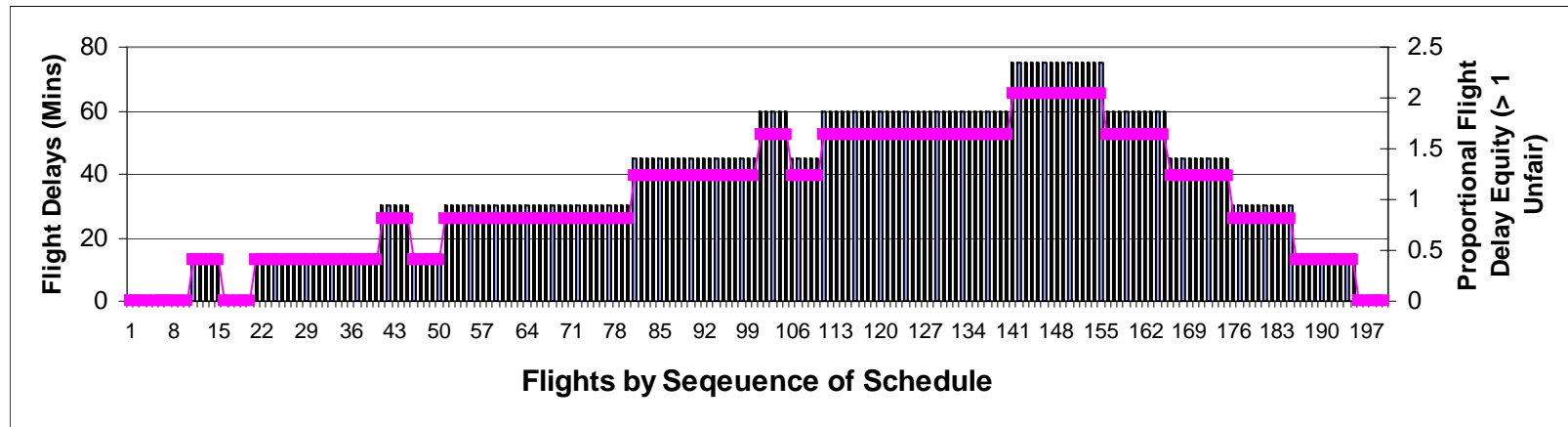
- Total Delay Time increases with the **SQUARE** of the duration of the overscheduled interval
- Total Delay Time is independent of the sequence of flights = Law of Conservation of Flight Delays

# Dynamical Properties of Overscheduled Resources



The amount of delays allocated to a flight depends on the flight's position in the schedule

# Flight Delay Profile vs. Individual Flight Delay (Proportional Equity)

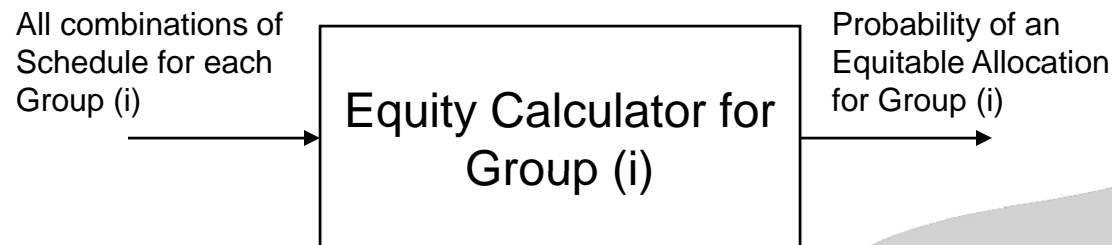


- *Inter-Airline Proportional Flight Delay Equity* = 
$$\frac{\sum \text{Flight Delays}(i) / \text{Total Flight Delays}}{\text{Number of Flights } (i) / \text{Total Number of Flights}}$$
  
 $i = \text{Airline } 1 \dots n$
- *Inter-Airline Proportional Flight Delay Equity* for individual flights is proportional to individual flight delays

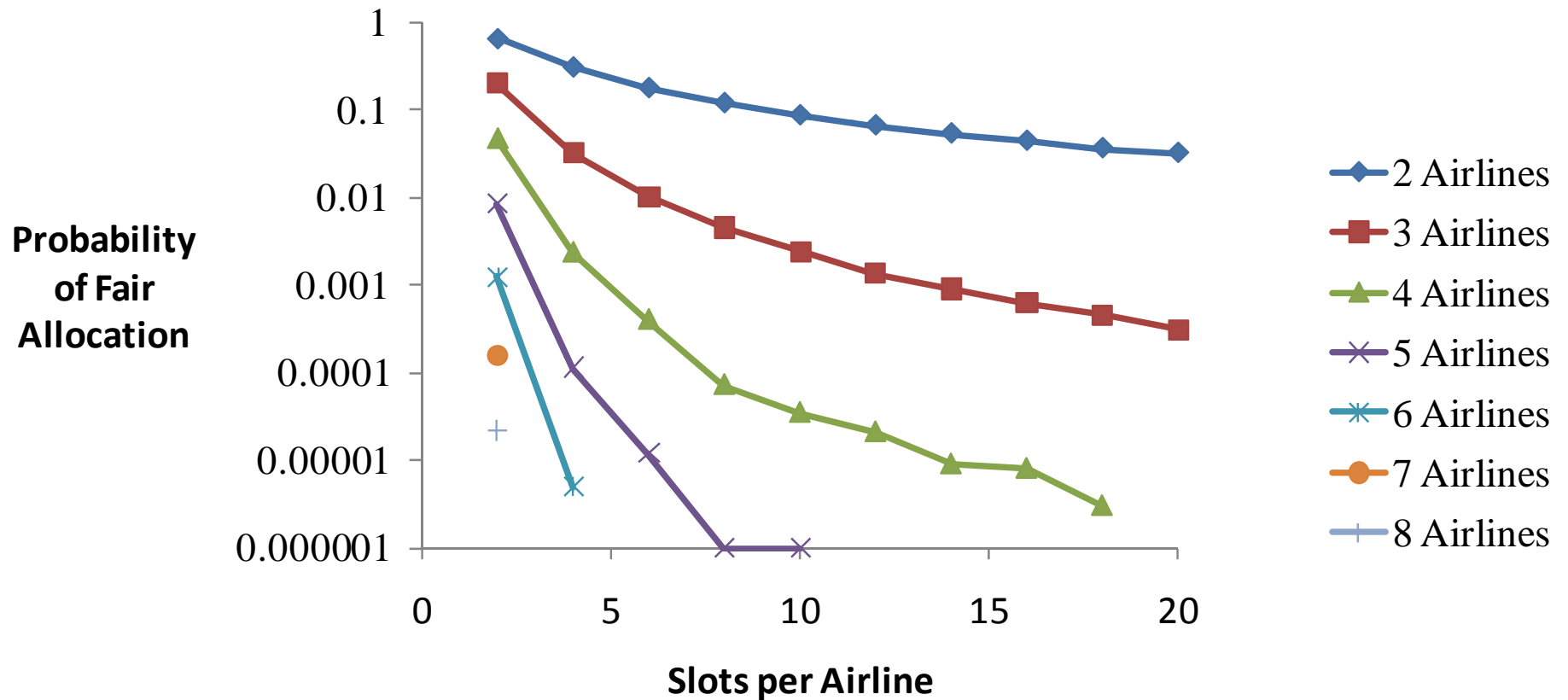
**Baseline equity is not biased for location in queue**

# Question?

- Given that there exists an asymmetry of delays assigned to flights, and
- Airlines schedule flights randomly (to meet their objectives)
- What is the likelihood that the schedule will result in a Equitable Allocation



# Probability of Equitable Allocation



# Results

- Randomly scheduled slots yield low probability of equity (< 10%)
  - individual groups (e.g. airlines, passenger demographics, aircraft/engine type)
- Increasing number of flights does not increase equity
  - Probability of obtaining an equitable allocation decreases both in the number of slots per airline
- Increasing Competition does not increase equity
  - Probability decreases extremely fast in the number of airlines
  - Since *every* airline must have the same total delay, more constraints on the situation when there are more airlines

# Viable Alternatives

- Market-based mechanisms:
  - economically efficient use of the resource.
  - Societal needs can be ignored and require regulatory intervention.
- Refining First-Scheduled/First-Allocated to Improve Equity:
  - Use “exemption” mechanism to create improved equity
- Temporal Measures of Equity:
  - Measure equity across multiple allocations (e.g. days).
- Variable Allocation Schemes:
- Hybrid Allocation Schemes:
  - Market-based allocation scheme with regulatory constraints may yield the most economically efficient and socially equitable allocation.