QUEUING MODEL ANALYSIS FOR A SUPERMARKET USING MONTE CARLO SIMULATION

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ABSTRACT:

Queuing theory is a mathematical approach used to analyze waiting lines or queues and to optimize their performances. It has numerous applications in different fields, such as telecommunications, transportation, healthcare and retail sectors. In this paper, we analyse the data of a supermarket. This research paper focuses on employing Monte Carlo Simulation to evaluate the queuing dynamics and determine the optimal number of servers required to achieve maximum efficiency within the surveyed supermarket. The results serve as a valuable resource for supermarket operators to make data-driven decisions to minimize customer waiting times, optimize staff utilization and improve overall service efficiency. The proposed queuing model and analytical framework can be extended and applied to other retail environments, thus contributing to the advancement of retail queuing theory.

Key Words: Queuing theory, Supermarket model, Service efficiency and Retail queuing theory.

I Introduction:

In this study, we consider the application of matrix theory in the context of a supermarket model. A supermarket is a prime example of a system in which customers queue up to purchase goods and services. Efficient management of supermarket queues is critical to customer's satisfaction and profitability. Therefore, the aim of this study is to determine the number of servers required for optimizing and enhancing the overall shopping experience of the customers while maximizing the use of supermarket resources, which can be used to improve supermarket performance to develop a model. This study provides valuable insight into the benefits of applying matrix theory to the supermarket industry and may lead to the development of new strategies to improve the customer experience in supermarkets. There are several queuing models, each with their own characteristics and assumptions. This section describes three common queuing models. Single-server, multi-server, and network queue models.

a) Single server queuing model: This model assumes that he has only one server available for customer support. Customers arrive at random times and are served on a first-come, first-served basis (FCFS). We also assume that service times are randomly and exponentially distributed. Single-server queuing. This system model can be used in such a system like a store cash register and a single doctor in a clinic.

b) Multi-server queuing model: In this model, multiple servers are available for customer support. Customers arrive randomly and are assigned to an available server. Service times are too exponentially disseminated. Examples of queuing systems with multiple servers are banks with multiple cashiers and restaurants with multiple waiters.

c) Network queuing model: This model is used to analyze complex queuing systems with multiple servers, multiple queues, and multiple customer classes. In this model, customers can arrive at different service points and move between service points within service hours. Examples of networked queuing systems include hospital emergency rooms and airports with multiple check-in counters and gates.

In addition to these three models, there are many variations and extensions of queuing models such as priority queuing, finite queuing systems, and bulk queuing systems. Each model has its own set of assumptions and limitations, and model choice depends on the specific application and system being analyzed. The ultimate goal of queue theory is to optimize system performance by minimizing customer waiting times and maximizing resource utilization.

II Literature Review:

This section comprises of the literature involved in enhancement of performance of the queuing models employed in supermarkets. In this sequence, **Rema, V., et al., (2017)** drag our attention on customer loyalty intentions at a well-established brick-and-mortar supermarket. A structured questionnaire was administered to 100 shoppers at a selected Supermarket in Bengaluru city. In this study the authors considered variety of product categories, quality, and availability of products as key factors driving customers of different age groups purchase behaviors. To analyze the operating characteristics of queues, efficiency, and server utilization a chi-square test, correlation and Monte Carlo Simulation technique was used. This study is very useful in evaluating service efficiency at the checkout points. **Pallikkara, V., et al., (2021)** showed that impulse buying at the store checkout area was minimal and sporadic for most of the product categories at the checkout. Impulse buying at the checkout was instigated by factors such as store environment, credit card availability, momentary mood, in-store promotion, offers and discounts and large merchandise. The study had important implications for retail stores by emphasizing on the choice of merchandise offered for sale at the checkout area. Pinto, P., & Hawaldar, I. T. (2022) investigated customer idle time and its implication on emotional discomfort resulting from crowding stress. Accordingly, 385 respondents (shoppers) visiting the leading organized retailers located in major localities in Bengaluru were approached. The responses were analyzed using a Chi-squared test and Pearson correlation. The outcome revealed that irrespective of age and gender, customers visiting the offline retail outlets experienced emotional discomfort due to the idleness during the checkout.

Safuri, A. A. M., & Kamardan, M. G. (2022) focused on a queuing simulation of a supermarket using Arena Simulation Software. Throughout this study, three factors were examined: Average Waiting Time of Customer (Wq), Average Number of Waiting Customers (Lq), and Instantaneous Utilization. They also tried to simulate the outcome if the supermarket adds another server. Murad, S. S., et al. (2022) aimed to provide a comprehensive background on social distancing with effective technologies to facilitate the social distancing practice. In addition, detailed taxonomy was proposed to summarize the essential elements like implementation type, scenarios, and technology being used to fight with COVID-19 pandemic systematically. De Melo, G. A., et al. (2022) aimed to optimize the cashier service macro process in a supermarket located in the Alto Paranaiba by using tools such as brainstorming, process mapping, Ishikawa diagram and PDCA cycle. In this study they focused on customer satisfaction and productivity through systematic control and continuous improvement of the cashiers' service macroprocess. Liu, Q., & Chen, H. (2022) worked on supermarket cashier system to enhance the service intensity and to minimize the cashier time taken the arrival time as Poisson distribution, and the service time as exponential distribution. Mushi, A. R., & Kagoya, S. M. (2022) explained that OR aims at deriving optimal or better solutions to maximize various attributes such as sales or profits and/or to minimize attributes such as costs, losses, or risks. This paper intended to review OR supermarkets applications around the world, collected data on specific features of the East African market. To optimize the management of the queue length, the average service time, and the time interval to the cashier in the process of supermarket queuing settlement based on M/M/C model was discussed by Hua, S., et al. (2022). Sasi, M. A., et al. (2023) investigated efficient queue management in FPS using M/M/C queueing model. The major goal of this research was to minimize customer waiting time in the FPS with a minimal number of servers. It demonstrated the application of simulation modeling as a method for optimizing the number of servers in a specific FPS in Kerala, India.

III Model Description:

Today's consumers are highly demanding due to the diversification of products and shopping options. Efficient management of supermarket queues is critical to providing a satisfying customer experience. By accurately analyzing queue behaviour, supermarkets can optimize processes and minimize customer waiting time. In this study we focus on evaluating queue dynamics using Monte Carlo Simulation to determine the optimal number of servers required to achieve maximum efficiency in the supermarket for which we have taken data from a well established super mart of Subhashnagar in Dehradun (India) during a specified time period from 04:00 p.m. to 6:00 p.m. The sampling design used was Simple Random Sampling. The store had two servers and two parallel queues. A multi-channel, multi-queuing system was analysed through Monte Carlo simulation technique. In the present study, the queuing system is described by arrival of customers at two checkout/billing counters in the supermarket, waiting in the queues, being served at one of the two counters and then leaving the Supermarket.

One of the key drivers of customer satisfaction may be associated with waiting time at the checkout counters. Delays at the billing or checkout points are of common occurrence in supermarkets which could prevent the customer from coming back to the store. With an objective to model the checkout process, data on customer arrival rate, service time, and other relevant parameters is collected to construct an accurate representation of supermarket's queuing system. Detailed analysis was carried out using MS EXCEL and ORIGIN and key findings are presented as graphs. Observation data was collected at the store. Arrival time, service time, number of customers in the queue, and departure time were observed and recorded for the two queues created on two servers in the checkout counter. Data was collected for 21 customers in each of the two queues. A supermarket queue system is modeled using Monte Carlo Simulation. The simulation recreates the customer arrival process and subsequent interactions with available servers. The RANDBETWEEN function in MS Excel was used to generate random numbers simulating up to 50 trials.

IV Result Analysis

a) Analysis for Queue 1:

For the first channel (server), Tables 1-4 show the computation of the arrival time, service time, and waiting time probability distributions, as well as a detailed Monte Carlo Simulation using random number generation. A random number generator was used to simulate trials based on probability distributions of inter-arrival times, service times, and waiting times. Key operating characteristics, i.e. arrival rate, service rate, and average waiting time of customers in queue and in the system (i.e. time spent in queue and at service) are calculated for the first queue. Based on the results, an average measure of operating characteristics was calculated.

Table 1:- Customer Inter-arrival time probability distribution for queue one (at the first server).

Inter Arrival time (in minutes)	Frequency	Cumulative frequency	Probability	Cumulative probability	Random number Interval
0	3	3	0.14	0.14	00-13
1	2	5	0.09	0.23	14-22
2	3	8	0.14	0.37	23-36
3	1	9	0.05	0.42	37-41
4	4	13	0.20	0.62	42-61
6	3	16	0.14	0.76	62-75
7	1	17	0.05	0.81	76-80
8	1	18	0.05	0.86	81-85
10	1	19	0.05	0.91	86-90
11	2	21	0.09	1.00	91-99
Total	**21**		**1.00**		

Table 2:- Service time distribution for server one

Service time (in minutes)	Frequency	Cumulative frequency	Probability	Cumulative Frequency	Random Number Interval
2	4	4	0.20	0.20	00-19
3	5	9	0.23	0.43	20-42
4	3	12	0.14	0.57	43-56
5	3	15	0.14	0.71	57-70
6	2	17	0.10	0.81	71-80
7	2	19	0.10	0.91	81-90
8	1	20	0.04	0.95	91-94
9	1	21	0.04	0.99	95-98
Total	**21**		**0.99 ≈ 1.00**		

Table 3:- Customer waiting time distribution for server one.

Waiting time (in minute)	Frequency	Cumulative frequency	Probability	Cumulative probability	Random number Interval
0	8	8	0.38	0.38	00-37
1	5	13	0.24	0.62	38-61
2	2	15	0.09	0.71	62-70
3	2	17	0.09	0.80	71-79
4	1	18	0.05	0.85	80-84
5	1	19	0.05	0.90	85-89
7	1	20	0.05	0.95	90-94
11	1	21	0.05	1.00	95-99
Total	**21**		**1.00**		

Table 4:- Detailed simulation of the queuing process for server one.

Trial	Random Number		Inter Arrival time	Service time distribution	Arrival time	Service time		Idle time	Customer waiting time
	Arrival time	Service time				start	end		
1	-	-	0	2	04:00	04:00	04:02	0	0
2	-	-	2	4	04:02	04:02	04:06	0	0
3	-	-	6	5	04:08	04:08	04:13	2	0
4	-	-	7	3	04:15	04:15	04:18	2	0
5	-	-	0	6	04:15	04:18	04:24	0	3
6	-	-	8	2	04:23	04:24	04:26	0	1
7	-	-	4	4	04:27	04:27	04:31	1	0

8	-	-	2	3	04:29	04:31	04:34	0	2
9	-	-	6	5	04:35	04:35	04:40	1	0
10	-	-	1	3	04:36	04:40	04:43	0	4
11	-	-	4	4	04:40	04:43	04:47	0	3
12	-	-	10	7	04:50	04:50	04:57	3	0
13	-	-	6	2	04:56	04:57	04:59	0	1
14	-	-	1	3	04:57	04:59	05:02	0	2
15	-	-	4	6	05:01	05:02	05:08	0	1
16	-	-	0	5	05:01	05:08	05:13	0	7
17	-	-	11	3	05:12	05:13	05:16	0	1
18	-	-	3	2	05:15	05:16	05:18	0	1
19	-	-	11	9	05:26	05:26	05:35	8	0
20	-	-	4	8	05:30	05:35	05:43	0	5
21	-	-	2	7	05:32	05:43	05:50	0	11
22	93	35	11	3	05:43	05:50	05:53	0	7
23	27	24	2	3	05:45	05:53	05:55	0	8
24	95	29	11	3	05:56	05:56	05:59	1	0
25	23	11	2	2	05:58	05:59	06:01	0	1
26	51	77	4	6	06:02	06:02	06:08	1	0
27	67	43	6	4	06:08	06:08	06:12	0	0
28	32	86	2	7	06:10	06:12	06:19	0	2
29	64	49	6	4	06:16	06:19	06:23	0	3
30	49	80	4	6	06:20	06:23	06:29	0	3
31	83	30	8	3	06:28	06:29	06:32	0	1
32	22	84	1	7	06:29	06:32	06:39	0	3
33	11	88	2	7	06:31	06:39	06:46	0	8
34	08	50	2	4	06:33	06:46	06:50	0	13
35	43	12	4	2	06:37	06:50	06:52	0	13
36	59	7	4	2	06:41	06:52	06:54	0	11
37	64	20	6	3	06:47	06:54	06:57	0	7
38	35	13	2	2	06:49	06:57	06:59	0	8
39	66	26	6	3	06:55	06:59	07:02	0	4
40	11	22	0	3	06:55	07:02	07:05	0	7
41	42	67	4	5	06:59	07:05	07:10	0	6
42	52	34	4	3	07:03	07:10	07:13	0	7
43	88	20	10	3	07:13	07:13	07:16	0	0
44	41	16	3	2	07:16	07:16	07:18	0	0
45	14	58	1	5	07:17	07:18	07:23	0	1
46	94	08	11	2	07:28	07:28	07:30	5	0
47	61	45	4	4	07:32	07:32	07:36	2	0
48	16	77	1	6	07:33	07:36	07:43	0	3
49	65	47	6	4	07:39	07:43	07:47	0	4
50	49	54	4	4	07:43	07:47	07:51	0	4

Computation of Operating Characteristics of Queue One:

- Mean Inter-arrival time = $\frac{\text{Total inter arrival time}}{\text{Total number of arrivals}} = \frac{223}{50}$ = 4.46 minutes per customer
- Arrival rate, $\lambda_1 = \frac{1}{\textit{Mean inter arrival time}} = \frac{1}{4.46}$ = 0.22 customers per minute
- Mean Service time = $\frac{\textit{Total service time}}{\textit{Number of customers served}}$

  $= \frac{205}{50} = 4.1\, \textit{minutes per customer}$
- Service rate, $\mu 1 = \frac{1}{\textit{Mean service time}} = \frac{1}{4.1} = 0.24\, \textit{customers per minute}$
- Mean waiting time of customers in queue = $\frac{\textit{Sum of customers waiting time}}{\textit{Total arrivals}} = \frac{202}{50}$

  $= 4.04\, \textit{minutes per customer}$
- Mean time a customer spends in the system (checkout counter)
  = Average serving time + Average waiting time in the queue
  = 4.10 + 4.04 = **8.14 minutes**
- Service facility utilization at server one = $\frac{\lambda}{\mu} = \frac{0.22}{0.24} = 0.9167$

b) Analysis for Queue 2:

Now for the second channel (server), similar computations are shown from tables 5 to 8. Key operating characteristics, i.e. arrival rate, service rate, and average waiting time of customers in queue and in the system (i.e. time spent in queue and at service) are calculated for the first queue. Based on the results, an average measure of operating characteristics was calculated.

Table 5:- Customer Inter-arrival time probability distribution for queue two (at the second server).

Inter Arrival time (in minutes)	Frequency	Cumulative frequency	Probability	Cumulative probability	Random number Interval
0	1	1	0.05	0.05	00-05
1	3	4	0.14	0.19	05-18
2	2	6	0.09	0.28	19-27
3	1	7	0.05	0.33	28-32
4	2	9	0.09	0.42	33-41
5	4	13	0.19	0.61	42-60
6	1	14	0.05	0.66	61-65
8	3	17	0.14	0.80	66-79
10	2	19	0.09	0.89	80-88
13	1	20	0.05	0.94	89-93
15	1	21	0.05	0.99	94-98
Total	**21**		**0.99 ≈ 1.00**		

Table 6:- Service time distribution for server two.

Service time (in minutes)	Frequency	Cumulative frequency	Probability	Cumulative Frequency	Random Number Interval
1	2	2	0.09	0.09	00-08
2	2	4	0.09	0.18	09-17
3	3	7	0.14	0.32	18-31
4	5	12	0.24	0.56	32-55
5	6	18	0.29	0.85	56-84
6	2	20	0.09	0.94	85-93
7	1	21	0.05	0.99	94-98
Total	**21**		**0.99 ≈ 1.00**		

Table 7:- Customer waiting time distribution for server two.

Waiting time (in minute)	Frequency	Cumulative frequency	Probability	Cumulative probability	Random number Interval
0	10	10	0.48	0.48	00-47
1	2	12	0.09	0.57	48-56
2	2	14	0.09	0.66	57-65
3	1	15	0.05	0.71	66-70
4	3	18	0.14	0.85	71-84
6	1	19	0.05	0.90	85-89
7	2	21	0.09	0.99	90-98
Total	**21**		**0.99≈1.00**		

Table 8:- Detailed simulation of the queuing process for server two.

Trial	Random Number		Inter Arrival time	Service time distribution	Arrival time	Service time		Idle time	Customer waiting time
	Arrival time	Service time				start	end		
1	-	-	5	5	04:05	04:05	04:10	5	0
2	-	-	8	4	04:13	04:13	04:17	3	0
3	-	-	6	3	04:19	04:19	04:22	2	0
4	-	-	8	6	04:27	04:27	04:33	5	0
5	-	-	5	4	04:32	04:33	04:37	0	1
6	-	-	3	5	04:35	04:37	04:42	0	2
7	-	-	4	3	04:39	04:42	04:45	0	3
8	-	-	10	6	04:49	04:49	04:55	4	0
9	-	-	2	1	04:51	04:55	04:56	0	4

10	-	-	13	5	05:04	05:04	05:09	8	0
11	-	-	1	4	05:05	05:09	05:13	0	4
12	-	-	8	3	05:13	05:13	05:16	0	0
13	-	-	5	4	05:18	05:18	05:22	2	0
14	-	-	2	5	05:20	05:22	05:27	0	2
15	-	-	0	1	05:20	05:27	05:28	0	7
16	-	-	15	7	05:35	05:35	05:42	7	0
17	-	-	1	5	05:36	05:42	05:47	0	6
18	-	-	4	2	05:40	05:47	05:49	0	7
19	-	-	10	5	05:50	05:50	05:55	1	0
20	-	-	1	2	05:51	05:55	05:57	0	4
21	-	-	5	4	05:56	05:57	06:01	0	1
22	37	40	4	4	06:00	06:01	06:05	0	1
23	6	85	1	6	06:01	06:05	06:11	0	4
24	19	37	2	4	06:03	06:11	06:15	0	8
25	41	10	4	2	06:07	06:15	06:17	0	8
26	59	19	5	3	06:12	06:17	06:20	0	5
27	70	55	8	4	06:20	06:20	06:24	0	0
28	45	28	5	3	06:25	06:25	06:28	1	0
29	76	7	8	1	06:33	06:33	06:34	5	0
30	88	51	10	4	06:43	06:43	06:47	9	0
31	52	6	5	1	06:48	06:48	06:49	1	0
32	86	71	10	5	06:58	06:58	07:03	9	0
33	24	89	2	6	07:00	07:03	07:09	0	3
34	82	14	10	2	07:10	07:10	07:12	1	0
35	25	52	2	4	07:12	07:12	07:16	0	0
36	41	77	4	5	07:16	07:16	07:21	0	0
37	4	24	0	3	07:16	07:21	07:24	0	5
38	37	65	4	5	07:20	07:24	07:29	0	4
39	54	92	5	6	07:25	07:29	07:35	0	4
40	94	39	15	4	07:40	07:40	07:44	5	0
41	44	46	5	4	07:45	07:45	07:49	1	0
42	35	27	4	3	07:49	07:49	07:52	0	0
43	63	64	6	5	07:55	07:55	08:00	3	0
44	18	75	1	5	07:56	08:00	08:05	0	4
45	11	22	1	3	07:57	08:05	08:08	0	8
46	83	98	10	7	08:07	08:08	08:15	0	1
47	55	18	5	3	08:12	08:15	08:18	0	3
48	1	74	0	5	08:12	08:18	08:23	0	5
49	2	38	0	4	08:12	08:23	08:27	0	4
50	77	18	8	3	08:20	08:27	08:30	0	7

Computation of Operating Characteristics of Queue Two:

- Mean Inter-arrival time = $\frac{\text{Total inter arrival time}}{\text{Total number of arrivals}} = \frac{245}{50}$ = 4.9 minutes per customer
- Arrival rate, $\lambda_2 = \frac{1}{\textit{Mean inter arrival time}} = \frac{1}{4.9}$ = 0.20 customers per minute

- Mean Service time = $\frac{Total\ service\ time}{Number\ of\ customers\ served}$ = $\frac{198}{50}$= 3.96 minutes per customer
- Service rate, μ_2 = $\frac{1}{Mean\ service\ time}$ = $\frac{1}{3.96}$ = 0.25 customers per minute
- Mean waiting time of customers in queue = $\frac{Sum\ of\ customers\ waiting\ time}{Total\ arrivals}$ = $\frac{115}{50}$
  = 2.3 minutes per customer
- Mean time a customer spends in the system (checkout counter)
  = Average serving time + Average waiting time in the queue
  = 3.96 + 2.3 = 6.26 minutes
- Service facility utilization at server one = $\frac{\lambda}{\mu}$ = $\frac{0.20}{0.25}$ = 0.8

Computation of the average of the Operating Characteristics of the queuing system represented at the checkout point with both servers:

- Mean inter-arrival time = $\frac{4.90 + 4.46}{2}$ = 4.68 minutes per customer
- Mean Arrival rate, λ = $\frac{1}{4.68}$ = 0.21 customers per minute
- Mean service time = $\frac{3.96 + 4.10}{2}$ = 4.03 minutes per customer
- Mean Service rate, μ = $\frac{1}{4.03}$ = 0.25 customers per minute
- Mean Waiting time in Queue = $\frac{4.04 + 2.30}{2}$ = 3.17 minutes per customer
- Mean Waiting time in System(Queue and in service) = $\frac{8.14 + 6.26}{2}$
  = 7.2 minutes per customer

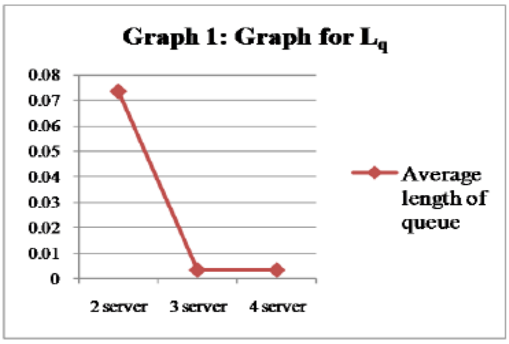
We see that the average time a customer has to wait in the system (queue and in service) is 7.2 minutes which may eventually lead the customer to either leave the queue and move to next queue because it is too long and he has no time to wait (balking), or leave due to impatience without getting the service (reneging). The above results provide insights into the relationship between the numbers of servers and queue metric such as queue length and waiting time so by varying the number of servers we can identify the optimal server quantity that minimizes these metrics and maximizes efficiency. Now in Table 9 we will compare the results for three and four servers which will also increase the service rate by 1.5 and 2 times respectively keeping the arrival rate constant i.e. 0.21 customers per minute.

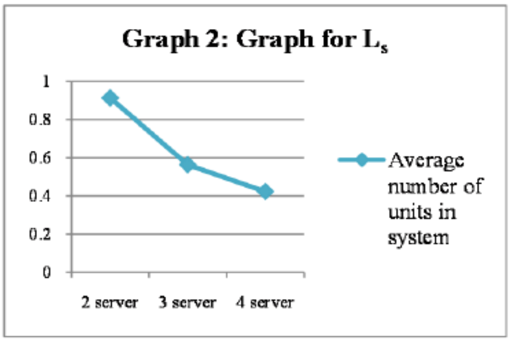
Table 9:- Comparison of measures for queuing model for 2, 3and 4 servers.

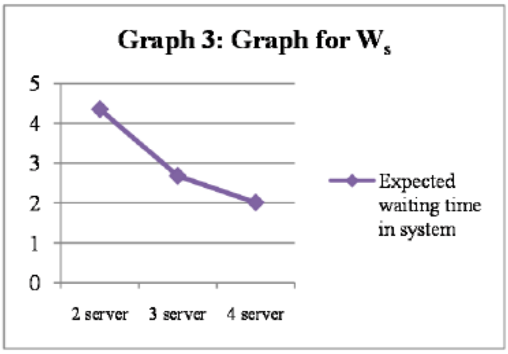
Number of servers	**2**	**3**	**4**
Server Utilization, ρ	0.42	0.187	0.105
P_0	0.408	0.570	0.657
P_s	0.144	0.0167	0.00852
Average length of queue, L_q	0.0734	0.00324	0.003236
Average number of units in system, L_s	0.9134	0.5632	0.4232
Expected waiting time in system, W_s	4.3495	2.6819	2.0152
Expected waiting time in queue, W_q	0.3495	0.01543	0.015409
Expected waiting time of a customer who has to wait, (w|w>0)	3.4482	1.0927	0.5587

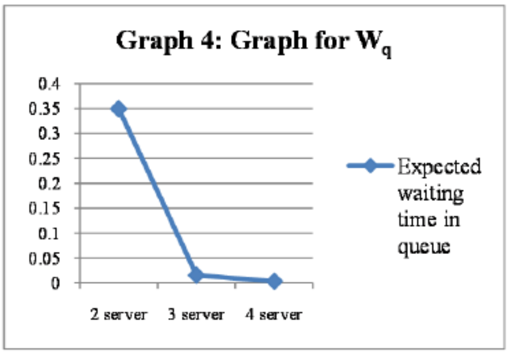
Probability of waiting time of a customer who has to wait, [w>0]	0.2482	0.0205	0.000952
Probability that there will be someone waiting	0.1042	0.0038	0.0000996

The graphical representation of the comparison between various parameters for the 2, 3 and 4 servers is shown below:









From the graphs 1, 2, 3 and 4, we conclude that both the three and four servers model gives almost the same values for the Average length of queue (L_q), Average number of units in system (L_s), Expected waiting time in system (W_s) and Expected waiting time in queue (W_q) respectively.

V Conclusion:

The findings of this study provide valuable insights into the queue behavior for the studied supermarket. The analysis demonstrates the relationship between the number of servers and key performance metrics. The data for two servers was thoroughly processed and compared through both graphical and analytical methods. Through this paper we conclude that if we increase the number of servers then we get a better overall performance. After extensive analysis, we observed that the three-server and four-server models exhibited comparable performance in terms of the aforementioned metrics. This implies that adding an extra server did not significantly improve the queuing system's overall performance. Thus, from a cost-benefit perspective, implementing a three-server model may be a more feasible option for the supermarket, as it can achieve similar outcomes without incurring the additional expenses associated with an extra server. However, it is important to acknowledge the limitations of our research. Our study focused on a specific context and may be directly applicable to other scenarios or industries and can perfectly replicate real-world conditions. In conclusion, our research highlights the importance of considering queuing theory and carefully evaluating the number of servers in a supermarket setting. By comparing the three-server and four-server models, we determined that they yield similar results in terms of performance metrics. This knowledge can assist supermarket managers in making informed decisions regarding their queuing systems, optimizing resource allocation and improving customer satisfaction. Further research can be conducted to explore additional factors that could impact queuing system performance and to validate our findings in different settings.

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