School of Engineering

Continuous Improvement (CIP)

Module 3 – Process

Managing Waiting Lines

Amin Kaboli

Week 4, Session 1& 2, Mar 14th, 2025

Course Framework

Change Plan
Strategic plan

Continuous Improvement (ME-498)

Module 1

Introduction

Feb 23rd

CIP Foundations
CIP case studies

Module 2

People

March-May

Managing Change
Emotional Intelligence
Managing Oneself
Connection & Bonding
Effective Change Comm.
Managing Conflict

Module 3

Process

March-May

Capacity Planning
Constraint Management
Managing waiting lines
Quality Planning
Quality Control
Quality Improvement
Process selection
Facility Layout
Lean Management

Module 4

Technology

March-May

AI for CIP
Data Analytics, ML&AI
Digital Ecosystems
Best case practices

Final

May 31st

Final presentation & solid understanding of the course

Agenda of the day

- **13:15 – 14:00** **Module 3 – Process:** Waiting lines (Lecture + Play & Practice)
- **14:15 – 15:00** **Module 3 – Process:** Waiting lines (Lecture + Play & Practice)
- **15:15 – 16:00** **Simulation –** Debrief
- **16:15 – 17:00** **Presentation of Assignment 3**

Question 1:

What Are Waiting Lines?

What Do They Have in Common?

Airport

Highway

Harbor

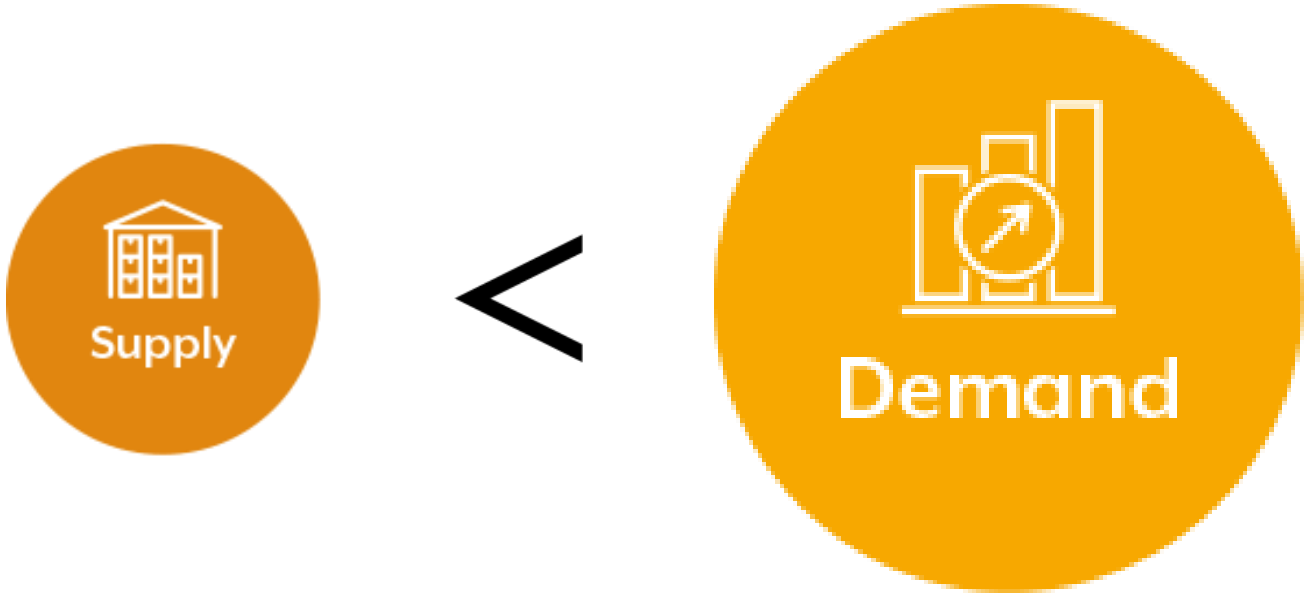
Image Source:

1. https://www.chroniclelive.co.uk/whats-on/travel-tourism/airport-security-queues-miss-flight-24377954
2. https://www.alamy.com/stock-photo/traffic-queue.html?sortBy=relevant
3. https://bigblue.academy/en/maritime-port-queuing

Why Does Waiting Feels So Painful?

- **Distraction** unoccupied time feels longer than occupied time
- **Moment** pre-process waits feel longer than in-process waits
- **Uncertainty** uncertain waits are longer than certain waits
- **Anxiety** anxiety makes waits seem longer
- **Explanation** unexplained waits are longer than explained waits
- **Fairness** unfair waits are longer than equitable waits
- **Value** the more valuable the service, the longer people will wait
- **Solo wait** waiting alone feels longer than waiting in a group

When Do We Experience Waiting Lines?

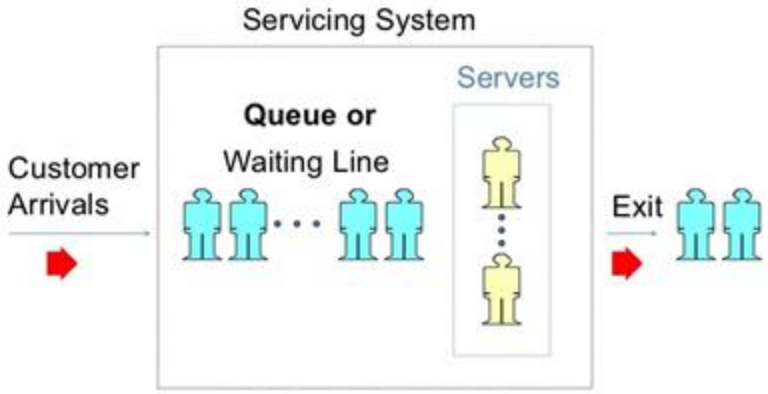


What Are The Consequences of Waiting Lines?

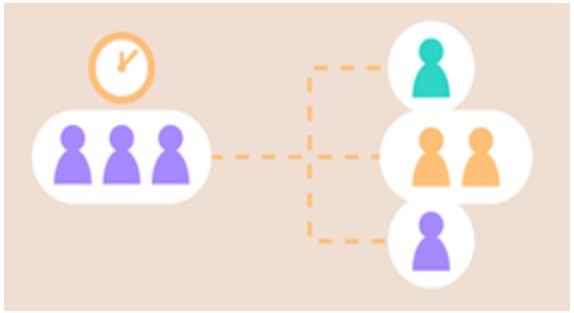
- Affect lead time
- Production scheduling
- Impact inventory costs
- Waste of resources
- Impact efficiency
- Influence customer satisfaction
- …

Definitions

Waiting lines (Queues):
Items or people in a line awaiting service.



Waiting lines (Queuing) Systems: Includes the customer population source as well as the process or service system.

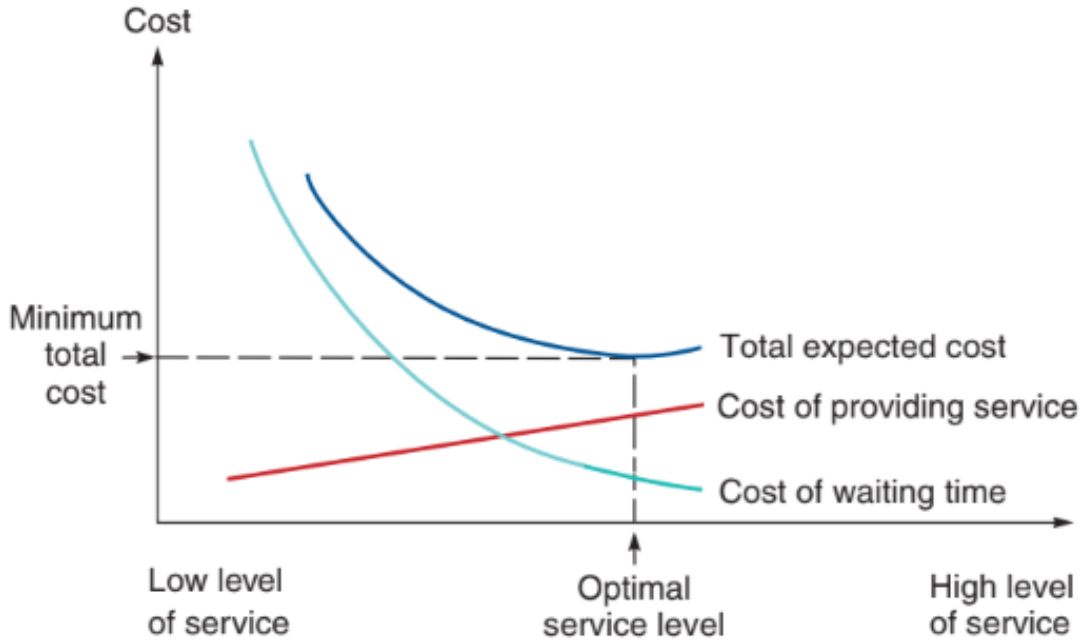


Queuing Theory:
A mathematical approach to the analysis of the waiting lines.

Question 2:

Why Are Waiting Lines Costly?

Waiting Cost & Service Level Trad-off



Total Costs (TC) = Cost of waiting time + Capacity Cost

What's the decision related to waiting lines:

defining optimal service level

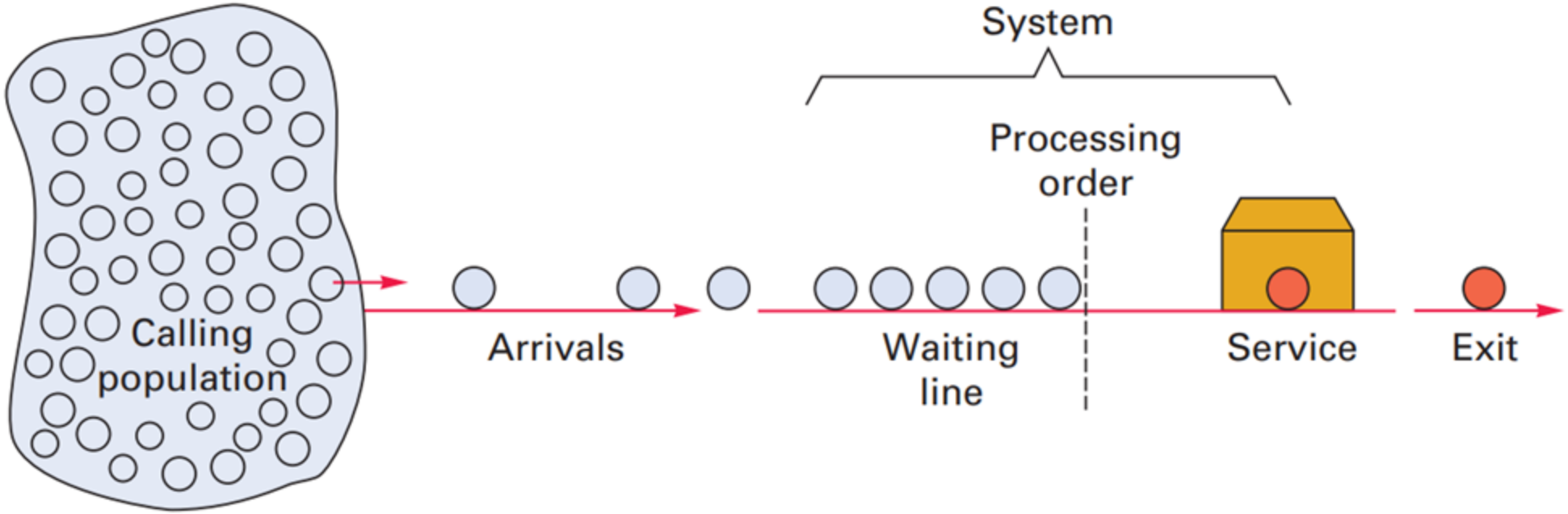
Question: what would be the waiting cost and service level trade-off for Rolex?

Source: Heizer, J., Render, B., & Munson, C. (2015). *Waiting-Line Models.* In *Operations Management: Sustainability and Supply Chain Management* (12th ed., Module D, pp. 747-767). Pearson.

Question 3:

What Are The Characteristics of Waiting Lines?

A Simple Waiting Line System



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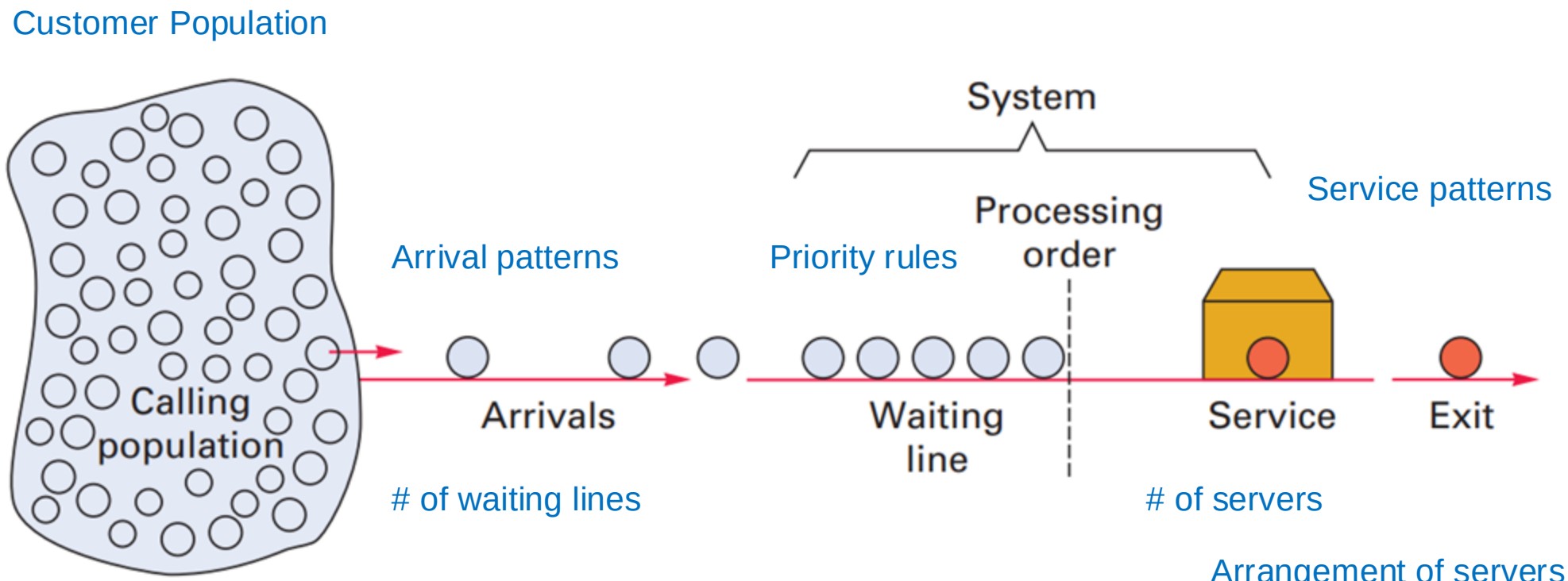

Balking: When a customer sees the queue and decides **not to join** because it is too long or slow.

Reneging: When a customer **joins the queue but leaves before being served**.

Jockeying: When a customer **switches between queues** in hopes of getting served faster.

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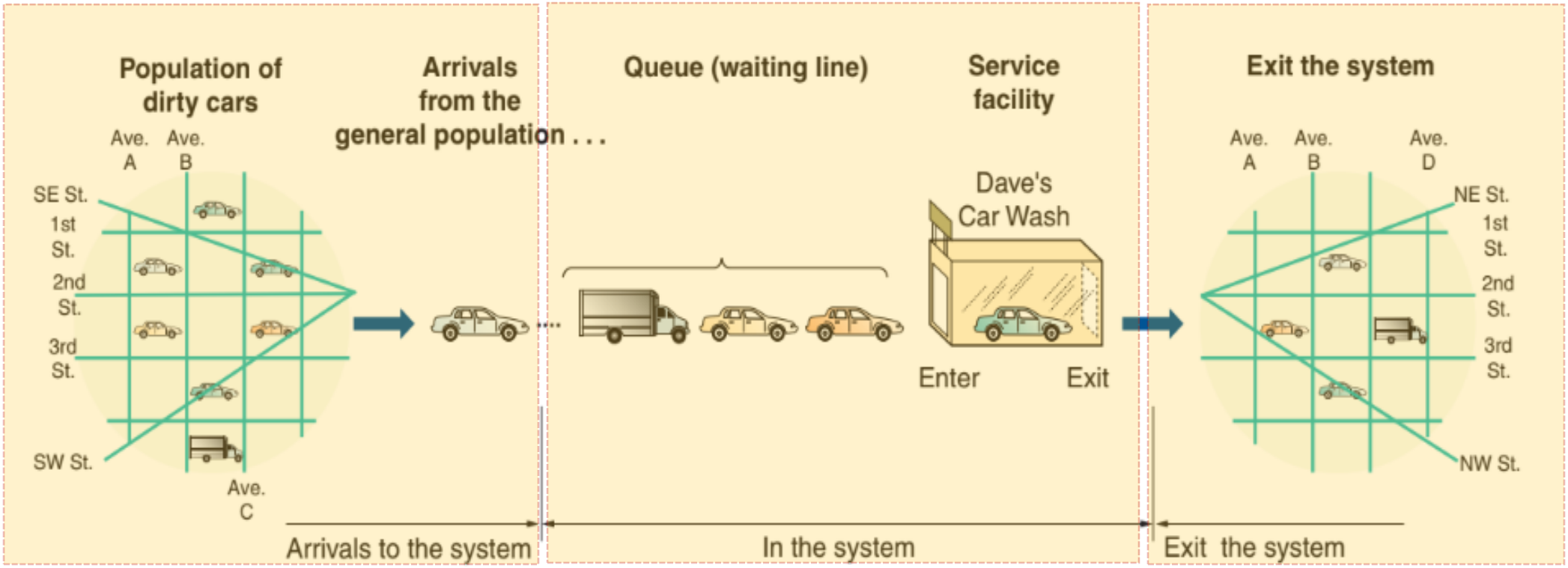
Three Parts of a Waiting Line, or Queuing System, at Car Wash



Arrival Characteristics
- Size of arrival population
- Behavior of arrivals
- Statistical distribution of arrivals

Waiting-Line Characteristics
- Limited vs. unlimited
- Queue discipline

Service Characteristics
- Service design
- Statistical distribution of service

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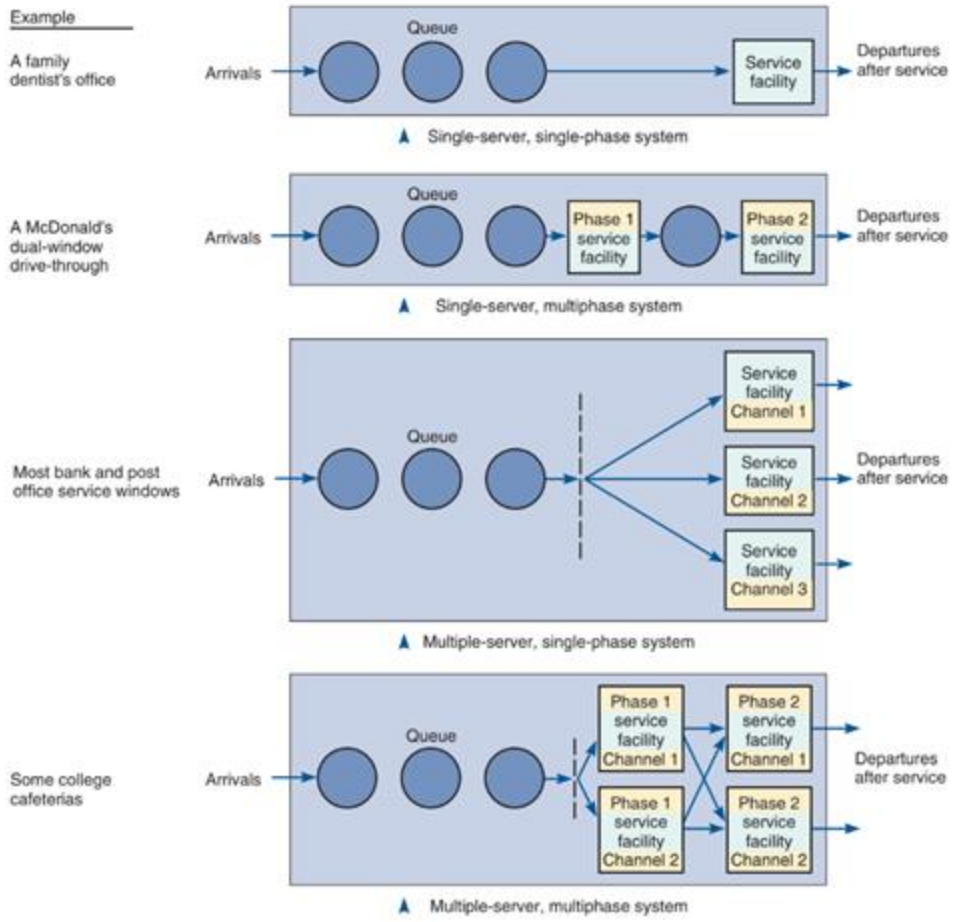
Designs of Waiting Line System



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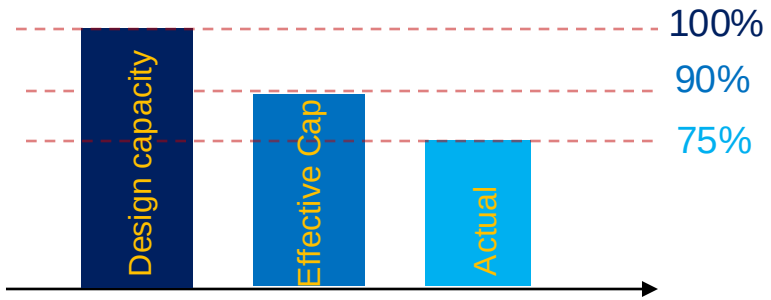
Question 4:

How to Measure Performance of Waiting Lines?

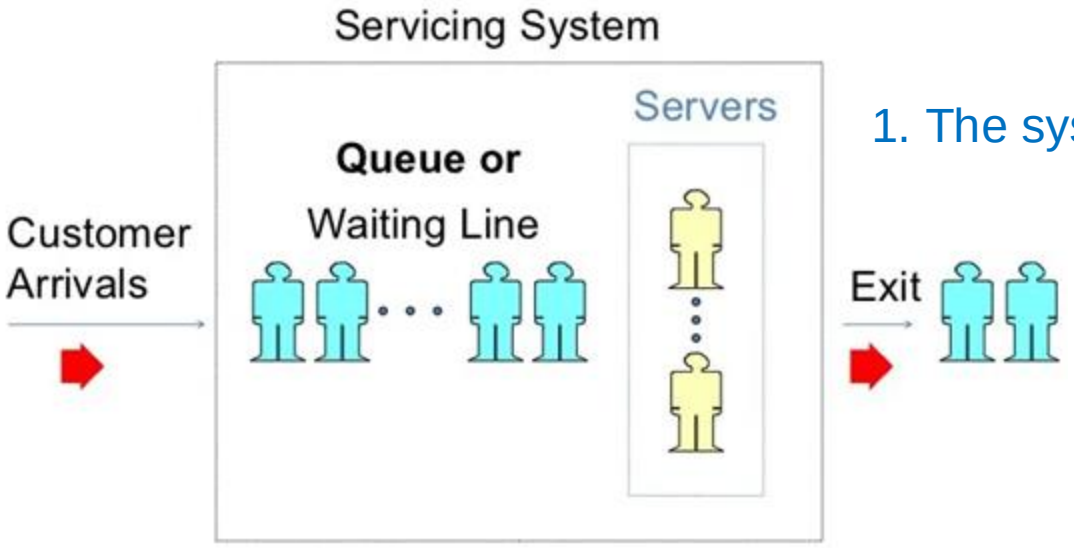
System Efficiency Measures

- **Utilization:** (Actual output/Design capacity) * 100%

- **Efficiency:** (Actual output/Effective Capacity) * 100%



Waiting Lines – Key Performance Indicators (KPIs)



1. The system utilization rate

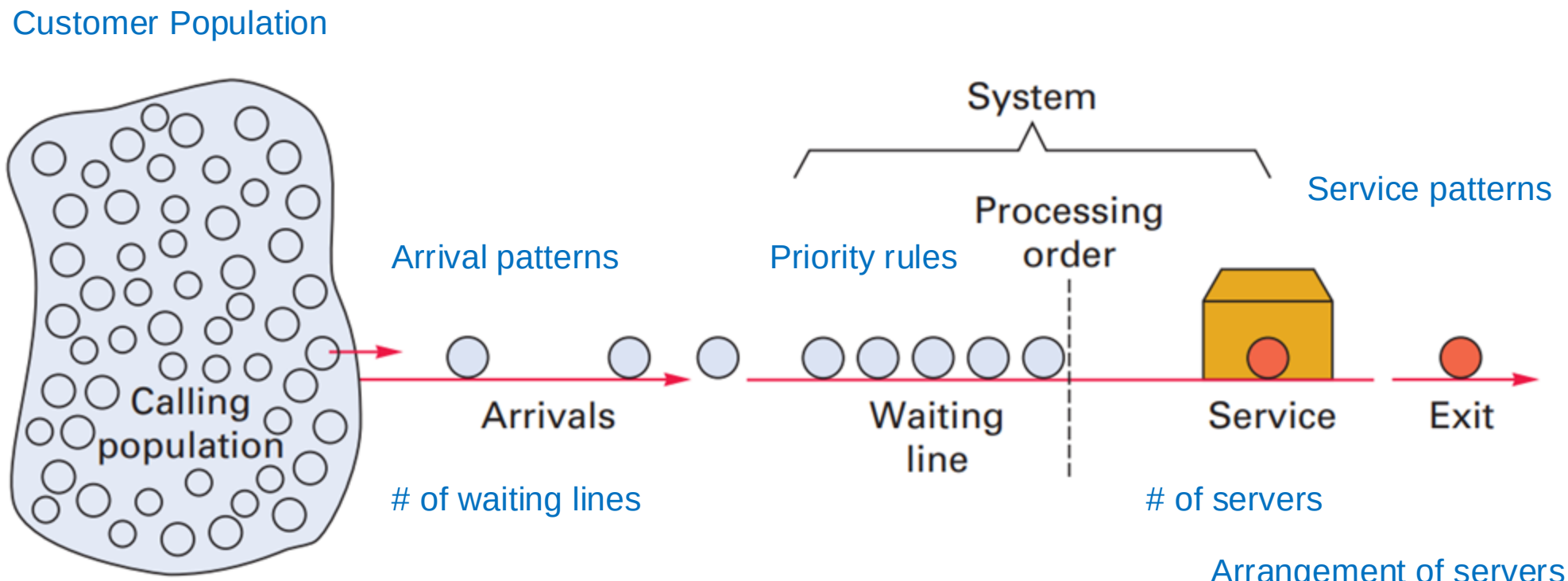
2. The average number of customers waiting in line and in the system.

3. The average time customers spend waiting in line and in the system

Question 5:

How to Model Waiting Lines?

A Simple Waiting Line System



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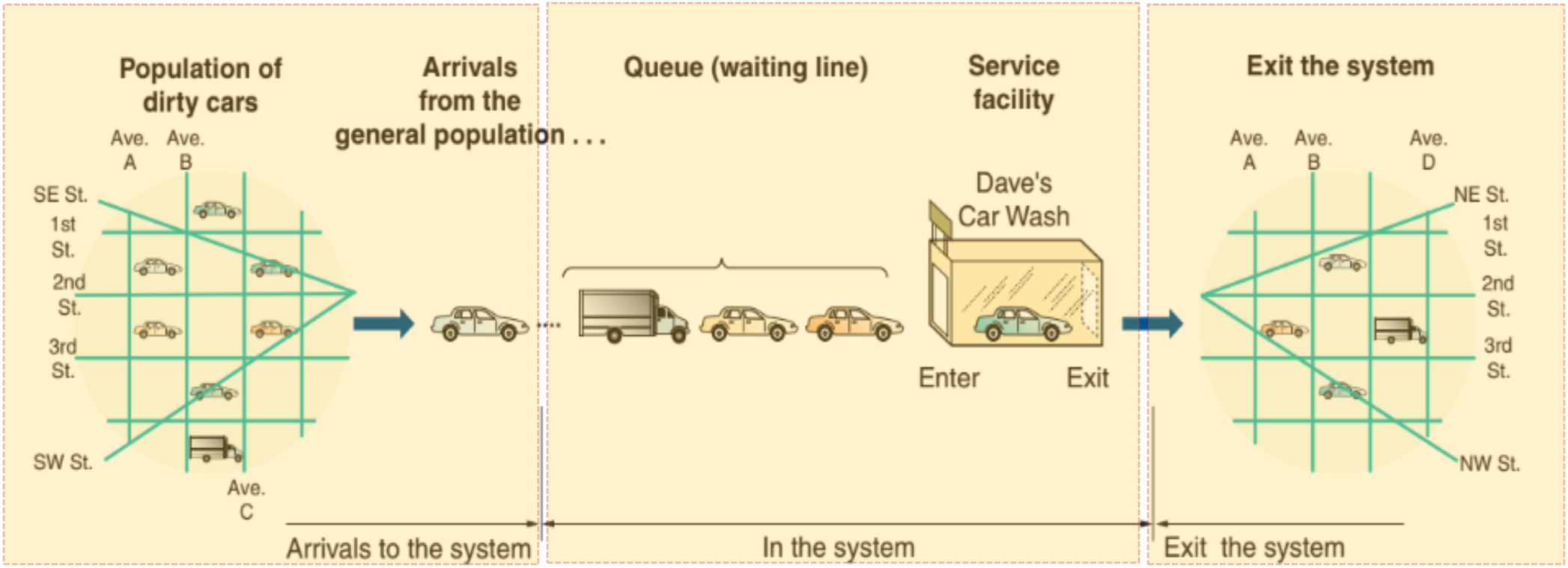

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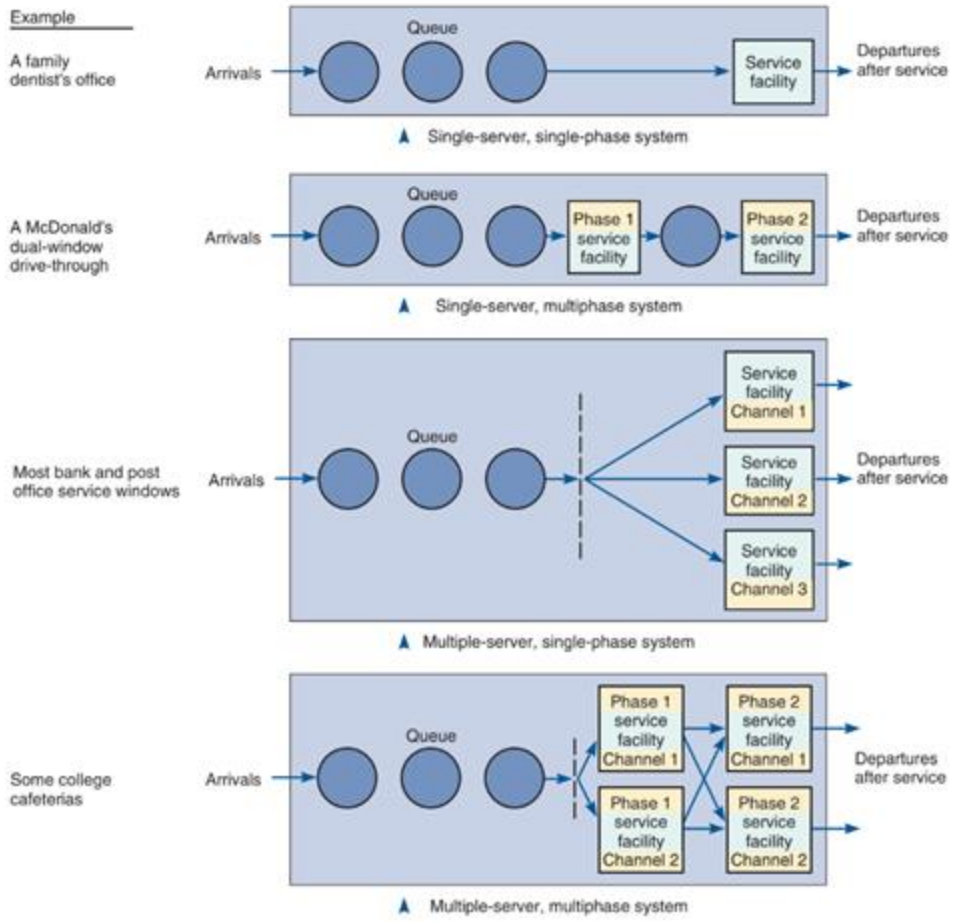


Source: Heizer, J., Render, B., & Munson, C. (2015). *Waiting-Line Models.* In *Operations Management: Sustainability and Supply Chain Management* (12th ed., Module D, pp. 747-767). Pearson.

Types of Waiting Lines - Kendall Notation

The distribution of the arrival time	The distribution of the service (process) time	The number of servers at each station (1, 2, …, m)	The max number of items allowed in the queue (1, 2, …,∞)

The most common distributions used:

M: Exponential (or Markovian) distribution

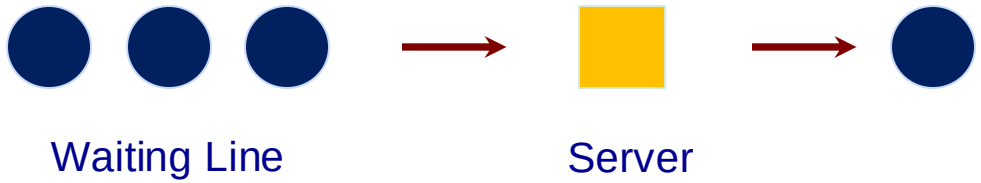
G: General (or Normal) distribution

M/M/1

M/M/m

G/G/1, G/G/m, M/D/1, …

Single-Server Model (M/M/1 Systems)



Assumptions:

- **Random Arrivals** – Customers arrive independently following a Poisson process.
- **Single Server** – Only one server processes requests sequentially.
- **Exponential Service** – Service times are memoryless and follow an exponential distribution.

Single-Server Model (M/M/1 Systems) – Modeling

Waiting Line Server

- **Arrival rate λ** : how many people arrive per hour
- **Service rate μ** : how many people are served per hour
- **System utilization** ρ = λ/μ
- **Average number of jobs in the queue** $Lq = \lambda^2 / (\mu*(\mu - \lambda))$
- **Waiting Times (W, WQ, QW)**:
  - **W**: Total waiting time in the system ($W=1/(\mu - \lambda)$)
  - **WQ**: Time spent waiting in queue.
  - **QW**: Time spent in service.

Exercise 1 – Single server

3 min

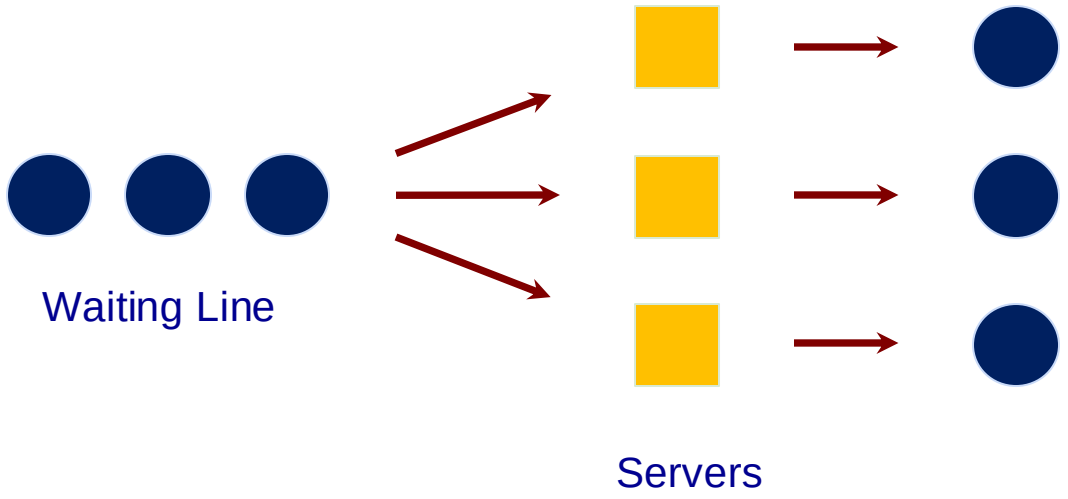
Data:

- Type of queuing system : M/M/1/∞ - FIFO
- Arrival rate λ = 10 jobs/hour
- Service rate μ = 12 jobs/hour

Questions:

1) What is the average waiting time?
2) What is the average number of jobs in queue?
3) What is the utilization?

Multiple-Server Model (M/M/m Systems)



Assumptions:

- **Random Arrivals** – Customers arrive independently following a Poisson process.
- **Multiple Server** – Multiple servers serving the same task and service rate.
- **Exponential Service** – Service times are memoryless and follow an exponential distribution.

Exercise 2 – Multiple server

3 min

Data:

- Type of queuing system: M/M/**3**/∞ - FIFO
- Arrival rate λ = 10 jobs/hour
- Service rate μ = 12 jobs/hour

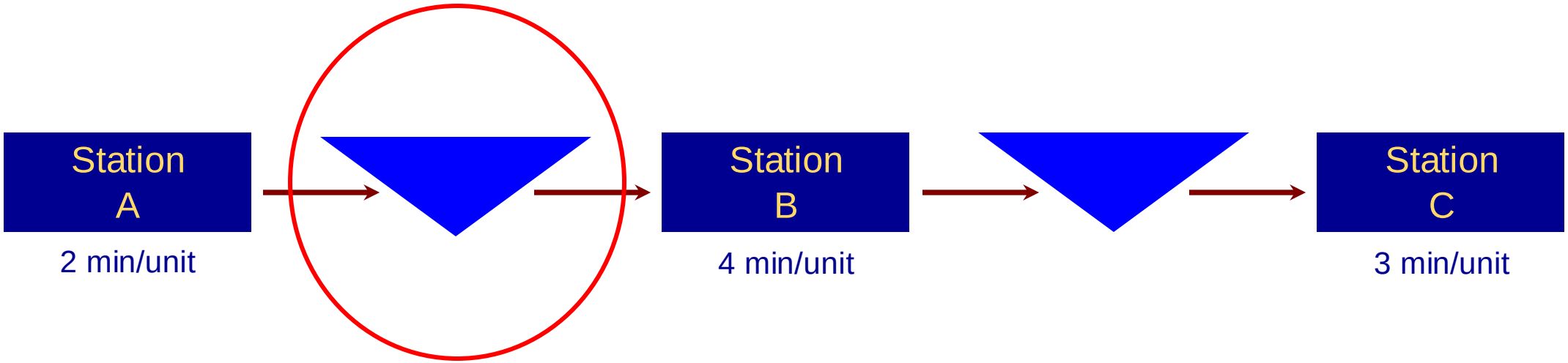
Questions:

1) What is the average waiting time?
2) What is the utilization?

Question 6:

How to Improve Waiting Lines?

Manufacturing System



Here the queue takes the form of a stock pile-up, how would you improve it?

JIT

Just-In-Time (JIT) is a lean manufacturing approach that aims to minimize inventory and reduce waste by producing goods only when needed.

Question 7:

How to Manage Large Scale Waiting Line Systems?

Harnessing the Power of Data

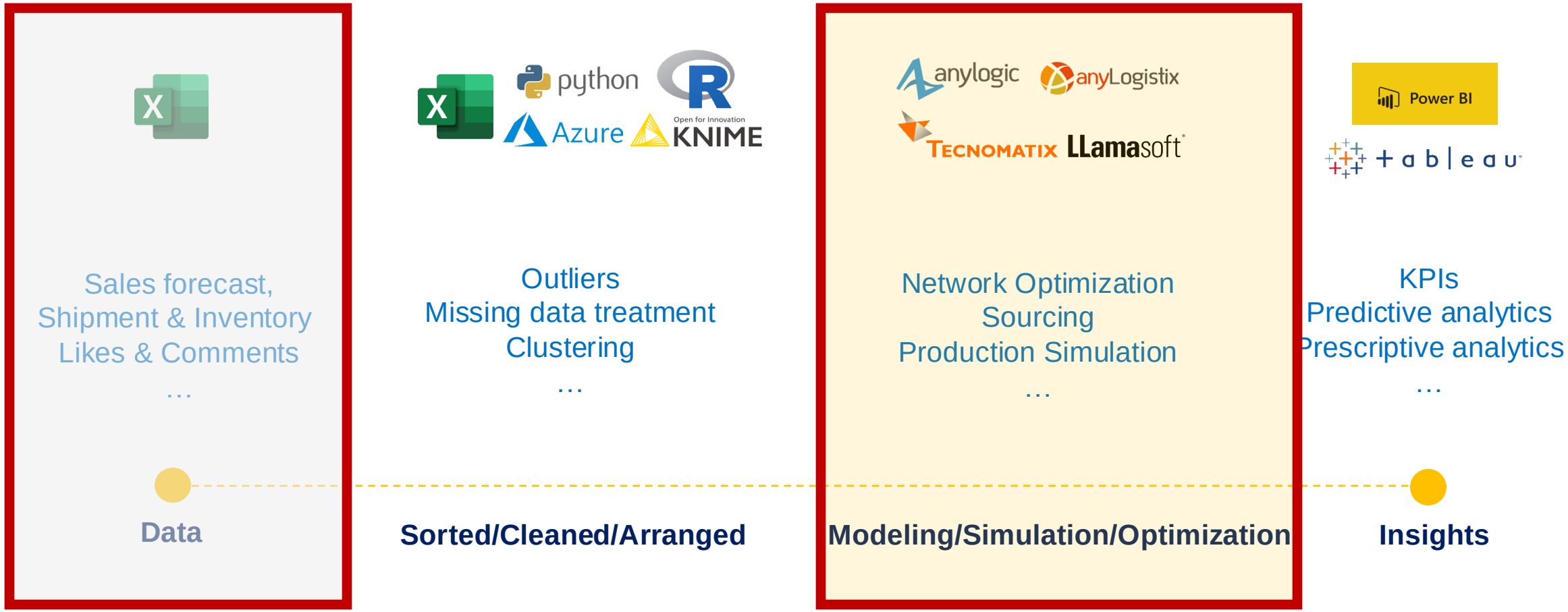
Data

Sorted/Cleaned/Arranged

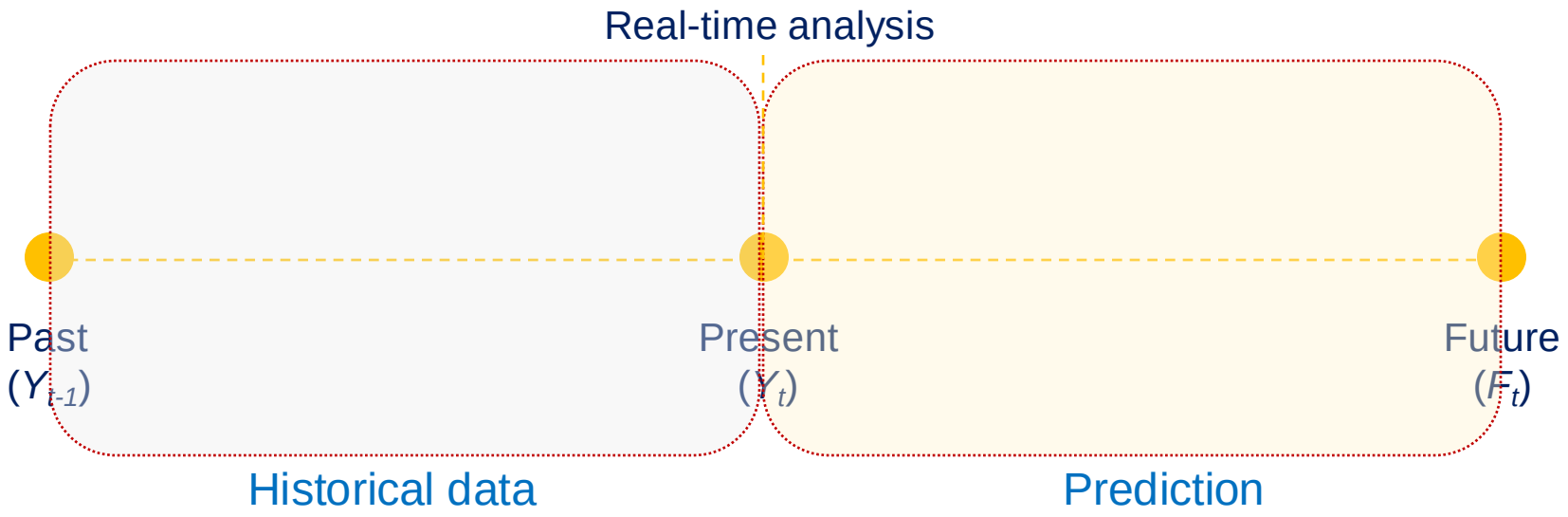
Modeling/Simulation/Optimization

Insights

From Data to Insights – Ranges



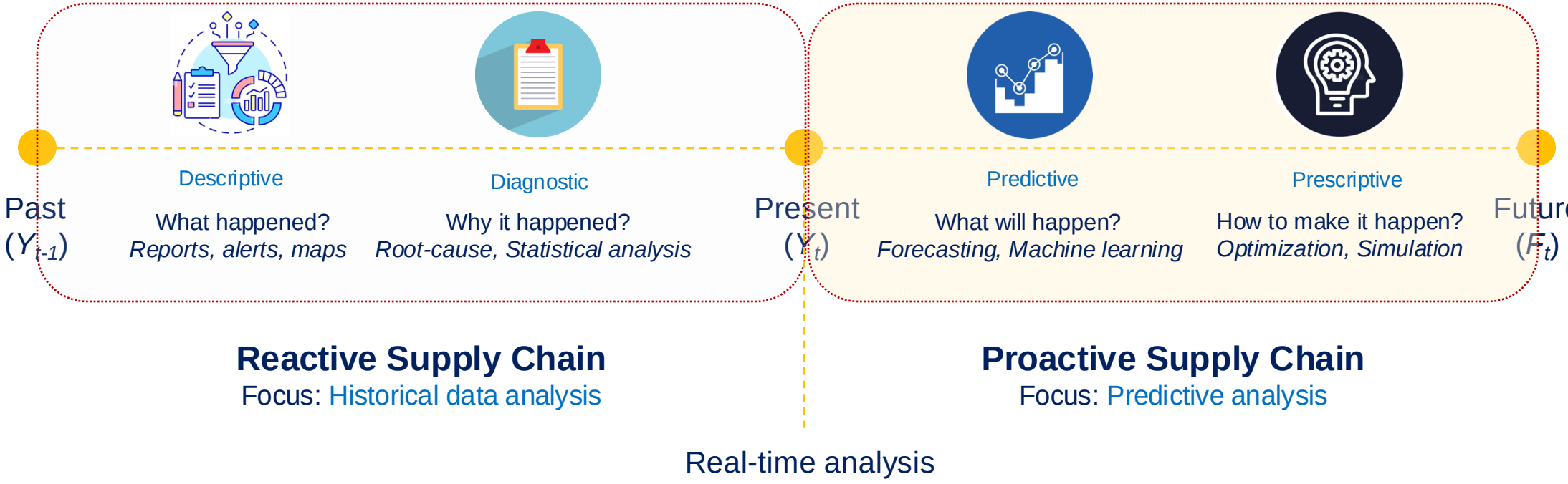
Prediction – Data-Driven



Assumption: The future will be the same as the past!

- F_t : demand forecast for period *t*
- Y_t : actual demand for period *t*

Supply Chain Analytics – From Reactive to Proactive



Assignment 4 – Constraint Management & Managing Waiting Lines

- **Constraint Management** (Tasks were shared last week)

- **Waiting Lines Management:**
  - Where in the process do waiting lines (queues) form, and what factors contribute to their length?
  - What queueing model (e.g., single-server, multi-server, M/M/1, M/M/c) best represents your case?
  - What performance metrics can you use to evaluate the waiting line (e.g., average wait time, queue length, customer/service utilization, probability of customer balking or reneging)?
  - How do variability in arrival and service rates impact waiting time?
  - What strategies can be used to reduce wait times and improve flow (e.g., adjusting service rates, implementing priority systems, increasing service capacity, using technology solutions)?
  - How do you balance efficiency with customer satisfaction in managing waiting lines?

- **Deadline:** March 21st