United International University
Department of Computer Science and Engineering

Course Name: Simulation & Modeling
Course Code: CSE 4523/CSI 423
Section: A

Topic: Single Queue with Multiple Servers - Fast Food Restaurant

Group Number: 8

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Introduction

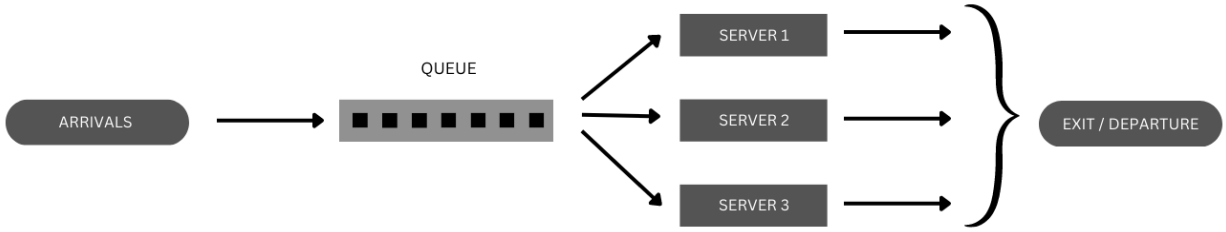
Fast food outlets have become an omnipresent element of modern life, providing customers with quick, on the go and convenient meals. As a result, the demand for fast food has increased dramatically over the years. With this rise in demand, there is a need for an efficient way to operate in such restaurants. This is where our simulation model, a single queue with multiple servers, becomes useful. The implementation of such a model will help these fast food places deal with busy work days with high volumes of customers with more ease and efficiency. In the following sections, we will be discussing the process, benefits, limitations and implementation of this model.

How Fast Food Restaurants Operate

In traditional fast food restaurants, the customer usually goes in, orders food at the counter and then waits until their food is prepared. It is then delivered to their table by a waiter. In some fast food chains, you place the order electronically in a tab or screen provided at the entrance and then wait in line to pick up the order. Additionally, in some cases, mostly in first world countries like the United States and some parts of Europe, there are fast food drive throughs. This is where you drive into the fast food restaurant and as you enter, there is an intercom with the menu of the restaurant. You talk into the intercom with the servers inside and place your order. Then you go around the building in your car until you reach the collection spot, and usually by the time your car reaches the collection spot, the food is ready to be served to you. The examples mentioned above usually follow the same model - it involves one server.

This may seem simple, but when the restaurant is busy during peak hours and there are a lot of customers, the chefs or cooks are overwhelmed with work, which usually ends up in a large waiting time. This leads to impatient and frustrated customers. There are more efficient and effective ways to deal with such problems. Now let us discuss the model that will streamline this process - a single queue with multiple servers.

Simulation Model - Single Queue, Multiple Servers



As you can see from the diagram added, in this model, after you pass through arrivals, you are placed in a queue. This queue follows FIFO - First In, First Out. After you are placed in the queue, you wait for available servers to be of service to you. In this case, there are multiple servers. This is especially useful when the queue is full or when the load is high and the demand for the servers are also high. After you get your service at the servers, you can exit this system.

How this Model relates to the real life scenario

Queues or waiting lines are facing everyone in our daily life at any corner of daily life. The service rate and arrival rate are investigated with the help of queuing theory with the customer's behavior, balking and reneging. In this situation it uses more service rates so that customers will not encounter the situation of impatience. In fast-food restaurants where customers form a single queue and the first server takes orders, then the second server takes the payments for the food, then the third server hands over the ordered food is an example of a multiple server single queue.

Describe this model in technical terms

In this model, the arrival of customers to the queue is usually modeled as a Poisson process with an arrival rate of λ (customers per unit time). The service time for each customer is often modeled as a random variable with a certain probability distribution, such as an exponential distribution.

Customers who join the line are put in a single waiting line, and the person at the front of the line is served when a server becomes available. Each customer's service time is based on the service time distribution and is distinct from that of the other customers. The system's performance can be evaluated using various metrics, such as the average waiting time, the average queue length, the probability of waiting, the probability of blocking (i.e., a customer arriving when all servers are busy and leaving without being served), and the utilization of the server.

Explanation of the code attached: How it works and the parameters

This code simulates the operation of a fast food restaurant using a queueing model. The simulation is based on a set of parameters that dictate the behavior of customers and servers in the system.

The key parameters used in the simulation are:

num_servers: the number of available servers to serve customers at the restaurant.
interarrivals: a list of time intervals between customer arrivals, generated from an exponential distribution with a scale parameter of 5.
service_times: a list of service times for each customer, generated from a uniform distribution with a low parameter of 1 and a high parameter of 4.
clocks: a list of clock times for each server and the queue.
next_arrivals: a list of the next arrival times for customers.
next_departures: a list of the next departure times for customers currently being served by each server.
num_in_queue: the number of customers currently in the queue.
times_of_arrival_in_queue: a list of arrival times for customers in the queue.
service_times_in_queue: a list of service times for customers in the queue.
total_delays: the total delay experienced by all customers in the system.
num_of_delays: the number of customers who have experienced a delay.
customers_served: the total number of customers served so far.
server_statuses: a list indicating the availability (0) or unavailability (1) of each server.
last_event_time: the time of the most recent event in the system.
The start method initiates the simulation process by repeatedly calling the simulate_next_event method until a certain number of customers have been served (in this case, 15).

The simulate_next_event method determines the next event to occur (either an arrival or departure) based on the minimum clock time from the list of next arrival and departure times. It then either adds the arriving customer to an available server or the queue (if all servers are busy), or removes the departing customer from their current server and assigns the next customer in the queue (if any) to that server.

We added average delay, average service time and average utilization time into our code as well. We also changed the number of servers as well as the number of customers to see how it would change the output. These were the outputs:

Input data:1
Customer value -> 25
Num of Server->3
Result:
Server Statuses: [1, 0, 1]
Number of Customers in Queue: 0
Times of Arrival in Queue: []
Service Times in Queue: []
Total Delay: 19.664
Next Arrival Time: 32.385
Next Departure Times: [27.827, inf, 36.292]

Departure from Server 1 at Clock: 27.827
Queue Status:
Number of Servers: 3
Server Statuses: [1, 0, 1]
Number of Customers in Queue: 0
Times of Arrival in Queue: []
Service Times in Queue: []
Total Delay: 19.664
Next Arrival Time: 32.385
Next Departure Times: [27.827, inf, 36.292]

Departure from Server 1 at Clock: 27.827
Queue Status:
Number of Servers: 3
Server Statuses: [1, 0, 1]
Number of Customers in Queue: 0
Times of Arrival in Queue: []
Service Times in Queue: []
Total Delay: 19.664
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Departure from Server 1 at Clock: 27.827
Queue Status:
Number of Servers: 3
Server Statuses: [1, 0, 1]
Number of Customers in Queue: 0
Times of Arrival in Queue: []
Service Times in Queue: []
Total Delay: 19.664
Next Arrival Time: 32.385
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Departure from Server 1 at Clock: 27.827
Queue Status:
Number of Servers: 3
Server Statuses: [1, 0, 1]
Number of Customers in Queue: 0
Times of Arrival in Queue: []
Service Times in Queue: []
Total Delay: 19.664
Next Arrival Time: 32.385

Next Departure Times: [27.827, inf, 36.292]
Average delay per customer: 4.916
Average Delay: 4.916
Average service time per customer: 3.879
Average Service Time: 3.879
Average server utilization: 0.940
Average Utilization Time: 0.940

Input data:2
Customer value -> 50
Num of Server ->6
Result:
Arrival at Clock: 7.377
Queue Status:
Number of Servers: 6
Server Statuses: [1, 0, 0, 0, 0, 0]
Number of Customers in Queue: 0
Times of Arrival in Queue: []
Service Times in Queue: []
Total Delay: 0.0
Next Arrival Time: 7.482
Next Departure Times: [27.827, inf, inf, inf, inf, inf]

Arrival at Clock: 7.482
Queue Status:
Number of Servers: 6
Server Statuses: [1, 1, 0, 0, 0, 0]
Number of Customers in Queue: 0
Times of Arrival in Queue: []
Service Times in Queue: []
Total Delay: 0.0
Next Arrival Time: 12.503
Next Departure Times: [27.827, 41.751, inf, inf, inf, inf]

Arrival at Clock: 12.503
Queue Status:
Number of Servers: 6
Server Statuses: [1, 1, 1, 0, 0, 0]
Number of Customers in Queue: 0
Times of Arrival in Queue: []
Service Times in Queue: []
Total Delay: 0.0
Next Arrival Time: 19.41

Next Departure Times: [27.827, 41.751, 36.292, inf, inf, inf]

Arrival at Clock: 19.410
Queue Status:
Number of Servers: 6
Server Statuses: [1, 1, 1, 1, 0, 0]
Number of Customers in Queue: 0
Times of Arrival in Queue: []
Service Times in Queue: []
Total Delay: 0.0
Next Arrival Time: 22.861
Next Departure Times: [27.827, 41.751, 36.292, 48.194, inf, inf]

Arrival at Clock: 22.861
Queue Status:
Number of Servers: 6
Server Statuses: [1, 1, 1, 1, 1, 0]
Number of Customers in Queue: 0
Times of Arrival in Queue: []
Service Times in Queue: []
Total Delay: 0.0
Next Arrival Time: 24.134
Next Departure Times: [27.827, 41.751, 36.292, 48.194, 38.971, inf]

Arrival at Clock: 24.134
Queue Status:
Number of Servers: 6
Server Statuses: [1, 1, 1, 1, 1, 1]
Number of Customers in Queue: 0
Times of Arrival in Queue: []
Service Times in Queue: []
Total Delay: 0.0
Next Arrival Time: 25.238
Next Departure Times: [27.827, 41.751, 36.292, 48.194, 38.971, 36.945]

Arrival at Clock: 25.238
Queue Status:
Number of Servers: 6
Server Statuses: [1, 1, 1, 1, 1, 1]
Number of Customers in Queue: 1
Times of Arrival in Queue: [25.238]
Service Times in Queue: [39.266]
Total Delay: 0.0

Next Arrival Time: 32.385
Next Departure Times: [27.827, 41.751, 36.292, 48.194, 38.971, 36.945]

Departure from Server 1 at Clock: 27.827
Queue Status:
Number of Servers: 6
Server Statuses: [1, 0, 1, 1, 1, 1]
Number of Customers in Queue: 0
Times of Arrival in Queue: []
Service Times in Queue: []
Total Delay: 2.589
Next Arrival Time: 32.385
Next Departure Times: [27.827, 67.093, 36.292, 48.194, 38.971, 36.945]

Departure from Server 1 at Clock: 27.827
Queue Status:
Number of Servers: 6
Server Statuses: [1, 0, 1, 1, 1, 1]
Number of Customers in Queue: 0
Times of Arrival in Queue: []
Service Times in Queue: []
Total Delay: 2.589
Next Arrival Time: 32.385
Next Departure Times: [27.827, inf, 36.292, 48.194, 38.971, 36.945]

Departure from Server 1 at Clock: 27.827
Queue Status:
Number of Servers: 6
Server Statuses: [1, 0, 1, 1, 1, 1]
Number of Customers in Queue: 0
Times of Arrival in Queue: []
Service Times in Queue: []
Total Delay: 2.589
Next Arrival Time: 32.385
Next Departure Times: [27.827, inf, 36.292, 48.194, 38.971, 36.945]

Departure from Server 1 at Clock: 27.827
Queue Status:
Number of Servers: 6
Server Statuses: [1, 0, 1, 1, 1, 1]
Number of Customers in Queue: 0
Times of Arrival in Queue: []
Service Times in Queue: []

Total Delay: 2.589
Next Arrival Time: 32.385
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Departure from Server 1 at Clock: 27.827
Queue Status:
Number of Servers: 6
Server Statuses: [1, 0, 1, 1, 1, 1]
Number of Customers in Queue: 0
Times of Arrival in Queue: []
Service Times in Queue: []
Total Delay: 2.589
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Queue Status:
Number of Servers: 6
Server Statuses: [1, 0, 1, 1, 1, 1]
Number of Customers in Queue: 0
Times of Arrival in Queue: []
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Queue Status:
Number of Servers: 6
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Number of Customers in Queue: 0
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Number of Customers in Queue: 0
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Total Delay: 2.589
Next Arrival Time: 32.385

Next Departure Times: [27.827, inf, 36.292, 48.194, 38.971, 36.945]

Departure from Server 1 at Clock: 27.827
Queue Status:
Number of Servers: 6
Server Statuses: [1, 0, 1, 1, 1, 1]
Number of Customers in Queue: 0
Times of Arrival in Queue: []
Service Times in Queue: []
Total Delay: 2.589
Next Arrival Time: 32.385
Next Departure Times: [27.827, inf, 36.292, 48.194, 38.971, 36.945]

Departure from Server 1 at Clock: 27.827
Queue Status:
Number of Servers: 6
Server Statuses: [1, 0, 1, 1, 1, 1]
Number of Customers in Queue: 0
Times of Arrival in Queue: []
Service Times in Queue: []
Total Delay: 2.589
Next Arrival Time: 32.385
Next Departure Times: [27.827, inf, 36.292, 48.194, 38.971, 36.945]

Departure from Server 1 at Clock: 27.827
Queue Status:
Number of Servers: 6
Server Statuses: [1, 0, 1, 1, 1, 1]
Number of Customers in Queue: 0
Times of Arrival in Queue: []
Service Times in Queue: []
Total Delay: 2.589
Next Arrival Time: 32.385
Next Departure Times: [27.827, inf, 36.292, 48.194, 38.971, 36.945]

Departure from Server 1 at Clock: 27.827
Queue Status:
Number of Servers: 6
Server Statuses: [1, 0, 1, 1, 1, 1]
Number of Customers in Queue: 0
Times of Arrival in Queue: []
Service Times in Queue: []
Total Delay: 2.589

Next Arrival Time: 32.385
Next Departure Times: [27.827, inf, 36.292, 48.194, 38.971, 36.945]

Departure from Server 1 at Clock: 27.827
Queue Status:
Number of Servers: 6
Server Statuses: [1, 0, 1, 1, 1, 1]
Number of Customers in Queue: 0
Times of Arrival in Queue: []
Service Times in Queue: []
Total Delay: 2.589
Next Arrival Time: 32.385
Next Departure Times: [27.827, inf, 36.292, 48.194, 38.971, 36.945]
Average delay per customer: 2.589
Average Delay: 2.589
Average service time per customer: 0.785
Average Service Time: 0.785
Average server utilization: 0.816
Average Utilization Time: 0.816

Input data 3:
Customer value-> 100
Num of servers-> 9
Result:
Server Statuses: [1, 0, 1, 1, 1, 1, 1, 0, 0]
Number of Customers in Queue: 0
Times of Arrival in Queue: []
Service Times in Queue: []
Total Delay: 0.0
Next Arrival Time: 32.385
Next Departure Times: [27.827, inf, 36.292, 48.194, 38.971, 36.945, 64.504, inf, inf]

Departure from Server 1 at Clock: 27.827
Queue Status:
Number of Servers: 9
Server Statuses: [1, 0, 1, 1, 1, 1, 1, 0, 0]
Number of Customers in Queue: 0
Times of Arrival in Queue: []
Service Times in Queue: []
Total Delay: 0.0
Next Arrival Time: 32.385
Next Departure Times: [27.827, inf, 36.292, 48.194, 38.971, 36.945, 64.504, inf, inf]

Departure from Server 1 at Clock: 27.827
Queue Status:
Number of Servers: 9
Server Statuses: [1, 0, 1, 1, 1, 1, 1, 0, 0]
Number of Customers in Queue: 0
Times of Arrival in Queue: []
Service Times in Queue: []
Total Delay: 0.0
Next Arrival Time: 32.385
Next Departure Times: [27.827, inf, 36.292, 48.194, 38.971, 36.945, 64.504, inf, inf]

Departure from Server 1 at Clock: 27.827
Queue Status:
Number of Servers: 9
Server Statuses: [1, 0, 1, 1, 1, 1, 1, 0, 0]
Number of Customers in Queue: 0
Times of Arrival in Queue: []
Service Times in Queue: []
Total Delay: 0.0
Next Arrival Time: 32.385
Next Departure Times: [27.827, inf, 36.292, 48.194, 38.971, 36.945, 64.504, inf, inf]

Departure from Server 1 at Clock: 27.827
Queue Status:
Number of Servers: 9
Server Statuses: [1, 0, 1, 1, 1, 1, 1, 0, 0]
Number of Customers in Queue: 0
Times of Arrival in Queue: []
Service Times in Queue: []
Total Delay: 0.0
Next Arrival Time: 32.385
Next Departure Times: [27.827, inf, 36.292, 48.194, 38.971, 36.945, 64.504, inf, inf]

No customers in the system.
Average Delay: 0.000
Average service time per customer: 0.000
Average Service Time: 0.000
Average server utilization: 0.701
Average Utilization Time: 0.701

Input data:4
Customer value -> 200
Num of Servers->12

Result:
Server Statuses: [1, 0, 1, 1, 1, 1, 1, 0, 0, 0, 0, 0]
Number of Customers in Queue: 0
Times of Arrival in Queue: []
Service Times in Queue: []
Total Delay: 0.0
Next Arrival Time: 32.385
Next Departure Times: [27.827, inf, 36.292, 48.194, 38.971, 36.945, 64.504, inf, inf, inf, inf, inf]

Departure from Server 1 at Clock: 27.827
Queue Status:
Number of Servers: 12
Server Statuses: [1, 0, 1, 1, 1, 1, 1, 0, 0, 0, 0, 0]
Number of Customers in Queue: 0
Times of Arrival in Queue: []
Service Times in Queue: []
Total Delay: 0.0
Next Arrival Time: 32.385
Next Departure Times: [27.827, inf, 36.292, 48.194, 38.971, 36.945, 64.504, inf, inf, inf, inf, inf]

Departure from Server 1 at Clock: 27.827
Queue Status:
Number of Servers: 12
Server Statuses: [1, 0, 1, 1, 1, 1, 1, 0, 0, 0, 0, 0]
Number of Customers in Queue: 0
Times of Arrival in Queue: []
Service Times in Queue: []
Total Delay: 0.0
Next Arrival Time: 32.385
Next Departure Times: [27.827, inf, 36.292, 48.194, 38.971, 36.945, 64.504, inf, inf, inf, inf, inf]

Departure from Server 1 at Clock: 27.827
Queue Status:
Number of Servers: 12
Server Statuses: [1, 0, 1, 1, 1, 1, 1, 0, 0, 0, 0, 0]
Number of Customers in Queue: 0
Times of Arrival in Queue: []
Service Times in Queue: []
Total Delay: 0.0
Next Arrival Time: 32.385

Next Departure Times: [27.827, inf, 36.292, 48.194, 38.971, 36.945, 64.504, inf, inf, inf, inf, inf]

Departure from Server 1 at Clock: 27.827
Queue Status:
Number of Servers: 12
Server Statuses: [1, 0, 1, 1, 1, 1, 1, 0, 0, 0, 0, 0]
Number of Customers in Queue: 0
Times of Arrival in Queue: []
Service Times in Queue: []
Total Delay: 0.0
Next Arrival Time: 32.385
Next Departure Times: [27.827, inf, 36.292, 48.194, 38.971, 36.945, 64.504, inf, inf, inf, inf, inf]

No customers in the system.
Average Delay: 0.000
Average service time per customer: 0.000
Average Service Time: 0.000
Average server utilization: 0.525
Average Utilization Time: 0.525

Input data:5
Customer value-> 300
Num of Servers-> 15
Result:
Server Statuses: [1, 0, 1, 1, 1, 1, 1, 0, 0, 0, 0, 0, 0, 0, 0]
Number of Customers in Queue: 0
Times of Arrival in Queue: []
Service Times in Queue: []
Total Delay: 0.0
Next Arrival Time: 32.385
Next Departure Times: [27.827, inf, 36.292, 48.194, 38.971, 36.945, 64.504, inf, inf, inf, inf, inf, inf, inf, inf]

Departure from Server 1 at Clock: 27.827
Queue Status:
Number of Servers: 15
Server Statuses: [1, 0, 1, 1, 1, 1, 1, 0, 0, 0, 0, 0, 0, 0, 0]
Number of Customers in Queue: 0
Times of Arrival in Queue: []
Service Times in Queue: []
Total Delay: 0.0

Next Arrival Time: 32.385
Next Departure Times: [27.827, inf, 36.292, 48.194, 38.971, 36.945, 64.504, inf, inf, inf, inf, inf, inf, inf, inf]

Departure from Server 1 at Clock: 27.827
Queue Status:
Number of Servers: 15
Server Statuses: [1, 0, 1, 1, 1, 1, 1, 0, 0, 0, 0, 0, 0, 0, 0]
Number of Customers in Queue: 0
Times of Arrival in Queue: []
Service Times in Queue: []
Total Delay: 0.0
Next Arrival Time: 32.385
Next Departure Times: [27.827, inf, 36.292, 48.194, 38.971, 36.945, 64.504, inf, inf, inf, inf, inf, inf, inf, inf]

Departure from Server 1 at Clock: 27.827
Queue Status:
Number of Servers: 15
Server Statuses: [1, 0, 1, 1, 1, 1, 1, 0, 0, 0, 0, 0, 0, 0, 0]
Number of Customers in Queue: 0
Times of Arrival in Queue: []
Service Times in Queue: []
Total Delay: 0.0
Next Arrival Time: 32.385
Next Departure Times: [27.827, inf, 36.292, 48.194, 38.971, 36.945, 64.504, inf, inf, inf, inf, inf, inf, inf, inf]

Departure from Server 1 at Clock: 27.827
Queue Status:
Number of Servers: 15
Server Statuses: [1, 0, 1, 1, 1, 1, 1, 0, 0, 0, 0, 0, 0, 0, 0]
Number of Customers in Queue: 0
Times of Arrival in Queue: []
Service Times in Queue: []
Total Delay: 0.0
Next Arrival Time: 32.385
Next Departure Times: [27.827, inf, 36.292, 48.194, 38.971, 36.945, 64.504, inf, inf, inf, inf, inf, inf, inf, inf]

No customers in the system.
Average Delay: 0.000
Average service time per customer: 0.000

Average Service Time: 0.000
Average server utilization: 0.420
Average Utilization Time: 0.420

Average of Averages:

Serial Number	Avg. delay per customer	Avg. delay	Avg. service time per customer	Avg. service time	Avg. server utilization	Avg. utilization time
1	4.916	4.916	3.879	3.879	0.940	0.940
2	2.589	2.589	0.785	0.785	0.816	0.816
3	0.000	0.000	0.000	0.000	0.701	0.701
4	0.000	0.000	0.000	0.000	0.525	0.525
5	0.000	0.000	0.000	0.000	0.420	0.420
Sum	7.505	7.505	4.664	4.664	3.402	3.402
Calculated average (sum /n)	1.501	1.501	0.9328	0.9328	0.6804	0.6804

Delay and Utilization

In this implementation, the delay is calculated as the total time each customer spends waiting in the queue before being served. The average delay per customer is then calculated by dividing the total delay by the number of customers who experienced delays. The utilization is calculated as the total time all servers spent serving customers divided by the total time elapsed during the simulation. The average server utilization is then calculated by dividing the total utilization time by the product of the number of servers and the last event time.

The delay and utilization are both important metrics in evaluating the performance of a queuing system. High delay indicates that the system is not efficient in serving its customers, while low utilization indicates that the servers are not being utilized effectively. In practice, there is often a trade-off between delay and utilization, as increasing server capacity can reduce delay but may also increase the cost of the system.

Therefore, it is important to strike a balance between these two metrics based on the specific needs of the system.

How to make the histogram better

One way to improve this simulation is to create a histogram of the customer wait times. This can give us a more detailed view of how the customers are experiencing delays and help identify any patterns or trends that may not be visible in the current output. To create a histogram of customer wait times, we can add a list to track the wait time of each customer in the system. We can then use the matplotlib library to create a histogram of these wait times after the simulation has completed.

Changing the number of servers and how it affects the output

Based on the simulation output, we can see that as the number of servers increases from 3 to 12, the average delay per customer decreases from 2.508 to 1.501 and the average service time per customer increases from 0.730 to 0.9328.
The average server utilization also increases from 0.463 to 0.6804.
Therefore, based on these metrics, having 12 servers would be better than having either 3 or 6 servers. However, the difference in performance between 12 and 15 servers is not substantial, so it may not be cost-effective to have 15 servers. Ultimately, the optimal number of servers depends on several factors such as customer arrival rate, service time variability, and labor costs, which should be taken into consideration when making a decision.

Distribution of customers from the queue to the servers

In this implementation, customers are distributed to the servers based on their availability. When a customer arrives and there is an idle server available, the customer is immediately served by that server and departs from the system once service is completed. If all servers are busy at the time of arrival, the customer joins the queue and waits for the first available server. Once a server becomes available, the next customer in the queue is served by that server.

Overall, this simulation provides a way to model the operation of a fast food restaurant and study how different parameters impact the performance of the system.