Airport Taxi Operations Modeling: GreenSim

John Shortle, Rajesh Ganesan, Liya Wang,
Lance Sherry,Terry Thompson, C.H. Chen

September 28, 2007

CENTER FOR AIR TRANSPORTATION SYSTEMS RESEARCH

GEORGE MASON UNIVERSITY

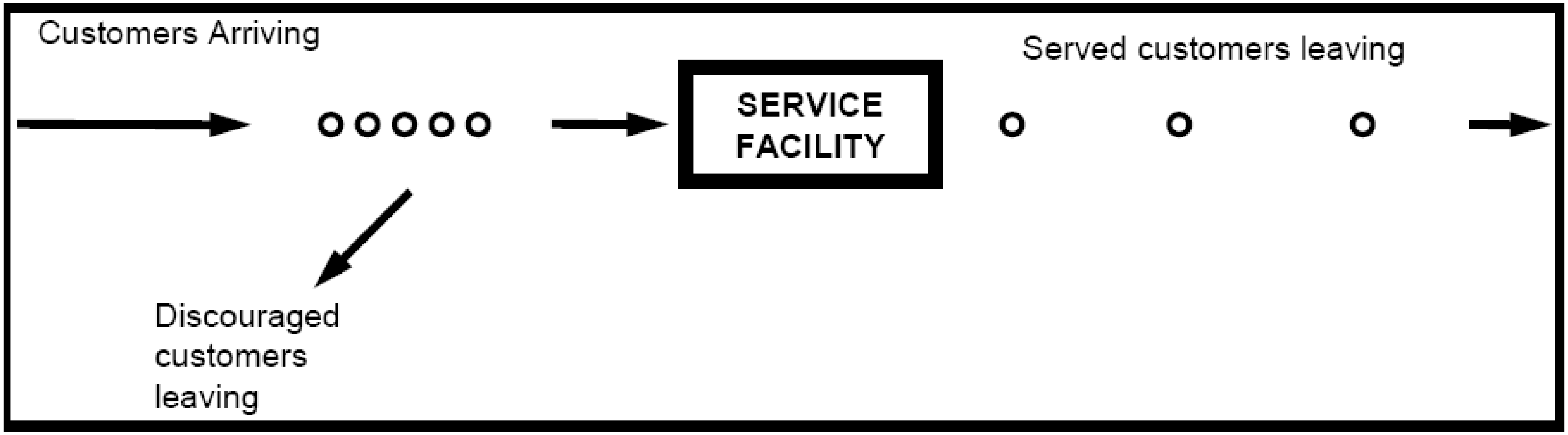
Outline

- 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



<u>Common Notation</u>

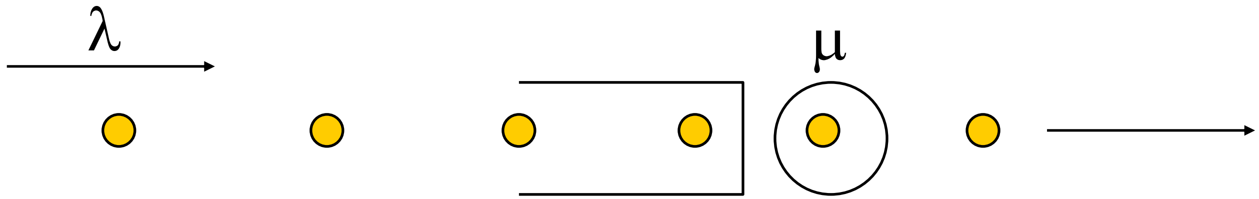
λ: Arrival Rate (e.g., customer arrivals per hour)

μ: Service Rate (e.g., service completions per hour)

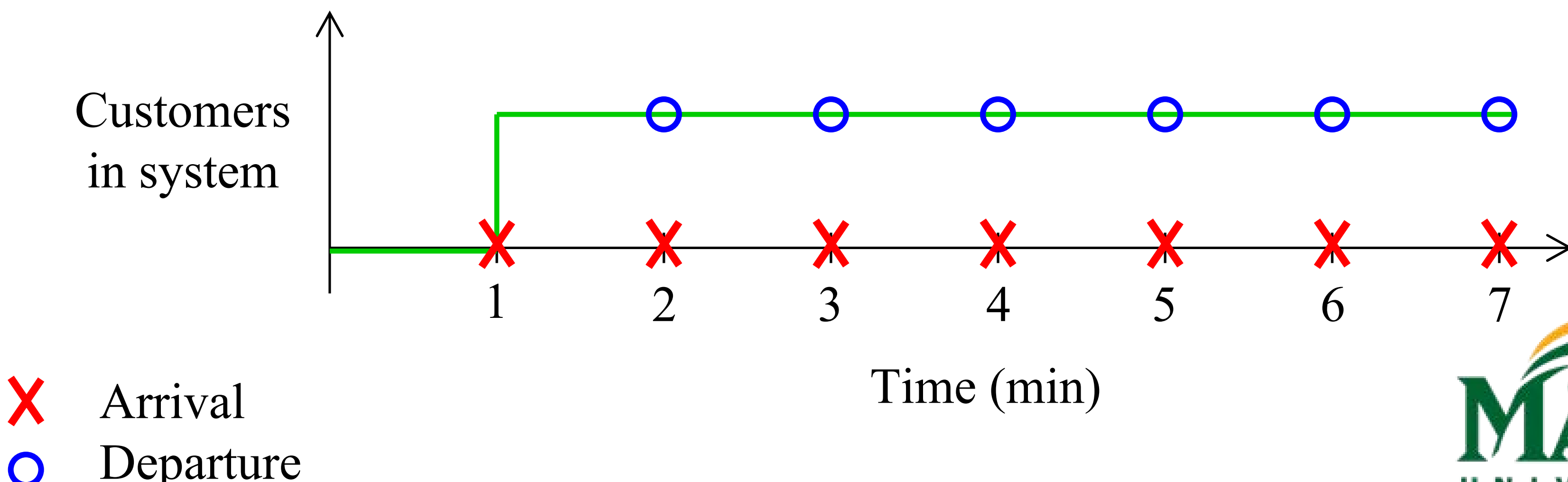
1/μ: Expected time to complete service for one customer

ρ: Utilization: $\rho = \lambda / \mu$

A Simple Deterministic Queue

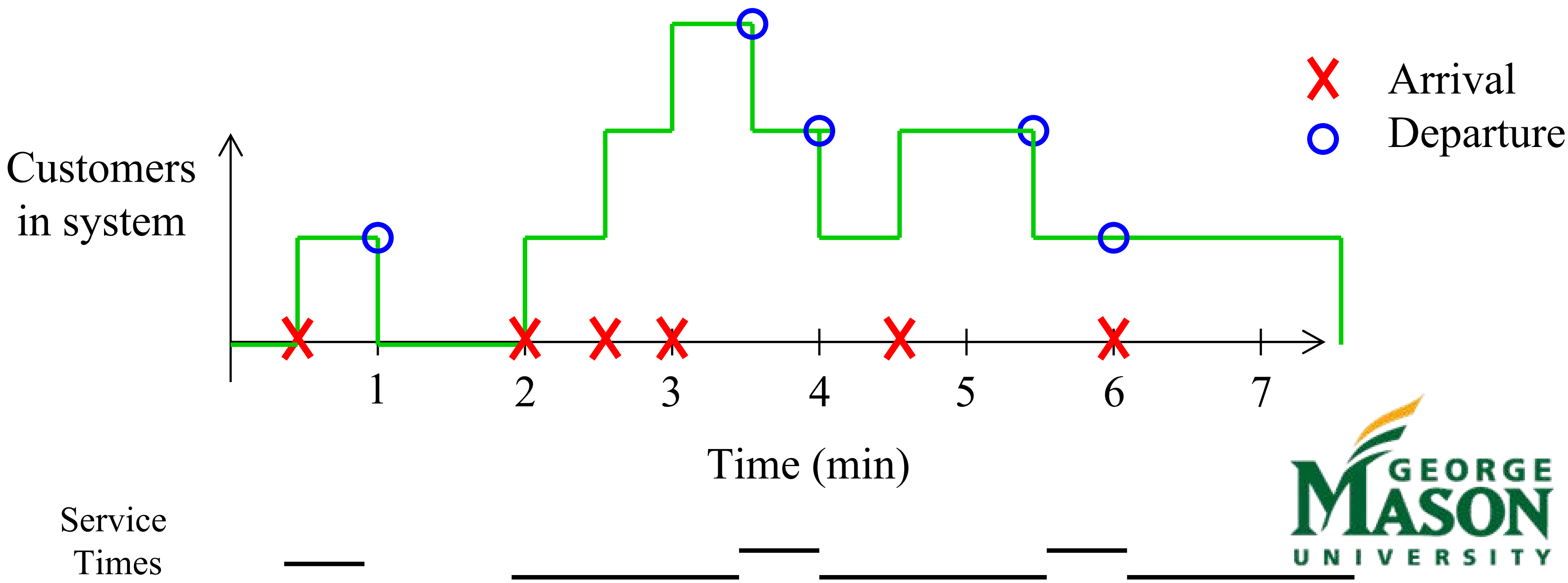


- Customers arrive at 1 min, 2 min, 3 min, etc.
- Service times are exactly 1 minute.
- What happens?

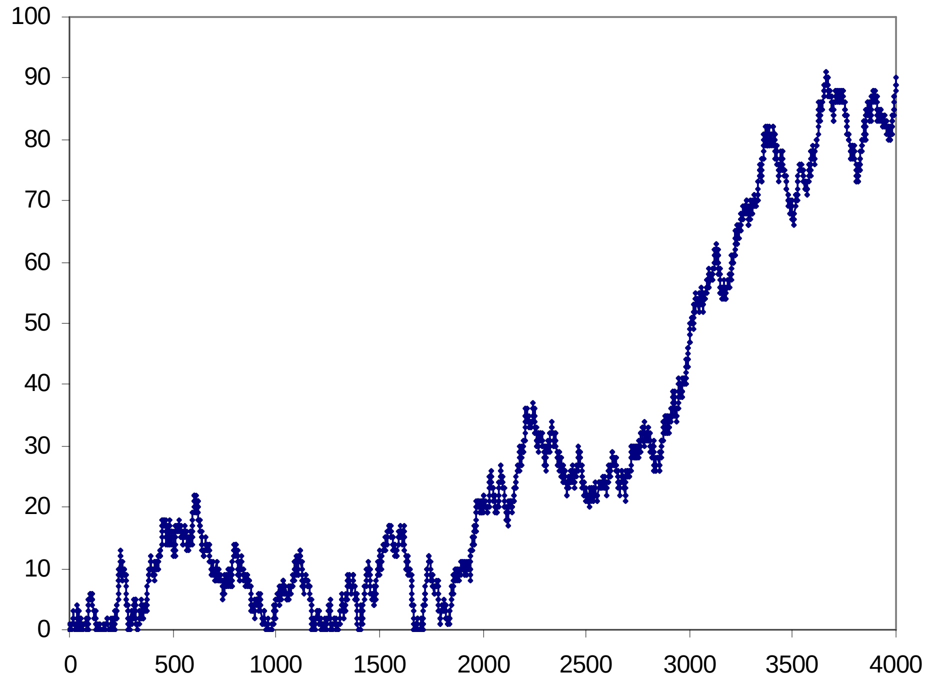


A Stochastic Queue

- Times between arrivals are ½ min. or 1½ min. (50% each)
- Service times are ½ min. or 1½ min. (50% each)
- Average inter-arrival time = 1 minute
- Average service time = 1 minute
- What happens?



Stochastic Queue in the Limit



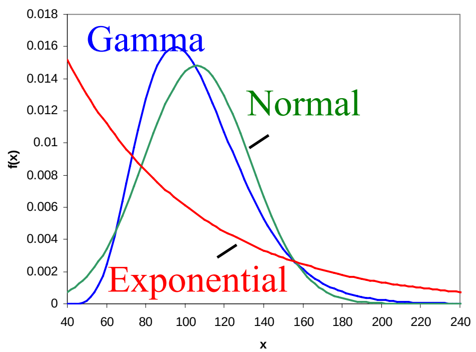
- Two queues with same average arrival and service rates
  - Deterministic queue: zero wait in queue for every customer
  - Stochastic queue: wait in queue grows without bound
- Variance is an enemy of queueing systems

The $M/M/1$ Queue

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

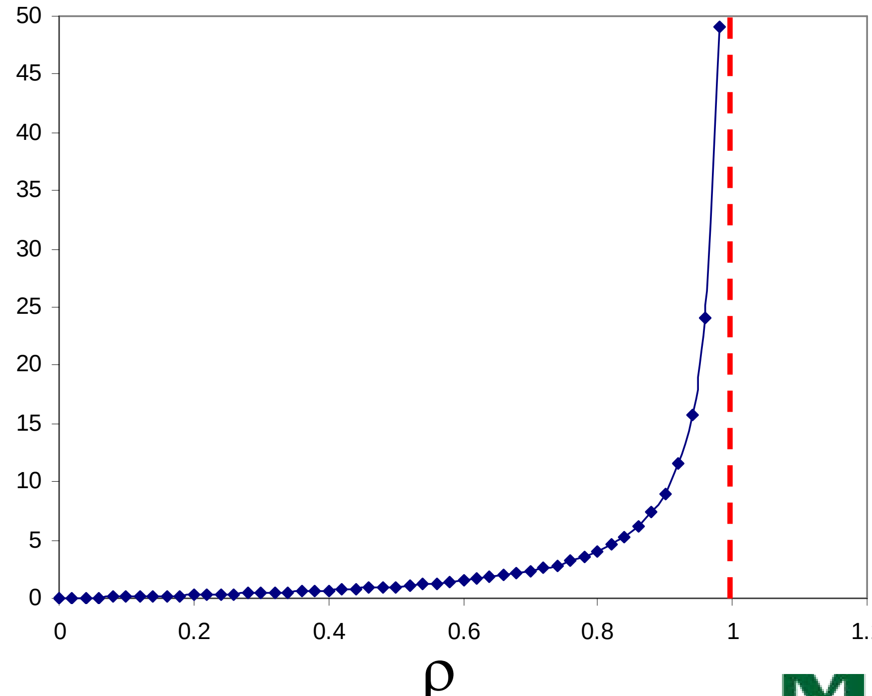
Service times follow an exponential distribution

A single server



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

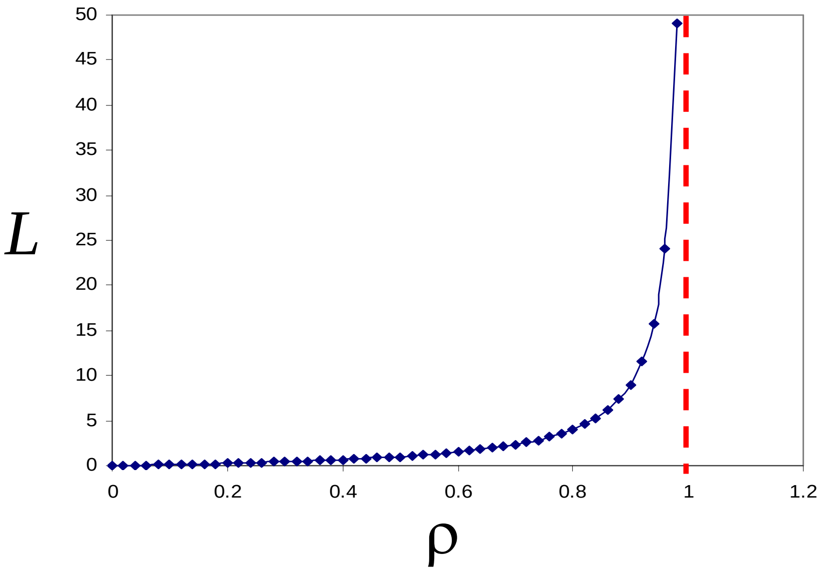
Avg. # in System



The $M/M/1$ Queue

- Observations
  - 100% utilization is not desired
- Limitations
  - Model assumes *steady-state*. Solution does not exist when ρ > 1 (arrival rate exceed service rate).
  - Poisson arrivals can be a reasonable assumption
  - Exponential service distribution is usually a bad assumption.

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

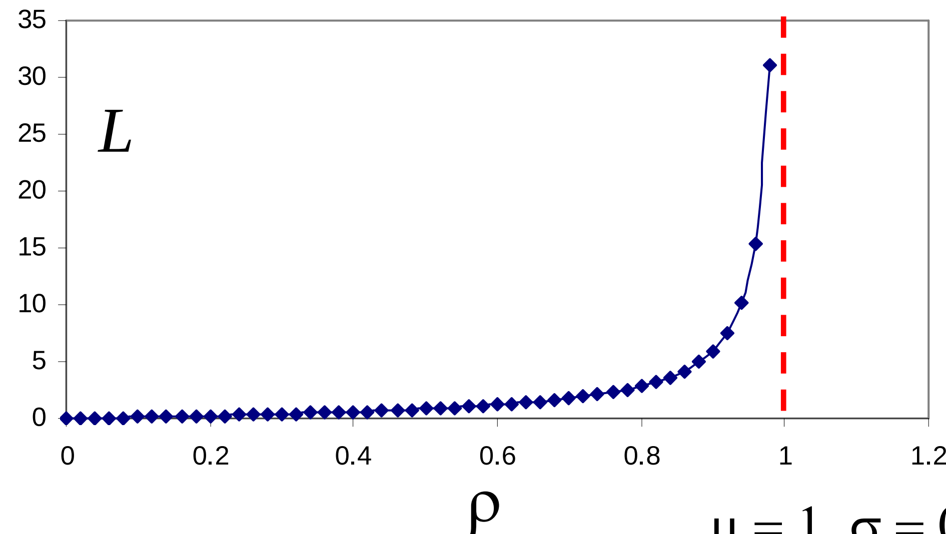


The $M/G/1$ Queue

Service times follow a *general* distribution

Required inputs:

- λ: arrival rate
- 1/μ: expected service time
- σ: std. dev. of service time

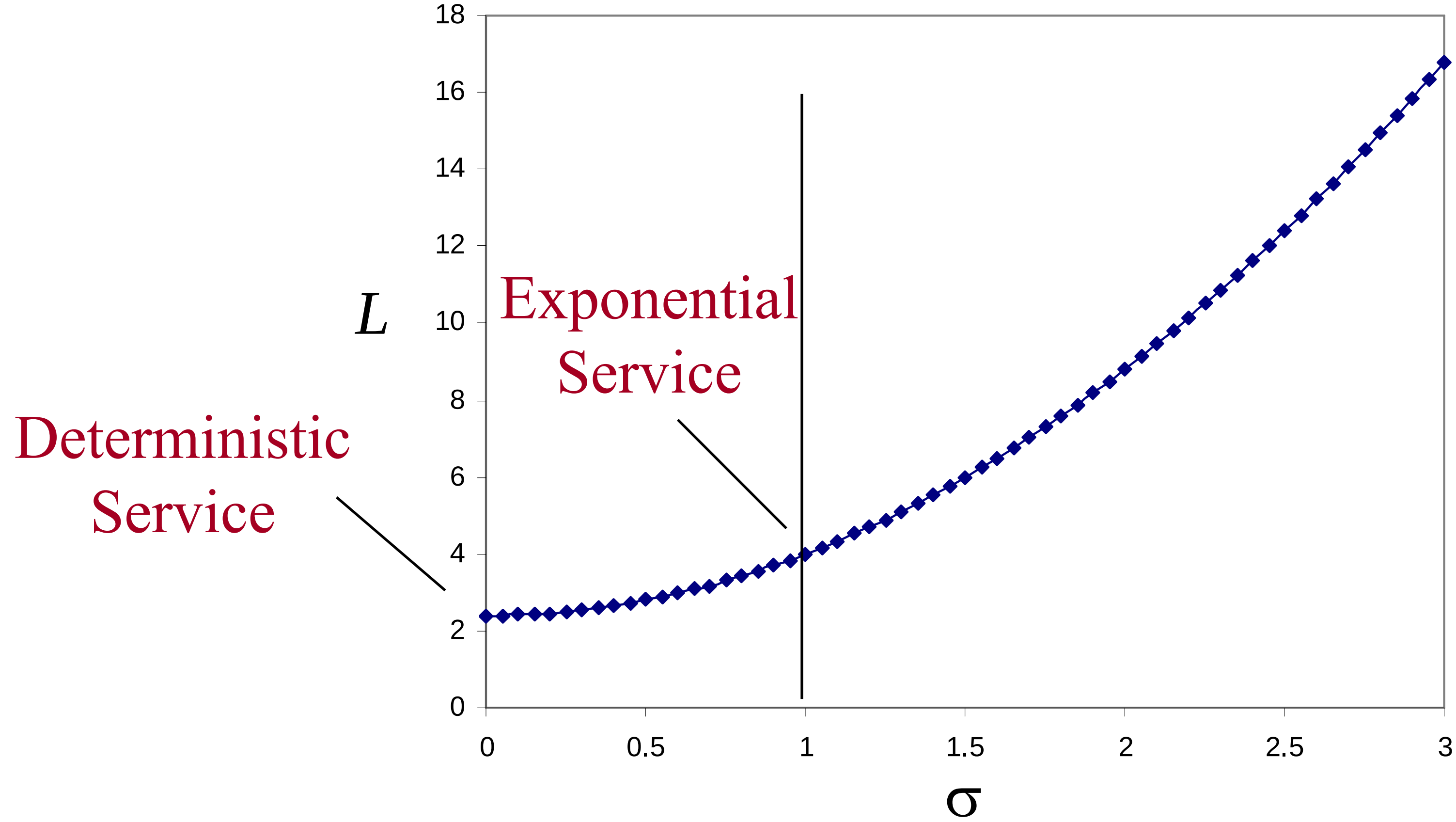


μ = 1, σ = 0.5

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

Avg. # in System

$M/G/1$: Effect of Variance



Arrival Rate Service Rate Held Constant

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

$\lambda = 0.8$, $\mu = 1$ ($\rho = 0.8$)

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

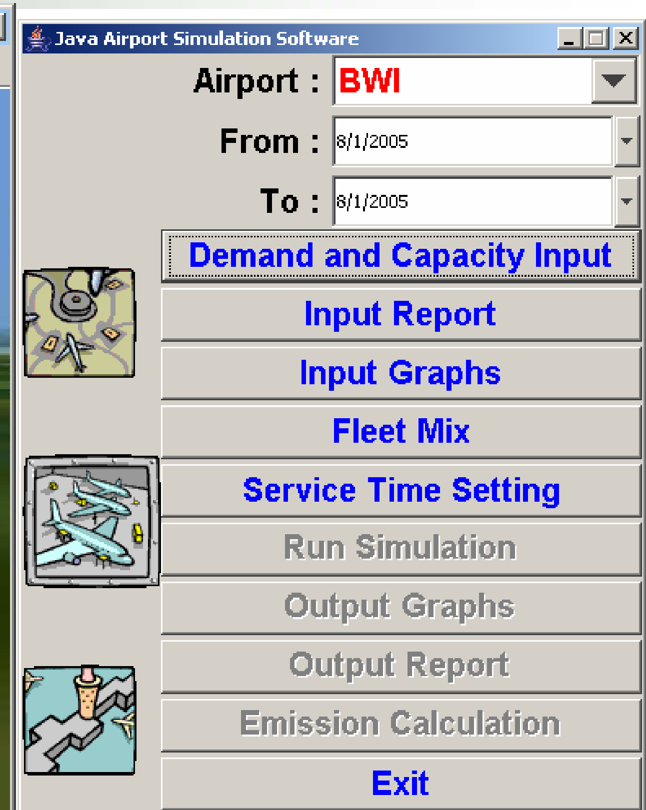
CATSR

- 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

GEORGE MASON UNIVERSITY

GreenSim


GreenSim
Simulation
Help
GreenSim Airport Operations Simulation
Developed by Liya Wang @ CATSR

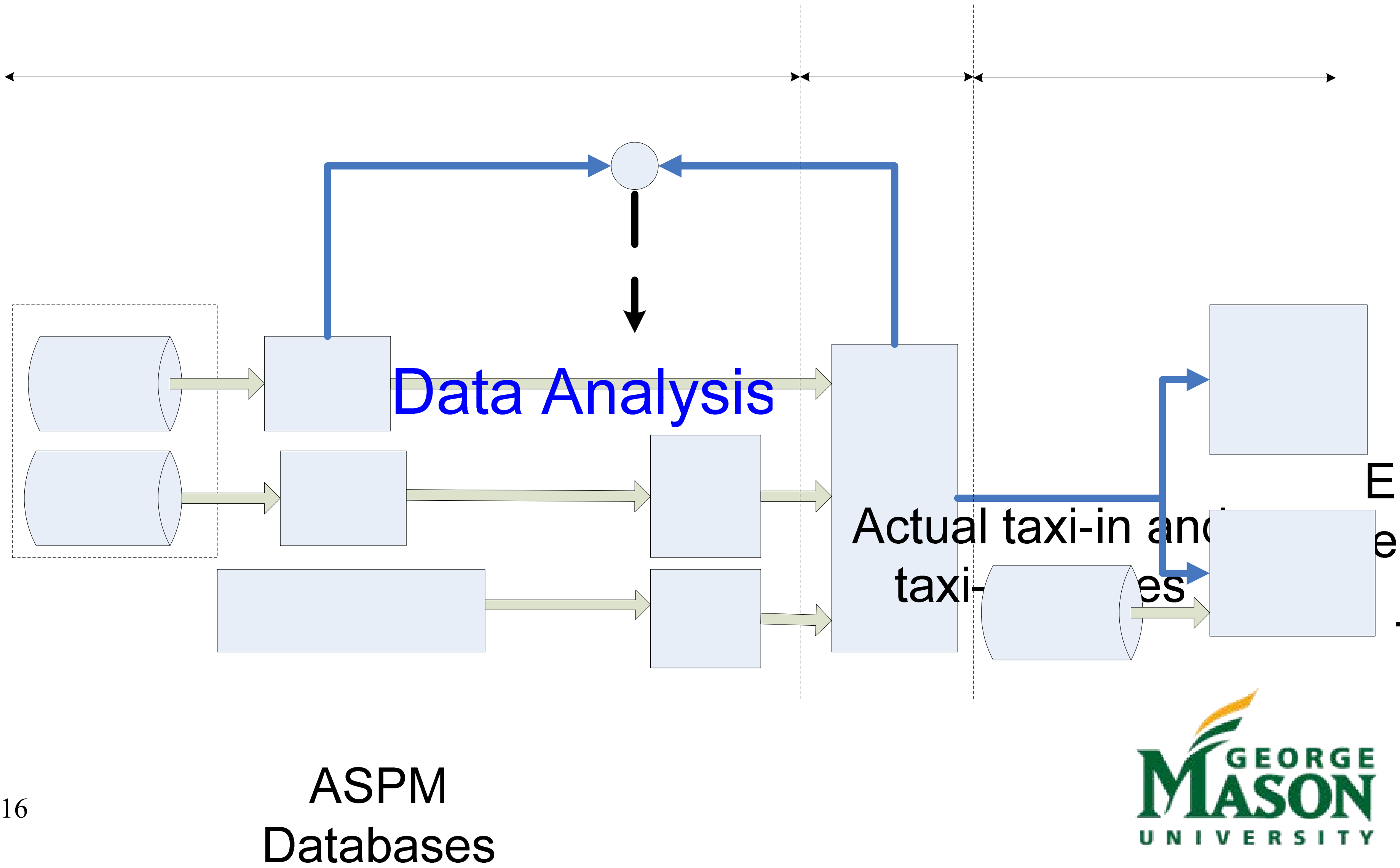

Java Airport Simulation Software
Airport :
BWI
From :
8/1/2005
To :
8/1/2005
Demand and Capacity Input
Input Report
Input Graphs
Fleet Mix
Service Time Setting
Run Simulation
Output Graphs
Output Report
Emission Calculation
Exit

GreenSim Input/Output Model

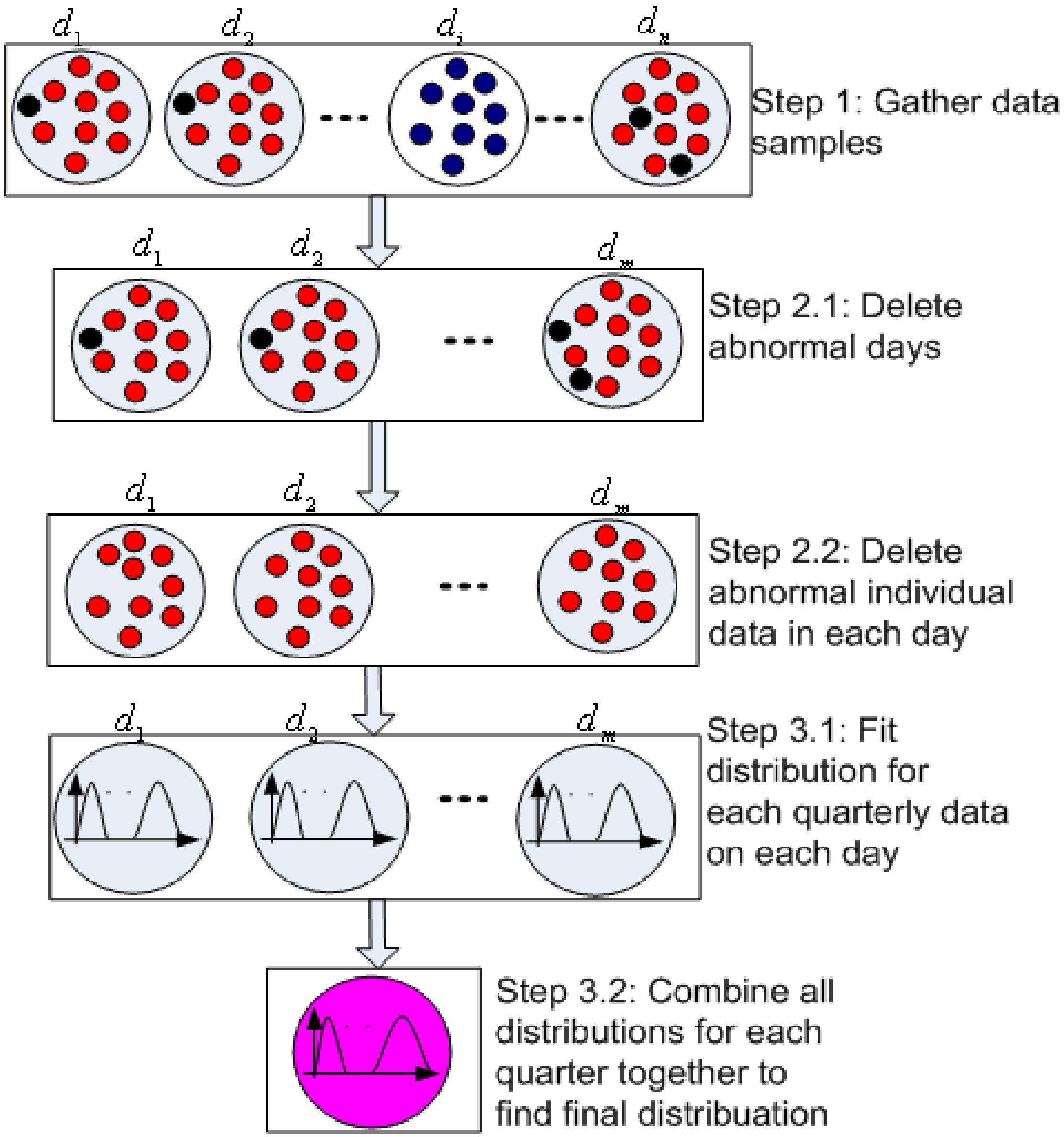
User adjustable input:
- Flights Schedule
- Aircraft type
- Capacity (AAR, ADR)

Outputs:
- Delays (taxi-in, taxi-out)
- ADOC
- Emission
- Departure Runway
- Queue Size
- Gate Utilization

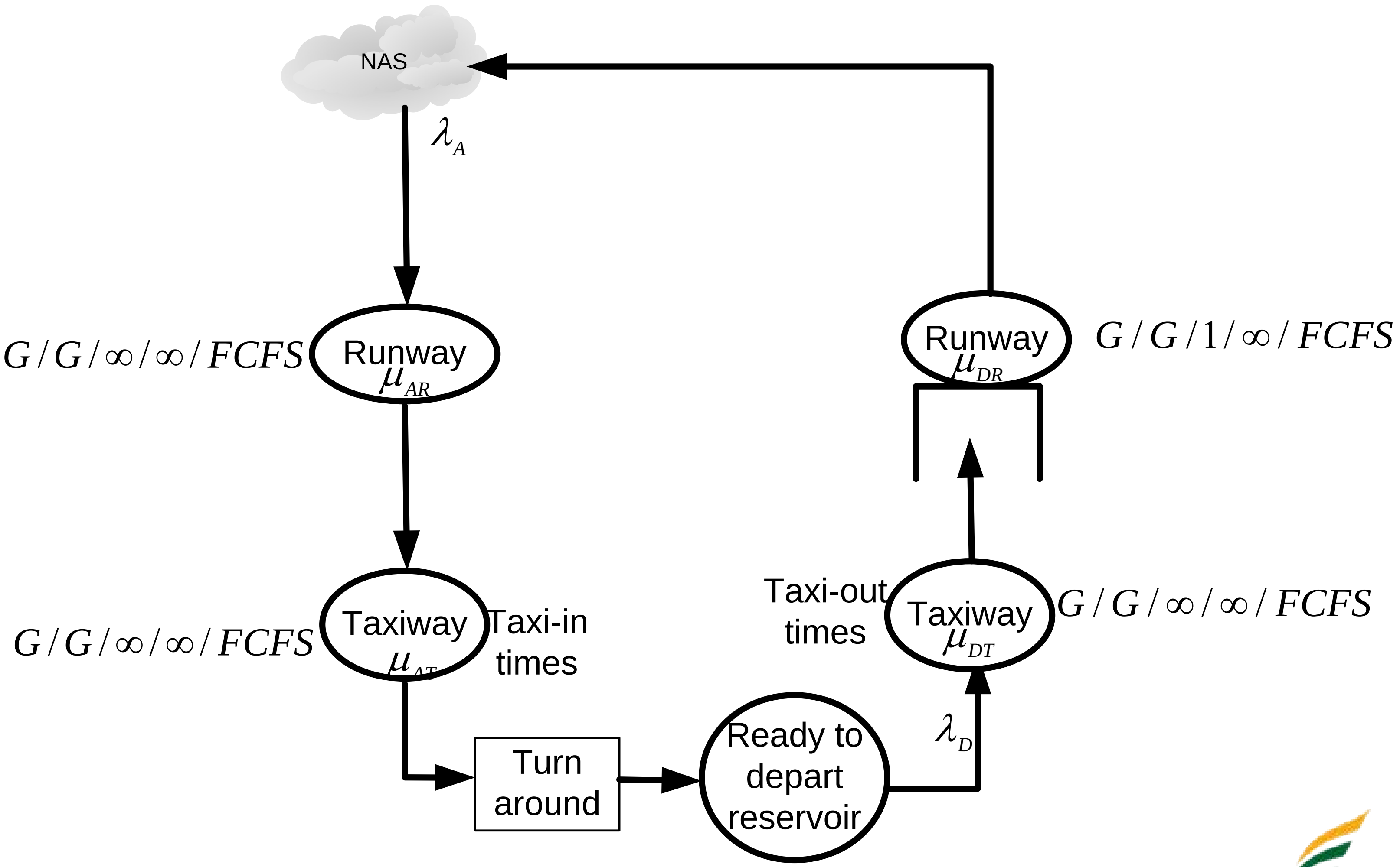
GreenSim Architecture



Data Analysis Process



Queueing Simulation Model



Service Times Settings

Segment Name	Settings	Notation
Arrival Runway	*S1*~Exponential(1/AAR)	
Arrival Taxiway	*S2*~NOMTI + DLATI- *S1*	DLATI~Normal (u_1, σ_1)
Departure Taxiway	*S3*~NOMTO + DLATO- *S4*	DLATO~Normal (u_2, σ_2)
Departure Runway	*S4*~Exponential(1/ADR)	

Performance Analysis

CATSR

- 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

GEORGE MASON UNIVERSITY

EWR Hourly Average Delays