Airside Congestion

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Airside Congestion

- Objective:
  - Introduce fundamental concepts regarding airside delay
- Topics
  - The airport as a queuing system
  - Dynamic behavior of queues
  - Long-term characteristics of airside delay
  - Non-linearity
  - Annual capacity of an airport
  - Measuring delay: ‘delay vs. schedule’ and ‘delay vs. nominal time’

Reference: Chapters 11, 20

Cost of Air Traffic Delays in US, 2007

Cost Component	**Cost (billion dollars)**
Cost to Airlines	8.3
Cost to Passengers	16.1
Cost of Lost Demand	7.9
Total Direct Cost	32.3
Indirect Impact on GDP	4.0
Total Cost Impact	36.3

Source: *Total Delay Impact Study: A Comprehensive Assessment of the Costs and Impacts of Flight Delay in the United States,* NEXTOR 2010

Queues

- Queuing Theory is the branch of operations research concerned with waiting lines (delays/congestion)
- A queuing system consists of a demand source, a queue and a service facility with one or more identical parallel servers
- A queuing network is a set of interconnected queuing systems
- Fundamental parameters of a queuing system:
  - Demand rate
  - Capacity (service rate)
  - Distribution of demand inter-arrival times
  - Distribution of service times
  - Queue discipline (FCFS, SIRO, priorities, etc)

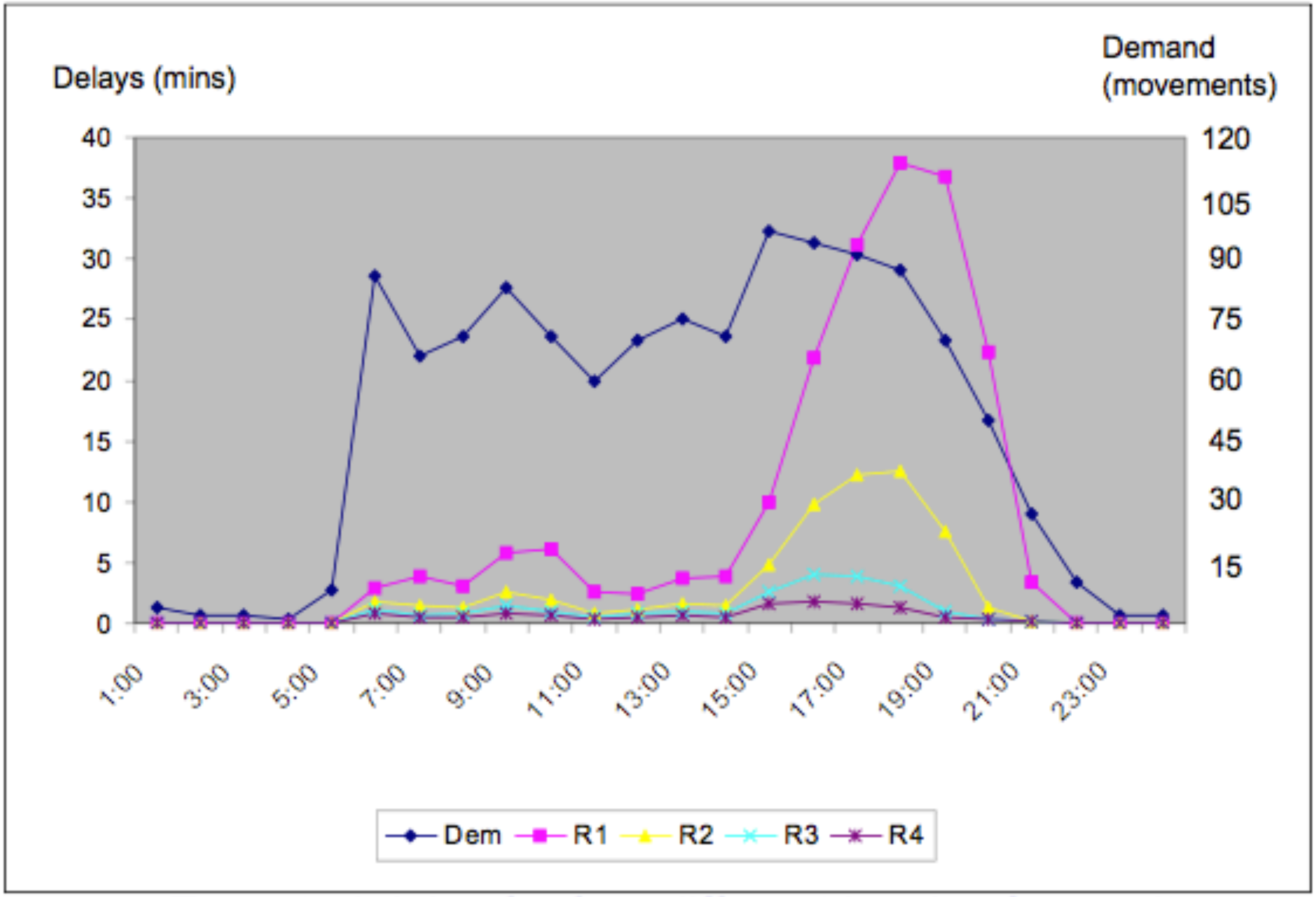
Dynamic ("Short-Run") Behavior of Queues

- Delays will occur when, over a time interval, the demand rate exceeds the service rate ("demand exceeds capacity")
- Delays may also occur when the demand rate is ***less*** than the service rate -- this is due to probabilistic fluctuations in inter-arrival and/or service times (i.e., to short-term surges in demand or to slowdowns in service)
- These "probabilistic" (or "stochastic") delays may be large if the demand rate is close to (although lower than) capacity over a long period of time

Dynamic Behavior of Queues [2]

1. The dynamic behavior of a queue can be complex and difficult to predict.
2. Expected delay changes non-linearly with changes in the demand rate or the capacity.
3. The closer the demand rate is to capacity, the more sensitive expected delay becomes to changes in the demand rate or the capacity.
4. The time when peaks in expected delay occur may lag behind the time when demand peaks.
5. The expected delay at any given time depends on the "history" of the queue prior to that time.
6. The variance (variability) of delay also increases when the demand rate is close to capacity.

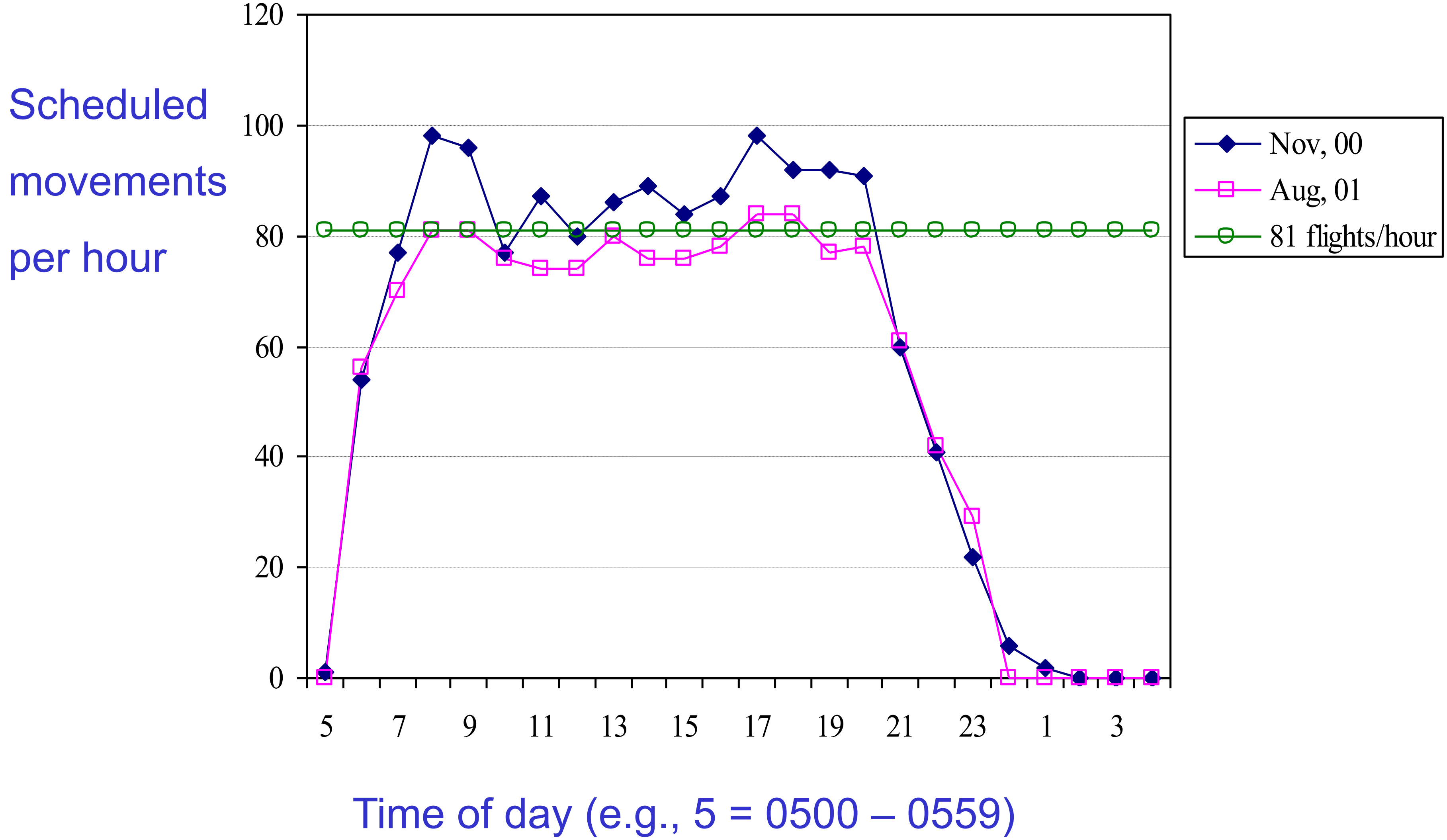
Example of the Dynamic Behavior of a Queue



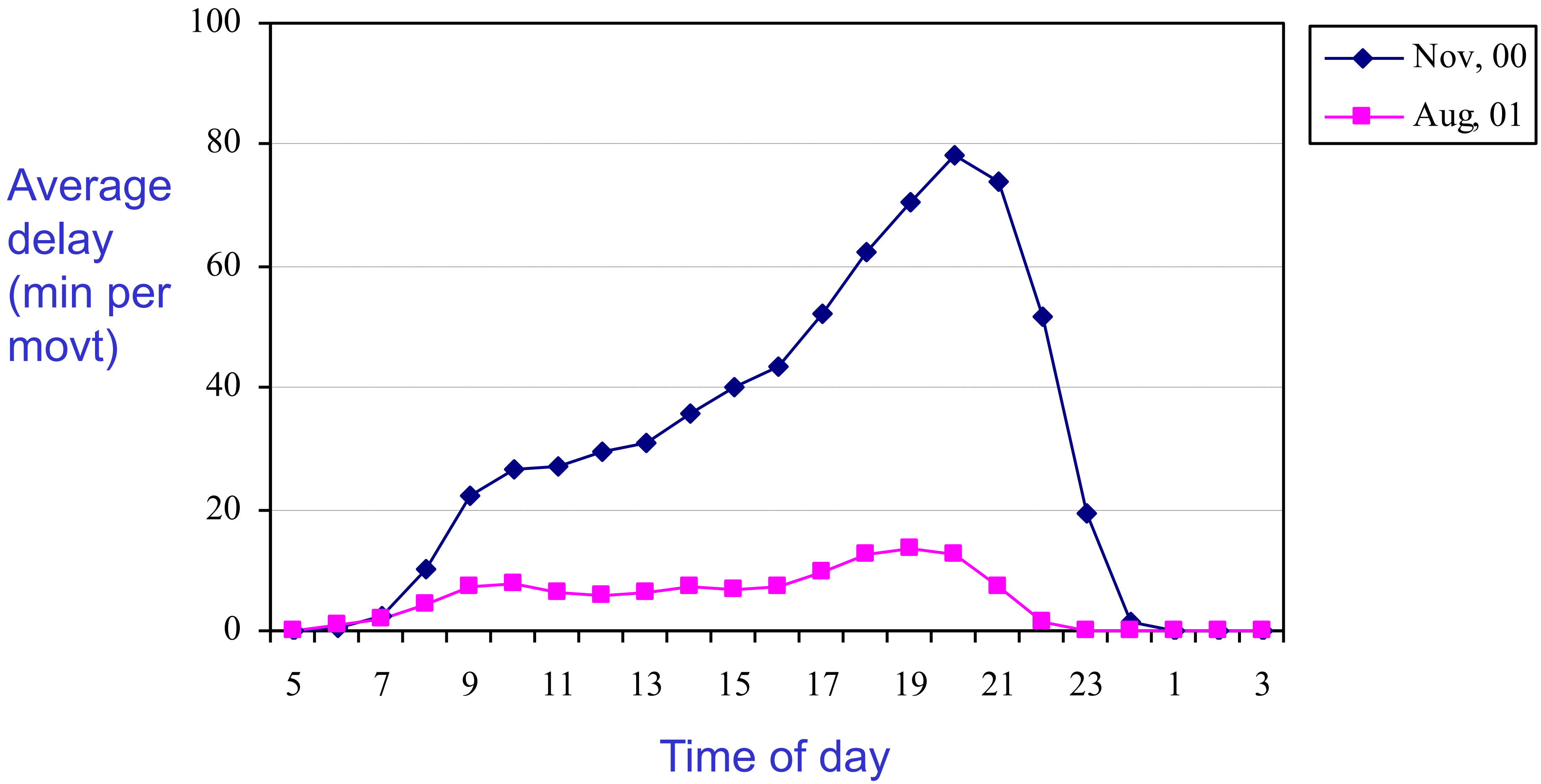
Expected delay for four different levels of capacity

(R1= capacity is 80 movements per hour; R2 = 90; R3 = 100; R4 = 110)

Scheduled aircraft movements at LGA before and after 2001 slot lottery



Estimated average delay at LGA before and after slot lottery in 2001



Behavior of Queuing Systems in the "Long Run"

- The "utilization ratio", ρ, measures the intensity of use of a queuing system:

$$\rho = \frac{\text{demand rate}}{\text{service rate}} = \frac{\text{"demand"}}{\text{"capacity"}} = \frac{\lambda}{\mu}$$

- A queuing system cannot be operated in the long run with a utilization ratio which exceeds 1; the longer such a system is operated, the longer the queue length and waiting time will be.
- A queuing system will be able to reach a long-term equilibrium ("steady state") in its operation, only if $\rho < 1$, in the long run.

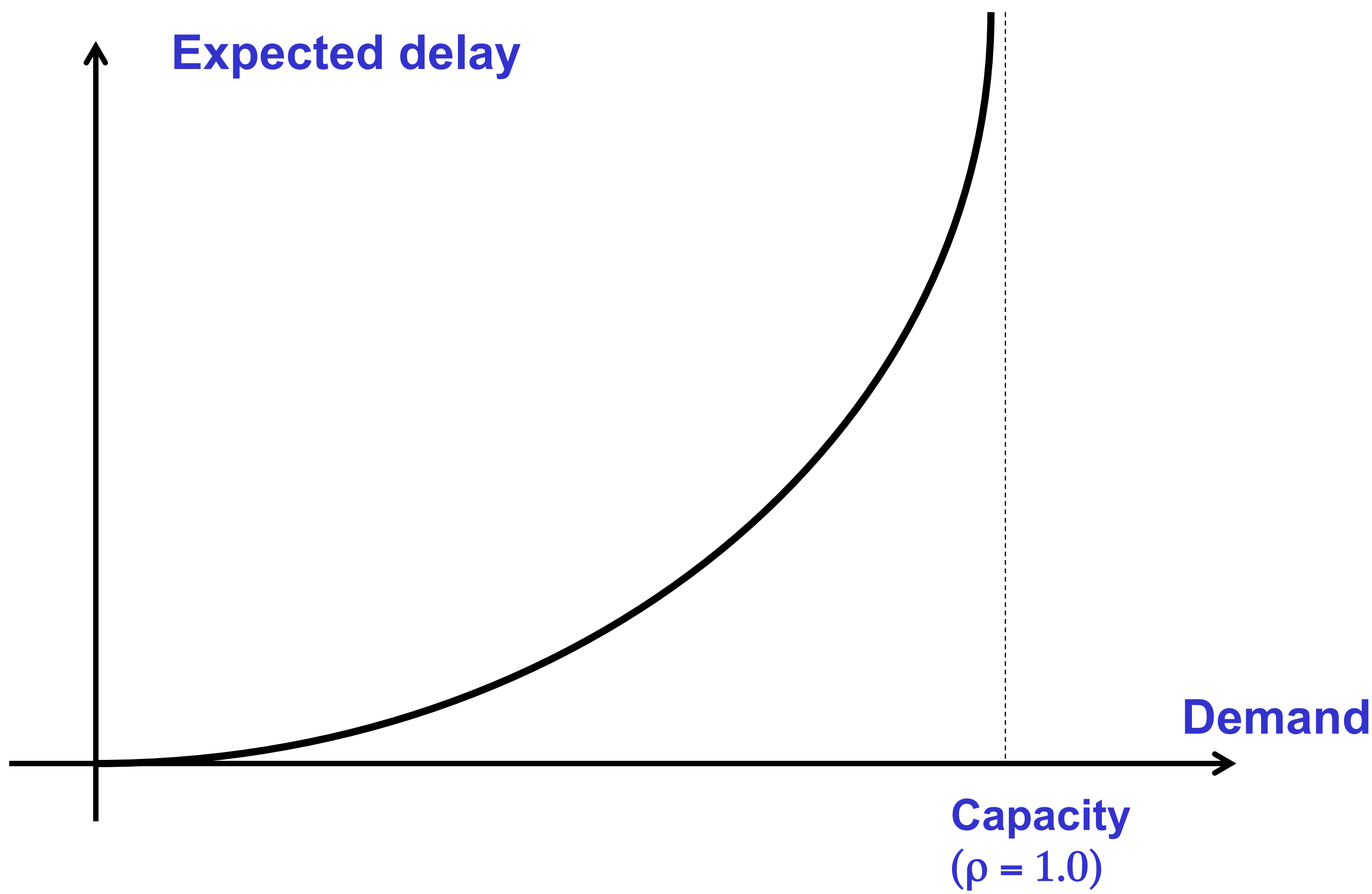
Behavior of Queuing Systems in the "Long Run" [2]

- For queuing systems that reach steady state the expected queue length and expected delay are proportional to:

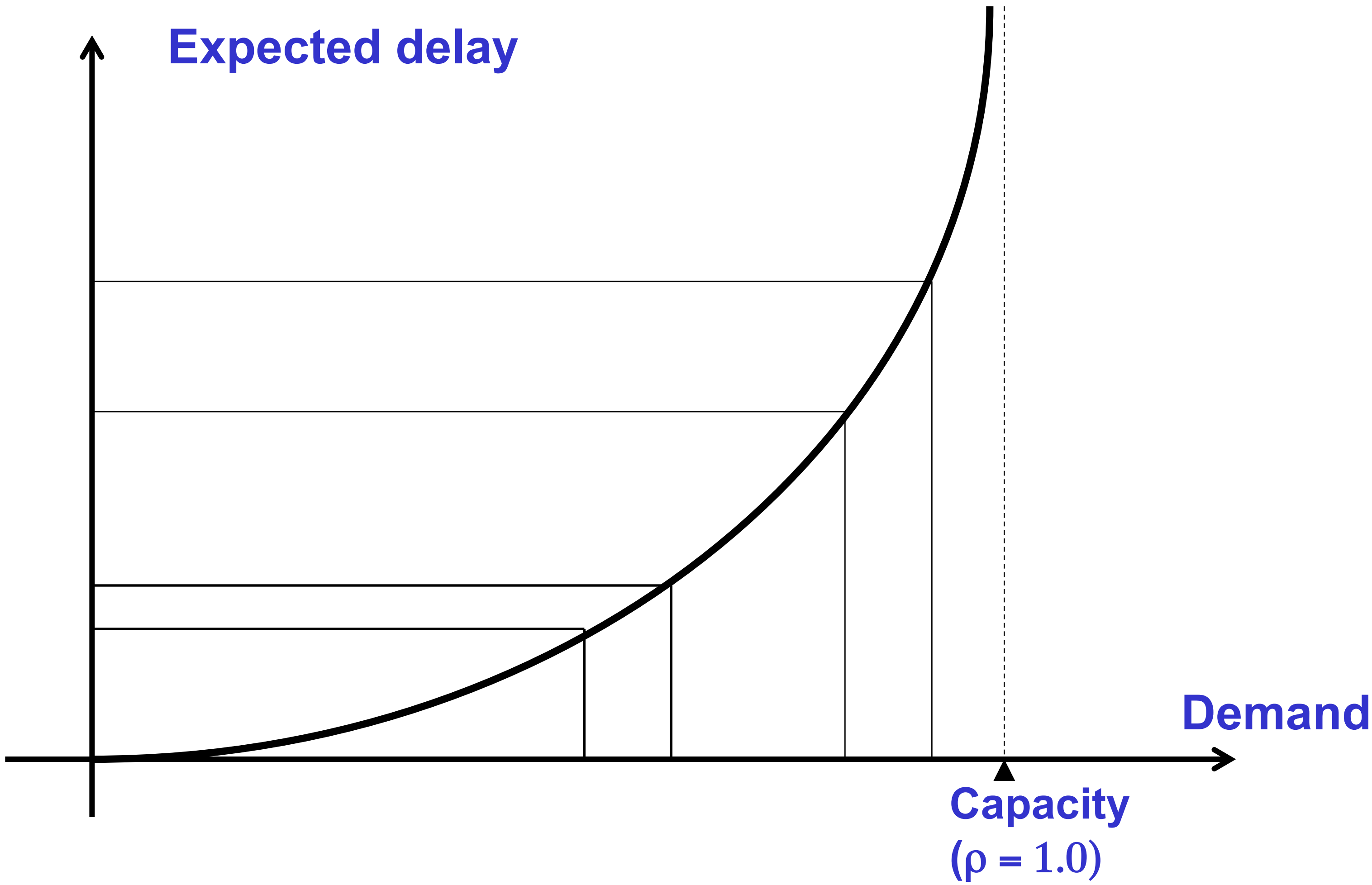
$$\frac{1}{1-\rho}$$

- Thus, as the demand rate approaches the service rate (or as $\rho \to 1$, or as "demand approaches capacity") the average queue length and average delay increase rapidly
- The "proportionality constant" increases with the variability of demand inter-arrival times and of service times

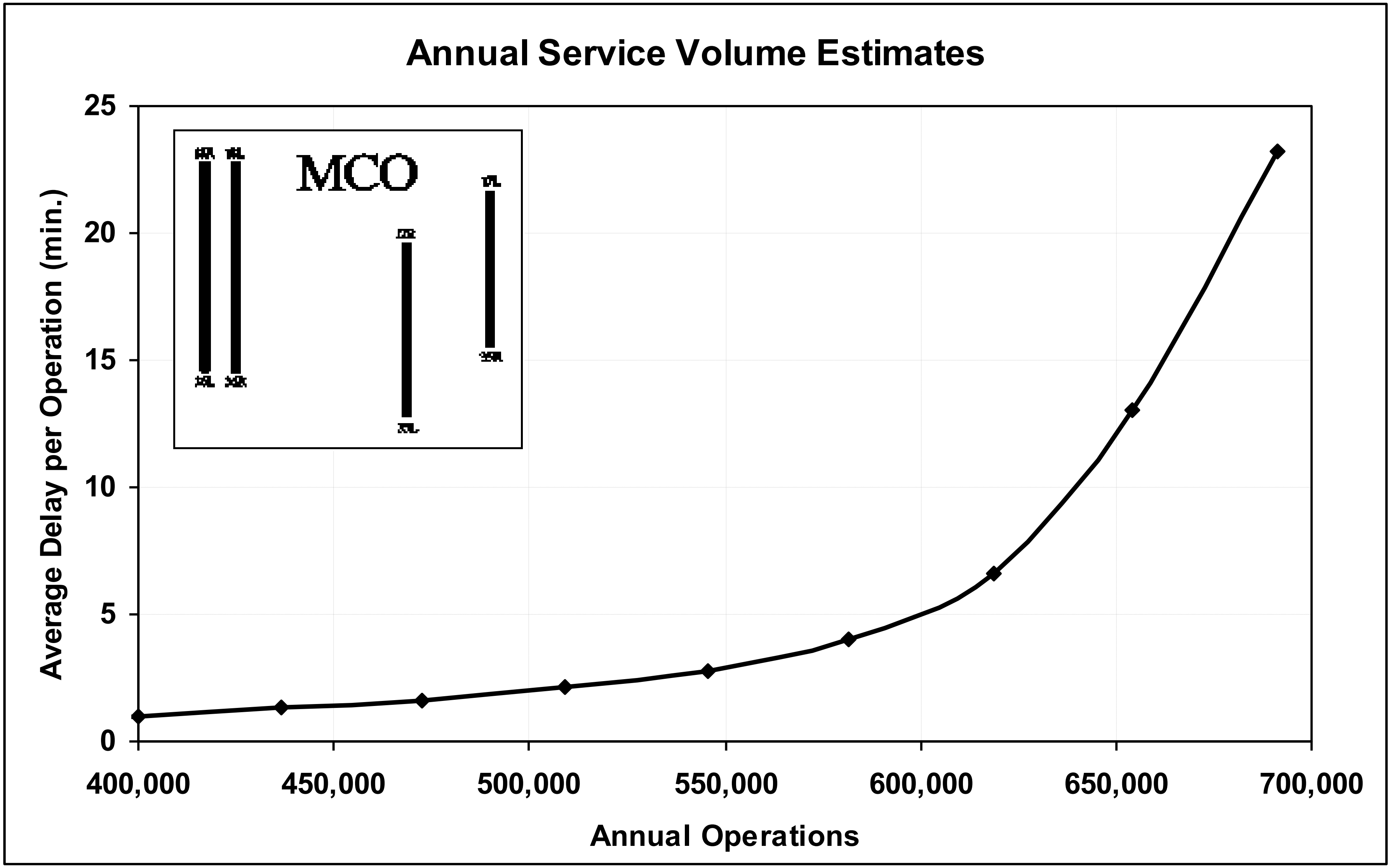
Delay vs. Demand and Capacity



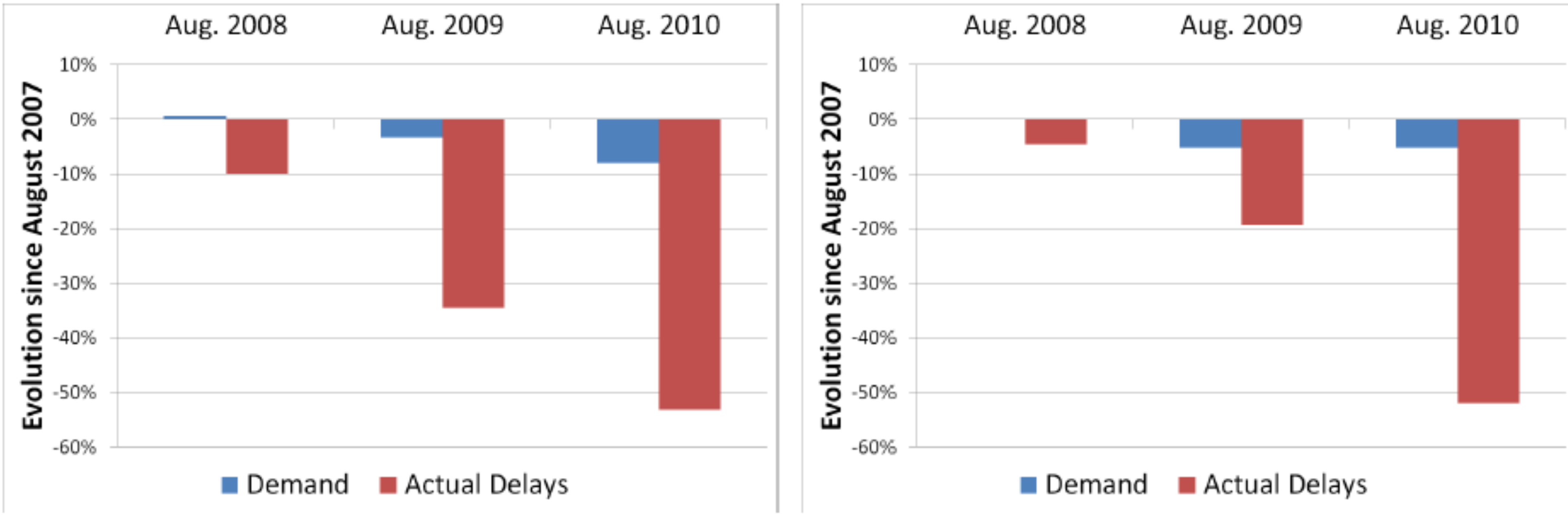
High Sensitivity of Delay at High Levels of Utilization



Delay vs. Annual Operations at Orlando Airport (MCO)



Evolution of NY Delays (2007 – 2010)



(a) JFK (b) EWR

	JFK		EWR	
Month in 2010	**July**	**August**	**July**	**August**
Demand	**-6.84%**	**-8.02%**	**-3.37%**	**-5.16%**
Actual Delays	**-46.90%**	**-53.15%**	**-32.93%**	**-52.02%**
Model-Predicted Delays	**-48.69%**	**-51.30%**	**-36.14%**	**-41.56%**

Jacquillat, 2012

Variability of Queues

- The variability of delay also builds up rapidly as demand approaches capacity.
- In "steady state," the standard deviation --a measure of variability -- of delay and of queue length is also proportional to:

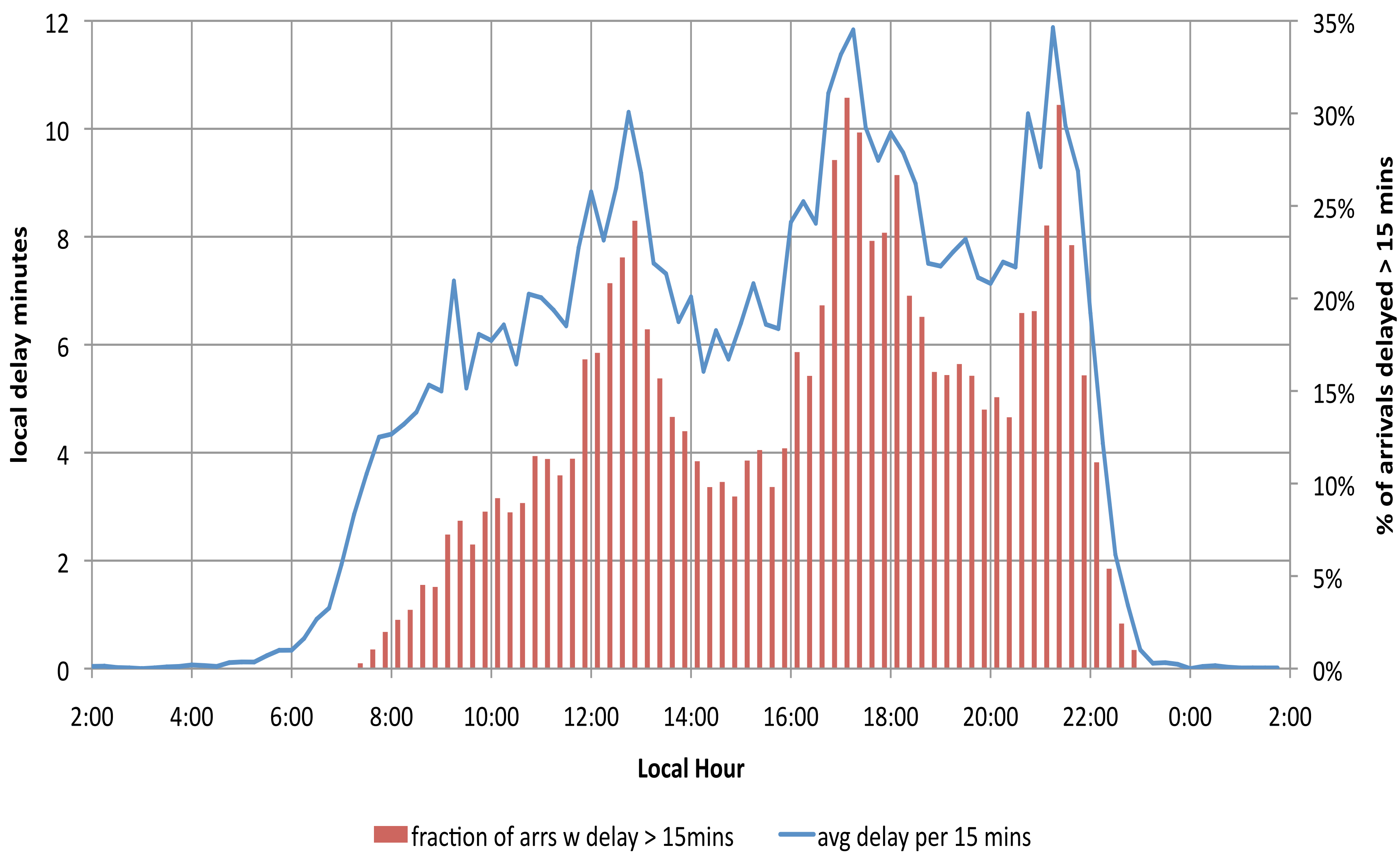
$$\frac{1}{1-\rho}$$

- A large standard deviation implies unpredictability of delays from day to day and low reliability of schedules

Tools for Estimating Delays Theoretically

- The estimation of delays at an airport is usually sufficiently complex to require use of computer-based models
  - Dynamic queuing models: solve numerically the equations describing system behavior over time
  - Simulation models (e.g., TAAM, SIMMOD)
- For very rough approximations, simplified models may sometimes be useful
  - Simple ("steady-state") queuing models
  - Cumulative diagrams
- *Note:* Field data on air traffic delays increasingly available, getting better in quality (e.g., ASPM, CODA)

Dynamic Delay Statistics for a Busy Airport



Annual Airside Capacity

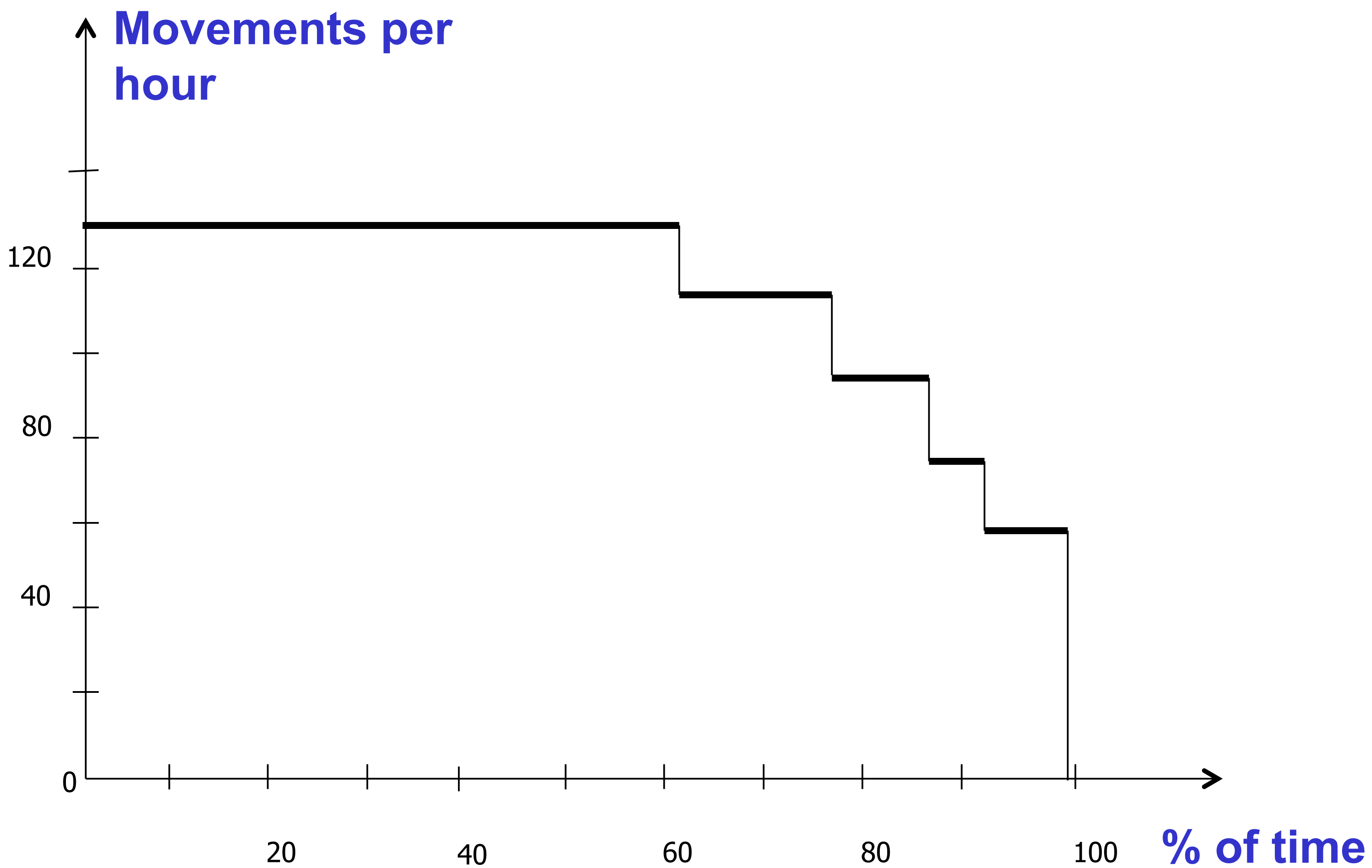
- The number of aircraft movements that can be handled at a reasonable level of service in one year
- Vaguely defined, but very important for planning purposes
- Runway system is typically the limiting element
- Estimation of annual capacity must consider:
  - Typical hourly (saturation) capacity
  - Pattern of airport use during a day
  - Reasonable level of delays during busy hours of day
  - Seasonal and day-of-the-week peaking patterns of demand

Annual Airside Capacity: Boston Example

1. Typical hourly runway capacity (based on CCC) = 115.
   Compute: A = 115 x 24 x 365 = 1,007,400
2. Equivalent of ~16–17 hours of strong activity per day.
   Compute: 1,007,400 x (16/24) = 671,600
3. ~85% utilization in busy hours for (barely) tolerable delays
   Compute: 671,600 x 0.85 = 570,860
4. Summer season days have about 15% more movements than winter season days
   $(570{,}860 / 2) + (570{,}860 / 2)\mathrm{x}(1/ 1.15) \cong 534{,}000$

This is a *rough estimate* of the ultimate capacity of Logan airport, absent any further capacity increase

Annual Capacity Coverage Chart: Boston/ Logan



Estimating Annual Capacity: Generalization

- Let C be the typical saturation capacity per hour of airport X and let

$$A = C \times 24 \times 365 = C \times 8760$$

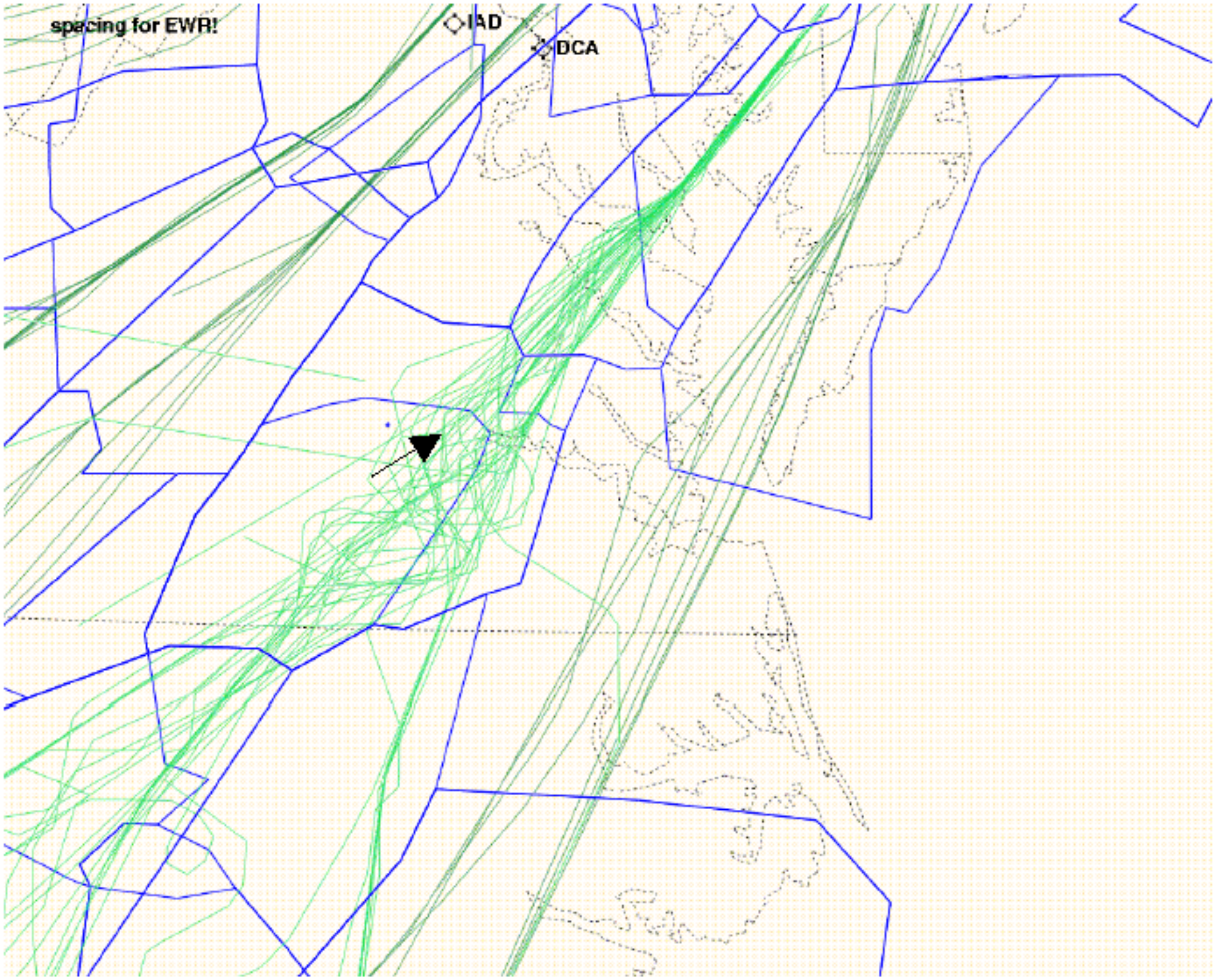
- Then the *annual capacity of X will be in the range of 50%- 60% of A,* the percentage depending on local conditions of use and peaking patterns.
- *Note:* If instead of saturation capacity, C is the *declared* capacity, then the annual capacity will be in the range of 60%- 70% of A, since the declared capacity is usually set to approximately 85%- 90% of saturation capacity.

Measuring and Attributing Delay

- It is difficult to use field data to measure and attribute delay when congestion is severe
- Tightly inter-connected, complex system
- Users react dynamically to delays (feedback effects, flight cancellations)
- Geographical spreading (no single location for measurement), temporal propagation and secondary effects
- Delay-free, nominal travel times are not readily available
- Causality is unclear

Sequencing and Spacing of EWR Traffic

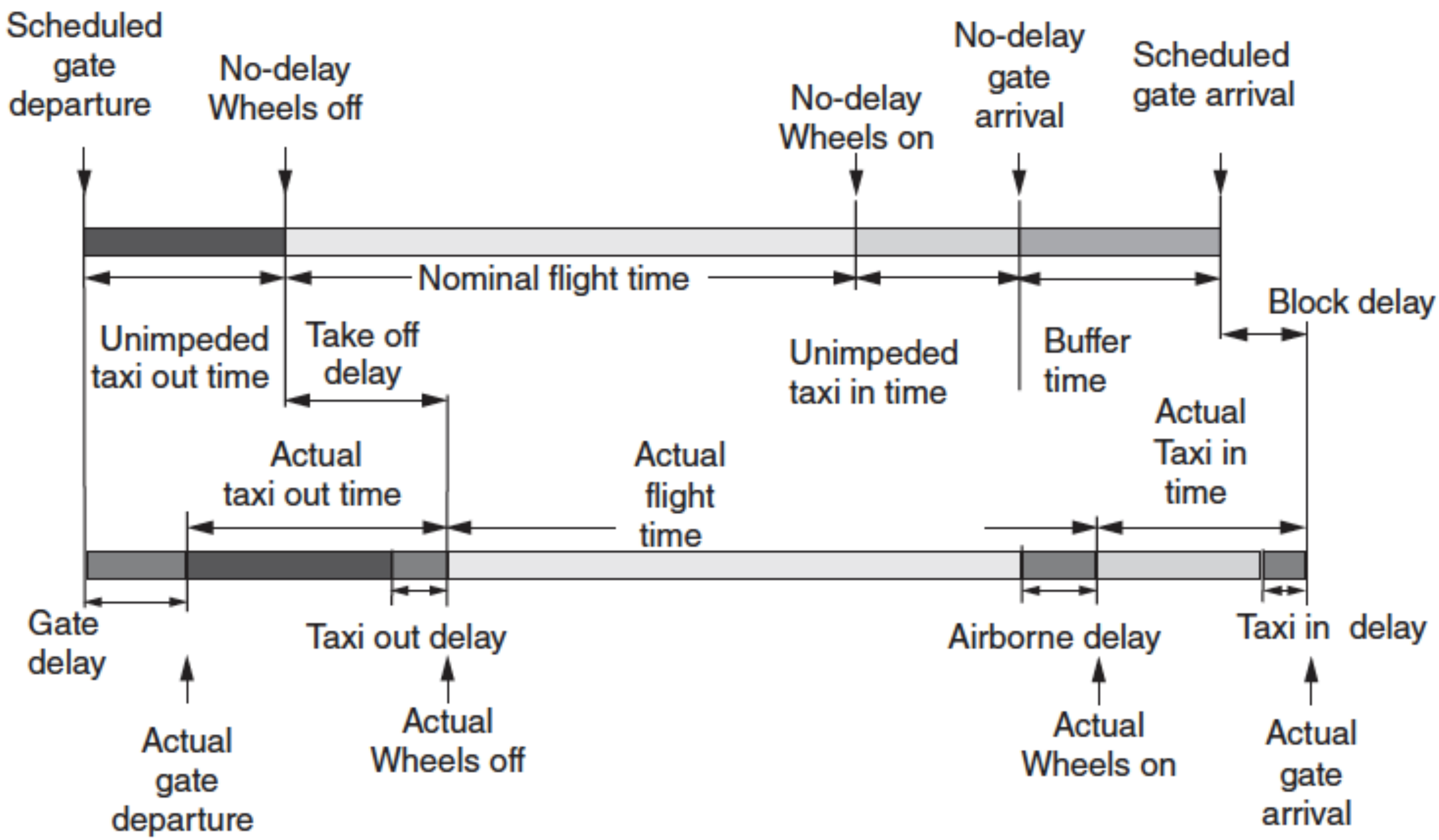
Source: FAA/Eurocontrol (2004)



The Two Fundamental Types of Delay

- Two types of delay measurements
  - Delay relative to schedule
  - Delay relative to some nominal time
- In the US (and in much of the world) a flight is counted as "late" if it arrives at the gate more than 15 minutes later than scheduled
- In recognition of habitual delays, airlines in the US have been lengthening ("padding") the scheduled duration of flights
    - improve "on-time arrival" statistics
    - improve reliability of their schedules
- Thus, airline scheduled flight durations include "hidden" delay
- A flight that arrives on schedule may in truth have been significantly delayed!

Understanding the Measurement of a Flight's Delay



True Delay = Buffer Time + Block Delay

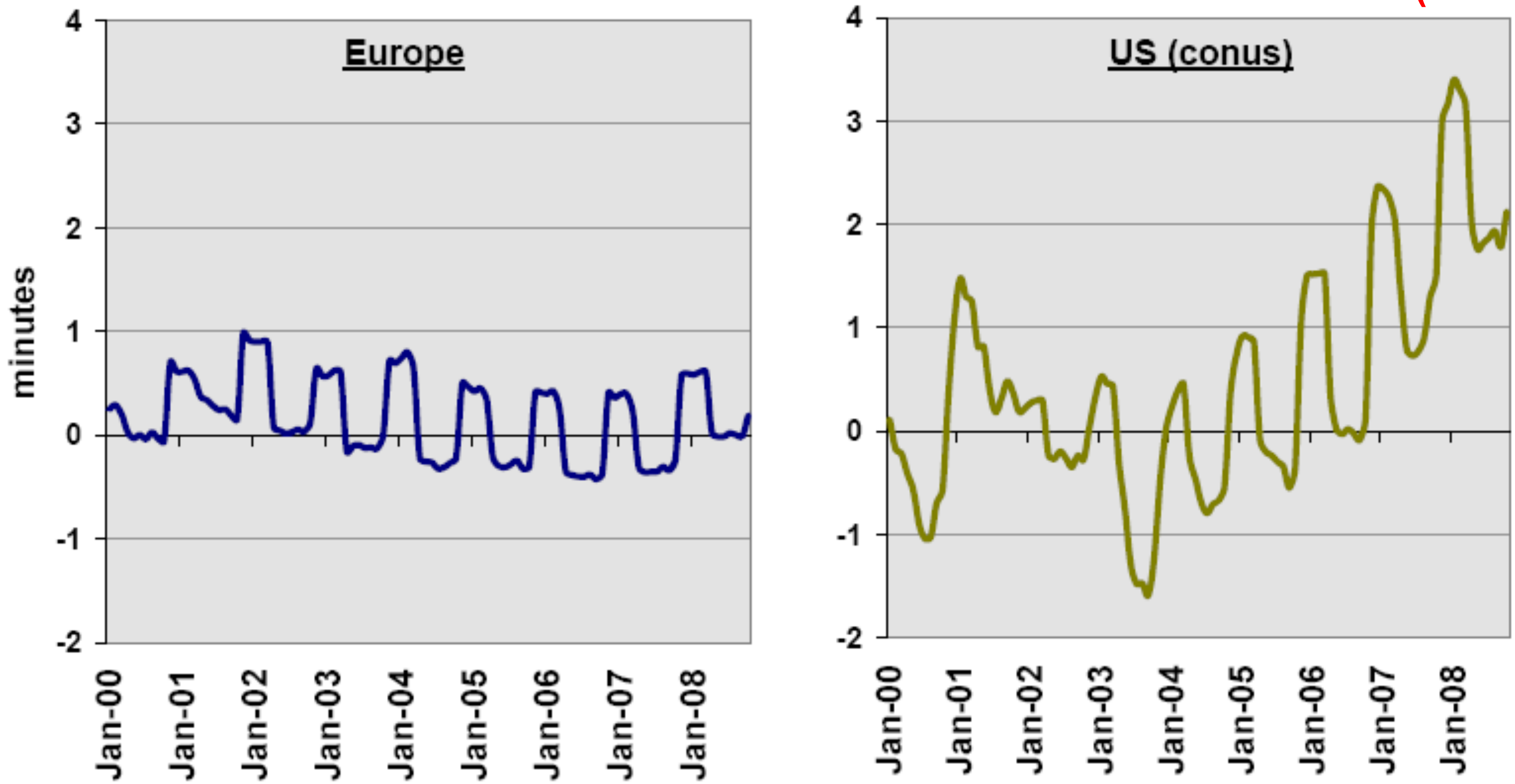
Cost to Airlines

Cost to airlines of flight delays ($ Billions):

	Delay Against Schedule	Buffer	Total
7 major airlines	3.3	2.6	5.9
Industry wide	4.6	3.7	8.3

Evolution of Scheduled Block Times
(34 top US and European airports)

Source: FAA/Eurocontrol (2009)



Between 1993 and 2000, scheduled block times for flights operating between 27 busiest US airports increased by 7 min on average [ElAlj, 2002] ➔ Total: ~10 min

Questions? Comments?