ATM Queue System at Jaffna Market

Case Study Report

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EEX5362 Performance Modelling

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2025/10/24

Introduction

Background of the System

The Jaffna Market is a busy commercial hub with high daily foot traffic. The market hosts a variety of shops, stalls, and service centers, which attract both locals and visitors. A key facility for convenience is the Automated Teller Machine (ATM) located near the market entrance, which allows customers to perform cash withdrawals and other banking transactions.

Due to varying customer arrival rates and transaction types, long queues often form at the ATM during peak hours, causing delays and customer dissatisfaction. Efficient operation of this ATM is critical to maintaining smooth customer flow in the market and ensuring that visitors have timely access to cash.

Stakeholders

i. Customers: Shoppers, vendors, and residents needing quick access to banking services in a busy market environment.
ii. Bank Management: Seeks to optimize service quality while managing operational costs in Jaffna's unique economic context.
iii. Market Authorities: Interested in efficient ATM operations to ensure a smooth shopping experience.
iv. ATM Maintenance Team: Ensures ATMs remain functional, handling cash refills and technical issues.

System Purpose

The main goal is to provide accessible and timely ATM services to all users. Since the ATM is often used during peak times, optimizing wait times is crucial for customer satisfaction and operational efficiency.

Performance Focus

The study focuses on the Wait Time for customers at the ATM, which directly impacts their experience. By reducing wait times, the system can handle more customers, increase throughput, and improve customer satisfaction.

Simulation Setup and Modelling Choices

Simulation Overview:

The ATM Queue System is modeled as an event-driven simulation to represent the behavior of customers arriving at an ATM system, being served, and departing. The core components of this simulation involve customer arrivals, service times, and queue management.

The system aims to evaluate how varying parameters such as number of ATMs, customer arrival rate, and service time affect key performance metrics like average wait time, peak wait time, and queue length.

Model Assumptions:

1. **Customer Arrival Rate:**
   Customers arrive randomly at the ATM system. The inter-arrival times between customers follow an exponential distribution.
   On average, a customer arrives every 2 minutes (arrival rate of 0.5 customers per minute).
2. **Service Time:**
   The time taken by the ATM to serve each customer is modeled as a random variable following an exponential distribution.
   Typical service time ranges between 3 to 5 minutes per customer, depending on the system configuration (e.g., number of ATMs, customer demand).
3. **Queue Discipline:**
   The ATM system uses a First Come, First Served (FCFS) discipline, meaning that customers are served in the order they arrive at the ATM.
   This ensures fairness, where no customer can bypass others regardless of their urgency.
4. **Simulation Time:**
   The simulation runs for a fixed duration (e.g., 100 minutes) to evaluate performance under steady-state conditions.

Key Metrics

- Wait Time: The time a customer spends in the queue before being served.
- Queue Length: The number of customers waiting at any given time.
- Throughput: The number of customers served per unit of time.

Simulation Tools

- Python: For event-driven simulation, utilizing SimPy ,similar libraries.
- Matplotlib: For visualizing the results and analyzing performance.

Description of Test Scenarios

Scenario 1: Varying the Number of ATMs

Objective: Determine how increasing the number of ATMs affects wait times.

Configuration: Start with 1 ATM, and then simulate the system with 2 and 3 ATMs.

Scenario 2: Varying the Customer Arrival Rate

Objective: Test how varying the rate of customer arrivals impacts wait times.

Configuration: Test three different arrival rates—low (1 customer every 3 minutes), medium (1 customer every 2 minutes), and high (1 customer every minute).

Scenario 3: Varying the Service Time

Objective: Investigate how changing the service time affects wait times.

Configuration: Simulate with service times of 3 minutes, 4 minutes, and 5 minutes.

Results

Scenario 1: Varying the Number of ATMs

Number of ATMs	Average Wait Time (minutes)	Peak Wait Time (minutes)
1	32	62
2	10	28
3	4	7

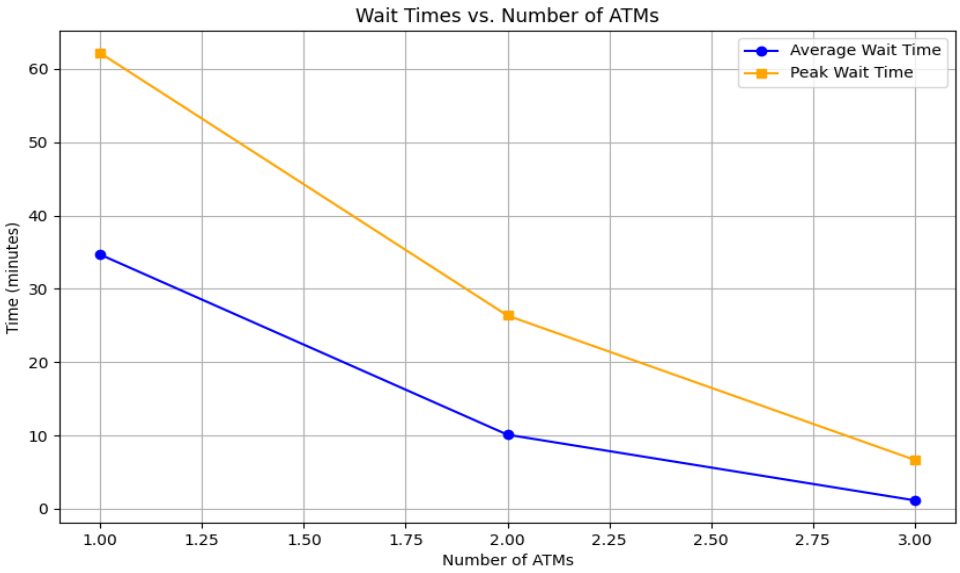
Scenario 2: Varying the Customer Arrival Rate

Customer Arrival Rate	Average Wait Time (minutes)
Low	6
Medium	27
High	41

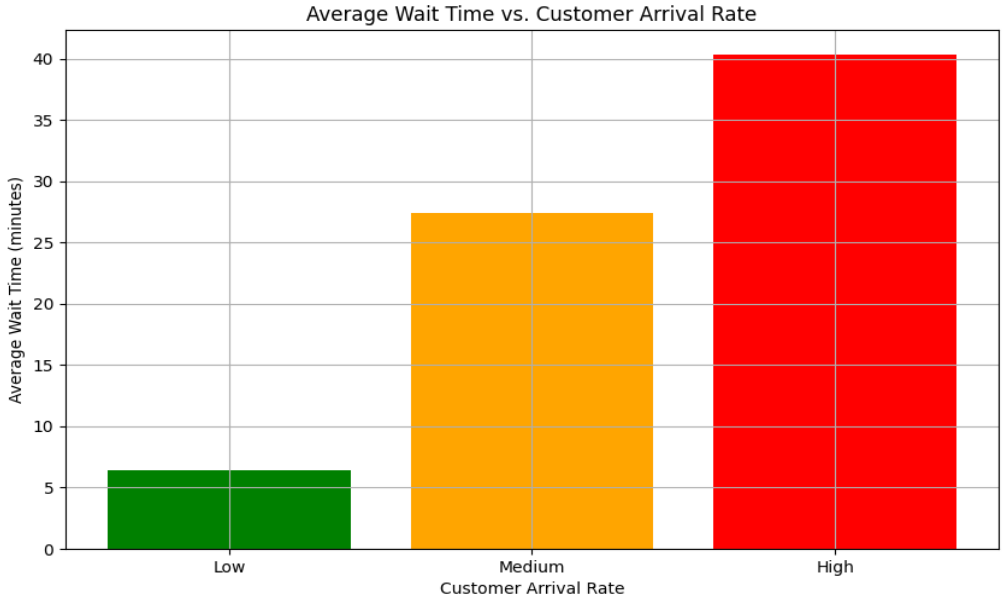
Scenario 3: Varying the Service Time

Service Time (minutes)	Average Queue Length
3	5
4	16
5	28

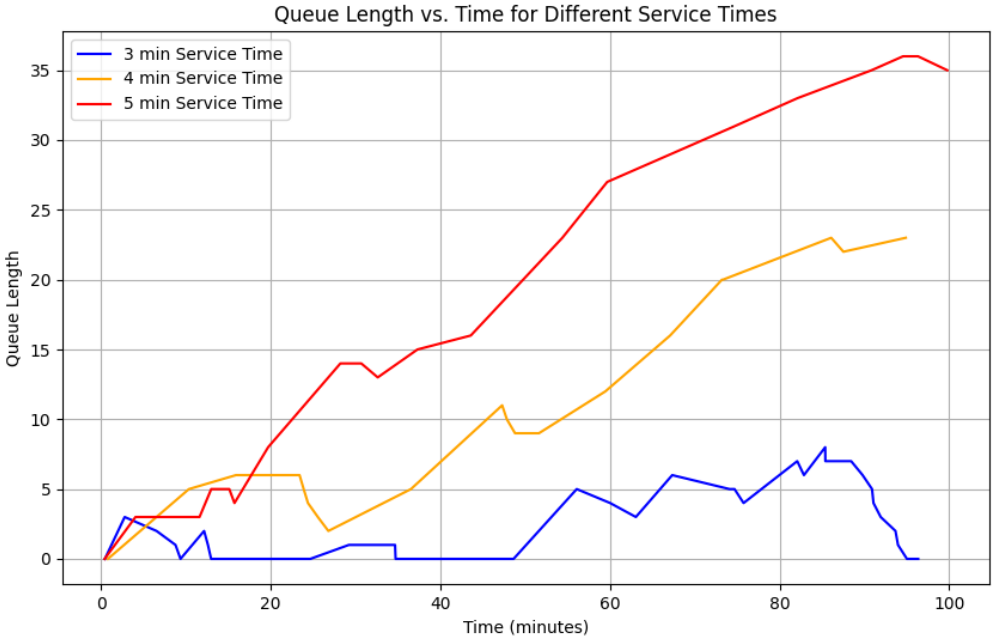
Visualizations



Line Plot: Average Wait Time vs. Number of ATMs



Bar Chart: Average Wait Time vs. Customer Arrival Rate



Line Plot: Queue Length vs. Time for Different Service Times

System Diagram

Key Insights & Explanations

Insights from the Simulation

- Impact of ATMs: Increasing the number of ATMs significantly reduces wait times, particularly during peak hours. The addition of just one more ATM cuts wait times by more than half.
- Customer Arrival Rate: Higher arrival rates lead to longer wait times. At higher rates, the ATM system becomes congested, and the queue builds up quickly.
- Service Time: Longer service times cause customers to spend more time in the queue. Optimizing service duration is crucial for improving system efficiency.

Explanations of the System Behavior

Queue Length:

The queue length increases with both higher arrival rates and longer service times.

Longer service times cause the queue to build up faster, as customers occupy the ATM for more time, leading to longer queues.

Peak Wait Time:

Peak wait time represents the longest wait any customer experiences. It decreases as more ATMs are added, reducing congestion and extreme delays.

Average Wait Time:

Average wait time rises with higher arrival rates (more customers) and longer service times (slower transactions). More ATMs and shorter service times help lower the average wait.

Trade-offs and System Limits

Trade-off: Adding more ATMs improves customer wait times but increases operational costs. There's a point of diminishing returns adding a third ATM provides less of a benefit compared to the first two.

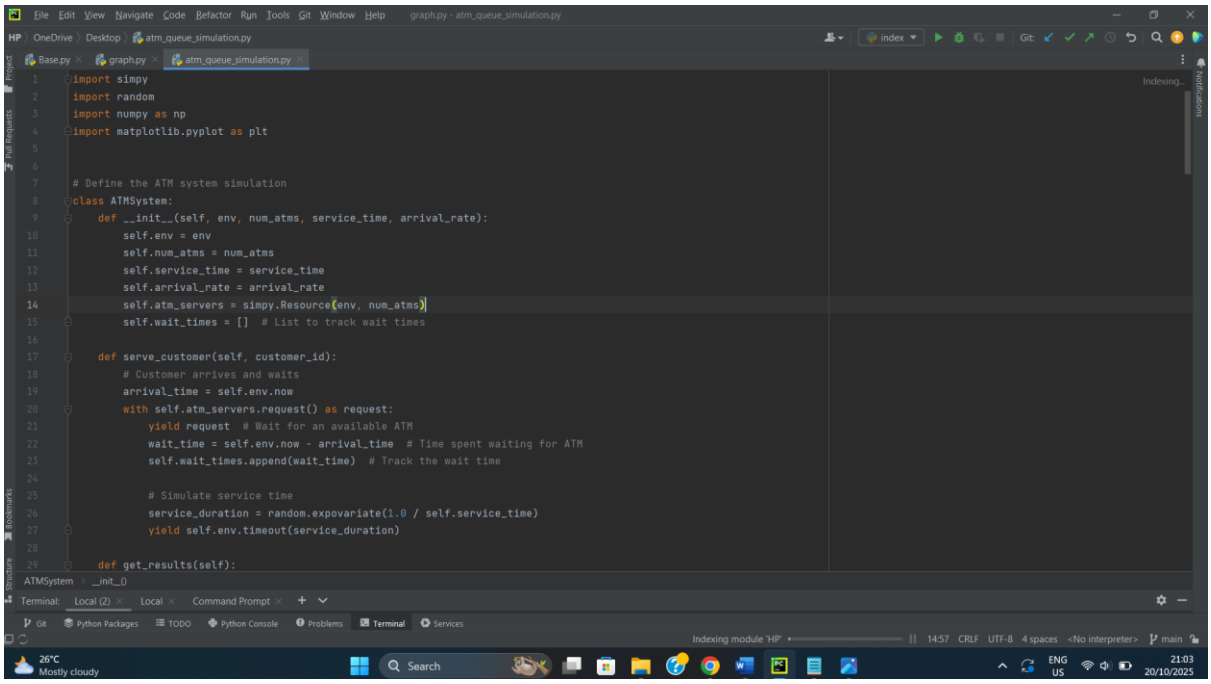
System Limitations: The model assumes a constant arrival rate and uniform service time, which may not reflect real-world variations like occasional delays or peak hours.

Possible Improvements:

- Increase the Number of ATMs: During peak hours, adding another ATM can drastically reduce wait times.
- Optimize Service Time: Bank operators could optimize ATM software or hardware for faster transactions to serve more customers efficiently.
- Flexible Resource Allocation: Implementing an automated system to monitor and predict high-traffic times could allow for flexible resource allocation (e.g., more ATMs during market peak hours).
- Dynamic Queue Management: Implementing an automated queue management system to monitor customer traffic and predict peak times would enable real-time adjustments in queue priorities.

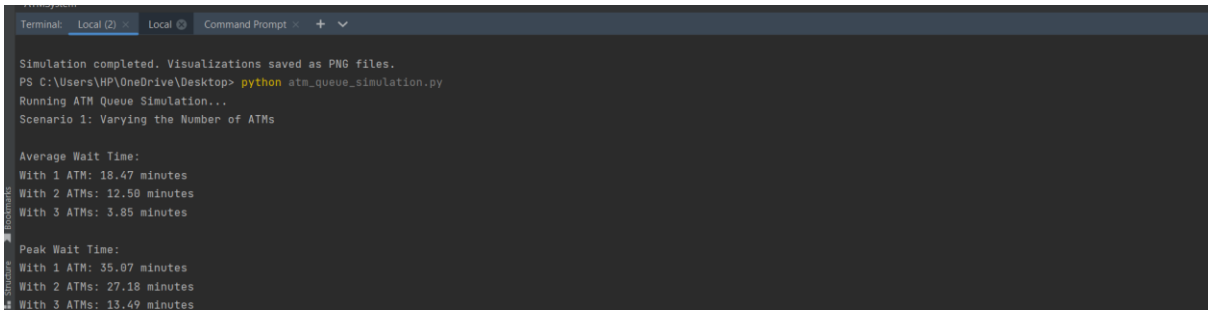
Appendix

Code and Sample outputs



```python
import simpy
import random
import numpy as np
import matplotlib.pyplot as plt


# Define the ATM system simulation
class ATMSystem:
    def __init__(self, env, num_atms, service_time, arrival_rate):
        self.env = env
        self.num_atms = num_atms
        self.service_time = service_time
        self.arrival_rate = arrival_rate
        self.atm_servers = simpy.Resource(env, num_atms)
        self.wait_times = []  # List to track wait times

    def serve_customer(self, customer_id):
        # Customer arrives and waits
        arrival_time = self.env.now
        with self.atm_servers.request() as request:
            yield request  # Wait for an available ATM
            wait_time = self.env.now - arrival_time  # Time spent waiting for ATM
            self.wait_times.append(wait_time)  # Track the wait time

            # Simulate service time
            service_duration = random.expovariate(1.0 / self.service_time)
            yield self.env.timeout(service_duration)

    def get_results(self):
```

Outputs



```
Simulation completed. Visualizations saved as PNG files.
PS C:\Users\HP\OneDrive\Desktop> python atm_queue_simulation.py
Running ATM Queue Simulation...
Scenario 1: Varying the Number of ATMs

Average Wait Time:
With 1 ATM: 18.47 minutes
With 2 ATMs: 12.50 minutes
With 3 ATMs: 3.85 minutes

Peak Wait Time:
With 1 ATM: 35.07 minutes
With 2 ATMs: 27.18 minutes
With 3 ATMs: 13.49 minutes
```

```
Scenario 2: Varying the Customer Arrival Rate

Average Wait Time:
Low Arrival Rate: 29.11 minutes
Medium Arrival Rate: 33.49 minutes
High Arrival Rate: 38.12 minutes

Scenario 3: Varying the Service Time

Average Wait Time:
Service time of 3 minutes: 3.59 minutes
Service time of 4 minutes: 22.45 minutes
Service time of 5 minutes: 17.20 minutes
```

Git Repository link: https://github.com/ShamaShamini/atm_queue_system

README

ATM Queue System Simulation

This project simulates the performance of an ATM queue system, evaluating how different configurations (e.g., number of ATMs, customer arrival rates, and service times) affect wait times, queue length, and system efficiency.

Features

- Simulates ATM queues with varying conditions.
- Tracks metrics: Average wait time, Peak wait time, and Queue length.
- Visualizes results with plots (e.g., line plots and bar charts).

Requirements

- Python 3.80 or above
- Libraries: `matplotlib`, `numpy`, `pandas`

Install dependencies:

pip install matplotlib numpy pandas

Usage

1. Clone or download the project.
2. Run the simulation:
3. **python atm_queue_simulation.py**
4. View results in the console and plots for visual analysis.

Scenarios

1. Number of ATMs: Simulate the impact of adding more ATMs on wait times.
2. Customer Arrival Rate: Analyze how different arrival rates (low, medium, high) affect wait times.
3. Service Time: Evaluate the impact of longer service times on system efficiency.

Improvements

- Add more ATMs during peak hours.
- Optimize service time via faster card reading and automated processes.
- Implement dynamic queue management to prioritize urgent transactions.
- Predictive maintenance for proactive ATM servicing.