CTMC and Queueing Lab: Vaccine Clinic Operations

Course Desorption

Who is the course for?

This workshop is designed for healthcare operations researchers, supply chain analysts, and graduate students interested in modeling system dynamics under uncertainty. Participants will learn how Continuous-Time Markov Chains (CTMCs) and basic queueing models can be applied to real-world healthcare logistics. The course assumes basic familiarity with probability and matrix operations in R (or Python).

Learning Objectives

By the end of this session, participants will be able to:

- Understand the key components and assumptions of Continuous-Time Markov Chains (CTMCs)
- Construct and analyze generator matrices for small-scale CTMC models
- Calculate steady-state probabilities for CTMCs using linear algebra
- Apply queueing theory to model service systems like clinics and pharmacies
- Distinguish between M/M/1, M/M/s, and M/M/s/b systems and assess their implications
- Simulate and interpret Markovian queueing systems in R
- Connect model insights to operational decisions in healthcare delivery (e.g., capacity planning, congestion, patient flow)

Prerequisites

- Familiarity with random variables and basic probability concepts
- Experience with R or Python for numerical computations and plotting
- No prior knowledge of CTMCs or queueing theory is required

Course Topics

Section 1: Recap

- Discrete-time vs. continuous-time Markov chains
- Markov property and memorylessness

Section 2: Foundations of Continuous-Time Markov Chains (CTMCs)

- Exponential timing and transition rates
- The generator matrix and its interpretation
- CTMC transition diagrams and modeling examples
- Steady-state analysis and long-run behavior
- Solving for steady-state probabilities
- Applications to customer flow and occupancy in small systems

Section 3: Queueing Theory Essentials

- What is a queueing system? Components and notation (A/B/S/d/e)
- The Poisson process and M/M/1 queue
- Birth-death process interpretation
- Generator matrices for queues
- Traffic intensity, stability conditions
- Key performance metrics
- Little's Law and system design

Section 4: Vaccine Clinic Case Study

- CTMC model for an observation room
- Scenario-based analysis and service optimization
- R-based lab activity: matrix methods, simulation, and performance metrics
- Translating modeling results to logistics planning