Airside Congestion

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M.Sc. Program

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Module 11

May 27, 2015

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 and 20 in de Neufville and Odoni

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

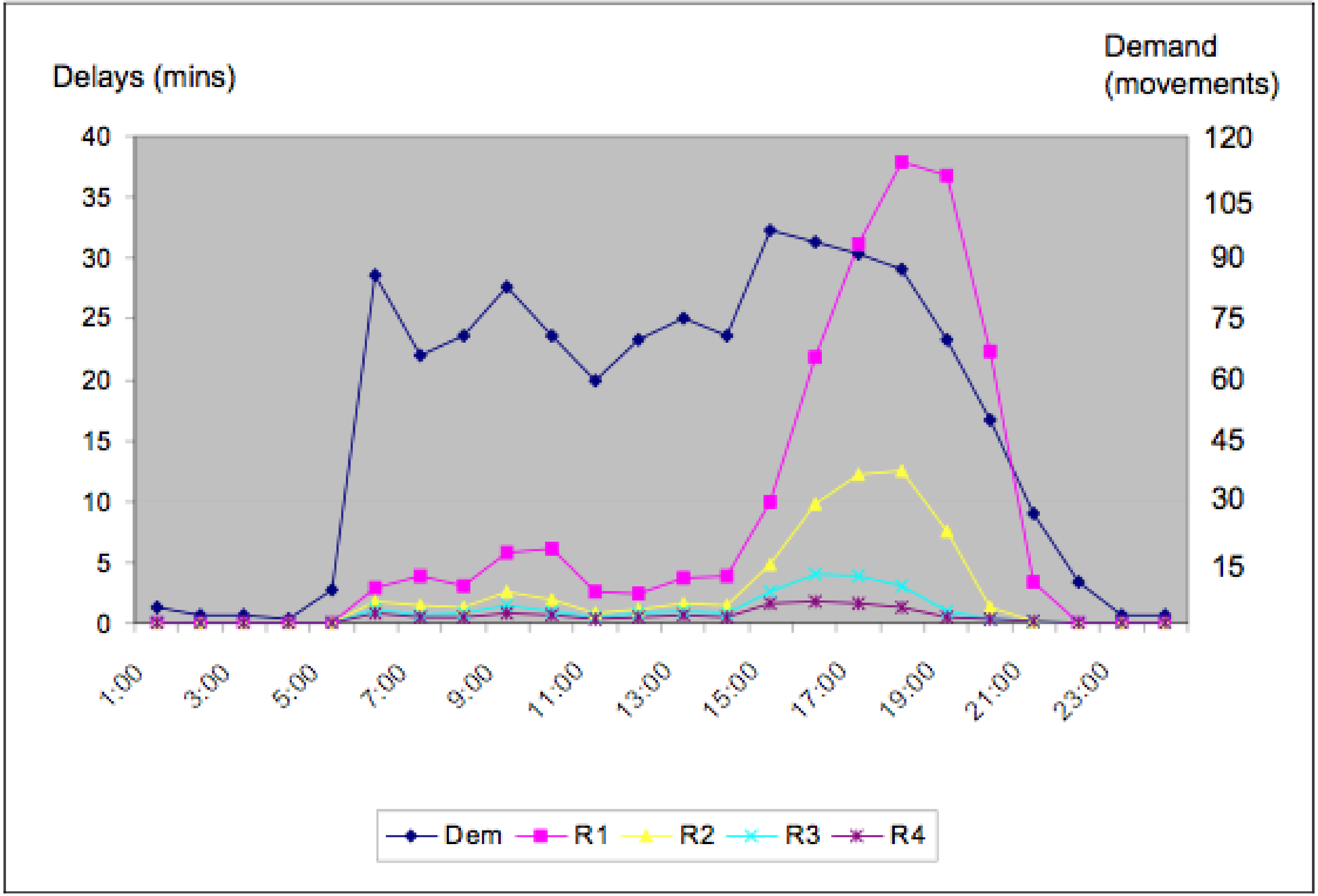
Dynamic (“Short-Run”) Behavior of Queues

- 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

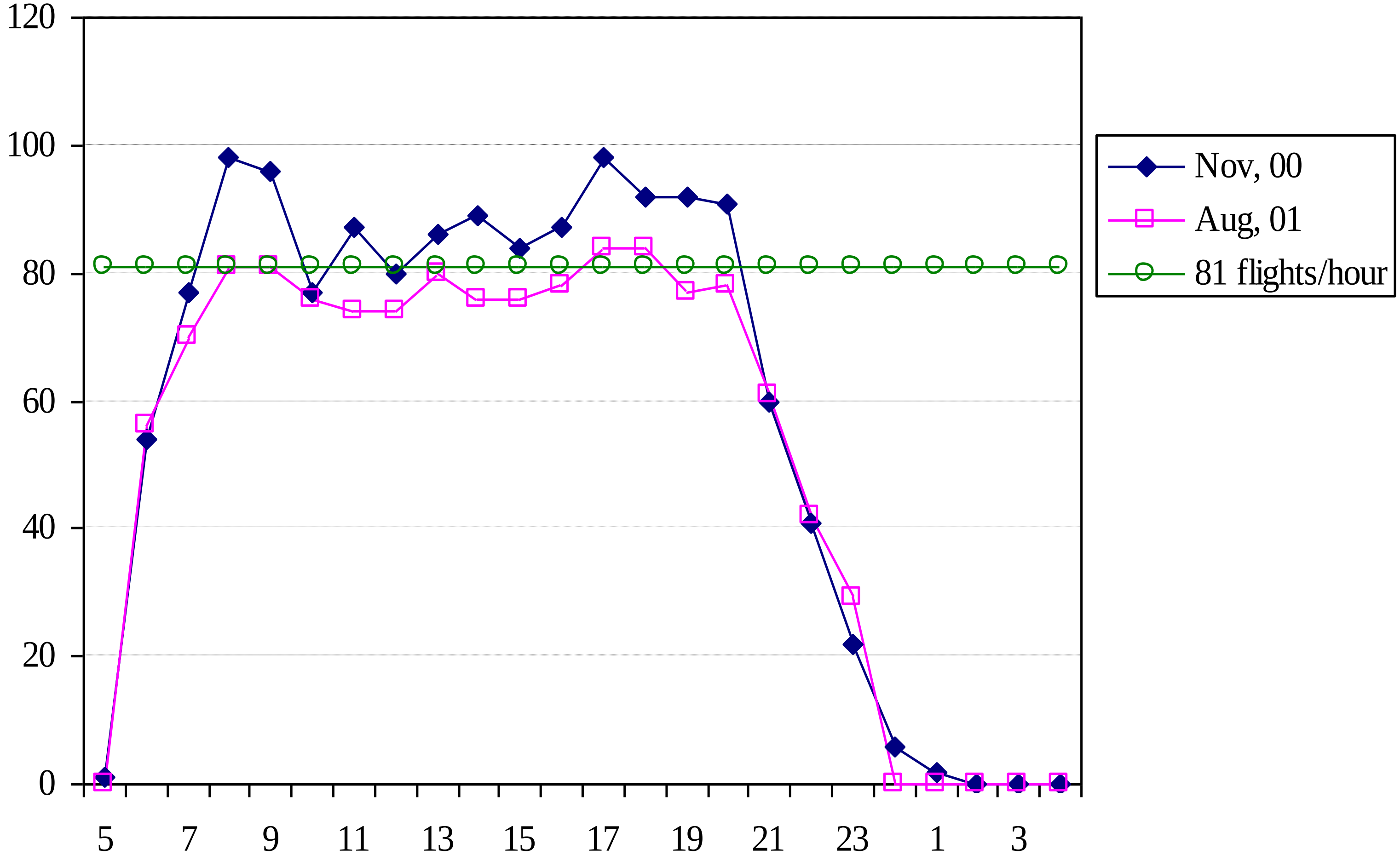


Expected delay for four different levels of capacity

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

Scheduled aircraft movements at LGA before and after 2001 slot lottery

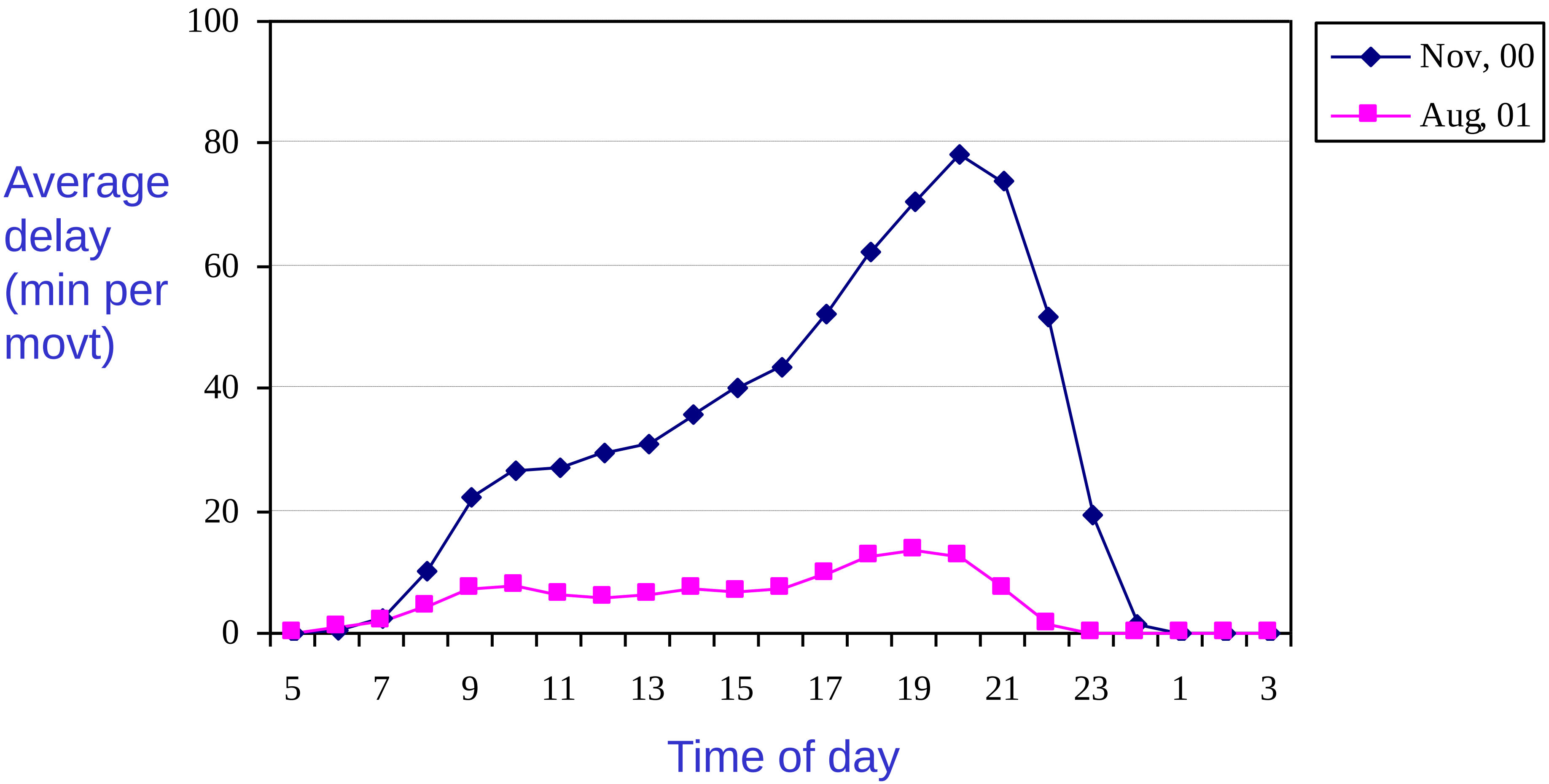
Scheduled movements per hour



Time of day (e.g., 5 = 0500 – 0559)

- **The green line shows the airport capacity in good weather**

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

Behavior of Queuing Systems in the "Long Run"

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

$$r = \frac{average\ demand\ rate}{average\ service\ rate} = \frac{"demand"}{"capacity"} = \frac{l}{m}$$

- 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.
- **But delays may occur even when $\rho < 1$ due to time-variability of demand and to probabilistic fluctuations of demand and capacity; these delays can be very large when ρ is close to 1.**

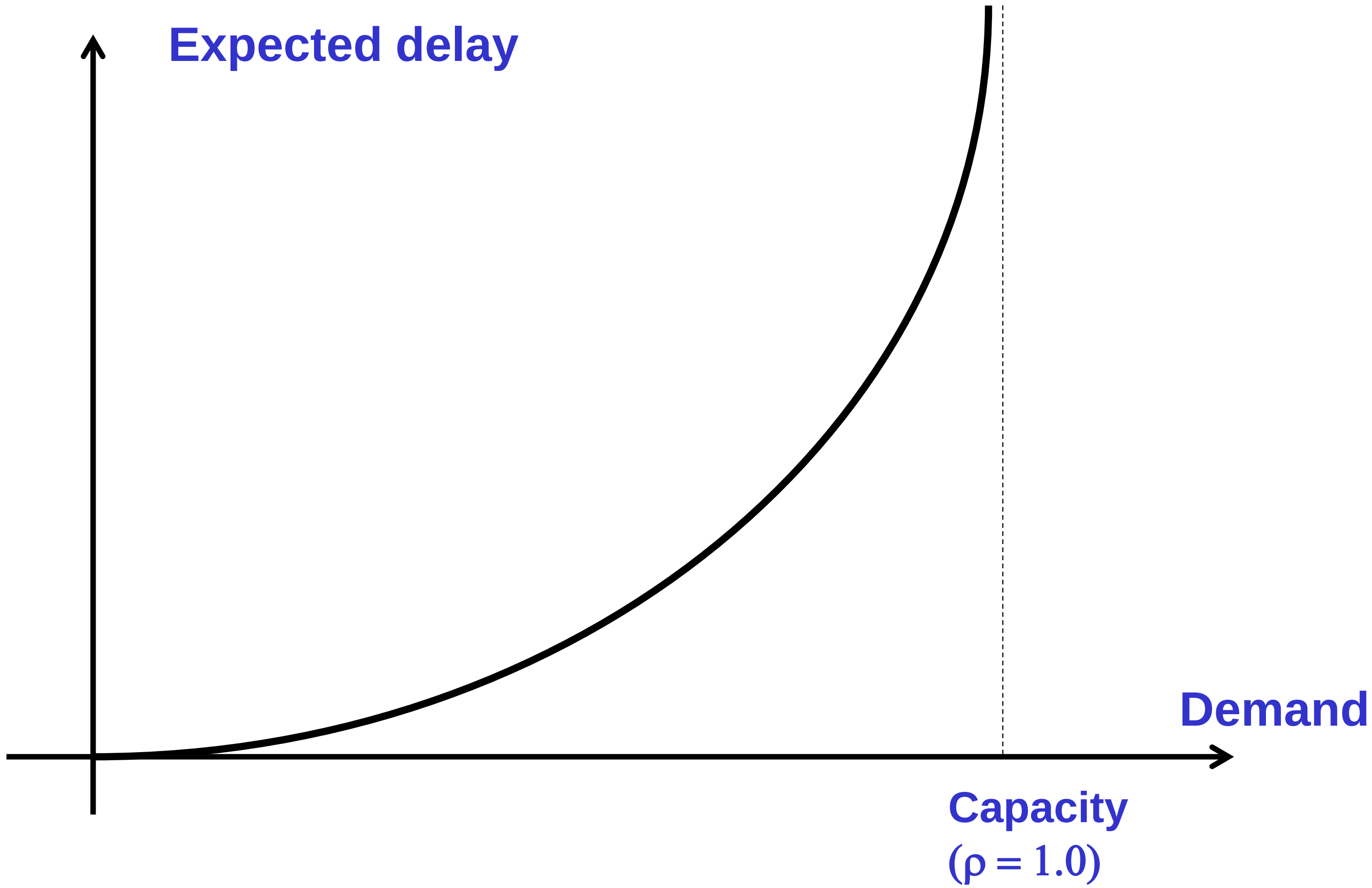
Behavior of Queuing Systems in the "Long Run"[2]

- In the "long run", the average queue length and average delay in a queuing system are proportional to:

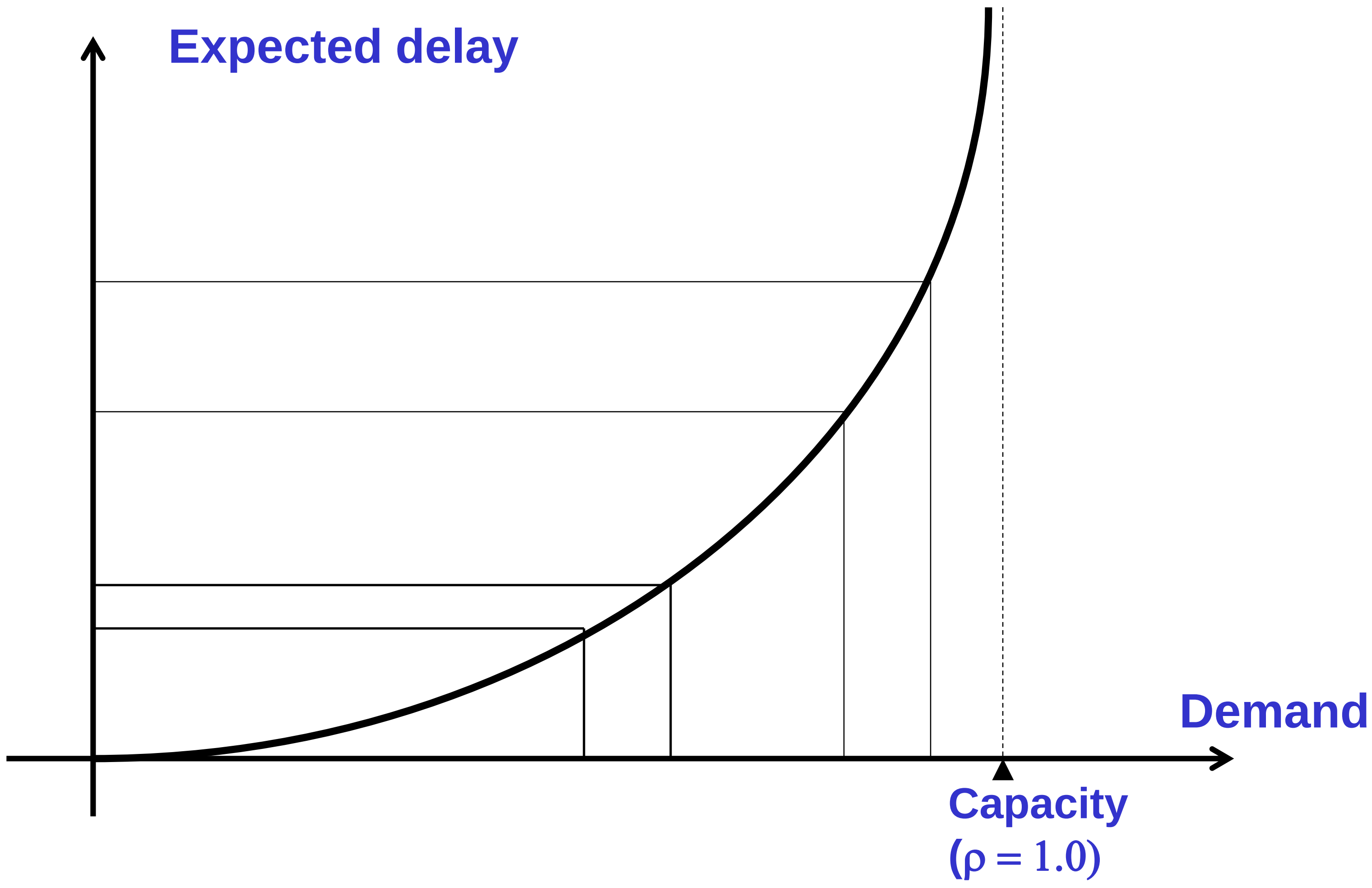
$$\frac{1}{1-\rho}$$

- 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 variability (= "standard deviation") of queue length and delay from day to day is also proportional to $$\frac{1}{1-\rho}$$

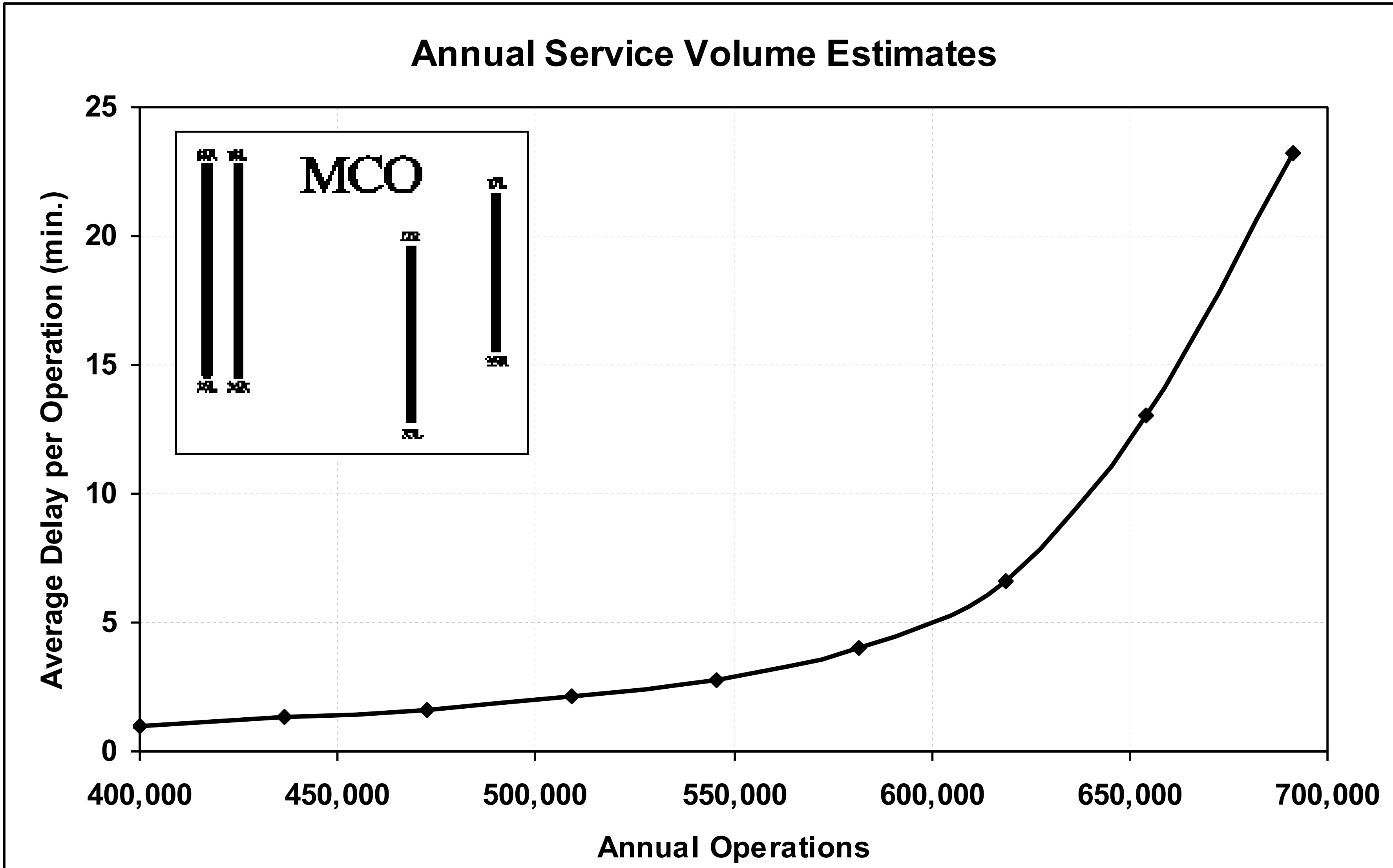
Delay vs. Demand and Capacity



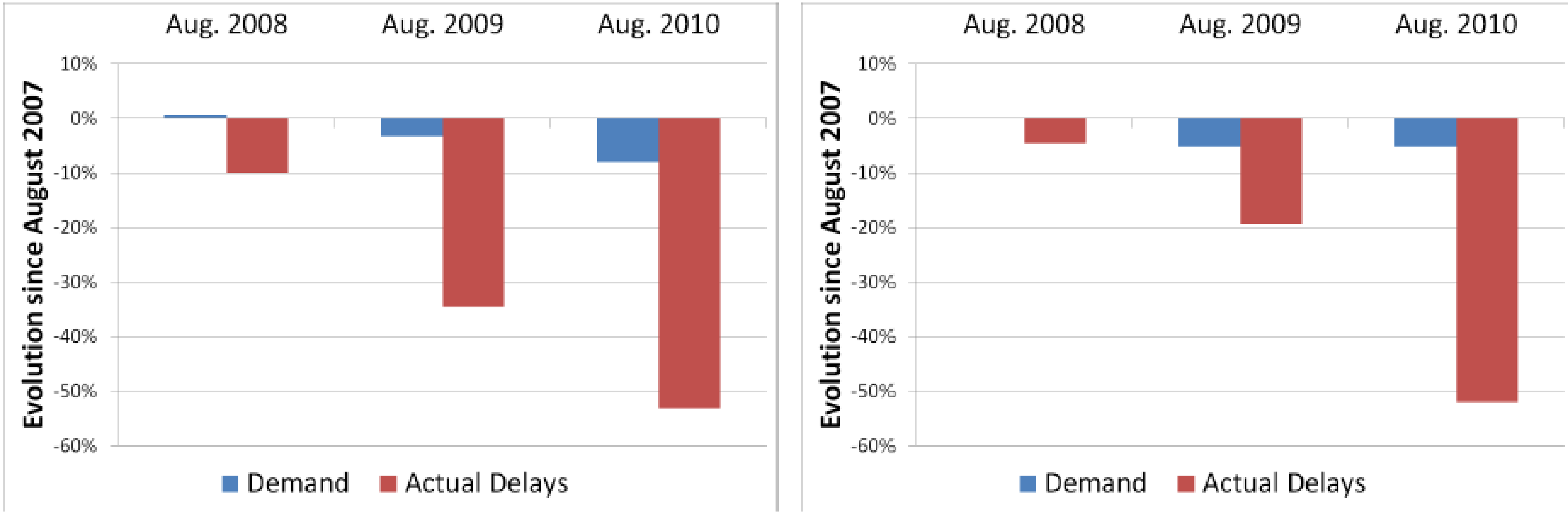
High Sensitivity of Delay at High Levels of Utilization



Delay vs. Annual Operations at Orlando Airport (MCO)



Evolution of NY Delays (2007 – 2010)



(a) JFK (b) EWR

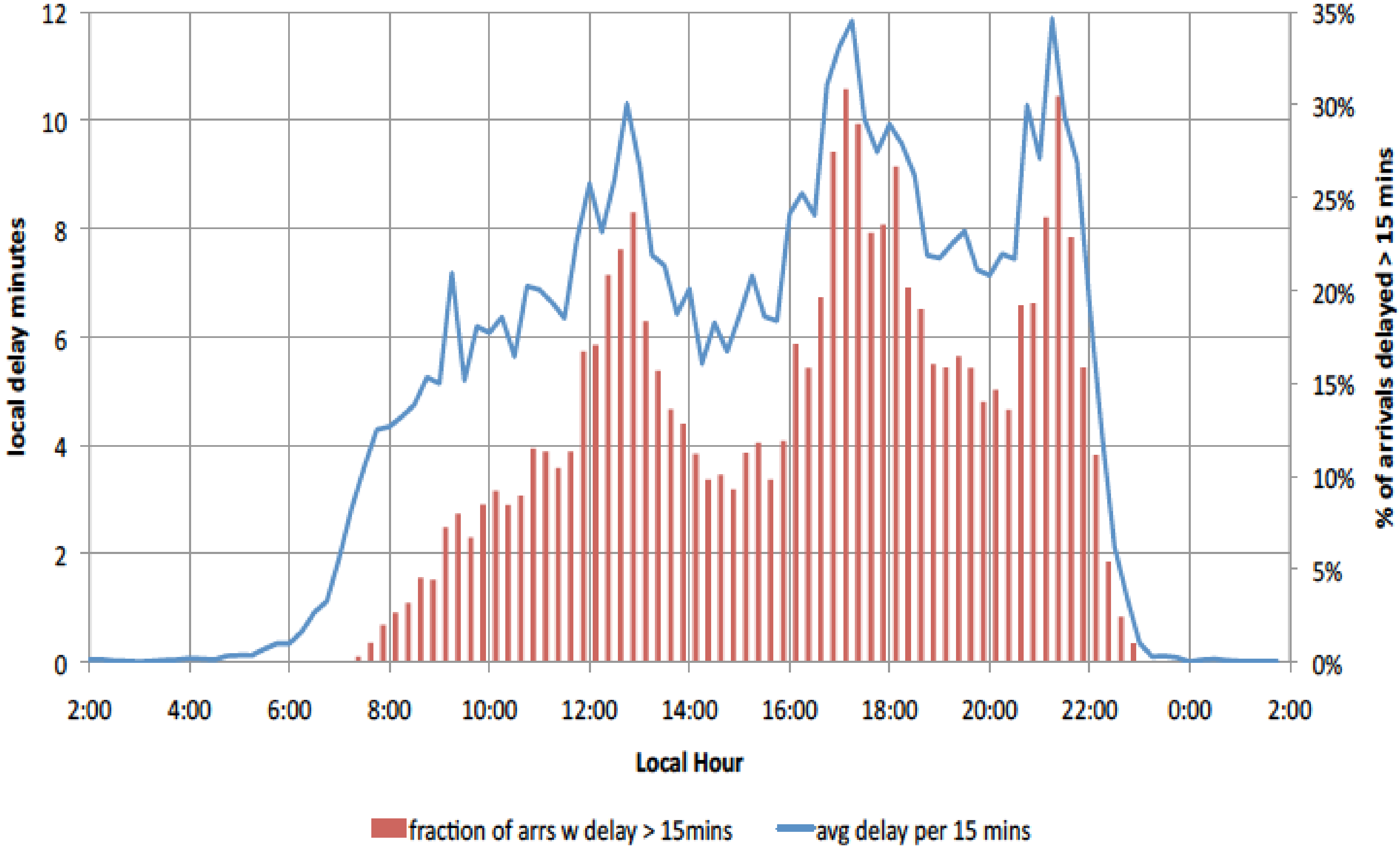
	JFK		EWR	
Month in 2010	**July**	**August**	**July**	**August**
Demand	**-6.84%**	**-8.02%**	**-3.37%**	**-5.16%**
Actual Delays	**-46.90%**	**-53.15%**	**-32.93%**	**-52.02%**
Model-Predicted Delays	**-48.69%**	**-51.30%**	**-36.14%**	**-41.56%**

Jacquillat, 2012

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)

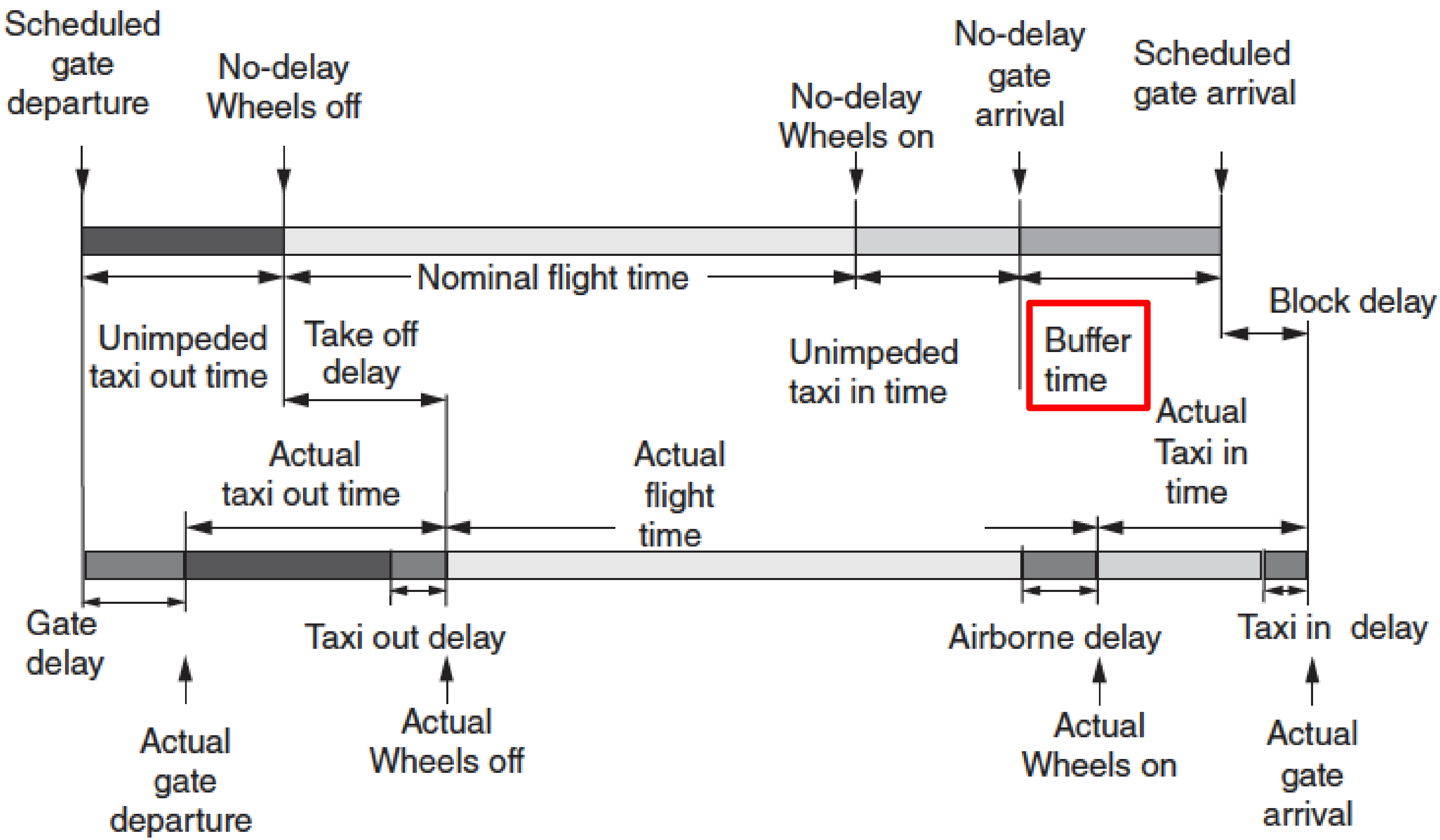
Dynamic Delay Statistics for a Busy Airport



Two Types of Delay Measurement

- Two types of delay measures; cause of much confusion:
  - "True" delay: the difference between the actual time it took to complete a flight (or a flight segment) and an estimate of the time ("nominal time") that would be required in the absence of delay
  - Delay relative to schedule
- In much of the world, a flight is counted as "late" if it arrives or departs (at gate) more than 15 minutes later than scheduled [note this is delay relative to schedule]
- In recognition of habitual "true" delays, airlines have been lengthening ("padding") the scheduled duration of flights
  - improve "on-time arrival" statistics
  - improve reliability and realism of their schedules
- Thus, airline scheduled flight durations include a delay allowance: 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

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

Tools for Estimating Delays Theoretically

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Questions? Comments?