Simulating Airport Delays and Implications for Demand Management

1.231: Course Project

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Delays are a big problem! and something needs to be done

- Delay cost to airlines and passengers = $16.5B
- Total operating profit of domestic carriers = $4.4B

Main cause is the demand-capacity mismatch

So what to do?

- We can reduce delays by:
  - Decrease in Demand and/or Increase in Capacity
- Delays will reduce...
  - But by how much?
  - What are the negative effects? Do the pros outweigh than the cons?
  - What strategies are the best?
- We need to know the effects of delay reduction before actually implementing it
...so we Simulate Queues

- **M|G|1 model with a ‘schedule’:**
  - Poisson arrival process: but with a schedule
  - Flight arrivals do have a schedule. So we will choose a process *somewhat less random than pure Poisson*
  - Moderate variation in service times (±5%)
  - More random than cumulative diagrams
Simulator Design

• Divide the entire day into discrete time periods (1 hour)
  – Actual demand per period equals scheduled number of arrivals (inconsistent with Poisson)

• For every arrival in the interval: \( t_0 \) to \( t_0+1 \)
  – Simulate actual arrival time \( \sim U[t_0, t_0+1] \) (Consistent with Poisson)
  – Simulate actual service time \( \sim U[0.95\mu, 1.05\mu] \)

• Tried Pure Poisson: Led to unrealistic results => Discarded

• For constant average service time:
  – Delay variance increases with increase in service time variance
  – Average delay increases with increase in service time variance

• Single server assumption: best for convenience and practicality
Choice of Sample Size

• Most important decision: Sample size
  – Greater the sample size lower is the variance of simulation statistics: **Good**
  – Greater the sample size more is the run time: **Bad**
  – Tradeoff

![Graph showing tradeoff between log(delay variance) and log(run time) vs. sample size (log scale)]
Delays when Capacity Exceeds Demand

- Delays can and do occur even when demand is lower than capacity

LGA under VFR
Average Vs Marginal Delays

- Average delays: depend on queue history
- Marginal delays: depend on queue future

LGA under IFR
Impact of GDP...

- Persists way beyond the end of capacity reduction period

JFK

Capacity back to normal

Impact of GDP persists
Implications for Demand Management

• Quantity based demand management
  – Delays depend almost entirely on the declared capacity and not on how slots are distributed among different airlines
  – Administrative Controls and Slot Auctions:
    • Extremely different from social welfare and economic efficiency perspective
    • Very similar from delay perspective

• Price based demand management
  – External costs computed in the absence of congestion pricing provide only a lower bound
  – Finding equilibrium prices is a fixed point problem
  – Solving iteratively has no guarantees of convergence
Quantity based Demand Management

• Capping the capacity at IFR level:
  – Analysis of one entire year of GDP data at LGA
  – 6 different categories based on weather conditions
  – A **4.2%** reduction in operations results in **47%** delay reduction
Price based Demand Management

- Demand depends on marginal delays (assume linear demand function)
- Marginal delays depend on demand
- Solution of a fixed point problem:
  - Solving a system of non-linear simultaneous equations

\[
D (C_T) = \max (D_0 - \alpha C_T, 0)
\]

\[
C_T = C_I + C_C
\]

\[
C_T = MC (D)
\]

- Calculation of MC(D) requires simulating delays
- We will try to solve using two different algorithms
  - Alternate
  - Alternate with moving averages
Alternate Algorithm

• Use each equation alternately
  – Start with a MC and D value.
  – Get D from MC, the MC from D then D from MC etc ...

– Keeps oscillating back and forth; does not converge
Alternate with Moving Averages

- Same as before, but use moving average of successive D values

- Converges very fast

- Fixed point:
  - Equilibrium Demand = 42 flights/hr, Congestion Toll = $11,815
Key Takeaways

• Delay simulator provides intuition about delay characteristics
  – Easy to code and test various concepts about dynamic queues
  – No added complexity for testing complex distributions

• Delays vary with instantaneous demand and capacity
  – Average and marginal delays also depend on the history and future behavior of queues

• Very small changes in demand may lead to drastic delay reduction

• Simulator can be used to test the theoretical and computational aspects of congestion pricing