Cairo University
Faculty of Computers and Artificial Intelligence

Department: Operations Research and Decision Support.
Course Name: Systems Modeling and Simulation.
Course Code: DS331/DS241.
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Supermarket Multi-Channel Queue

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Problem formulation & Objectives

Problem formulation:

The supermarket checkout area currently operates with one express cashier and one regular cashier. The express cashier is designated for customers with 12 items or less, while the regular cashier serves all customers regardless of the number of items. Both cashiers exhibit the same service efficiency, and there is adequate space to accommodate all waiting customers in their respective queues. The queuing system is governed by specific rules for express and regular customers.

Objectives:

1. Optimization of Checkout Process:
    - Design a queuing system that optimizes the efficiency of the checkout process by strategically allocating customers to either the express or regular cashier queues based on their item count.
    - Minimize waiting times for customers and ensure a smooth flow through the checkout area.
2. Queue Length Management:
    - Develop strategies to manage and balance the queue lengths for both express and regular cashiers.
    - Establish guidelines for express customers to join the express cashier’s queue and regular customers to join the regular cashier’s queue, taking into account the relative lengths of the two queues.
3. Customer Distribution:
    - Implement a customer distribution strategy that aligns with the supermarket's goal of accommodating 60% express customers and 40% regular customers.
    - Ensure fair and efficient service for both types of customers, considering their proportions.
4. System Flexibility:
    - Build flexibility into the system to adapt to varying customer loads and optimize resource utilization during peak and off-peak hours.

- Implement mechanisms to dynamically adjust the threshold for express customers based on real-time queue lengths.

5. Performance Evaluation:
    - Establish metrics and benchmarks to evaluate the performance of the checkout system, including average waiting times, throughput, and overall customer satisfaction.
    - Continuously monitor and analyze the system's performance to identify areas for improvement.

System component:

System:

- The entire supermarket checkout system.

Entity:

- Express Cashier.
- Regular Cashier.
- The customers.

Attributes:

- Express Percentage.
- Arrival Time.
- Service Time.

Activities:

- Generating Customers.
- Serving Customers.

Event:

- Customer Arrival.
- Customer Service.

States:

- Idle Time.
- Number of Customers Waiting in the queue.

System Analysis:

1- Cumulative Distribution Tables:

❖ **The time between customers' arrivals to the checkout area:**

Time Between Arrivals	Probability	Cumulative distribution	Random digit assignment
0 min	0.16	0.16	0 – 0.16
1 min	0.23	0.39	0.16 – 0.39
2 min	0.30	0.69	0.39 – 0.69
3 min	0.21	0.90	0.69 – 0.90
4 min	0.1	1.00	0.90 – 1.00

❖ **service-time distributions of express customers:**

Service Time for Express Customers	Probability	Cumulative distribution	Random digit assignment
1 min	0.30	0.30	0 – 0.30
2 min	0.40	0.70	0.30 – 0.70
3 min	0.30	1.00	0.70 – 1.00

❖ **service-time distributions of regular customers:**

Service Time for Regular Customers	Probability	Cumulative distribution	Random digit assignment
3 min	0.20	0.20	0 – 0.20
5 min	0.50	0.70	0.20 – 0.70
7 min	0.30	1.00	0.70 – 1.00

2- Simulation table for supermarket (for 10 customers):

Customer	Customer Type	Inter arrival time	Arrival time	Start service	Waiting time	Service time	Express compilation	Regular compilation	Time in system
1	Express	3	3	3	0	3	6	——	3
2	Regular	1	4	4	0	3	6	7	3
3	Express	2	6	6	0	2	8	7	2
4	Express	1	7	8	1	2	10	7	3
5	Express	2	9	10	1	2	12	7	3
6	Regular	3	12	12	0	7	12	19	7
7	Regular	3	15	19	4	5	12	24	9
8	Express	3	18	18	0	3	21	24	3
9	Express	2	20	21	1	2	23	24	3
10	Regular	4	24	24	0	7	23	31	7

Experimental Design Parameters:

1-Queue Length Threshold:

Determine the optimal threshold for allowing express customers to join the express cashier's queue based on the length of the regular cashier's.

2-Express Customer Proportion:

Adjust the percentage of express customers in the overall customer population.

3-Staffing Levels:

Explore variations in the number of express and regular cashiers on duty.

4-Customer Distribution Patterns:

Test different patterns for distributing express and regular customers throughout the day.

5-Feedback Mechanisms:

Implement and vary the mechanisms for collecting customer feedback.

6-Service Efficiency Metrics:

Define and measure service efficiency metrics for both express and regular cashier services.

7-Customer Wait Time:

Assess the impact of varying queue management strategies on customer wait times.

Justification of Experiment Parameters Values:

1-Queue Length Threshold:

Variation in the threshold allows us to assess the impact on the balance between express and regular queues. A higher threshold may favor express customers but could lead to longer wait times for regular customers.

2-Express Customer Proportion:

Adjusting the express customer proportion simulates different customer demographics, helping to understand how the system copes with varying demands and whether adjustments are needed in staffing or queue management strategies.

3-Staffing Levels:

Varying staffing levels helps assess the impact on overall efficiency and customer wait times. Different levels of staffing can address fluctuations in customer traffic and demand during peak and off-peak hours.

4-Customer Distribution Patterns:

Different distribution patterns help simulate real-world scenarios and evaluate the system's adaptability. This can uncover whether certain patterns lead to more balanced queues and improved overall performance.

5-Feedback Mechanisms:

Experimenting with different feedback mechanisms provides insights into customer satisfaction and preferences. This information is crucial for making informed decisions about system improvements.

6-Service Efficiency Metrics:

Measuring metrics such as transaction time and cashier utilization allows for a quantitative assessment of cashier performance. Identifying disparities in efficiency helps in addressing potential bottlenecks.

7-Customer Wait Time:

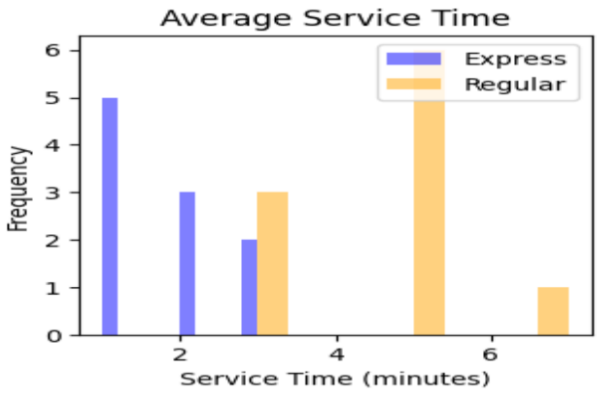
Measuring and comparing wait times under different conditions provides valuable insights into the effectiveness of the experimental parameters in achieving the goal of minimizing customer wait times while maintaining fairness between express and regular queues.

Results Analysis:

Results for 10 customers (Express 60%, Regular 40%):

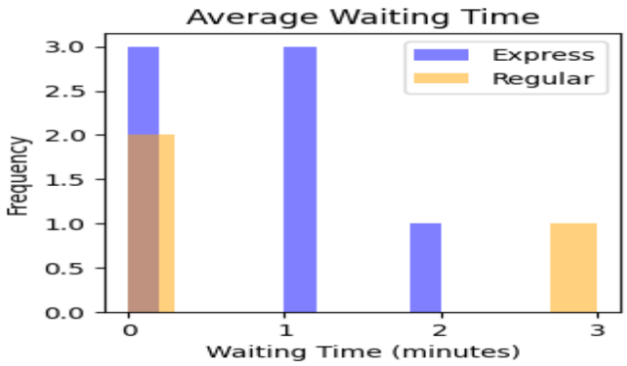
1-Average Service Time:

- ➔ Average service time of express customers: 1.7 minutes
- ➔ Average service time of regular customers: 4.6 minutes



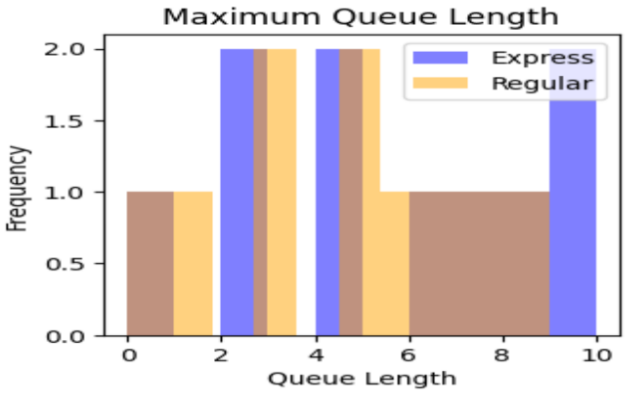
2-Average Waiting Time:

- ➔ Average waiting time in express cashier's queue: 0.71 minutes
- ➔ Average waiting time in regular cashier's queue: 1.0 minutes



3-Maximum Queue Length:

- ➔ Maximum express cashier's queue length: 10
- ➔ Maximum regular cashier's queue length: 9

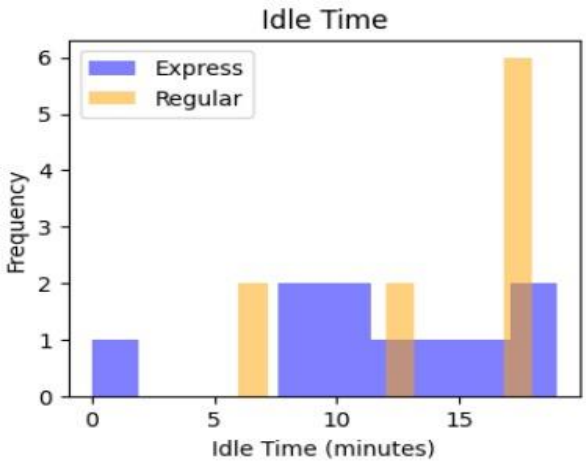


4-Probability of waiting in queues:

- ➔ Probability that a customer waits in express cashier queue: 0.7
- ➔ Probability that a customer waits in regular cashier queue: 0.3

5-The Idle time of cashiers:

- ➔ Portion of idle time of express cashier: 0.1
- ➔ Portion of idle time of regular cashier: 0.2



6-Does the theoretical average service time of the service time distribution match with the experimental one for both types of customers?

- ➢ No, there is a slight difference between them.

⇨In theoretical we get that:

average service time distribution of express customers = 2.3 min.

average service time distribution of Regular customers = 5.5 min

⇨In experimental we get that:

average service time distribution of express customers = 1.7 min.

average service time distribution of Regular customers = 4.6 min.

7-Does the theoretical average inter-arrival time of the inter-arrival time distribution match with the experimental one?

- ➢ No, there is a slight difference between them.

⇨In theoretical we get that:

average inter-arrival time distribution of express customers = 2.17 min.

average inter-arrival time distribution of Regular customers = 2.75 min.

⇨In experimental we get that:

average inter-arrival time distribution of express customers = 1.67 min.

average inter-arrival time distribution of Regular customers = 2 min.

8- How does using a different percentage of both types of customers (for example,40% express customers and 60% regular customers) affect the system?

- changing in percentage of both types of customers affect the system because the service time depends on the type of customer and waiting time is affected by service time.

When we use 40% express customers and 60% regular customers **instead of** 40% regular customers and 60% express customers;

we find that:

→The Average service time distribution for both customer is changed as follow:

average service time of express customers is changed from 2.3 to 2.25 min.

average service time of Regular customers is changed from 5.5 to 5.67 min.

→The Average waiting time distribution for both customer is changed as follow:

average waiting time in express cashier's queue is changed from 0.5 to 0 min.

average waiting time in regular cashier's queue is changed from 0.25 to 4.2 min.

Extra Statistics (Average Results for 30 Runs with different random seed):

- AvgServiceTimeExpress = 1.97 min.
- AvgServiceTimeRegular = 5.27 min.
- AvgWaitingTimeExpress = 0.67 min.
- AvgWaitingTimeRegular = 2.33 min.
- MaxQueueLengthExpress = 9.53
- MaxQueueLengthRegular = 9.47
- ProbWaitExpress = 0.61 min.
- ProbWaitRegular = 0.39 min.
- IdleTimeExpress = 0.17 min.
- IdleTimeRegular = 0.22 min.

Conclusion:

The simulation results provide valuable insights into the supermarket checkout system's performance, helping identify areas for improvement. Recommendations for system enhancements or adjustments to meet customer demand more efficiently will be discussed based on the findings.

- In this problem, there is a Positive relationship between percentage of both types of customers and waiting time in system.
- If the percentage of express customers is bigger than percentage of regular customers the average waiting time will be increased in express's queue and will be decreased in regular's queue.
- If the percentage of express customers is smaller than percentage of regular customers the average waiting time will be decreased in express's queue and will be increased in regular's queue.