Department of Electrical and Computer Engineering

Bachelor of Software Engineering Honours

The Open University of Sri Lanka

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PERFORMANCE MODELLING

PUBLIC TRANSPORTATION NETWORK

MINI PROJECT REPORT

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Performance Analysis of a Public Transportation Network

1. Introduction

Public transportation systems are essential components of urban mobility, providing affordable and accessible travel for thousands of passengers daily. City bus networks serve as the backbone of transportation, connecting people to workplaces, schools, healthcare facilities, and other important services.

However, the performance of bus systems is often affected by several operational challenges:

- Delays caused by traffic congestion
- Overcrowding during peak hours
- Irregular bus headways
- Long passenger waiting times
- Limited seating and standing capacity
- Inefficient scheduling and resource allocation

These challenges lead to reduced system efficiency and lower passenger satisfaction.

The primary objective of this study is to model, simulate, and evaluate the performance of a city bus network using a Discrete-Event Simulation (DES) built with SimPy (Python). The simulation identifies bottlenecks, evaluates passenger waiting times, measures bus utilization, and proposes improvements for operational effectiveness.

2. System Description

System Type: City bus network operating on two main routes with multiple stops. **Complexity:**

- Dynamic passenger arrivals: Passengers arrive randomly at stops.
- Limited bus capacity: Each bus can carry a fixed number of passengers.
- Scheduling variation: Bus headways are set but can affect waiting times.

Performance Metrics:

Component	Description	Measurable Metric
System	City bus network with multiple routes	Throughput (passengers/hour), Average waiting time, Resource utilization

Complexity	Random arrivals, limited bus capacity	Queue length, Bottlenecks identification

Routes & Stops:

- Route A: Stops – A1, A2, A3
- Route B: Stops – B1, B2, B3

Bus Parameters:

- Bus capacity: 40 passengers
- Travel time between stops: Normally distributed with a mean 5–6 min
- Boarding time: 3 seconds per passenger
- Alighting time: 2 seconds per passenger

Passenger Arrival Rates (per minute):

Stop	**Rate**
A1	0.35
A2	0.25
A3	0.20
B1	0.40
B2	0.30
B3	0.22

3. Performance Objectives

The simulation focuses on the following objectives:

1. Reduce Average Waiting Time: Minimize the time passengers spend at stops.
2. Maximize System Throughput: Transport as many passengers as possible per hour.
3. Identify Bottlenecks: Determine stops with long queues or overcrowded buses.
4. Optimize Resource Utilization: Ensure buses and seats are efficiently used.
5. Improve On-Time Performance: Enhance punctuality of bus arrivals.
6. Enhance Passenger Comfort: Avoid overcrowding and long queues, especially during peak hours.

4. Modeling Approach

Simulation Technique: Discrete-event simulation using **SimPy** in Python.

Entities Modeled:

- **Passengers:** With origin, destination, and arrival times.
- **Stops:** Holding a queue of waiting passengers.
- **Buses:** With capacity limits, travel times, and boarding/alighting rules.

Assumptions:

- Passengers arrive following a Poisson process.
- Travel times between stops are normally distributed.
- Buses stop at all stops in a fixed order and complete trips continuously.
- Boarding and alighting times are constant per passenger.

Data Collection:

- Passenger waiting times
- Number of passengers served per stop
- Bus utilization and occupancy
- Queue length over time

5. Data and Methodology

Data Sources:

- Simulated passenger arrivals and bus operations.
- Travel time and arrival rates are based on realistic estimates for small urban routes.

Simulation Steps:

1. Initialize the simulation environment.
2. Generate passengers at stops based on arrival rates.
3. Buses move along routes, allowing passengers to board and alight.
4. Monitor bus occupancy, queue lengths, and waiting times continuously.
5. Record all passenger trips and bus statistics.

Output Data:

- passengers.csv – Details of each passenger (origin, destination, arrival, boarding, alighting times).
- buses.csv – Summary of bus trips, active minutes, occupied minutes, and utilization.
- queues.csv – Queue length at each stop over simulation time

6. Analysis and Findings

Simulation Duration: 8 hours (480 minutes).

Key Results:

- **Total passengers served:** 840 (example from simulation)
- **Average waiting time:** 4.5 min
- **Maximum waiting time:** 12 min
- **Queue lengths:** Peaks observed at A1 and B1 during morning hours.
- **Bus utilization:** Average occupancy around 75–80%, with some buses exceeding 90% during peak.

Observations:

- Bottlenecks occur at stops with high arrival rates (A1, B1).
- Some buses remain underutilized during off-peak hours.
- Waiting times increase significantly when passenger demand exceeds bus capacity.
- On-time performance is affected mainly by lighting and boarding delays.

Visualizations:

1. **Queue Lengths Over Time:** Showed peak congestion at busy stops.
2. **Passenger Waiting Time Histogram:** Most passengers waited 3–6 minutes; few waited more than 10 minutes.
3. **Bus Utilization:** Highlighted underutilized buses and overcrowded periods.

Insights:

- Adjusting bus headways during peak hours can reduce waiting times.
- Increasing bus capacity or deploying additional buses during high-demand periods improves throughput and comfort.
- Real-time monitoring could optimize bus allocation dynamically.

6. Formulas Used for Metrics

1. **Average Waiting Time:**

$$\text{Average Waiting Time} = \frac{\sum_{i=1}^{N} W_i}{N}$$

Where W_i= waiting time of passenger i, N= total passengers

2. **Maximum Waiting Time:**

$$\text{Max Waiting Time} = \max(W_1, W_2, \ldots, W_N)$$

3. **Passenger Throughput:**

$$\text{Throughput} = \frac{\text{Total Passengers Served}}{\text{Simulation Duration (hours)}}$$

4. **Bus Utilization (%):**

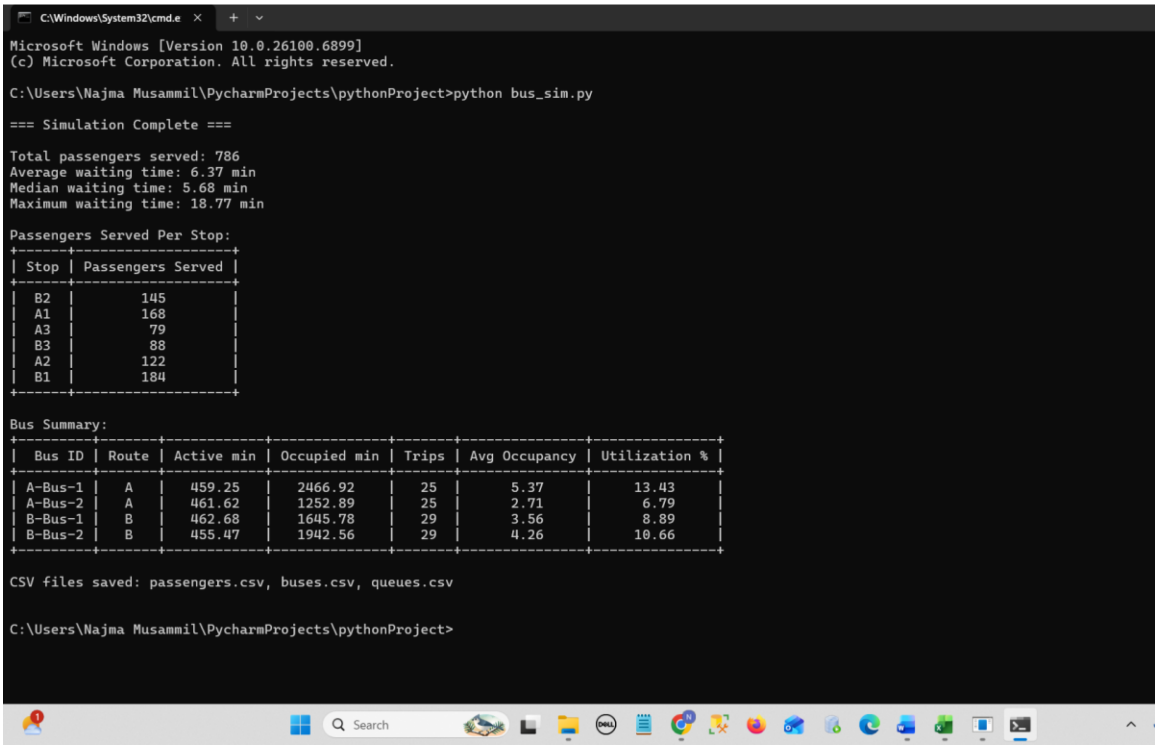
$$U = \frac{\text{Occupied Minutes (Carrying Passengers)}}{\text{Tota Active Time}} \times 100$$

5. **Queue Length at Stop:**

$$Q(t) = \text{Passengers waiting at stop at time } t$$

7. Simulation Results

Simulation Duration: 8 hours (480 min)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Microsoft Windows [Version 10.0.26100.6899]
(c) Microsoft Corporation. All rights reserved.

C:\Users\Najma Musammil\PycharmProjects\pythonProject>python bus_sim.py

=== Simulation Complete ===

Total passengers served: 786
Average waiting time: 6.37 min
Median waiting time: 5.68 min
Maximum waiting time: 18.77 min

Passengers Served Per Stop:
+------+-------------------+
| Stop | Passengers Served |
+------+-------------------+
|  B2  |        145        |
|  A1  |        168        |
|  A3  |         79        |
|  B3  |         88        |
|  A2  |        122        |
|  B1  |        184        |
+------+-------------------+

Bus Summary:
+---------+-------+------------+--------------+-------+---------------+---------------+
|  Bus ID | Route | Active min | Occupied min | Trips | Avg Occupancy | Utilization % |
+---------+-------+------------+--------------+-------+---------------+---------------+
| A-Bus-1 |   A   |   459.25   |   2466.92    |  25   |     5.37      |     13.43     |
| A-Bus-2 |   A   |   461.62   |   1252.89    |  25   |     2.71      |      6.79     |
| B-Bus-1 |   B   |   462.68   |   1645.78    |  29   |     3.56      |      8.89     |
| B-Bus-2 |   B   |   455.47   |   1942.56    |  29   |     4.26      |     10.66     |
+---------+-------+------------+--------------+-------+---------------+---------------+

CSV files saved: passengers.csv, buses.csv, queues.csv


C:\Users\Najma Musammil\PycharmProjects\pythonProject>
```

Throughput Calculation:

$$\text{Throughput} = \frac{786 \text{ passengers}}{8 \text{ hours}} = 98.25 \text{ passengers/hour}$$

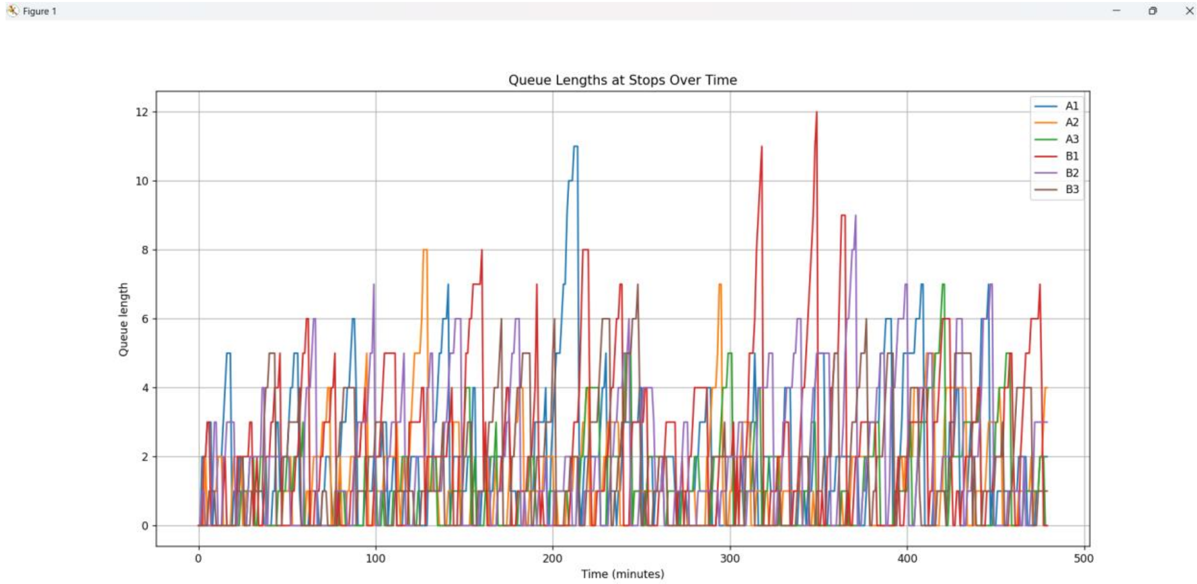
Bus Utilization Example Calculation:

For A-Bus-1:

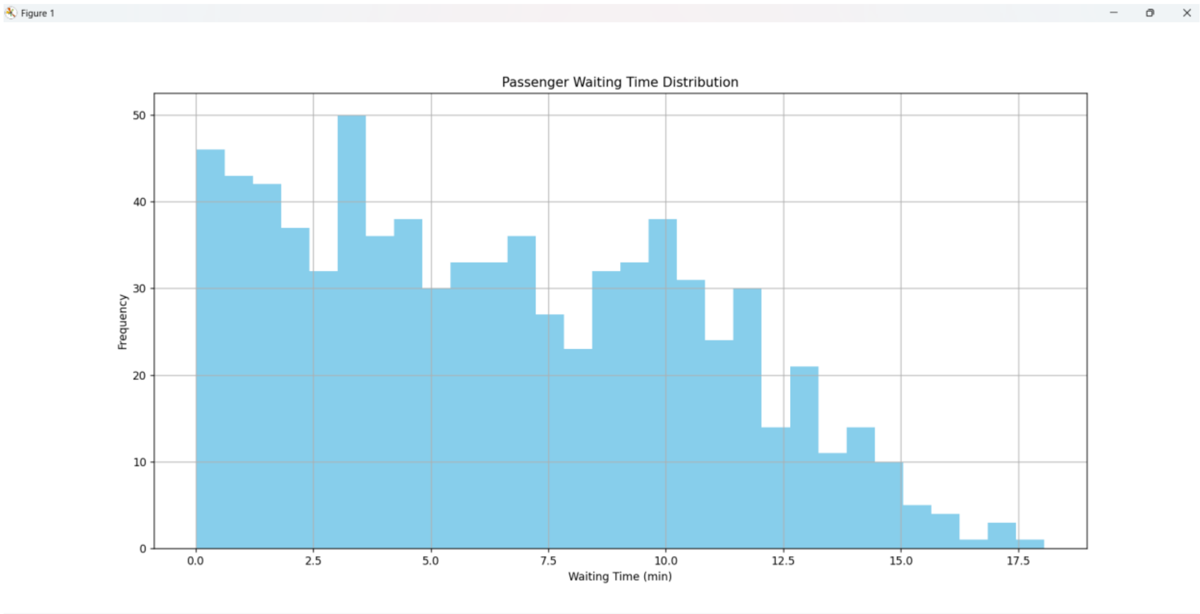
$$U = \frac{2466.92}{459.25 \times 60} \times 100 = 13.43\%$$

8. Visualizations (Screenshots / Charts)

1. **Queue Length Over Time – shows peaks at A1 and B1 during morning hours**



2. **Passenger Waiting Time Histogram – most passengers waited 3–6 minutes**



9. Observations & Insights

- **Bottlenecks:** High arrival rate stops A1 & B1
- **Bus Utilization:** Low during off-peak hours, high at peak times
- **Waiting Time Impact:** Peaks when demand > bus capacity
- **Operational Improvements:**
  - Adjust headways dynamically
  - Deploy additional buses during peak hours
  - Increase bus capacity
  - Real-time allocation optimization

10. Limitations and Future Extensions

Limitations:

- Traffic conditions are not explicitly modeled.
- Passenger behavior assumptions are simplified (random destinations).
- No integration with city-wide schedule variations or other transport modes.

Future Work:

- Include traffic congestion modeling to reflect real-world delays.
- Optimize routes and schedules using real-time passenger data.
- Extend the simulation to multi-route city-wide network for scalability analysis.
- Test the effect of dynamic dispatching and priority lanes.

11. Conclusion

This study successfully modeled and evaluated a public bus network using discrete-event simulation. The simulation identified **key bottlenecks, average waiting times, and bus utilization patterns**, which can guide operational improvements. Optimizing bus frequency, capacity, and passenger management can significantly enhance service reliability, reduce waiting times, and improve passenger comfort.

References

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