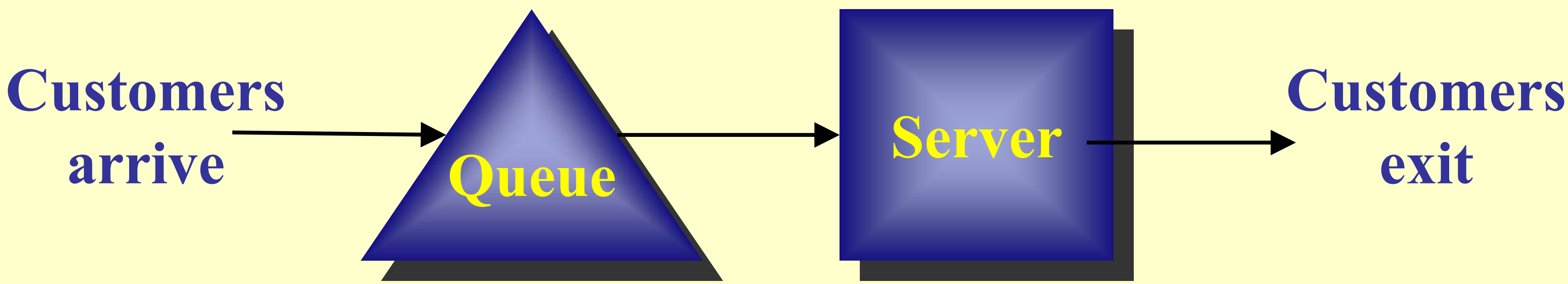
A Simple Process Flow



Patients	Doctors
Moreno's Output	Clark
Customers	ATM
Phone Calls	Operator
Web Content	Servers
Fish	Cannery

Principal Driver: Variability

- Predictable
  - Seasonal Arrivals
    - Ski Wear
    - Lunch & Dinner @ BK
  - Seasonal Servers
    - Workers/Shift
    - Winter Traffic
- Unpredictable
  - Arrivals
    - ATM,
    - ER,
    - JobShop WIP
  - Services
    - Machine Breakdowns
    - Car Repairs
    - ER

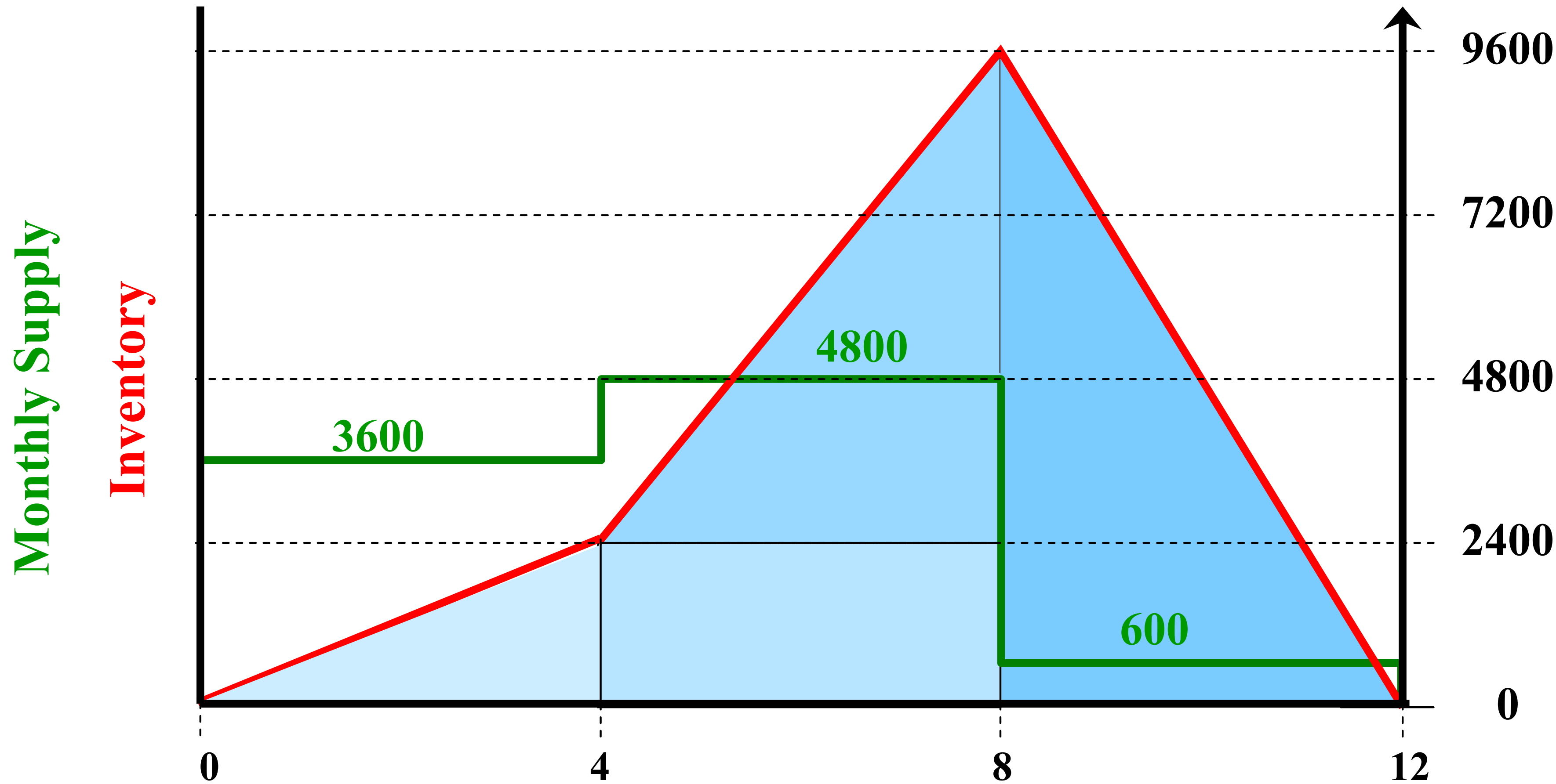
Most Systems have both variabilities, but one usually dominant.

Inputs & Outputs

- INPUTS
  - Arrival rate
  - Service Rate
  - # of Servers
  - Size of Waiting Room
  - Variability
- OUTPUTS
  - Output Rate ⇑
  - Inventory Level ⇓ (Queue Size)
  - Waiting Time ⇓
  - Server Utilization

Inventory Build-Up Diagrams

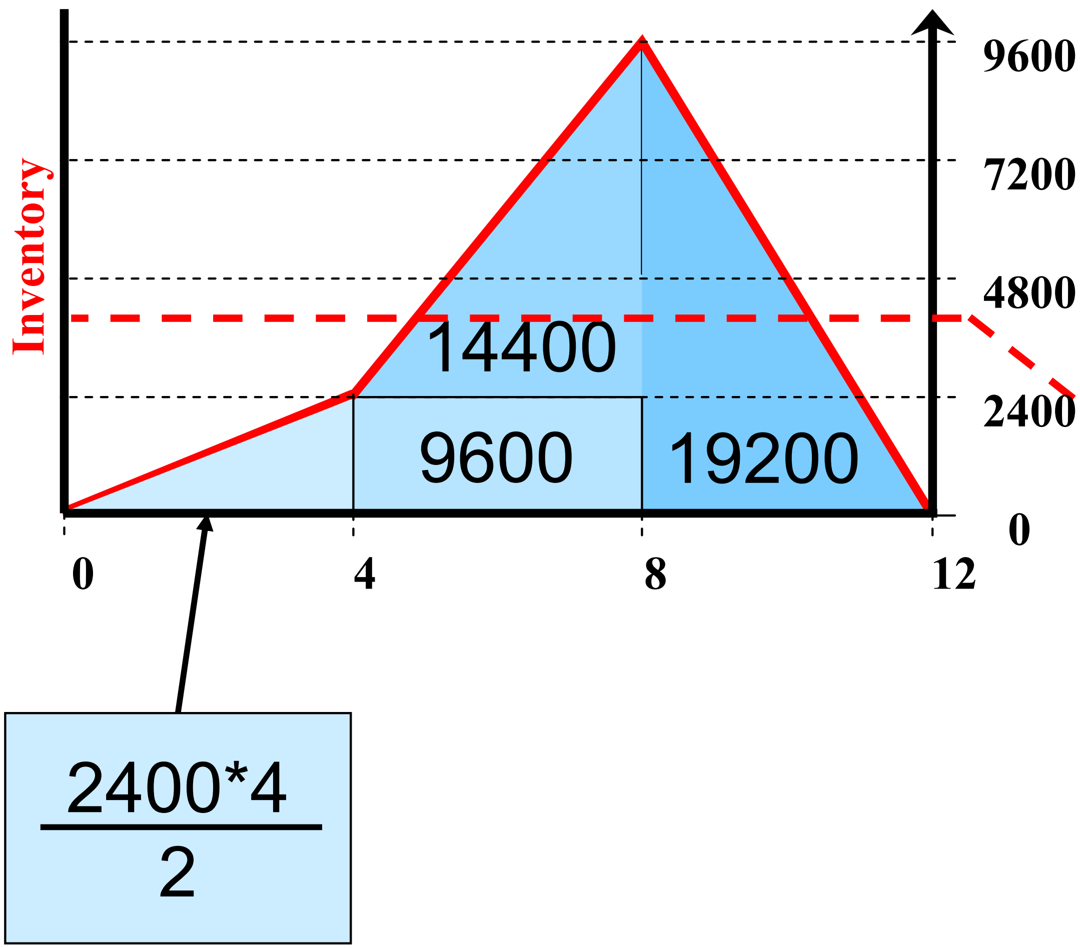
Avg. Arrival Rate:	3000/month	Service Rate:	3000/month



Output Rate:	3000/month

MIT Sloan

Average Inventory



Total Inventory:

	4800
+	9600
+	14400
+	19200
=	48000

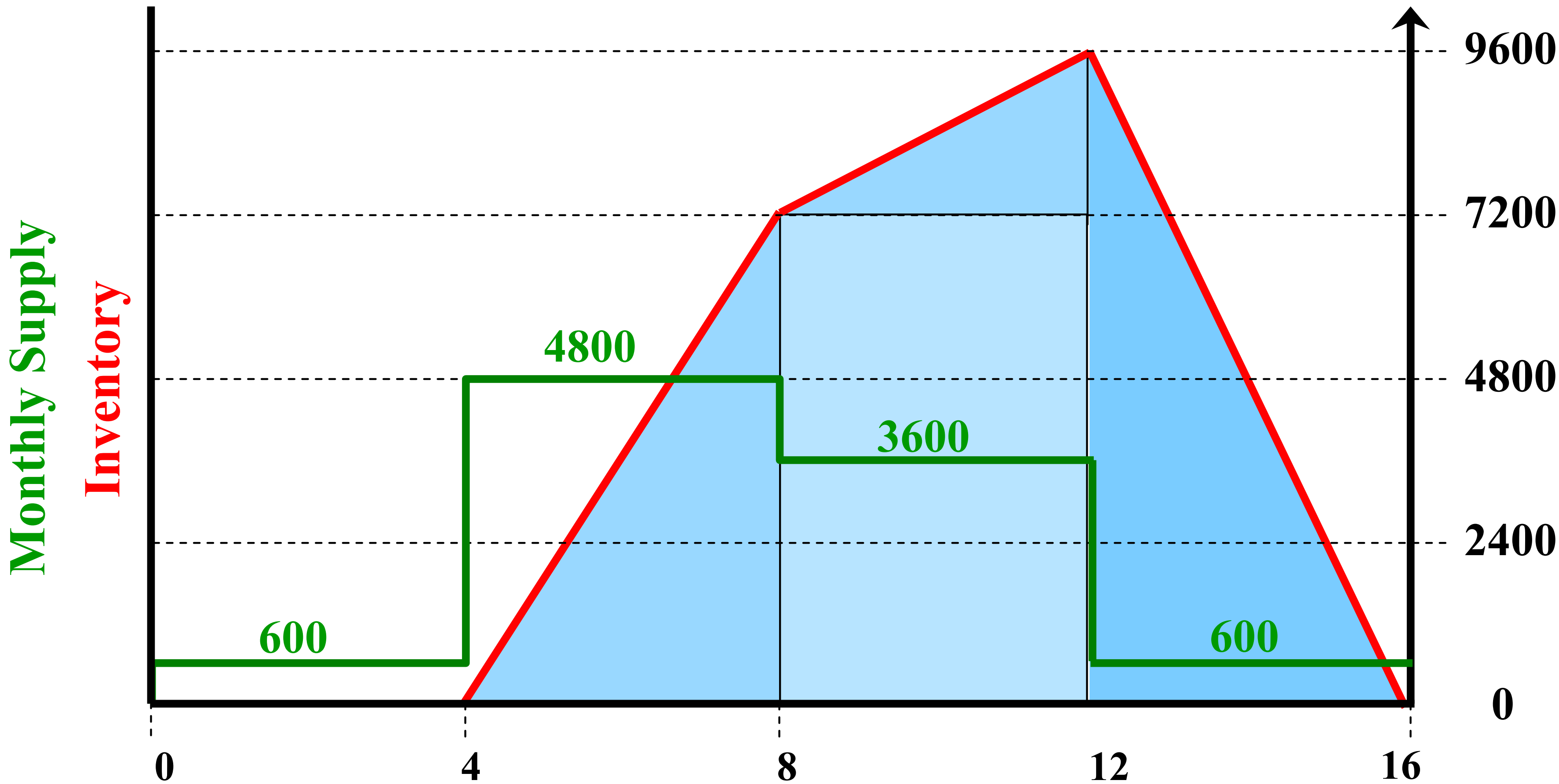
Average Inventory:

= 48000/12

= 4000

Different Supply Pattern…

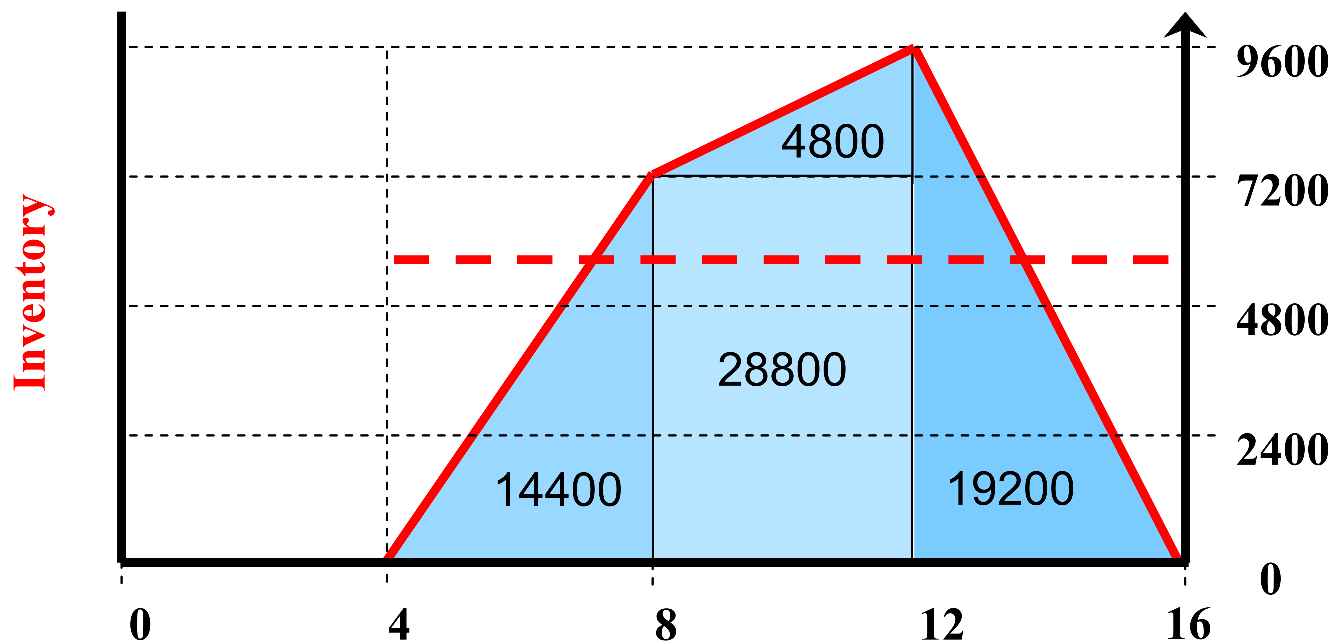
Avg. Arrival Rate: 3000/month | **Service Rate: 3000/month**



Output Rate: 2200/3000/month

MIT Sloan

...Different Supply Pattern



Total Steady State Inventory: 67200
Average Steady State Inventory: 5600 vs. 4000 previously

System Configuration

Increase in...	Output	Inventory	
Service Rate	Up	down	+++
Arrivals Rate	UP	UP	Trade-Off
Waiting Room size	UP	UP	Trade-Off
Variability	Down	UP	---
# Servers	UP	Down	+++

Unpredictable Variability

Queueing Theory

Queueing Theory

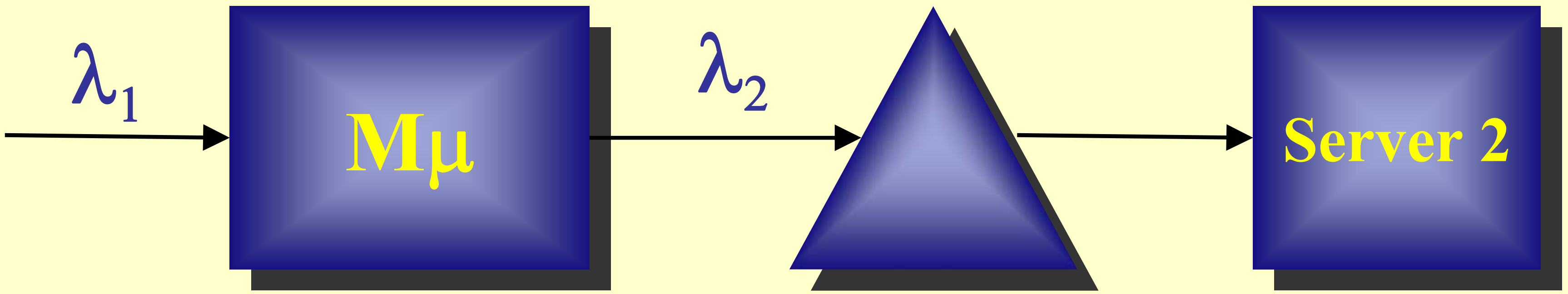
- Poisson Arrivals
  - Random
  - Time until next Arrival not function of last arrival
  - λ = Arrival Rate (customers/min)
  - Memoryless
- Poisson Service Rates
  - μ = Service Rate (= 1/mean service time)
- M = Number of Servers
- FCFS (Bank, not Supermarkt)
- Infinite Waiting Room
- Long Run Behavior

3 Easy Steps

- Capacity Utilization: $\rho = \lambda/(M\mu)$
- Average time in Queue: $L_q = f(\lambda/\mu, M)$

  (as in Exhibit 3 of Reader)
- Average time in queue $W_q = L_q/\lambda$
  - $L_q = \lambda * W_q$ **Little's Law**
- Average number in system $L = L_q + \lambda/\mu$
- Average time in system $W = W_q + 1/\mu$

Multi-Stage Process

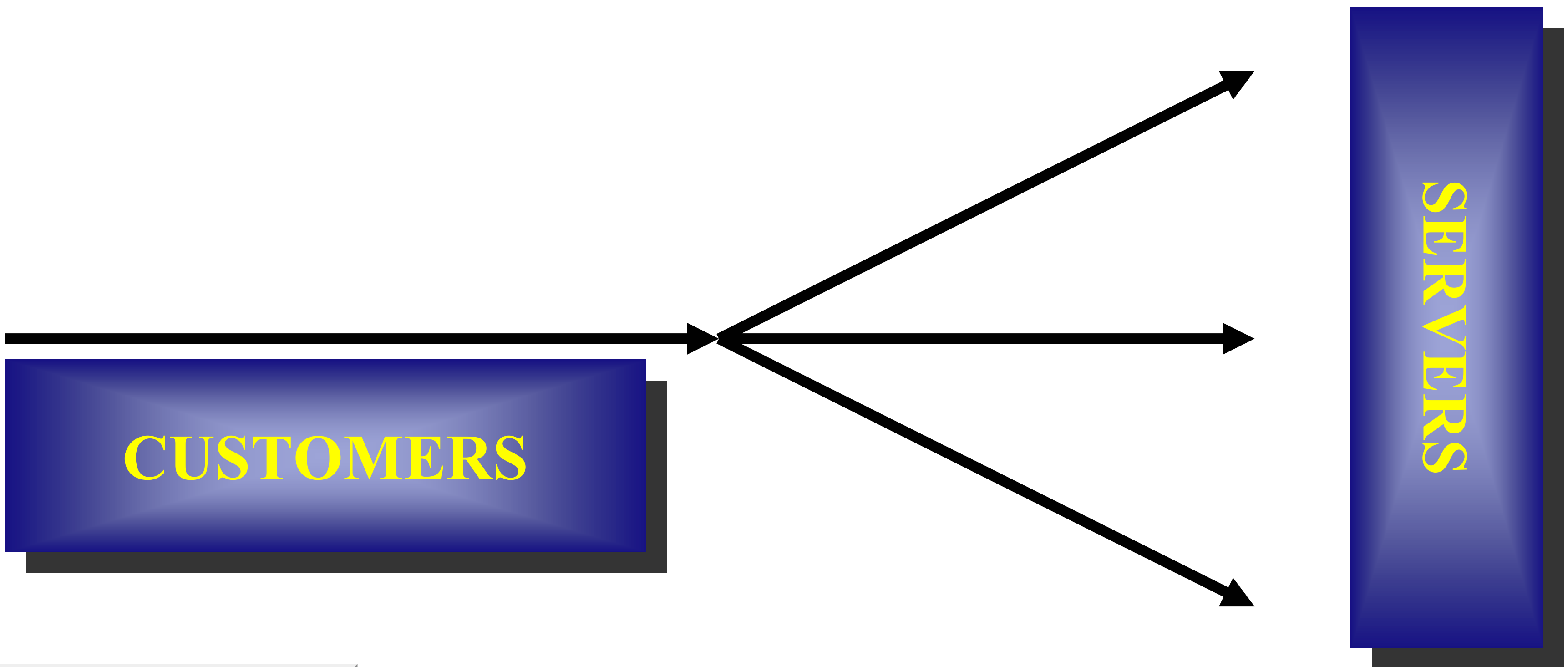


$$\lambda_2 = \min[\lambda_1, M\mu]$$

Wrap Up

- Inventory Build-Up Diagrams
  - Predictable Variability
  - Utilization > 1 o.k.
  - Short Run o.k.
  - Varibale Time/Service rates o.k.
- Queueing Formulas
  - Unpredictable Variability
  - Utilization < 1 only
  - Long Run only
  - Fixed Time/Service rates only
- Steps in Process Flow Analysis
  1. Process Flow Diagram
  2. Find Utilization Levels (Bottlenecks)
  3. Use Buildup Diagrams or Queueing Formulas

FCFS Queuing Discipline



Memoryless Property