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# Simulation of a Cafeteria System

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### Abstract

*This report focused on the optimization of the cafeteria system in order to increase performance on the basis of customer satisfaction and economical subtlety of the system. Different possible configurations were compared to find the best configuration in which the model performs best. The challenges associated with implementing the optimum configuration was also discussed in the later part of the report.*



### Keywords

**Simulation; Computer science; IUT Cafeteria; Semester Project**

# Contents

# 1 Introduction

The cafeteria system is a common spectacle in everyday life of urban people. It is a form of service that gives equal treatment to all the customers by means of time taken for service as well as the choice of items based on availability. It is a common scenario in most developed countries but in Bangladesh, it is mostly common in educational institutions. The experiment focused on the common cafeteria found in Bangladesh and provide some optimizations.

There are numerous variations of the cafeteria system found in various places each having its own distinctions. The general structure of a cafeteria contains a set of servers serving food and a single long queue of customers. This experiment simulates the model of a hypothetical cafeteria having similar characteristics to the cafeteria found in the Halls of Residence inside the Islamic University of Technology, Gazipur[1] campus with some assumptions and distinctions.

The cafeteria model is simulated for some set of input variables following a recommended experimental design ($2^k$ Factorial Design). The output of the simulation is analysed for performance based on some performance criteria and the best performing configuration is selected.

The remainder of this report is structured as follows. Section 2 explores the problem statement of the experiment and identifies the goals and objectives of the simulation. Section 3 outlines the conceptual model of the simulation along with the relations. Section 4 explores the specification model followed by the computational model in section 5. Section 6 summarizes the experimental outline and the performance criteria. Section 7 contains the result discussion and finally section 8 drives a conclusion.

# 2 Problem Statement

## 2.1 Scenario

This section describes the characteristics of the hypothetical cafeteria model and identifies the problems relating to the current system as well as scope for improvement of the cafeteria structure for better performance. The cafeteria is of self-service nature consisting of one or more counters (one will be considered for the simulation). Each of the counters contains several sub-counters serving different food items. Some sub-counters serve as option for food (the customers can only select one item or none) and others as additional item. A customer has to enter from one end of the counter, pass through several sub-counters and take food items, and finally exit from the other

[1] www.iutoic-dhaka.edu

end of the counter. In each sub-counter, they would find one or two food containers from where they can take food. A group of sub-counters from where the customer can only take one food item is termed as a level. For example, from level one, a customer can take either rice or bread but not both where rice can be taken from two containers in the same sub-counter. Conversely from level two, the customer has only one food choice that is the dessert. The customer can choose to not take any dessert and skip to the next level.

The current system has only one queue for the level one sub-counters, occasionally separate queues for the two sub-counters, which results in longer queue length (sometimes exceeding 40 or 50). To mitigate this problem, this experiment introduces individual queues for each servers. A customer enters the leftmost server with the shortest queue length after arriving at a sub-counter. There is no jockeying as the queues might be arranged in different dimensions (perpendicular to one another). After taking service from a server, the customer moves to the next level where they may choose to skip to the next level if they do not like the choices.

The customers arrive in batches where each batch size can be modeled by a discrete uniform random distribution with values 1 to 4. The customers in a batch are independent in the sense of food choice i.e. they may enter different sub-counters upon arrival. Each customer has independent choice of food and the amount of food they decide to take as well as time time they take to take the service. Depending on the service time, the customers of a batch can leave the cafeteria at different times and probably out of order.

Customers can take their desired portion of food from the server they enter. If their desires portion of food is not available at the time they enter service, they wait at the front of the queue. After the food is refilled, they start taking the food. The cafeteria keeps account of customers who were stalled due to insufficient food. Each server has a unit of food associated with it. A customer has to take an amount that is an integer multiple of the food unit associated with that server. This characteristic signifies that, a customer may not take half a bread from a server and rather take a full bread or take none.

Each food server associated with the cafeteria has a maximum capacity of food they can contain. After serving a customer, the amount of food available reduces by the amount the customer has taken. There is a minimum threshold of food for each server which determines whether the server needs refilling. All the servers are evaluated at a fixed interval and a refilling is ordered if any server has food amount less than the minimum threshold. The value of the minimum threshold can vary from server to server, but the evaluation interval and the maximum capacity of food is

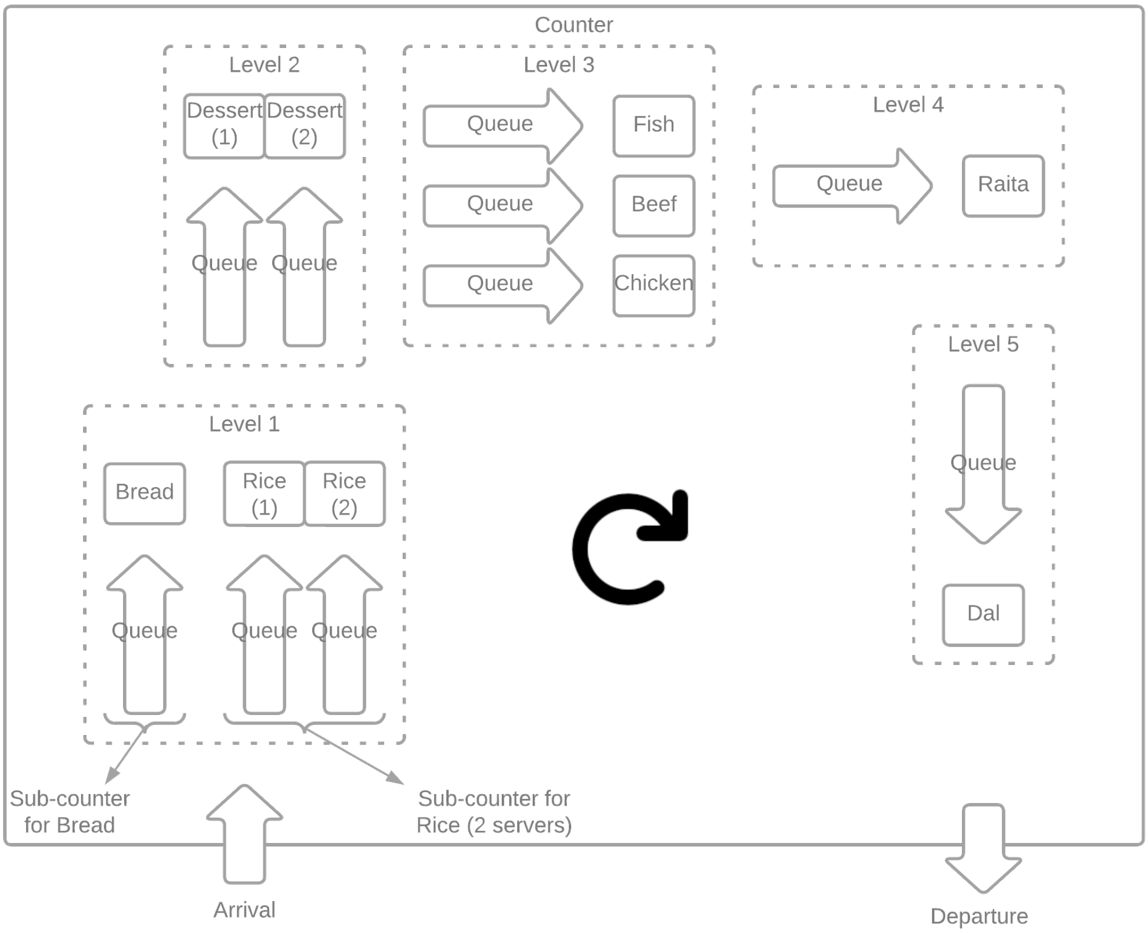


Figure 1: Conceptual Diagram of a Single Counter in the Cafeteria Model

fixed. After an evaluation requires refilling, the server will be refilled to its maximum capacity after a random amount of time.

The cafeteria runs for a period of 2 hours and 30 minutes at each meal. After this time ends, the cafeteria does not allow any more customers, but the customers already inside the system continues to get service. No more evaluation occurs after the time ends, so the customers who cannot get their desired portion take what they can and proceed to the next level. Those who find the servers empty while staying in queue are unsatisfied and the cafeteria keeps account of the number of unsatisfied customers.

## 2.2 Goals and Objectives

The goals of the experiment along with the objectives and specific output variables associated with them are listed below.

- Maximizing Customer Satisfaction
  - Minimize average queuing delay of customers
    * Find optimum number of servers for each sub-counter
  - Minimize number of stalled customers (due to insufficient food)
    * Find optimum server threshold
  - Minimize number of unsatisfied customers (stayed in queue but did not receive food)
    * Find optimum evaluation interval
- Minimizing Resource Wastage
  - Maximize utilization rate of each server
    * Find optimum number of servers for each sub-counter
  - Minimize remaining food after simulation ends
    * Find optimum evaluation interval
    * Find optimum server threshold

# 3 Conceptual Model

## 3.1 State Variables

The components describing the state of the model are the status of the servers, their queue length and food level. The cafeteria is represented by a single object $C$. There are $N$ counters in the cafeteria each having an unique id starting from 0. All counters $C_i$ are identical, where $i = 0, 1, ..., N$. A counter has a fixed $L$ number of levels starting from 0. In a level $l$, there are $M_l$ sub-counters and a sub-counter $C_i^l$ in counter $i$ and level $l$ has $M_l^{(j)}$ servers represented by $C_i^{l,(j)}$.

The State variables are as follows.

For server $i$ where $i = 0, ..., M_l^{(j)}$,

$$X_i(t) = \text{status of the i-th server}$$
$$Q_i(t) = \text{queue length of the i-th server}$$
$$L_i(t) = \text{food level of the i-th server}$$

## 3.2 Events

There are five types of events in the simulation. They are as follows.

- *Arrival Event:* The arrival event signifies the arrival of customer batches in the cafeteria. A batch of up to four customers arrive at the counter, decides on their food item from the first level and stands in the queue in front of the server with the least queue size in the corresponding sub-counters. If the server is free, the customer doesn't have to wait in the queue and directly enter service.

- *Departure Event:* Associated with a server, the departure event signifies the completion of service of a customer from a specific server. If there is a next level, the customer forgoes the item selection process and admits to the corresponding server. If there are no more levels left or the customer decides to skip the next levels, the customer exits from the counter and from the system.

- *Evaluation Event:* At regular intervals, the food level of the servers are evaluated. If the food level is below the minimum threshold associated with that server, a refill event is triggered which occurs after a random amount of time.

- *Refill Event:* Being triggered by the evaluation event, the refill event refills the fool level of the server to its maximum capacity. If there are stalled customers in the queue, their demands are satisfied first.

- *Termination Event:* This event signifies the end of the meal period. Following this event, there are no more arrivals and evaluations. That means, there are more refilling and stalled customers have to leave the queue to the next level.

## 3.3 Input Variables

The following are the input variables of the simulation.

- *Number of servers in each sub-counter:* Depending on the performance metrics, the number of servers of an individual sub-counter is increased until an optimal configuration is found.

- *Evaluation interval:* The interval between the evaluation events that leaves the least number of unsatisfied customers is chosen as the most optimal one. Two values (below and higher than 10 minutes) are tested. The values are

  - 8 (eight minutes)
  - 13 (thirteen minutes)

- *Minimum food level:* The threshold below which a refill event is triggered is tested for the optimal one between the following two values.
  - maximum amount a customer can take
  - twice the amount a customer can take

## 3.4 Output Variables

The following are the output variables representing the performance criteria by which the best configuration was chosen.

- Percentage of customers served
- Percentage of customers stalled
- Average server utilization
- Average queue length
- Maximum queue length
- Average food level
- Average queuing delay
- Average service delay
- Total number of refill events
- Amount of food remaining after closing

# 4 Specification Model

## 4.1 State Equations

For server $i$ where $i = 0, ..., M_l^{(j)}$,

$$X_i(t^+) = \left\{ \begin{array}{ll} X_i(t) == 0 \; and \; L_i(t) \geq A_j ? 1 : 0, & \text{Arrival of Customer } j \text{ at time } t \\ Q_i(t) > 0 \; and \; L_i(t) \geq A_j ? 1 : 0, & \text{Departure of customer before } j \text{ at time } t \\ Q_i(t) > 0 ? 1 : X_i(t), & \text{Refill event at time } t \\ X_i(t), & \text{otherwise} \end{array} \right\} \tag{1}$$

$$Q_i(t^+) = \left\{ \begin{array}{ll} X_i(t) == 1 \; or \; L_i(t) < A_j ? Q_i(t) + 1 : Q_i(t), & \text{Arrival of Customer } j \text{ at time } t \\ Q_i(t) > 0 \; and \; L_i(t) \geq A_j ? Q_i(t) - 1 : Q_i(t), & \text{Departure of customer before } j \text{ at time } t \\ Q_i(t), & \text{otherwise} \end{array} \right\} \tag{2}$$

$$L_i(t^+) = \left\{ \begin{array}{ll} L_i(t) \geq A_j ? L_i(t) - A_j : L_i(t), & \text{Start of service of Customer } j \text{ at time } t \\ L_i(t) < A_j ? 0 : L_i(t) - A_j, & \text{Start of service of Customer } j \text{ at time } t \text{ after termination} \\ L_{max}, & \text{Refill event at time } t \\ L_i(t), & \text{otherwise} \end{array} \right\} \tag{3}$$

Here,

- $A_j$ is the amount of food customer $j$ takes from server $i$
- $L_{max}$ is the maximum capacity of server $i$

## 4.2 State Space

The following are the equations of the state space.

For server $i$ where $i = 0, ..., M_l^{(j)}$,

- $X_i = \{0, 1\}$
- $Q_i = \{0, 1, 2, ...\}$
- $L_i \in R$

## 4.3 Output Equations

The following are the output equations.

For server $i$ where $i = 0, ..., M_l^{(j)}$,

- *Average Server Utilization: (Time averaged)*

$$\bar{u} = \frac{1}{\tau} \int_0^\tau X_i(t)dt \tag{4}$$

- *Average Queue Length: (Time averaged)*

$$\bar{q} = \frac{1}{\tau} \int_0^\tau Q_i(t)dt \tag{5}$$

- *Maximum Queue Length: (Job maximized)*

$$q_{max} = \max Q_i \tag{6}$$

- *Average Food Level: (Time averaged*

$$\bar{l} = \frac{1}{\tau} \int_0^\tau L_i(t)dt \tag{7}$$

- *Average Queuing Delay: (Job averaged* For $n$ jobs,

$$\bar{d} = \frac{1}{n} \sum_{j=1}^{n} d_j \tag{8}$$

- *Average Service Delay: (Job averaged* For $n$ jobs,

$$\bar{s} = \frac{1}{n} \sum_{j=1}^{n} s_j \tag{9}$$

## 4.4 Input Data Modeling

The following are the input variables and their probability distributions.

- *Inter-arrival time:* Exponential random with mean 1.4 minutes.
- *Customer batch size:* Discrete uniform random between 1 to 6.
- *Customer food amount:* Discrete random between server specific constants (min, max and unit).

- *Service time:* Exponential random with mean 0.4 minutes.
- *Delivery lag:* Continuous uniform between 5 and 7 minutes.
- *Other deterministic values:*
  - Simulation run time 150 minutes
  - Evaluation interval
  - Customer minimum food amount
  - Customer maximum food amount
  - Server maximum food capacity
  - Server minimum food threshold
  - Probability of a customer choosing a food item
  - Server food unit

# 5 Computational Model[2]

## 5.1 Event Handlers

The flow chart for the five event handlers can be found in Figure 2-6.

## 5.2 Variance Reduction

The model uses variance reduction technique i.e. Common Random Number (CRN) in order to reduce the variance between the output of different runs of the simulation program. The objective was to use identical random numbers for different simulation runs in order to get positively correlated random numbers. The random number generation steps were synchronized by generating all the random values associated with a customer at the time of arrival of that customer. This way the variance of the generated output variables were minimized. Another step was taken to generate and drop random numbers at the time of evaluation if refill event was not triggered. This way the same set of random numbers were used to generate the delays at which the refill events were triggered.

[2]The code for the simulation model can be found at `https://github.com/SamiKhan-cse19/CafeteriaSystem`.

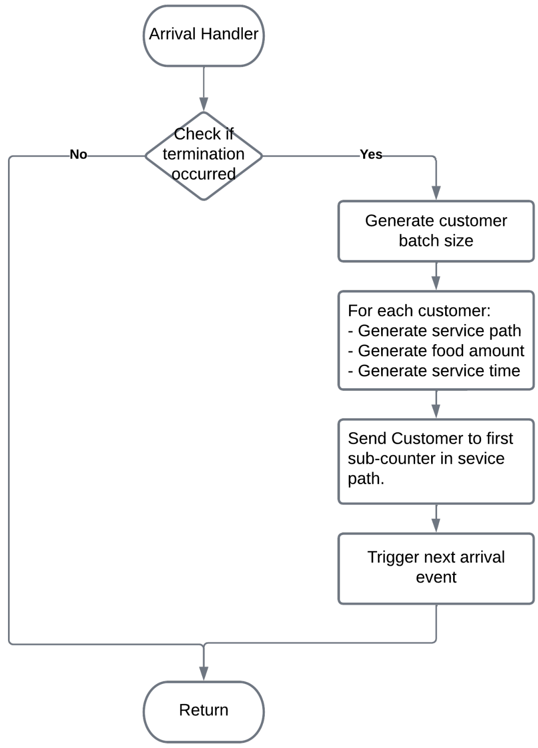


Figure 2: Flow Chart for Arrival Handler

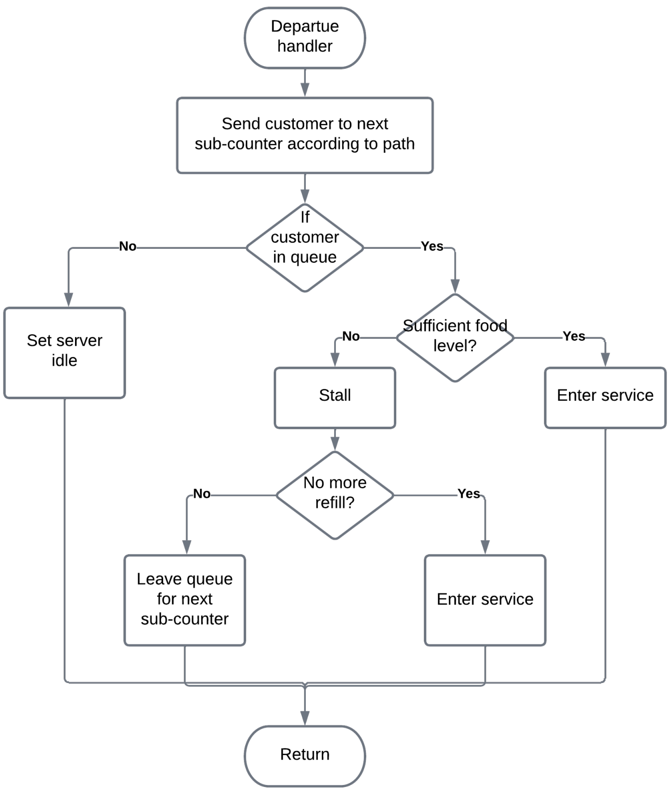


Figure 3: Flow Chart for Departure Handler

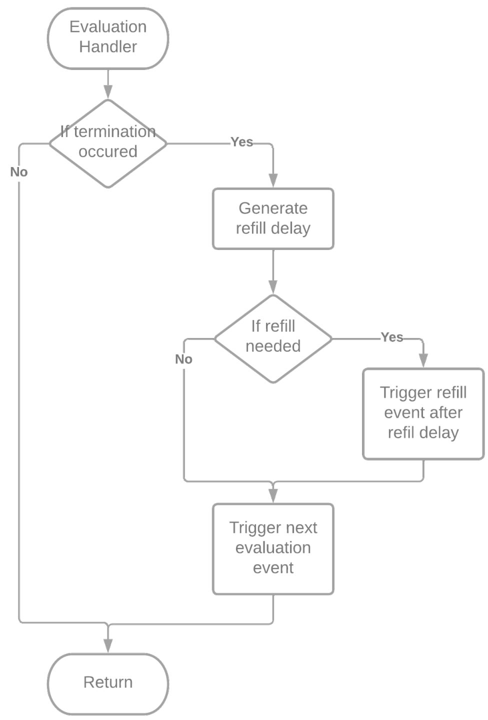


Figure 4: Flow Chart for Evaluation Handler

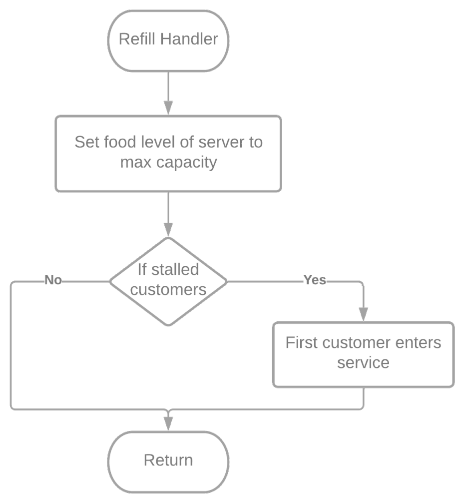


Figure 5: Flow Chart for Refill Handler

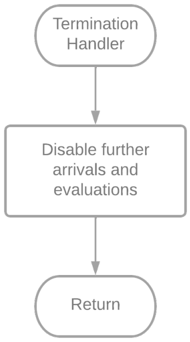


Figure 6: Flow Chart for Termination Handler

## 6 Experimental Outline

As discussed previously, there are three input variables for this experiment. Of the three variables, two variables can be adjusted globally i.e. one value for the whole system. The number of servers at each sub-counter can differ based on the amount of traffic entering the sub-counter as the entry to a particular sub-counter depends on how popular the food item is. Through input data modeling, it was found that about 70% of customers prefer rice to bread as the item from the first level of sub-counters. So, most of the pressure of the incoming customers go through the rice sub-counter. This load might exceed the handling capacity of the server inside the rice sub-counter. During experiment, the system was simulated with all sub-counters having one server and the performance was measured. If it was seen that the configuration resulted in larger queue length and consequently highly increasing queuing delay, the number of servers in that sub-counter was increased by one and the simulation was done again. This was done preceding any proper experimentation with the input variables to have a comparable starting point.

After adjusting the starting values of the number of servers, the $2^k$ factorial design was applied for the factors evaluation interval and minimum food threshold, and their expected main effects and interaction effects were taken into consideration for choosing the best configuration. Since the number of servers is not too small, the experiment was done on the maximum output of all the servers to get the worst case scenario.

## 7 Results and Discussion

The experiment was conducted to simulate the cafeteria at a worst case scenario in terms of traffic. All the configurations were simulated at the arrival mean of 1.4 minutes and the service mean of 0.4 minutes.

### 7.1 Experimentation protocol

The first phase of the experiment was carried out where the optimum number of servers for each sub-counter were determined. The first simulation was conducted with all sub-counters having a single server (Configuration 1). Table 1 shows the performance of all the servers with an evaluation interval of 8 minutes and a minimum food level threshold equal to the maximum amount per customer in terms of maximum queue length for configuration 1 and table 2 shows the same in terms of average server utilization. It is evident from the tables that some servers were overloaded and reached queue length as high as 38. Figure 7 shows a gradual rise of maximum queue length with average server utilization.

For the next configuration (Configuration 2), sub-counters 0-0-0, 0-1-0 and 0-4-0 were given two servers whereas all the other sub-counters were given one server. Table 3 shows the maximum queue length of all the servers in configuration 2. The load in this configuration was distributed evenly between the servers in each sub-counter and the variance was greatly reduced.

As the performance of configuration 2 was chosen for performing the $2^k$ factorial analysis and the next phase of the experiment with $k = 2$ factors were carried out using the design matrix given in table 4. The major and interaction effects and their expected average over all the servers can be found in the tables 5 through 8. Analysing the effects, it was found that the minimum food threshold is the most affecting of the two factors and their combined effect.

Changing the minimum food threshold from the maximum amount of food per customer to twice the maximum amount of food per customer increased the average server utilization by around 2%, while decreasing the average food level by around 16.5 units. But this change increased average service delay per customer by 0.42 minutes. Conversely, increasing the evaluation interval from 8 minutes to 13 minutes decreased the average service delay by 0.27 minutes while increasing average food level and average server utilization slightly.

Based on the results, the best configuration was the configuration 2 (+-) with minimum food threshold as the maximum amount of food per customer and an evaluation interval of 13 minutes. The overall performance of the model in this configuration can be found in table 9 and the graphical form can be found in figure 3.

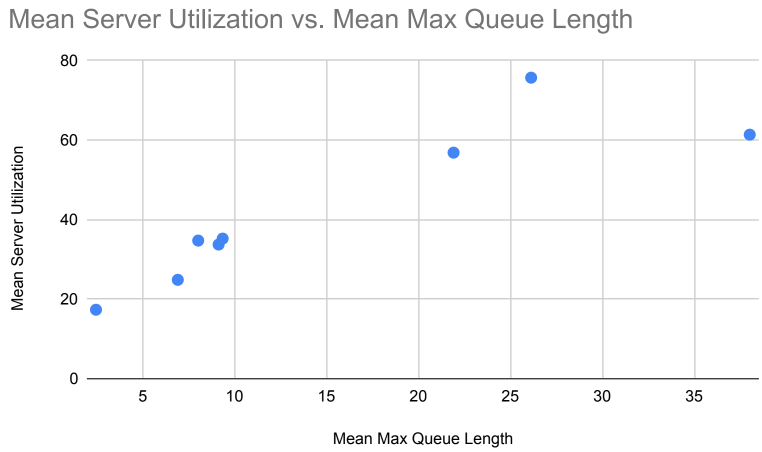


Figure 7: Mean Average Server Utilization vs Mean Maximum Queue Length plot for all servers in Configuration 1

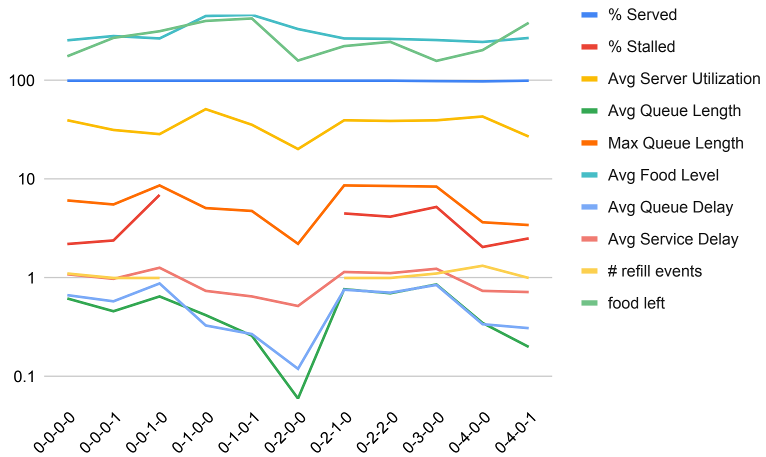


Figure 8: Overall performance of Configuration 2 (+-) plotted from Table 9

| Maximum Queue Length (Configuration 1) | | | | |
|---|---|---|---|---|
| Server | Mean | S.D. | CI (-) | CI (+) |
| 0-0-0-0 | 38.00 | 11.72 | 30.74 | 45.26 |
| 0-0-1-0 | 6.89 | 1.76 | 5.80 | 7.98 |
| 0-1-0-0 | 26.11 | 11.69 | 18.87 | 33.36 |
| 0-2-0-0 | 2.44 | 0.53 | 2.12 | 2.77 |
| 0-2-1-0 | 9.33 | 4.18 | 6.74 | 11.93 |
| 0-2-2-0 | 8.00 | 4.61 | 5.14 | 10.86 |
| 0-3-0-0 | 9.11 | 3.76 | 6.78 | 11.44 |
| 0-4-0-0 | 21.89 | 4.81 | 18.91 | 24.87 |

Table 1: Average of maximum queue length of all the servers for configuration 1 over 10 replications.

| Average Server Utilization (Configuration 1) | | | | |
|---|---|---|---|---|
| Server | Mean | S.D. | CI (-) | CI (+) |
| 0-0-0-0 | 61.36 | 6.51 | 57.32 | 65.39 |
| 0-0-1-0 | 24.85 | 3.98 | 22.39 | 27.32 |
| 0-1-0-0 | 75.69 | 9.50 | 69.80 | 81.58 |
| 0-2-0-0 | 17.33 | 3.48 | 15.18 | 19.48 |
| 0-2-1-0 | 35.22 | 6.69 | 31.07 | 39.37 |
| 0-2-2-0 | 34.72 | 6.74 | 30.54 | 38.90 |
| 0-3-0-0 | 33.73 | 3.30 | 31.68 | 35.77 |
| 0-4-0-0 | 56.84 | 5.01 | 53.73 | 59.94 |

Table 2: Average server utilization percentage of all the servers for configuration 1 over 10 replications.

### 7.2 Data tables

### 7.3 Discussion

The flexibility of this experiment resulted in a vast amount of data which were composed of both beneficial and noisy attributes. Choosing which data to use was one of the major difficulty of the experiment. The techniques used in this experiment were covered in the theory classes of the course but there was lack of practical examples to use for guidance throughout the project. The results found were satisfactory and comparable to the real world scenario. The simulation model produced for this project had a lot of features and could be extended for a number of scenario with minimal changes.

## 8 Conclusion

The goal of this experiment was to find a suitable cafeteria configuration for the system matching a real life cafeteria. The input data provided to the model were inspired from real life and the

| Maximum Queue Length (Configuration 2) | | | | |
|---|---|---|---|---|
| Server | Mean | S.D. | CI (-) | CI (+) |
| 0-0-0-0 | 6.22 | 1.30 | 5.42 | 7.03 |
| 0-0-0-1 | 5.67 | 1.22 | 4.91 | 6.43 |
| 0-0-1-0 | 10.22 | 5.52 | 6.80 | 13.64 |
| 0-1-0-0 | 5.44 | 1.59 | 4.46 | 6.43 |
| 0-1-0-1 | 5.11 | 1.45 | 4.21 | 6.01 |
| 0-2-0-0 | 2.44 | 0.53 | 2.12 | 2.77 |
| 0-2-1-0 | 10.00 | 4.50 | 7.21 | 12.79 |
| 0-2-2-0 | 9.89 | 4.43 | 7.14 | 12.63 |
| 0-3-0-0 | 9.33 | 3.50 | 7.16 | 11.50 |
| 0-4-0-0 | 5.22 | 1.64 | 4.20 | 6.24 |
| 0-4-0-1 | 5.00 | 1.66 | 3.97 | 6.03 |

Table 3: Average of maximum queue length of all the servers for configuration 2 over 10 replications.

| Design Matrix for $2^2$ factorial design | | | |
|---|---|---|---|
| Design Point | e | m | e$\times m$ |
| 1 | - | - | + |
| 2 | + | - | - |
| 3 | - | + | - |
| 4 | + | + | + |

Table 4: Design matrix of $2^2$ factorial design on evaluation interval (e) and minimum food threshold (m) used in experimentation.

| Average Server Utilization | | | |
|---|---|---|---|
| Server | $e_e$ | $e_m$ | $e_{em}$ |
| 0-0-0-0 | -0.42 | 0.84 | -0.85 |
| 0-0-0-1 | 0.24 | 0.76 | 0.68 |
| 0-0-1-0 | -0.01 | 0.81 | -0.01 |
| 0-1-0-0 | 0.01 | -0.20 | -0.19 |
| 0-1-0-1 | -0.04 | 4.43 | 0.16 |
| 0-2-0-0 | 2.95 | 3.09 | -2.96 |
| 0-2-1-0 | -0.01 | 3.46 | -0.01 |
| 0-2-2-0 | -0.01 | 6.08 | -0.01 |
| 0-3-0-0 | -0.02 | 3.39 | -0.02 |
| 0-4-0-0 | 1.76 | 0.04 | -0.58 |
| 0-4-0-1 | -0.63 | -0.29 | 1.37 |
| Expectation | 0.35 | 2.04 | -0.22 |

Table 5: Expected effect over average server utilization of all servers.

protocol used were made as realistic as possible. From this model, the optimum number of servers per sub-counter was found which was discussed in the result section. It was seen that after setting up the optimum number of servers, the percentage of served customers reached 100%. As all the customers were passing through most of the levels of the cafeteria, the load were shared by the sub-counters according to the assigned probability, which were further divided as the number of

| Average Queue Length | | | |
|---|---|---|---|
| Server | $e_e$ | $e_m$ | $e_{em}$ |
| 0-0-0-0 | -0.27 | 0.35 | -0.03 |
| 0-0-0-1 | -0.36 | 0.43 | -0.24 |
| 0-0-1-0 | -0.28 | 0.12 | 0.13 |
| 0-1-0-0 | -0.01 | 0.02 | 0.00 |
| 0-1-0-1 | -0.02 | 0.05 | 0.00 |
| 0-2-0-0 | 0.01 | 0.02 | -0.01 |
| 0-2-1-0 | -0.77 | 1.28 | -0.43 |
| 0-2-2-0 | -0.81 | 1.22 | -0.43 |
| 0-3-0-0 | 0.06 | 0.47 | 0.16 |
| 0-4-0-0 | -0.13 | 0.24 | 0.03 |
| 0-4-0-1 | -0.16 | 0.28 | -0.05 |
| Expectation | -0.25 | 0.41 | -0.08 |

Table 6: Expected effect over average queue length of all servers.

| Average Food Level | | | |
|---|---|---|---|
| Server | $e_e$ | $e_m$ | $e_{em}$ |
| 0-0-0-0 | 11.74 | -20.98 | 0.14 |
| 0-0-0-1 | 7.45 | -23.44 | 7.77 |
| 0-0-1-0 | 8.33 | -4.02 | -0.80 |
| 0-1-0-0 | -0.40 | -3.84 | -0.15 |
| 0-1-0-1 | -0.13 | -7.67 | 0.06 |
| 0-2-0-0 | -14.65 | -47.17 | 13.57 |
| 0-2-1-0 | 11.81 | -19.53 | 4.70 |
| 0-2-2-0 | 7.12 | -11.78 | 0.63 |
| 0-3-0-0 | -2.88 | -17.10 | -4.30 |
| 0-4-0-0 | -0.83 | -24.36 | 4.76 |
| 0-4-0-1 | 6.28 | -1.68 | 2.10 |
| Expectation | 3.08 | -16.51 | 2.59 |

Table 7: Expected effect over average food level of all servers.

| Average Service Delay | | | |
|---|---|---|---|
| Server | $e_e$ | $e_m$ | $e_{em}$ |
| 0-0-0-0 | -0.27 | 0.32 | 0.00 |
| 0-0-0-1 | -0.45 | 0.52 | -0.32 |
| 0-0-1-0 | -0.35 | 0.17 | 0.18 |
| 0-1-0-0 | -0.02 | -0.03 | -0.01 |
| 0-1-0-1 | -0.01 | 0.11 | 0.02 |
| 0-2-0-0 | -0.01 | 0.00 | 0.02 |
| 0-2-1-0 | -0.76 | 1.40 | -0.41 |
| 0-2-2-0 | -0.77 | 1.13 | -0.39 |
| 0-3-0-0 | 0.05 | 0.46 | 0.13 |
| 0-4-0-0 | -0.09 | 0.18 | 0.06 |
| 0-4-0-1 | -0.25 | 0.40 | -0.09 |
| Expectation | -0.27 | 0.42 | -0.07 |

Table 8: Expected effect over average service delay of all servers.

| Server | % Ser. | % Stal. | A.S.U. | A.Q.L. | M.Q.L. | A.F.L. | A.Q.D. | A.S.D | Refill | R.F.L |
|---|---|---|---|---|---|---|---|---|---|---|
| 0-0-0-0 | 100.00 | 2.21 | 39.71 | 0.62 | 6.11 | 256.51 | 0.67 | 1.09 | 1.11 | 176.69 |
| 0-0-0-1 | 100.00 | 2.40 | 31.65 | 0.46 | 5.56 | 283.35 | 0.58 | 0.98 | 1.00 | 271.56 |
| 0-0-1-0 | 100.00 | 6.95 | 28.71 | 0.65 | 8.67 | 267.93 | 0.88 | 1.27 | 1.00 | 317.01 |
| 0-1-0-0 | 100.00 | 0.00 | 51.44 | 0.42 | 5.11 | 452.16 | 0.33 | 0.74 | 0.00 | 403.22 |
| 0-1-0-1 | 100.00 | 0.00 | 35.73 | 0.26 | 4.78 | 464.26 | 0.27 | 0.65 | 0.00 | 427.11 |
| 0-2-0-0 | 100.00 | 0.00 | 20.28 | 0.06 | 2.22 | 333.58 | 0.12 | 0.52 | 0.00 | 159.94 |
| 0-2-1-0 | 100.00 | 4.51 | 39.68 | 0.77 | 8.67 | 267.82 | 0.76 | 1.15 | 1.00 | 224.01 |
| 0-2-2-0 | 100.00 | 4.18 | 39.06 | 0.70 | 8.56 | 265.44 | 0.71 | 1.12 | 1.00 | 247.39 |
| 0-3-0-0 | 98.98 | 5.25 | 39.63 | 0.86 | 8.44 | 258.02 | 0.85 | 1.24 | 1.11 | 158.69 |
| 0-4-0-0 | 98.34 | 2.06 | 43.34 | 0.35 | 3.67 | 246.72 | 0.34 | 0.74 | 1.33 | 204.03 |
| 0-4-0-1 | 100.00 | 2.52 | 27.12 | 0.20 | 3.44 | 270.98 | 0.31 | 0.72 | 1.00 | 385.84 |

Table 9: Average performance of Configuration 2 (+-) over 10 replications. Refer to section 3.4 for full name of attributes

servers increased in the sub-counter. The criteria used to get the optimum number of servers were the maximum queue length and the average server utilization which had positive correlation with each other. By providing 2 servers for the sub-counters suffering from avalanche effect due to huge load of customers, the maximum queue length reduced down to 10 which is a reasonable queue length considering most of the servers had queue length less than 6. This gave the confidence to proceed to the next phase of the experiment.

In the second phase of experimentation, the effect of two factors i.e. evaluation interval and minimum food threshold were observed through $2^2$ factorial design which showed that minimum food threshold had more impact on the output variables. Further analysis showed that increase in evaluation interval had positive impact on the performance while increasing minimum food threshold had negative impact on the performance. Overall best performance was achieved with an evaluation interval of 13 minutes and a minimum food threshold equal to the maximum food amount taken by a customer. These values combined with the findings of the first phase of the experiment gave the best configuration for the cafeteria system model.

The outputs from the second phase of experimentation were very close to each other and the changes could be considered negligible compared to the results of the first phase. From an economical point of view, changing from configuration 1 to configuration 2 costs considerably more as more servers are added which also includes associated stuff for service. Configuration 1 is more economical but results is longer queues and lower service rate which affects the customer satisfaction ratio. It might be possible to implement a system somewhere in the middle of configuration 1 and configuration 2 that balances out both sides of the situation. Moreover, for some intermediate values of the factors used in the second phase of experiment there might be better results than the one proposed, but as it was seen that the changes were insignificant compared to the results of the first phase.

# References

[1] A. M. Law, W. D. Kelton, and W. D. Kelton, *Simulation modeling and analysis.* Mcgraw-hill New York, 2007, vol. 3.

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