Gas Station Queueing Simulation Report

Prepared by Abdullah Elsayed

July 6, 2025

1 Executive Summary

This report analyzes a discrete-event simulation of a gas station with three fuel pumps (Pump 95, Pump 90, and Gas) serving three car types (A, B, C). The simulation, run for 100 iterations with 30 cars each, evaluates key performance indicators (KPIs) such as average service time, waiting times, queue lengths, and pump idle times. Results reveal a significant bottleneck at the Gas pump due to high demand from Type C cars, which constitute 46.1% of traffic and experience long waiting times (12.63 minutes on average). Recommendations include adding a second Gas pump to reduce waiting times and improve efficiency.

2 Introduction

The gas station simulation models a queuing system with three fuel pumps, each associated with specific car types:

- **Car Type A**: Uses Pump 95 exclusively.

- **Car Type B**: Prefers Pump 90 but may switch to Pump 95 if the Pump 90 queue exceeds three cars (60% probability).

- **Car Type C**: Prefers Gas but may use Pump 90 if the Gas queue exceeds four cars (40% probability).

Implemented in Python using `numpy`, `pandas`, and `matplotlib`, the simulation tracks car arrivals, service times, and queue dynamics to compute KPIs. This report outlines the methodology, results, visualizations, and recommendations based on the simulation.

3 Methodology

3.1 Simulation Design

The simulation models a discrete-event system with the following components:

- **Car Type Distribution**: Type A (20%), Type B (35%), Type C (45%), determined by random sampling.

1

- **Inter-Arrival Times**: Discrete distribution (0 min: 17%, 1 min: 23%, 2 min: 25%, 3 min: 35%).

- **Service Times**:

  – Type A and B: 1 min (30%), 2 min (30%), 3 min (40%).

  – Type C: 3 min (20%), 5 min (30%), 7 min (50%).

- **Queue Logic**: Cars are assigned to their preferred pump, with reassignment based on queue thresholds.

- **Metrics**: Include average service time, waiting times per pump, maximum queue lengths, probability of waiting, pump idle time percentages, and car type proportions.

3.2 Simulation Execution

The simulation was run for 100 iterations, each with 30 cars. Metrics were averaged across runs for statistical reliability. A CSV file can be generated for detailed results of a single run.

4 Results

The table below summarizes key performance indicators averaged across 100 runs with 30 cars each.

4.1 Analysis

- **Service Time Validation**: The experimental average service time (3.81 minutes) closely matches the theoretical value (3.75 minutes), validating the model.

- **Inter-Arrival Time**: The experimental inter-arrival time (1.72 minutes) is slightly below the theoretical value (1.78 minutes), indicating a slightly higher arrival rate.

- **Queue Dynamics**: The Gas pump exhibits the highest waiting time (12.63 minutes) and maximum queue length (5.90 cars), driven by the 46.1% prevalence of Type C cars and their longer service times (up to 7 minutes).

- **Pump Utilization**: The Gas pump has the lowest idle time (12.24%), indicating high utilization and congestion. Pumps 95 and 90 have higher idle times (80.78% and 57.32%), suggesting underutilization.

- **Car Type Distribution**: The proportions of car types (A: 20.0%, B: 33.9%, C: 46.1%) align with input probabilities.

5 Visualizations

The simulation includes histograms to visualize key metrics across 100 runs:

Table 1: Key Performance Indicators (Averaged Across 100 Runs)

Metric	Value
Experimental Average Service Time	3.81 minutes
Theoretical Average Service Time	3.75 minutes
Average Waiting Time (Pump 95)	0.20 minutes
Average Waiting Time (Pump 90)	0.78 minutes
Average Waiting Time (Gas)	12.63 minutes
Total Average Waiting Time	4.53 minutes
Maximum Queue Length (Pump 95)	1.25 cars
Maximum Queue Length (Pump 90)	2.35 cars
Maximum Queue Length (Gas)	5.90 cars
Probability of Waiting (Pump 95)	0.11
Probability of Waiting (Pump 90)	0.30
Probability of Waiting (Gas)	0.86
Idle Time Percentage (Pump 95)	80.78%
Idle Time Percentage (Pump 90)	57.32%
Idle Time Percentage (Gas)	12.24%
Experimental Inter-Arrival Time	1.72 minutes
Theoretical Inter-Arrival Time	1.78 minutes
Percentage of Car Type A	20.0%
Percentage of Car Type B	33.9%
Percentage of Car Type C	46.1%

- **Inter-Arrival Time**: The histogram shows a distribution peaking around 1.8 minutes, with a range from 1.2 to 2.2 minutes, reflecting the discrete inter-arrival time probabilities.

- **Average Waiting Time for All Cars**: The histogram peaks between 10 and 15 minutes, with a range from 0 to 20 minutes, indicating a right-skewed distribution due to long waiting times at the Gas pump.

(Instruction: To include the histograms, upload the images $inter_arrival_time.png$ and $average_waiting_time$)

6 Discussion

The Gas pump is the primary bottleneck, driven by the high proportion of Type C cars (46.1%) and their longer service times. The average waiting time at the Gas pump (12.63 minutes) significantly impacts the total average waiting time (4.53 minutes). Reassignment of Type C cars to Pump 90 when the Gas queue exceeds four cars mitigates some congestion, but the Gas pump's capacity remains insufficient. The low idle time (12.24%) at the Gas pump confirms high demand, necessitating operational adjustments.

7 Recommendations

To optimize gas station operations, we recommend:

1. **Add a Second Gas Pump**: This would reduce the average waiting time (currently 12.63 minutes) and maximum queue length (5.90 cars) for Type C cars, lowering the total average waiting time.

2. **Adjust Reassignment Rules**: Increase the probability of reassigning Type C cars to Pump 90 (currently 40%) to better balance load across pumps.

3. **Enhance Service Efficiency**: Explore faster fueling methods for Type C cars to reduce service times at the Gas pump.

8 Conclusion

The simulation, conducted on July 6, 2025, validates the gas station's operational model, with experimental metrics closely aligning with theoretical expectations. The Gas pump's high utilization and long queues highlight the need for additional capacity. Adding a second Gas pump is the most effective solution to minimize waiting times and enhance customer satisfaction. Future simulations could explore dynamic scheduling or additional pumps to further optimize performance.