Airport Taxi Operations Modeling: GreenSim

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September 28, 2007
Outline

• Queueing 101
• GreenSim: Modeling and Analysis
• Tool Demonstration & Case Study
Motivation

• GreenSim
  • Airport as a “black-box”
    – 5 stage queueing model
  • Schedule and configuration dependent
    – Queueing models configured based on historic data
  • Stochastic behavior (i.e. Monte Carlo)
    – Behavior determined by distributions
  • Comparison of procedures (e.g. RNP procedures) and technologies (e.g. surface management)
    – Adjust distributions to reflect changes
• Rapid (< 1 week)
  – Fast set-up and run
Typical Queueing Process

Common Notation

- $\lambda$: Arrival Rate (e.g., customer arrivals per hour)
- $\mu$: Service Rate (e.g., service completions per hour)
- $1/\mu$: Expected time to complete service for one customer
- $\rho$: Utilization: $\rho = \lambda / \mu$
A Simple Deterministic Queue

- Customers arrive at 1 min, 2 min, 3 min, etc.
- Service times are exactly 1 minute.
- What happens?
A Stochastic Queue

- Times between arrivals are \( \frac{1}{2}\) min. or \( 1\frac{1}{2}\) min. (50% each)
- Service times are \( \frac{1}{2}\) min. or \( 1\frac{1}{2}\) min. (50% each)
- Average inter-arrival time = 1 minute
- Average service time = 1 minute
- What happens?
Stochastic Queue in the Limit

- Two queues with same average arrival and service rates
  - Deterministic queue: zero wait in queue for every customer
  - Stochastic queue: wait in queue grows without bound
- Variance is an enemy of queueing systems
The $M/M/1$ Queue

Inter-arrival times follow an exponential distribution (or arrival process is Poisson)

Service times follow an exponential distribution

A single server

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

Avg. # in System

$\rho$
The $M/M/1$ Queue

- **Observations**
  - 100% utilization is not desired

- **Limitations**
  - Model assumes *steady-state*. Solution does not exist when $\rho > 1$ (arrival rate exceed service rate).
  - Poisson arrivals can be a reasonable assumption
  - Exponential service distribution is usually a bad assumption.

\[
L = \frac{\rho}{1 - \rho}
\]
The $M/G/1$ Queue

Service times follow a general distribution

Required inputs:
- $\lambda$: arrival rate
- $1/\mu$: expected service time
- $\sigma$: std. dev. of service time

$\rho = \mu = 1$, $\sigma = 0.5$

$L = \rho + \frac{\rho^2 + \lambda^2 \sigma^2}{2(1 - \rho)}$

Avg. # in System
**M/G/1: Effect of Variance**

\[
L = \rho + \frac{\rho^2 + \lambda^2 \sigma^2}{2(1 - \rho)}
\]

\[\lambda = 0.8, \mu = 1 (\rho = 0.8)\]
Other Queues

- **$G/G/1$**
  - No simple analytical formulas
  - Approximations exist
- **$G/G/\infty$**
  - Infinite number of servers – no wait in queue
  - Time in system = time in service
- **$M(t)/M(t)/1$**
  - Arrival rate and service rate vary in time
  - Arrival rate can be temporarily bigger than service rate
Queueing Theory Summary

• **Strengths**
  – Demonstrates basic relationships between delay and statistical properties of arrival and service processes
  – Quantifies cost of variability in the process
  – Analytical models easy to compute

• **Potential abuses**
  – Only simple models are analytically tractable
  – Analytical formulas generally assume steady-state
  – Theoretical models can predict exceptionally high delays
  – Correlation in arrival process often ignored

• **Simulation can be used to overcome limitations**
GreenSim

**GreenSim Airport Operations Simulation**

Developed by Liya Wang @ CATSR

![Java Airport Simulation Software](image)

- Airport: BWI
- From: 8/1/2005
- To: 11/1/2005

- Demand and Capacity Input
  - Input Report
  - Input Graphs
  - Fleet Mix
  - Service Time Setting
  - Run Simulation
  - Output Graphs
  - Output Report
  - Emission Calculation
  - Exit

George Mason University
GreenSim Input/Output Model

User adjustable input:
- Flights Schedule
- Aircraft type
- Capacity (AAR, ADR)

GreenSim Airport Operations Simulation

Outputs:
- Delays (taxi-in, taxi-out)
- ADOC
- Emission
- Departure Runway
- Queue Size
- Gate Utilization
GreenSim Architecture
Data Analysis Process

1. Gather data samples

2.1. Delete abnormal days

2.2. Delete abnormal individual data in each day

3.1. Fit distribution for each quarterly data on each day

3.2. Combine all distributions for each quarter together to find final distribution
Queueing Simulation Model

The diagram illustrates a queueing simulation model for an airport runway and taxiway system. The model is represented by the following Markovian queues:

1. **Runway (μ_{AR})**
   - Type: G/G/∞/∞/FCFS
   - Service rate: μ_{AR}
   - Arrival rate: λ_A

2. **Taxiway (μ_{AT})**
   - Type: G/G/∞/∞/FCFS
   - Service rate: μ_{AT}
   - Times: Taxi-in times

3. **Runway (μ_{DR})**
   - Type: G/G/1/∞/FCFS
   - Service rate: μ_{DR}
   - Arrival rate: λ_D

4. **Taxiway (μ_{DT})**
   - Type: G/G/∞/∞/FCFS
   - Service rate: μ_{DT}
   - Times: Taxi-out times

5. **Turn around**
   - Transition between Runway and Taxiway

6. **Ready to depart reservoir**
   - Transition from Taxiway to Runway

The model captures the flow of aircraft through the runway and taxiway system, including arrivals, service times, and transitions between states.
### Service Times Settings

<table>
<thead>
<tr>
<th>Segment Name</th>
<th>Settings</th>
<th>Notation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arrival Runway</td>
<td>$S_1 \sim \text{Exponential}(1/AAR)$</td>
<td></td>
</tr>
<tr>
<td>Arrival Taxiway</td>
<td>$S_2 \sim \text{NOMTI} + \text{DLATI- } S_1$</td>
<td>$\text{DLATI} \sim \text{Normal}(u_1, \sigma_1)$</td>
</tr>
<tr>
<td>Departure Taxiway</td>
<td>$S_3 \sim \text{NOMTO} + \text{DLATO- } S_4$</td>
<td>$\text{DLATO} \sim \text{Normal}(u_2, \sigma_2)$</td>
</tr>
<tr>
<td>Departure Runway</td>
<td>$S_4 \sim \text{Exponential}(1/ADR)$</td>
<td></td>
</tr>
</tbody>
</table>
Performance Analysis

- Delays (individual, quarterly average, hourly average, daily average)
- Fuel \[ Fuel = \sum_j (TIM_j) \times (FF_j / 1000) \times (NE_j) \]
- Emission (HC, CO, NOx, SOx)

\[ Emission_i = \sum_j (TIM_j) \times (FF_j / 1000) \times (NE_j) \times EI_{ij} \]

- \( TIM_j \) = taxi time for type-\( j \) aircraft
- \( FF_j \) = fuel flow per time per engine for type-\( j \) aircraft
- \( NE_j \) = number of engines used for type-\( j \) aircraft
- \( EI_{ij} \) = emissions of pollutant \( i \) per unit fuel consumed for type-\( j \) aircraft
EWR Hourly Average Delays

**Taxi-in Hourly Average Delays Comparison**

**Taxi-out Hourly Average Delays Comparison**