

Cairo University

Faculty of Computers and Artificial Intelligence

**Petrol Station Multi-Channel Queue**

Department: Operations Research and Decision Support

Course Name: Systems Modeling and Simulation

Course Code: DS331/DS241

Instructor: Assoc. Prof. Ayman Ghoneim

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## **Problem formulation & Objectives.**

The problem: To design a multi-channel queuing system to simulate a petrol station that has 3 types of pumps (95 Octane, 90 Octane, Gas) and serves 3 car categories (A, B, C) that arrives randomly

**Categorization of Vehicles**

Cars that arrive are:

Category A with probability 0.2

Category B with probability 0.35

Category C with probability 0.45

Cars belong to one of three categories based on their fuel compatibility.

Dynamic Queuing Behavior:

Categories B, C may opt for alternative pumps depending on the queue length:

category B cars can opt for 95 pumps with probability 0.6 if the queue when arriving to the 90-octane has more than 3 cars

category C cars can go for the 90-octane petrol pump with probability 0.4 if the queue when arriving to the gas has more than 4 cars

Performance Metrics to Estimate:

Average service times, waiting times, queue lengths, idle times, and probabilities of waiting for each pump.

Policy Decisions:

Give insight of the best type of pump to add to minimize overall waiting times.

# System Components.

1. Entities

Entities are the moving parts of the system, primarily the cars that arrive and require service.

**Cars**:

Each car belongs to one of three categories:

**Category A**: Requires 95 octane petrol.

**Category B**: Can use either 90 octane or 95 octane petrol.

**Category C**: Can use either 90 octane petrol or gas.

Behavior:

**Category B** cars may switch to 95 octane if the 90-octane queue exceeds 3 cars (60% probability).

**Category C** cars may switch to 90 octane if the gas queue exceeds 4 cars (40% probability).

2. Resources

Resources are the service points in the system.

**Pumps**:

1. **octane Pump**: Serves cars of categories A and B.
2. **octane Pump**: Serves cars of categories B and C.

**Gas Pump**: Serves cars of category C.

3. Queues

Each pump has a queue to manage waiting cars.

**95 Octane Queue**

**90 Octane Queue**

**Gas Queue**

Queues can grow as cars arrive and wait for service.

4. Events

Discrete events drive the system's state changes.

**Arrival Events**:

Cars arrive at the petrol station based on the inter-arrival time distribution (Table 1).

**Service Events**:

Cars are served based on service time distributions (Tables 2 and 3).

**Queue Switching Events**:

Cars of categories B and C may switch to other queues based on queue lengths and their switching probabilities.

A table with numbers and a few black text

Description automatically generated5. Statistical Distributions

Used to model randomness in the system:

**Inter-Arrival Times**

Time intervals between car arrivals follow a probability distribution.

**Service Times**:

Service durations for each category follow their respective distributions

A table with numbers and text

Description automatically generated

7. State Variables

Variables that represent the system's state at any given time:

**Queue Lengths**: Current number of cars waiting at each pump.

**Idle Time**: Tracks when pumps are not in use.

**Waiting Times**: Time spent by cars in queues.

**Service Times**: Time spent by cars being served.

## A number of numbers on a white background Description automatically generatedSystem analysis including cumulative distribution simulation table

## (for 20 cars).

|  |  |  |  |
| --- | --- | --- | --- |
| Inter-Arrival Time (minutes) | Probability | Cumulative Probability | Random No. |
| 0 | 0.17 | 0.17 | 0-17 |
| 1 | 0.23 | 0.40 | 18-40 |
| 2 | 0.25 | 0.65 | 41-65 |
| 3 | 0.35 | 1.00 | 66-100 |

|  |  |  |  |
| --- | --- | --- | --- |
| Service Time for Category A, B | | | |
| Service Time (minutes) | **Probability** | **Cumulative Probability** | **Random No.** |
| 1 | 0.20 | 0.20 | 0-20 |
| 2 | 0.30 | 0.50 | 21-50 |
| 3 | 0.50 | 1.00 | 51-100 |

|  |  |  |  |
| --- | --- | --- | --- |
| Category | Probability | Cumulative Probability | Random No. |
| A | 0.20 | 0.20 | 0-20 |
| B | 0.35 | 0.55 | 21-55 |
| C | 0.45 | 1.00 | 56-100 |

|  |  |  |  |
| --- | --- | --- | --- |
| Service Time for Category C | | | |
| Service Time (minutes) | **Probability** | **Cumulative Probability** | **Random No.** |
| 3 | 0.20 | 0.20 | 0-20 |
| 5 | 0.50 | 0.70 | 21-70 |
| 7 | 0.30 | 1.00 | 71-100 |

## Experimental Design Parameters

**Experiment 1: Medium-Scale Simulation**

* **Number of Cars**: 1000
* **Number of Runs**: 30

**Experiment 2: Large-Scale Simulation**

* **Number of Cars (per day)**: 3000
* **Number of Days (runs)**: 50

## Justification of experiment parameters

**Experiment 1 justification:**

1. **Number of Cars per Day**:  
   Simulating 1000 cars per day represents a typical workload for a petrol station during an average day. This provides enough data to observe common system behaviours without making the simulation too time-consuming.
2. **Number of Days**:  
   Simulating 30 days (runs) allows the experiment to cover a full month of operation. This is sufficient to account for randomness in daily traffic and service times, ensuring the results represent a range of typical scenarios.

**Experiment 2 Justification**:

1. **Number of Cars per Day**:  
   Simulating 3000 cars per day tests the system under heavy traffic conditions. This helps evaluate its performance when demand is much higher, such as during peak periods or special events. It also allows rare cases, like very long queues, to appear more often in the results.
2. **Number of Days**:  
   Simulating 50 days provides a more detailed analysis. This longer time frame helps reduce the effect of randomness, offering more reliable averages and confidence in the results, especially under extreme conditions.

## Results Analysis: Using graphs & discussions stating the results for the 8 questions.

**Experiment 1**

All the answers are given after running the simulation 30 times with 1000 cars in each run.

1. Average Service Time per Category

**Observations**:

A: 2.29

B: 2.31

C: 5.21

A graph of a service

Description automatically generated**Graph**:

**Discussion**:

Cars in **Category C (Gas)** have significantly longer service times, likely due to the nature of their fuel requirements which are 60% Gas if the queue has more than 4 cars and 100% Gas if it’s less than or equal to 4 cars

Categories A and B (95 and 90 octane, respectively) have similar service times, aligning with their theoretical averages.

2. Average Waiting Time in Queues

**Per Pump**:

**95 Octane**: 4.18 minutes

**90 Octane**: 0.95 minutes

**Gas**: 7.36 minutes

**Overall Average**: 3.71 minutes

A graph of a number of red squares

Description automatically generated with medium confidence**Graph**:

**Discussion**:

The **Gas pump** has the highest waiting time, reflecting its longer service times and higher utilization.

**95 Octane** has the least waiting time, suggesting underutilization or fewer cars requiring this fuel type.

3. Maximum Queue Length per Pump

**Values**:

**95 Octane**: 394 cars

**90 Octane**: 337 cars

**Gas**: 269 cars

**Discussion**:

The **95 Octane pump** shows the longest queues, indicating a bottleneck in the system.

This aligns with its relatively high waiting probability

4. Probability That a Car Waits

**Per Pump**:

**95 Octane**: 39%

**90 Octane**: 34%

**Gas**: 27%

**Discussion**:

The **95 Octane pump** has the highest waiting probability, corroborating the findings of maximum queue lengths and waiting times.

The **Gas pump** has a lower waiting probability despite higher waiting times, indicating variability in car arrivals and service.

5. Idle Time Ratios

**Per Pump**:

**95 Octane**: 3%

**90 Octane**: 0%

**Gas**: 1%

**Discussion**:

The **90 Octane pump** has no idle time, indicating it is either perfectly utilized or slightly overloaded since it’s the backup plan for category C cars if the queue length is more than 4 cars

The **95 Octane pump** shows minimal idle time despite its high waiting probabilities, suggesting it operates near capacity.

6. Theoretical vs Experimental Average Service Time

**Comparison**:

**Category A**: Theoretical = 2.3, Experimental = 2.28

**Category B**: Theoretical = 2.3, Experimental = 2.34

**Category C**: Theoretical = 5.2, Experimental = 5.19

**Graph**:

**A graph of a service time

Description automatically generatedA graph of a service time

Description automatically generated**

**A graph of gas pump service

Description automatically generated**

**Discussion**:

Experimental values approximately match theoretical ones, validating the simulation model.

7. Theoretical vs Experimental Average Inter-Arrival Time

**Comparison**:

Theoretical = 1.78 minutes

Experimental = 1.78 minutes

8. Recommendation for Adding an Extra Pump

**Effect on Average Waiting Time**:

Adding a **95 Octane pump**: Reduces to **3.68 minutes**

Adding a **90 Octane pump**: Reduces to **3.57 minutes**

Adding a **Gas pump**: Reduces to  **3.61 minutes**

**Discussion**:

Adding an extra **95 Octane pump** has the greatest impact on reducing average waiting time, aligning with its high queue length and waiting probability.

This suggests that the **95 Octane pump** is the most strained resource in the current setup.

**Experiment 2**

All the answers are given after running the simulation 50 times with 3000 cars in each run.

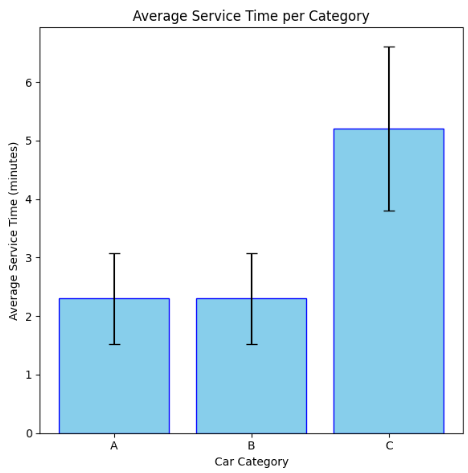
1. Average Service Time per Category

**Observations**:

A: 2.3

B: 2.3

C: 5.2

**Graph**:

**Discussion**:

Same as experiment 1, Cars in **Category C (Gas)** have significantly longer service times, likely due to the nature of their fuel.

Also, similar to the first experiment , Categories A and B (95 and 90 octane, respectively) have similar service times, aligning with their theoretical averages.

2. Average Waiting Time in Queues

**Per Pump**:

**90:**  4.49

**95:**  0.94

**Gas:** 8.41

**Overall Average Waiting Time:** 4.09

A graph of a diagram

Description automatically generated with medium confidence**Graph**:

**Discussion**:

Similarly, The **Gas pump** has the highest waiting time, reflecting its longer service times and higher utilization.

**95 Octane** has the least waiting time, suggesting underutilization or fewer cars requiring this fuel type.

**Average waiting time** in this experiment is more than experiment 1, which may be closer to real life scenarios

3. Maximum Queue Length per Pump

**Values**:

**95 Octane**: 1251 cars

**90 Octane**: 958 cars

**Gas**: 791 cars

**Discussion**:

When simulating a large number of cars, rare scenarios like very long queue lengths happen , like in this experiment the maximum queue is around **3x more** than the first experiment

4. Probability That a Car Waits

**Per Pump**:

**95 Octane**: 42%

**90 Octane**: 32%

**Gas**: 26%

**Discussion**:

Waiting probability in **Octane 95** is objectively higher than the first experiment due to its busy nature

5. Idle Time Ratios

**Per Pump**:

**95 Octane**: 0.056%

**90 Octane**: 0.037%

**Gas**: 0.056%

**Discussion**:

The idle ratios are **much lower** than in experiment 1 due to the rush of the cars and severe increase in demand

6. Theoretical vs Experimental Average Service Time

**Comparison**:

**Category A**: Theoretical = 2.3, Experimental = 2.29

**Category B**: Theoretical = 2.3, Experimental = 2.33

**Category C**: Theoretical = 5.2, Experimental = 5.19

**Graph**:

**A graph of a service time

Description automatically generatedA graph of a service time

Description automatically generated**

**A graph of gas pump service time

Description automatically generated**

**Discussion**:

Similar to the first experiment , Experimental values closely match theoretical ones, validating the simulation model.

7. Theoretical vs Experimental Average Inter-Arrival Time

**Comparison**:

Theoretical = 1.78

Experimental = 1.78

8. Recommendation for Adding an Extra Pump

**Effect on Average Waiting Time**:

Adding a **95 Octane pump**: Reduces to **4.1 minutes**

Adding a **90 Octane pump**: Reduces to **4.05 minutes**

Adding a **Gas pump**: Reduces to **4.08 minutes**

**Discussion**:

Similar to experiment 1 , Adding an extra **95 Octane pump** has the greatest impact on reducing average waiting time, which validates the suggestion **that the best course of action is adding an extra 95 Octane pump**

## Conclusion

This project aims to model a petrol station using simulation, focusing on a multi-channel queuing system. The station has three pump types (95, 90 Octane, and Gas) serving three car categories (A, B, and C). Cars arrive randomly and have different fuel needs, sometimes switching queues based on length.

A simulation table was used to track the system over time, considering system components like:

* **Entities:** Cars, categorized by fuel type
* **Resources:** Pumps for each fuel type
* **Queues:** Lines at each pump
* **Events:** Car arrivals, service completion, queue switching
* **Distributions:** Probabilities for arrival times and service durations
* **State variables:** Queue lengths, pump idle times, waiting and service times

The experiment involved simulating a specific number of cars and running the simulation multiple times to ensure reliable results. Analysis focused on key performance indicators like average service/waiting times, queue lengths, and idle time ratios.

Results showed the 95 Octane pump was a bottleneck, with the longest waits and highest probability in queues. The 90 Octane pump had little idle time due to Category C cars using it as an alternative. Theoretical and experimental values were closely aligned, validating the model's accuracy.

**Key recommendation:** Add another 95 Octane pump to reduce overall waiting time.