Optimizing the Queuing System in Fast-Food Restaurants through Modeling and Simulation

Jan Edgar E. Tupas
School of Information Technology
Mapúa University
Makati, Philippines
jeetupas@mymail.mapua.edu.ph

Christian Henry Miguel E. Caruz
School of Information Technology
Mapúa University
Makati, Philippines
chmecaruz@mymail.mapua.edu.ph

Rafaello Jose M. Viera
School of Information Technology
Mapúa University
Makati, Philippines
rjmviera@mymail.mapua.edu.ph

Miguel T. Soniel
School of Information Technology
Mapúa University
Makati, Philippines
mtsoniel@mymail.mapua.edu.ph

Elcid A. Serrano
School of Information Technology
Mapúa University
Makati, Philippines
easerrano@mapua.edu.ph

***Abstract*— The study identifies solutions for optimizing the queuing system of fast-food restaurants dealing with the problem using modeling and simulations with principles of Queuing Theory. The researchers used modeling and simulation to replicate queues in fast-food restaurants using key variables. The queuing models were defined using Kendall's Notation, and relevant principles from Queuing Theory were utilized. The simulations were performed to identify solutions that can optimize the queuing system of fast-food restaurants and improve the overall performance of the existing system. The results show that the most effective solution to optimize the queuing system of fast-food restaurants is to transform the existing SCMP queuing system of fast-food restaurants into an MCMP queuing system by adding servers to the channels of each phase. Decreasing the maximum service times provided by the system also contributes to optimizing the queuing system of fast-food restaurants.**

Keywords— Queuing Theory, Monte-Carlo simulation, Modelling, Simulation, fast-food restaurant, MCSP

I. INTRODUCTION

An essential element of fast-food restaurants is the capacity to generate quick service to accommodate a customer's order and payment swiftly and provide the products ordered. Although the service rates of fast-food restaurants are immensely faster than traditional restaurants, service delays still occur. Given the first come, first serve environment of a fast-food restaurant where customers transact directly to the service provider, commonly the cashier, and receive their order from the cashier as well, service delays paired with a sudden surge in the number of customers result in customers lining up and waiting for the completion of the service of the initial parties to take their place and receive service for their own. The event where customers line up and wait for service are known as queues.

A queue is a line of entities waiting to receive service from a service provider. A queue in a fast-food restaurant signifies that a queuing system exists in said restaurant. A queuing system comprises a service facility where entities, generally called "customers," arrive to receive service. When the number of entities in the system exceeds the service facility's capacity, a queue or waiting line forms. The queued entities are served based on a predetermined rule, and once they receive service, they exit the system. The system's input comprises the customers seeking service, and the output comprises the customers serviced [1]. Customers are only willing to endure long waiting times for products or services if they are genuinely essential or offer significant value compared to waiting [2]. Fast-food establishments often face the challenge of efficiently handling customer lines during busy hours. To ensure a positive customer experience and improve overall system efficiency, fast-food businesses must optimize their queueing systems.

The paper analyzes and utilizes the principles established by Queuing Theory to effectively optimize queuing systems in popular fast-food restaurants in the Philippines. Fast-food institutions that operate in the Philippines share a similar structure, which allows for a coherent analysis, production, and manipulation of queuing models that provide a universal optimized queuing system. The attempt to understand and implement the principles of Queuing Theory in identifying key factors and queue metrics contributing to queuing system delays was pursued. Analyzing, comparing, and optimizing existing queuing structures, models, and management configurations by utilizing gathered data serves as the foundation of the study. Queuing simulations that mimic the real-world scenario of a queuing system in a fast-food restaurant were produced and executed to generate data for the essential performance metrics that ultimately defined the effectiveness and efficacy of the queuing model and queuing system. The queuing process for fast-food restaurants was dissected and analyzed to replicate the existing queuing structures in the simulations. Furthermore, A queuing model using Kendal's Notation was utilized and implemented to represent the queuing system of fast-food restaurants in the Philippines. The queuing model was the basis for implementing the four queuing management structures in the simulations. The produced results were compared and analyzed, translating to insights utilized to manipulate existing queuing parameters to improve the queuing system's performance. The optimizations to the existing queuing systems in fast-food restaurants would aid establishments in identifying the primary causes of bottlenecks and delays in service production.

II. REVIEW OF RELATED LITERATURE

Significant literature on queuing systems and Queuing Theory is published and accessible. The applications of Queuing Theory in various real-world scenarios are widespread and necessary for operations such as traffic flow, scheduling, telecommunications, logistics, emergency services, and more.

Queuing theory is a mathematical discipline dedicated to studying and modeling waiting phenomena in lines or queues. The occurrence of queues is commonplace, arising due to the presence of limited resources. Designing effective queueing systems necessitates balancing customer service satisfaction and cost considerations [4].

Metrics define the operations of queues in Queuing Theory. Arrival rate (λ) and service rate (μ) manifest the foundations of computing the established performance metrics of a queuing system. Analysis for metrics which encompass Utilization Factor (ρ), average waiting time in the queue (Wq), average waiting time in the system (W), average number of customers in the queue (Lq), and average number of customers in the system (L), pave the way for optimizing the existing queuing system and model implemented by fast-food restaurants.

Little's theorem formally describes the interrelation between the throughput rate, cycle time, and work in process. The relationship between the distribution rate of customers and the time spent by the customers in the system is defined. The theorem establishes that, in a system operating in a steady state, the expected number of customers (L) can be determined using the equation:

$$L = \lambda * W$$

Where L represents the expected number of customers in the system, λ is the average customer arrival rate, and W is the average service time for a customer [5].

The Kendall-Lee notation provides the means for describing the essential characteristics of a queue. The notation utilizes six abbreviations that represent each characteristic separated by a slash.

M/M/2/FCFS/inf/inf

The initial two characteristics pertain to the arrival and service processes, and their probability distributions are represented by M (exponential), E (Erlang), and G (general). The third characteristic defines the number of concurrent servers operating simultaneously. The fourth characterizes the queue discipline using its designated acronym. The fifth denotes the maximum capacity of customers permissible within the system. The sixth indicates the size of the customer pool from which the system can draw [3].

The various queue management structures play a crucial role in representing and examining practical queuing systems. The Single Channel Single Phase (SCSP) denotes a queuing system that comprises a solitary service channel (server) where customers are served individually. The Single Channel Multi Phase (SCMP) defines a single service channel as employed, but the service time is fragmented into multiple distinct phases or stages. The Multi-Channel Single Phase (MCSP) setup involves the simultaneous operation of multiple service channels (servers). The Multi-Channel Multi Phase (MCMP) configuration incorporates multiple service channels, and the service time is partitioned into several phases or stages.

In the domain of queuing theory, distributions assume a fundamental significance as they establish a mathematical underpinning for representing the arrival times of entities and their corresponding service times within a queuing system. In the context of such systems, entities approach a service facility seeking service, necessitating them to be queued until a server becomes accessible for their assistance. In the context of the study, the distributions used to define the arrival rate and service rate of entities as presented in the produced model was the Markovian Distribution. The Markovian Distribution refers to an exponential distribution that characterizes the time intervals between consecutive arrivals in a queuing system. It is extensively employed to model the inter-arrival times of entities, assuming a memoryless property, wherein the probability of the next entity arriving does not depend on the time elapsed since the previous arrival.

III. Methodology and Data

The study focused on optimizing the queuing system of fast-food restaurants in the Philippines. A universal queuing system among fast-food restaurants in the Philippines is adopted, where the primary processes are taken to generate a universal model. Data were collected to grant insight into how to construct the model. Representative fast-food restaurants in the Philippines were selected through reviewing articles and other available resources. Data were collected from specific branches of the identified fast-food restaurants in Ayala Mall Circuit Makati City during lunchtime from 12:00 to 1:00 to capture peak customer visits. They were used to generate models implemented through simulations. The data collected were the queuing management structures of each restaurant, the interarrival time, which is the arrival time between customers, and the service time when the customer orders food to when the customer receives the ordered food. The interarrival and service time ranges were then taken from the collected data. Table 1 shows the data collected.

TABLE 1 DATA OF SELECTED FAST-FOOD RESTAURANTS

Fast-food Restaurant	Jollibee	Mcdonald's	Mang Inasal
Queue Management	SCMP	SCMP	SCMP
Interarrival Range (minutes)	0.5 – 5	0.5 – 4	0.5 – 5
Service Time Range for Phase 1 (minutes)	1 – 3	0.5 – 3	1 – 2
Service Time Range for Phase 2 (minutes)	1 – 4	1 – 3	4 – 4.5
Number of Servers	2	2	2
Number of phases	2	2	2

With the collected data, the primary queue management identified was the SCMP structure. The restaurants encompassed two phases, one for ordering and payment and one for collecting the ordered food. The restaurants' interarrival time during peak hours ranges from 30 seconds to 5 minutes. The service time during peak hours in the restaurants for phase 1 ranges from 30 seconds to 4 minutes. The service time during peak hours in the restaurants for phase 2 ranges from 1 minute to 4.5 minutes. The restaurants had two active servers, one for phase one and one for phase two.

The queuing systems and models of the identified fast-food restaurants are depicted in Figures 1 and 2. The figures illustrate the primary components of the queuing system and the corresponding model.

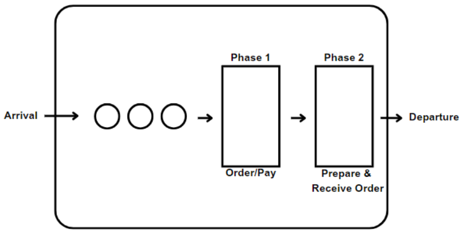

Fig. 1. Data of Selected Fast-Food Restaurants

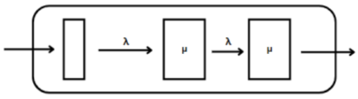

Fig. 2. SCMP Model

Additional queuing management structures and corresponding models are presented in Figures 3, 4, 5 and 6.

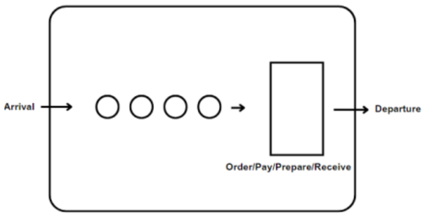

Fig. 3. SCSP Queuing System

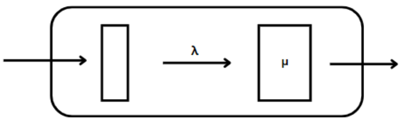

Fig. 4. SCSP Model

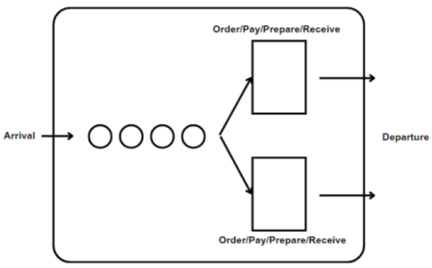

Fig. 5. MCSP Queuing System

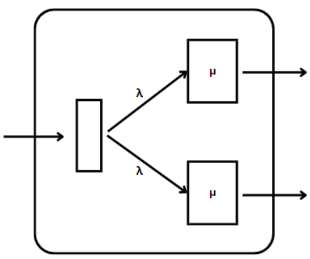

Fig. 6. MCSP Model

As discussed, the Kendall-Lee notation provides seven essential characteristics of a queueing system and are defined by the arrival time distribution, service time distribution, number of servers, queue lengths, calling population, and queuing discipline.

With the provided data of the specified fast-food restaurants, a queuing model of the fast-food restaurants of the Philippines utilizing the Kendall-Lee Notation is defined.

M/M/s/Inf/Inf/FCFS

M represents Markovian Distribution for arrival time distribution. *M* represents Markovian Distribution for service time distribution. s represents multiple parallel servers available to provide service. Inf represents an infinite capacity for the queue. Inf represents an infinite calling population. FCFS represents a First Come and First Serve queuing discipline.

Performance metrics were utilized to define, analyze, and compare the model's performance when implemented through various simulations with various parameters. The simulations designed were Monte Carlo Simulations to mimic actual life instances of customer arrivals and service production in fast-food restaurants. The primary parameters of the simulations were the interarrival time range, service time range, number of customers, number of servers, and number of phases. The unit time used for the simulation was minutes. The metrics computed from the results of the simulations are the following:

1. Arrival Rate (λ):

$$\lambda = 1 / E[I]$$

2. Service Rate (μ):

$$\mu = 1 / E[S]$$

3. Utilization Factor (ρ):

$$\rho = \lambda * (S / n)$$

4. Average Time in Queue (Wq):

$$Wq = E[Wt]$$

5. Average Time in System (W):

$$W = E[Tt]$$

6. Average Number of Customers in Queue (Lq):

$$Lq = \lambda * Wq$$

7. Average Number of Customers in System (L):

$$L = \lambda * W$$

Where I is average interarrival time, S is average service time, n is the number of servers, Wt is the total wait time, and Tt is the total time.

Three methods were identified to optimize the queuing system. The first method was to increase the number of servers in the queuing system. Increasing the number of servers optimizes the queuing system by reducing waiting times and increasing the system's capacity to handle incoming entities simultaneously, resulting in improved efficiency and customer satisfaction. The method was implemented by adjusting the number of servers parameter in the simulations. The second method was to identify optimal service times. The method was implemented by adjusting the service time range parameter of the simulation. The last method was identifying the most effective queuing management structure by analyzing and comparing performance metrics from simulation results. The method was implemented by creating simulations for SCSP and MCSP models.

IV. RESULTS

The collected data from the fast-food restaurants, which were the interarrival time range, service time range, number of servers, and number of phases, were used as the parameters in running the created Monte-Carlo simulation that simulated the queuing system of the restaurants. The number of samples, where one sample represents one customer, was set to 250. The simulation mimics fast-food restaurants' Single Channel Multi Phase queuing system during peak hours. The performance metrics of the simulation using the parameters from the data gathered are shown in Table 3.

TABLE 2 SIMULATION RESULTS

Performance Measure	Value
Arrival Rate (λ)	0.36 customers per minute
Service Rate (μ)	0.35 customers per minute
Utilization Factor (ρ)	52.62%
Average Time Spent in Queue (Wq)	14.09 minutes
Average Time Spent in System (W)	16.98 minutes
Average Number of Customers in Queue (Lq)	2.24 customers
Average Number of Customers in System (L)	6.17 customers

Table 3 shows the simulation results using the data collected from the fast-food restaurants as parameters. The results imply that in a sample of 250 customers: A customer arrives approximately every three (3) minutes; A customer is served approximately every three (3) minutes; There is a utilization factor of 52.62% which means that the resources of the system are busy 52.62% of the time and is idle 47.38% of the time. It suggests that the system is moderately utilized and still can handle more tasks during specific periods; A customer spends approximately a total of 14.09 minutes waiting in the queues produced by the two phases before receiving service; A customer spends approximately 16.89 minutes in the entire queuing system encompassing the processes of waiting in queue and receiving service; There are on average two (2) customers in each queue produced by each phase at a given period; There are on average six (6) customers in the entire queuing system at a given period.

The results imply that improvements to the queuing system can still be made and implemented to decrease customer wait times in the queue and the total time a customer spends in the system, and adjust the utilization factor of the system. Achieving the aforementioned translates to a lessened average number of customers in the waiting line and the system.

A. *Increasing the Number of Service Channels*

Increasing the number of servers would distribute the workload in the queuing system, ensuring smooth processes while preventing overloads. However, it would translate to adding resources to the queuing system, generating costs. The simulation was modified, adding servers to phases 1 and 2, translating to four (4) active servers and resulting in two (2) active servers in phase 1 and two (2) active servers in phase 2. The parameters which were from the data gathered were retained for the simulation. The results of the simulation are shown in Table 4.

TABLE 3 INCREASING NUMBER OF SERVERS SIMULATION RESULTS

Performance Measure	Value
Arrival Rate (λ)	0.36 customers per minute
Service Rate (μ)	0.18 customers per minute
Utilization Factor (ρ)	50.48%
Average Time Spent in Queue (Wq)	0.28 minutes
Average Time Spent in System (W)	5.88 minutes
Average Number of Customers in Queue (Lq)	0.02 customers
Average Number of Customers in System (L)	2.09 customers

The table shows the simulation results when the number of servers for Phase 1 and Phase 2 was increased to two (2). The results imply that in a sample of 250 customers: A customer arrives approximately every three (3) minutes; A customer is served approximately every five (5) minutes; There is a utilization factor of 50.48% which suggests that the system resources are moderately used; A customer spends approximately a total of 0.28 minutes waiting in the queues of the two phases before receiving service; A customer spends approximately 5.88 minutes in the entire queuing system; There are on average 0.02 customers in each queue produced by each phase at a given period; There are on average two (2) customers in the entire queuing system at a given period.

Increasing the number of servers in phase 1 and phase 2 from one (1) to two (2) provides a very effective and efficient queuing system that immensely minimizes wait times and lessens the number of customers in the queue and the system. The structure also produces a 50.48% utilization factor which ensures that the system's resources are moderately utilized while negating the instances of inefficiencies and bottlenecks. Thus, modifying the queuing system into an MCMP queue management structure where the number of servers per channel is increased to two (2) is a highly effective method to optimize the queuing system of fast-food restaurants. However, hiring more servers would translate to additional expenses. The optimized MCMP queuing management structure and model are shown in Figures 7 and 8.

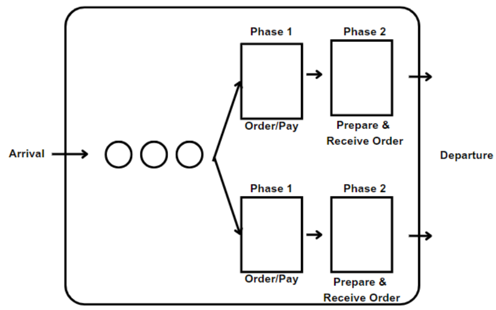

Fig. 7. MCMP Queuing System

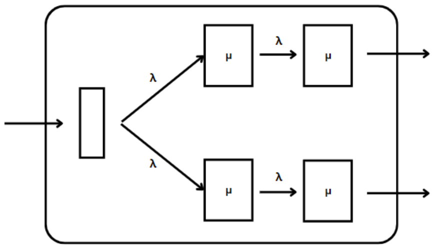

Fig. 8. MCMP Model

B. *Optimizing Service Times*

Identifying optimal service times provides improvement on the queuing system. Reducing the service time in an optimal manner results in the customer completing the service process swiftly and translates to lesser waiting times for waiting customers as well as lesser time spent in the system. Given the service time range data gathered, the maximum service time produced were 5 for both phases. The simulations were run with decreased maximum service parameters to identify an optimal service time range. The arrival rate was kept constant to ensure consistency. The results are shown in Table 5 where M1 represents the maximum time for phase 1 and M2 represents the maximum time for phase 2 in minutes.

TABLE 4 SERVICE TIME OPTIMIZATION SIMULATION RESULTS

M1	M2	λ	μ	ρ	Wq	W	Lq	L
4	5	0.36	0.38	46.61%	15.24	17.84	2.29	6.40
3	5	0.36	0.43	42.32%	12.76	15.09	2.00	5.49
2	5	0.36	0.50	35.80%	8.11	10.13	1.28	3.59
5	4	0.36	0.38	47.04%	6.63	9.26	1.18	3.31
4	4	0.36	0.42	43.16%	3.34	5.71	0.76	2.08
3	4	0.36	0.47	38.39%	2.49	4.59	0.61	1.67
2	4	0.36	0.53	33.98%	1.80	3.69	0.48	1.33
5	3	0.36	0.42	42.79%	6.26	8.62	1.13	3.13
4	3	0.36	0.48	37.75%	0.96	3.06	0.40	1.10
3	3	0.36	0.55	32.93%	0.37	2.19	0.29	0.79
2	3	0.36	0.61	29.59%	0.36	2	0.26	0.72

The simulation results with the modified service time parameters show that the utilization factor decreases when the maximum service time is decreased. However, this also translates to a decrease in metrics Wq, W, Lq, and L, implying that resources are not utilized to the maximum despite shorter queues and lesser customers waiting in queues and the system. To ensure optimization, the target is an optimized and realistic system that produces a utilization factor of 50% or less and a waiting time of 10 minutes or less. Given the results of the simulation, the optimal maximum service time for phase 1 and phase 2 are 5 and 4, respectively, as this produces a utilization factor of 47.04%, ensuring the efficiency of resources and avoiding bottlenecks while also reducing customer wait times in the queues and the system, and reducing the total number of customers in the queues and system following the SCMP queuing structure.

C. *Comparison of Queue Management Structures*

The resource specifications of the current queuing systems of the restaurants show a Single Channel Multi Phase model with two active servers, one server for accepting orders and payments and one server for providing the ordered food to the customer. The possible queuing management structures that could be utilized given the resources are the Single Channel Single Phase model with one active server that all accepts orders and payments and provide the ordered food and the Multi-Channel Single Phase model with two active servers that all accept orders and payments, and provide the ordered food. Utilizing the parameters used in the original simulation of the SCMP model, the results of the SCSP and MCSP simulations are shown in Table 5 and Table 6, respectively.

TABLE 5 SCSP SIMULATION RESULTS

Performance Measure	Value
Arrival Rate (λ)	0.36 customers per minute
Service Rate (μ)	0.13 customers per minute
Utilization Factor (ρ)	274.64%
Average Time Spent in Queue (Wq)	594.67 minutes
Average Time Spent in System (W)	602.21 minutes
Average Number of Customers in Queue (Lq)	216.66 customers
Average Number of Customers in System (L)	219.41 customers

Table 5 shows the results of the SCSP simulation. The results suggest that in a sample of 250 customers: A customer arrives approximately every three (3) minutes; A customer is served approximately every 8 (eight) minutes; There is a utilization factor of 274.64%, meaning that the resources are immensely over-utilized; A customer spends approximately a total of 594.67 minutes waiting in the queues which are highly unrealistic and should never be the case in a fast-food restaurant; A customer spends approximately 602.21 minutes in the entire queuing system which is highly unrealistic and should never be the case in a fast-food restaurant; There are on average 216.66 customers in the queue at a given period which is not probable and improper; There are on average 219.41 customers in the entire queuing system at a given period which is not probable and improper.

The results of the SCSP simulation imply that the model is highly inefficient and ineffective as it produces a high utilization percentage value translating to inefficient use of resources, high customer wait times result, and high values of the number of customers in the queue and system which translates to an ineffective and unreliable queuing system. Thus, the SCSP model should not be used as a model for the queuing system of a fast-food restaurant.

TABLE 6 MCSP SIMULATION RESULTS

Performance Measure	Value
Arrival Rate (λ)	0.36 customers per minute
Service Rate (μ)	0.13 customers per minute
Utilization Factor (ρ)	135.60%
Average Time Spent in Queue (Wq)	121.95 minutes
Average Time Spent in System (W)	129.43 minutes
Average Number of Customers in Queue (Lq)	44.21 customers
Average Number of Customers in System (L)	46.92 customers

Table 6 shows the results of the MCSP simulation. The results suggest that in a sample of 250 customers: A customer arrives approximately every three (3) minutes; A customer is served approximately every eight (8) minutes; There is a utilization factor of 135.60%, implying that the resources are immensely over utilized and is inefficient; A customer spends approximately a total of 121.95 minutes waiting in the queues which are highly unrealistic and should never be the case in a fast-food restaurant; A customer spends approximately 129.43 minutes in the entire queuing system which is highly unrealistic and should never be the case in a fast-food restaurant; There are on average 44.21 customers in the queue at a given period which is not probable and improper; There are on average 46.92 customers in the entire queuing system at a given period which is not probable and improper.

Similar to the results of the SCSP simulation, the findings from the MCSP simulation indicate that the model is remarkably inefficient and ineffective. It generates a high utilization percentage, indicating a wasteful use of resources, leading to extended customer wait times and significant queue lengths. Consequently, the queuing system based on the MCSP should not be considered suitable for a fast-food restaurant due to its ineffectiveness and unreliability.

Overall the SCMP and MCMP structures still provide the optimal structures for the queuing system of fast-food restaurants. The SCSP and MCSP structures are unrealistic, ineffective, and inefficient models for a queuing system for fast-food restaurants and should not be utilized.

V. Conclusion

The current queuing system of the fast-food restaurants specified is represented by an M/M/s/Inf/Inf/FCFS model and utilizes an SCMP management structure with one server per phase. Using Monte Carlo Simulations and the data gathered from the specified restaurants as the parameters, simulations were conducted to identify a more optimal solution to the queuing system of the fast-food restaurants. The methods used were optimizing by increasing the number of servers, adjusting the maximum service times concerning the current management structure and the data gathered, and comparing the existing management structure to other structures concerning the data gathered. Of the three methods, only two methods were successful in solving to optimize the queuing system.

The existing SCMP queuing system of fast-food restaurants could be improved by optimizing the maximum service times for each phase. Reducing the maximum service time of phase 2 in the system from five (5) to four (4) while retaining the maximum service time for phase 1 ensures that the resources are efficiently and effectively utilized to avoid bottlenecks while significantly reducing the waiting times of customers in both the queue and the entire system. The number of customers in the queue and the entire system is also reduced, translating to a less crowded capacity. Thus, to optimize the queuing system of the restaurants, the maximum service time for phase 2, which refers to the service that prepares and provides the ordered food of the customer, must be reduced from a maximum of 5 (five) minutes to 4 (minutes).

The existing queuing system could be immensely optimized by increasing the number of Phases 1 and 2 servers from one (1) to two (2). The additional servers ensure that the workload is distributed effectively, translating to smoother processes and fewer inefficiencies. Increasing the number of servers would transform the existing SCMP management structure into an MCMP management structure. The simulation of the MCMP queuing system concerning the data gathered implies that resources are moderately utilized, ensuring efficient and effective service processes with reduced chances of bottlenecks. The results also suggest that customer wait times are significantly and immensely reduced, ensuring customer satisfaction is fulfilled with swift service production. The results also show that the number of customers in the queues and the system is reduced, translating to a less crowded capacity. Thus, to optimize the queuing system of fast-food restaurants, the number of servers for each phase should be increased to two (2). The method provides the most effective manner of significantly improving and optimizing the queuing system of fast-food restaurants

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