Modeling and Simulation of Queuing Systems Using Arena Software: A Case Study

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Modeling and Simulation of Queuing Systems Using Arena Software: A Case Study

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Abstract **- This paper includes a simulation model for KSU Main Student Restaurant that built using Arena simulation software. We proposed some performance measures to be evaluated for our case study, which is the average waiting time in system and the average number of students in queues. The system faced a big pressure in the first hour of serving the lunch, a slightly pressure in the second hour and we can say there is no pressure on the system in the last hour.**
We used Arena simulation software to build a simulation model and after that, we analyzed the output from the simulation program results and applying "what if" analysis to produce a group of alternatives (scenarios). We ranked these alternatives to choose the best alternative to improve the efficiency of our system to get better service quality during rush hours. We used Arena Process Analyzer to rank and select the best scenario beside the D&D procedures for ranking and selecting the best alternative, which we will explain it latter in details. At the end, we describe some recommendations and future work as the last part of our study.

Index Terms - Queuing systems, KSU student restaurant, Arena software, Arena process analyzer, D&D procedure.

I. Introduction

Simulation is the imitation of the operation of a real-world process or system over time [1]. Simulation A descriptive technique that enables a decision maker to evaluate the behavior of a model under various conditions [2]. The act of simulating something first requires that a model be developed; this model represents the key characteristics or behaviors of the selected physical or abstract system or process [3]. The model represents the system itself, whereas the simulation represents the operation of the system over time [4].

Simulation is used in many contexts, such as simulation of technology for performance optimization, safety engineering, testing, training, education, and video games [1]. Training simulators include flight simulators for training aircraft pilots to provide them with a lifelike experience [5]. Simulation is also used with scientific modeling of natural systems or human systems to gain insight into their functioning. Simulation can be used to show the eventual real effects of alternative conditions and courses of action [6]. Simulation is also used when the real system cannot be engaged, because it may not be accessible, or it may be dangerous or unacceptable to engage, or it is being designed but not yet built, or it may simply not exist [6].

A computer simulation (or "sim") is an attempt to model a real-life or hypothetical situation on a computer so that it can be studied to see how the system works [1]. By changing variables in the simulation, predictions may be made about the behavior of the system. It is a tool to virtually investigate the behavior of the system under study.

Simulation can be defined as a series of "what-if" type experiments are carried out on the simulation model. Therefore, simulation has a wide range of applications [6]. Here we want to use the simulation to study and analyze the system in The Main KSU Restaurant, especially the Queuing System and this study will be done to reduce the waiting time of the customers in our system.

II. Problem Definition

A. Problem Statement

The main problem in our system is the waiting time in the system during specific period times (at Lunch) every day except Thursday. Because of the long waiting time in system in rush hours sometimes the queue reach outside the main gates of the restaurant.

B. Objective

The objective of our study is to model and analyse the system during rush hours in **The Main KSU Restaurant** using **Arena** simulation software for reducing **The Waiting Time in System** to produce a group of alternatives that may improve the efficiency of the system to get better service quality during rush hours.

C. System Description

The Main KSU Restaurant has two floors. The first floor consist of four identical lines that each line has a single queue and in second floor there is a small line serving a special meal named Combo (Fast food). The Kitchen and Toilets are in the first floor and there are two sitting areas in each floor. The layout can be seen in Fig. 1.

The line consist of four parts, first part is a self-service part contains a small menu consist of Salad, Desert, Fruits, Yogurt, and Laban etc. The student get in this part choose whatever he wants and move to the second part which is a food-service part with two servers and a menu of rice, meat or fish, chicken, soups or whatever the menu consist of each day because it is changed every day to deliver a verity menu to the student weekly. In the second part of the line, the first server serves the rice only and the second server serve the rest of the menu, after the student finished his service in the food-service part he moves directly to the third part of the line, which is a self-service part again. In this part, the student can take Bread, Cold Drink, Spoons, Ketchup, Salt or Pepper. However, for Cold Drink, not all the students take it and also there is no blocking in this part of the line. If a student take a lot of time to choose any thing, the follow students can leave him and walk forward to the last part, which is the cahier area. Nevertheless, in first and second parts of the line there is blocking.

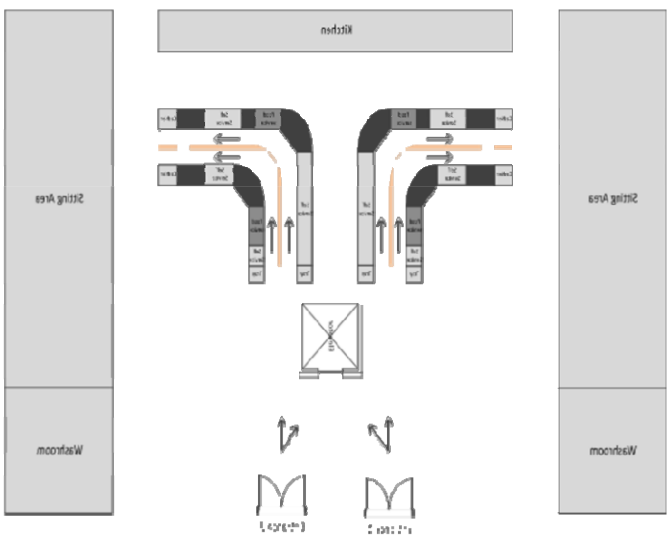

Fig. 1 KSU Restaurant Layout.

In the last part (Cashier area), the cashier ask for the student's ID and count the number of the items that student chosen, because there is a limit of six items for each student on the lunch meal and the student should pay the regular price 2 SR for the meal.

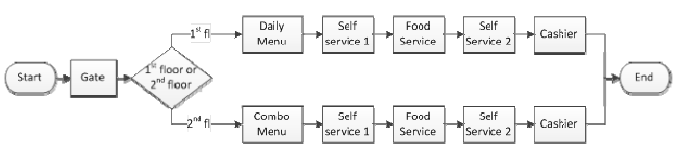

Fig. 2 Process Chart.

However, if the student choose more than six items he will pay extra money for the extra items and it will be without the university discount or insurance. And in the layout of the first floor, the outlet of the 1st and 2nd lines goes to the first sitting area, and the outlet for the 3rd and 4th lines it goes to the second area sitting. That means that lines 1 and 2 share the same outlet and the same for lines 3 and 4, and the students in the cashier area for lines 1 and 2 can take cashier 1 or 2 depends on the number in queue for each cashier and the same for students in lines 3 and 4.

III. Model Building

As mentioned previously, the Main KSU Restaurant is a queuing system. It is a system consist of four identical service lines in first floor and one service line in second floor, each line consist of four parts as described previously.

Students who arrive to the restaurant select one of the two sections (first or second floor), and in first floor they also select one of the two areas (Area 1, line 1 and 2 – Area 2, line 3 and 4). If all the lines in each section or area are busy that means there are students in service so the student will wait in the queue, in front of any line of the five lines in the system.

The Main KSU Restaurant characterized by three components: the arrival process, the service mechanism and the queue discipline. The arrival process is a description of how students arrive to the system. If we assume that Ai be the interarrival time between $(i-1)^{th}$ and i^{th} arrivals of students ($A_i = t_i - t_{i-1}$, where t_i is time of arrival of i^{th} student). If A_1, A_2 , ... are assumed to be IID random variables, we shall denote the mean interarrival time by $E(A)$ and we call $\lambda = 1/E(A)$ the arrival rate of students.

The service mechanism for the system is expressed by specifying the number of servers and the probability distribution of student's service times. Let S_i be the service time of the i^{th} arriving student. If S_1 , S_2 , ... are IID random variables, we shall denote the mean service time by $E(S)$ and we call $\mu = 1/E(S)$ the service rate of a server.

The queue discipline of the Main KSU Restaurant refers to the rule First in First out (FIFO) and each line has his own queue. The distribution of the service times (S_i) need to be specified for each part of service in each line (Self-service part 1 , 2 and the two servers in food service part, for each line). Also, the distribution of interarrival time (A_i) needs to be specified for the system. And that what will be done in the following section of the project (Data Gathering and Test).

IV. Data Gathering and Test

Data were collected over a period of 6 days (all the day accept Thursday) in 5 weeks. Data were collected on inter-arrival times (in seconds) for two periods from 12:00 to 1:00 pm, which is the rush hour period.

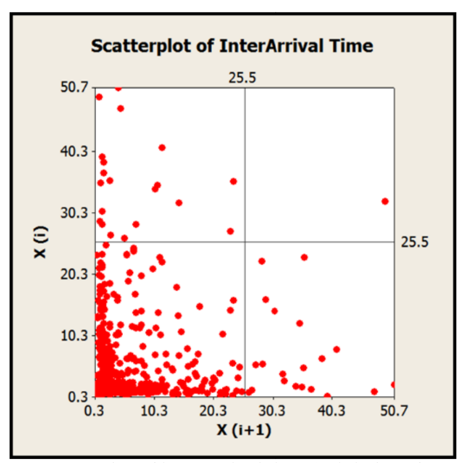

Fig. 3 Scatterplot of inter-arrival time (Minitab Software).

Proposed inputs data are as follows: Time between arrivals for the students, percentage of the students goes second floor, percentage of the students chooses first or second area in first floor, and percentage of the students takes cold drink. And for service times: Time of service in the first self-service part in each line, service time for each one of the two servers in food-service part in each line, time of service in third part of the lines (second self-service), and service time for cahier in each line.

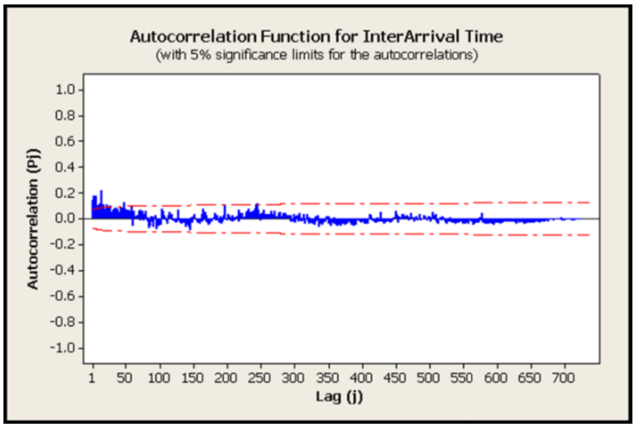

Fig. 4 Correlation plot for inter-arrival time (Minitab Software).

The data collected tested and summarized in a meaningful way that would allow us to determine the associated distributions of arrival and service times which is the inputs of our simulation model. The data were tested using scatter diagram, correlation plot, and Chi Square and Kolmogorov Smirnov tests. Minitab, and Arena input analyser softwares used to do so. One of the tests listed in Fig. (3-6), and the rest are summarized in Table III.

Distribution Summary	
Distribution:	Lognormal
Expression:	LOGN(4.43, 7.42)
Square Error:	0.005996
Chi Square Test	
Number of Intervals	6
Degrees of freedom	3
Test Statistic	66.2
Corresponding p-value	< 0.005
Kolmogorov-Smirnov Test	
Test Statistic	0.116
Corresponding p-value	< 0.01
Data Summary	
Number of Data Points	738
Min Data Value	0.3
Max Data Value	50.7
Sample Mean	4.83
Sample Std Dev	7.37
Histogram Summary	
Histogram Range	= 0 to 51
Number of Intervals	13

Fig. 5 Correlation plot for inter-arrival time Arena input analyzer).

V. Simulation Model Building and Description

As we describe before – in System Description section – the flow chart for our system can be as in Fig. 7. Fig. 8 shows the Arena Model for our system. Entities to be model in this system are the students and as we mentioned in System Description we analyzed the system at lunch period, which is, begin at 12pm through 3pm. The rush hour is from 12 to 1 pm, after 1 pm the system seems to be normal or we can say there is no rush.

TABLE I

Estimation of Parameters, Goodness of fit tests

Proposed inputs data		**Distribution**	**Expression**
Time between Arrivals (In the rush hour)		Lognormal	LOGN(4.43,7.42)
Time between Arrivals (After the rush hour)		Gamma	GAMM(18.5,0.712)
Cashier of Line1		Lognormal	LOGN(12.6,5.7)
Cashier of Line2		Lognormal	LOGN(17.2,7.91)
Cashier of Line3		Gamma	GAMM(2.93,4.83)
Cashier of Line4		Lognormal	LOGN(12.8,5.58)
Cashier of Combo Line		Lognormal	LOGN(12.4,6.66)
Line1 Food Server1		Lognormal	1+LOGN(9.29,5.98)
Line1 Food Server2		Gamma	1+GAMM(3.64,2.99)
Line2 Food Server1		Gamma	1+GAMM(3.12,4.07)
Line2 Food Server2		Erlang	1+ERLA(3.74,3)
Line3 Food Server1		Gamma	1+GAMM(2.7,2.27)
Line3 Food Server2		Lognormal	1+LOGN(10,6.39)
Line4 Food Server1		Lognormal	1+LOGN(8.92,6.05)
Line4 Food Server2		Erlang	1+ERLA(2.53,4)
Combo Line Food Server		Gamma	1+GAMM(5.09,2.53)
Self Service	Salads & Water	Uniform	UNIF(17.40,28.80)
	Cold Drink	Uniform	UNIF(8.20,25.9)
	Adds & Spoons	Uniform	UNIF(8.6,18.3)

VI. Model verification and validation

Pilot runs were used to validate the model. The model was run 10 times (10 replications). The results used to verify and validate the model we built as follows:

- Process step is similar between model and real system
- Compiler in program was used to check that program run is correct. This was known that there is no error while program execution.
- Comparing output between model and real system.
  - Comparison with Expert Opinion.
  - Using statists:

TABLE I

Verification and validation results

Experiment	Sample Mean (Real System)	Sample Mean (Simulation Model)	Difference
Line 1	8.4165	7.2812	1.1353
Line 2	9.3650	8.8469	0.5181

The results show that the model we built was a good represent for the real system.

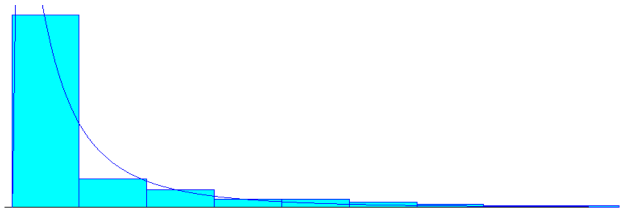

Fig. 6 Graphical representation for inter-arrival time (Arena input analyzer).

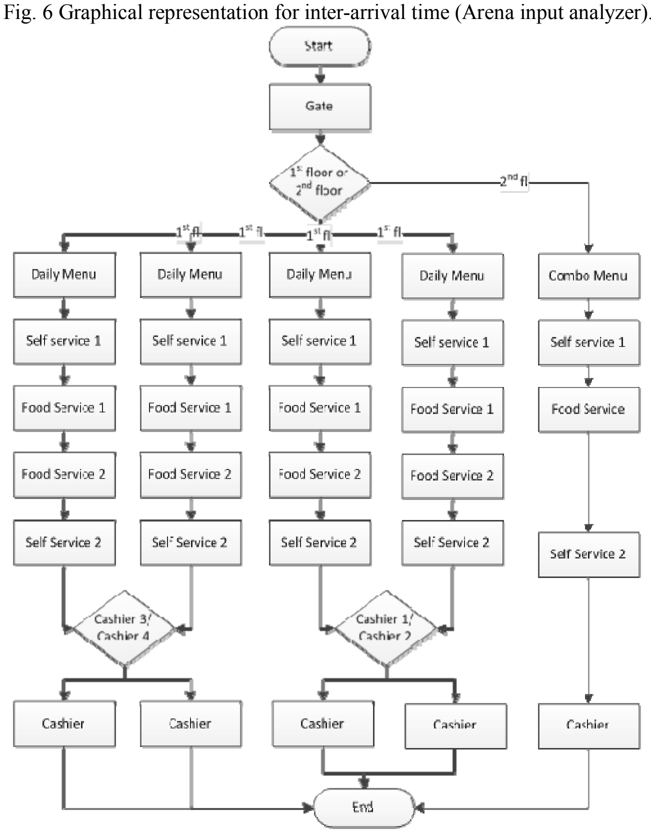

Fig. 7 Process flow chart.

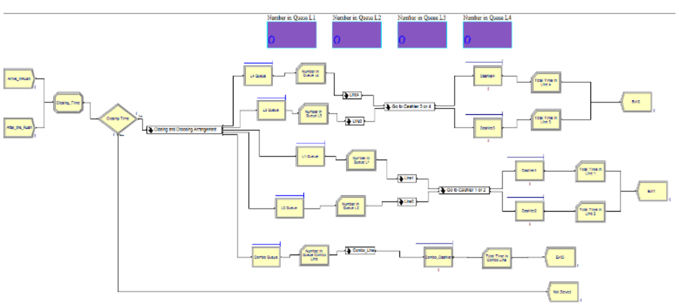

Fig. 8 Arena model.

VII. Results and Discussion

A. Estimate Means – Obtaining a specific precision

At the end of the simulation, the number of replications should be done to get good results. Relative error ( ) and level of confidence were considered to determine the number of replications. In this project, 0.2 relative error and 95% level of confidence was used. The equations below were used to calculate the number of replications [6].

$$\bar{X}(n) = \frac{\sum_{i=1}^{n} X_i}{n} \quad ; \quad S^2(n) = \frac{\sum_{i=1}^{n}(X_i - \bar{X}(n))^2}{n-1}$$

$$\textit{Point of estimate}: \bar{X}(n) \pm t_{n-1,1-\alpha/2}\sqrt{\frac{S^2(n)}{n}} \quad ; \quad n_r^*(\gamma) = min\left\{ i \geq n : \frac{t_{i-1,1-\alpha/2}\sqrt{\frac{S^2(n)}{i}}}{|\bar{X}(n)|} \leq \gamma' \right\}$$

Where: $\gamma' = \gamma/_{1+\gamma}$, for this study: $\gamma' = 0.2/_{1+0.2} =$ 1.6667.

The maximum number of replications was 52, which was for the number in queue for line 4. With the minimum 52 number of replications, the model then simulated with 60 numbers of replications. The data obtained then used in the calculations to get the estimated mean. The results of the estimated means for the proposed performance measures were as follows:

- Time in system: we can claim with approximately 95 percent confidence interval that E(X) is contained in the interval [5.77, 7.49] unit.
- Number in queue1: we can claim with approximately 95 percent confidence interval that E(X) is contained in the interval [0, 35.98] units.
- Number in queue2: we can claim with approximately 95 percent confidence interval that E(X) is contained in the interval [3.92, 33.239] units.
- Number in queue3: we can claim with approximately 95 percent confidence interval that E(X) is contained in the interval [0, 20.237] units.
- Number in queue4: we can claim with approximately 95 percent confidence interval that E(X) is contained in the interval [0, 18.845] units.

B. Alternatives Development

The purpose of simulation is developing several alternatives to get better system. Based on the real model analysis, several alternatives was developed, which are:

- Remove second self-service (Move cold drink to first self-service; move spoon and adds after cashier)
- Combines the line one and two to be one line and line three and four to be one line based on main model.
- Combines the line one and two to be one line and line three and four to be one line based on first alternatives.
- Make line three and four operate on two hours based on main model.
- Make line three and four operate on two hours based on first alternatives.

Arena process analyser [5] and D&D (Dudewicz and Dalal) [6] procedures were used to obtain the result for each alternative.

C. Alternatives comparison

C.1 Arena process analyzer tool

We use simulation model designed by ARENA to run these alternative and by using ARENA Process Analyzer Tool with 60 replications we got these results:

- The Scenarios (Alternatives)

	S	Name	Program File	Reps	Total Time in System	Number in Queue L1	Number in Queue L2	Number in Queue L3	Number in Queue L4
	Scenario Properties				Responses				
1		Exsisting Model	6 : Existing System - by Arena.p	60	6.632	15.155	18.580	7.578	6.185
2		Alternative 1	7 : Alternative 1 - by Arena.p	60	5.920	13.983	17.378	7.066	6.259
3		Alternative 3	8 : Alternative 3 - by Arena.p	60	54.765	182.695	106.814	---	---
4		Alternative 2	7 : Alternative 2 - by Arena.p	60	55.790	184.383	108.690	---	---
5		Alternative 4	6 : Alternative 4 - by Arena.p	60	6.296	14.808	19.506	6.171	4.337
6		Alternative 5	12 : Alternative 5 - by Arena.p	60	5.596	13.751	18.322	5.789	3.987

Fig. 8 Arena process analyzer.

- The Results of comparison the scenarios: Average time in system Fig. 9, average number waiting in line1 queue Fig. 10, average number waiting in line2 queue Fig. 11, average number waiting in line3 queue Fig. 12, and average number waiting in line4 queue Fig. 13.

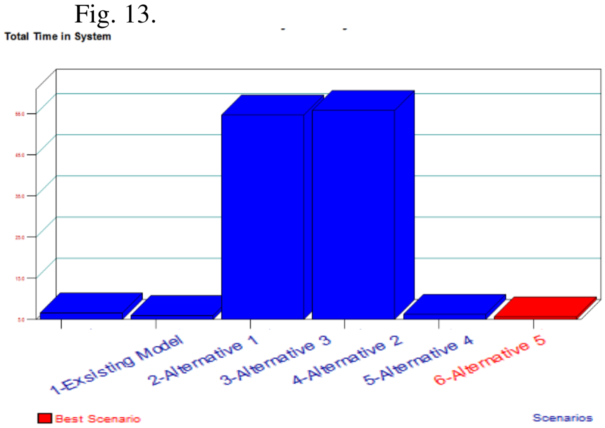

Fig. 9 Average time in system.

The Process Analyzer tool results showed that the second and third alternatives generate worst result compared with the existing model. So that, these two alternatives was not compared using D&D procedure.

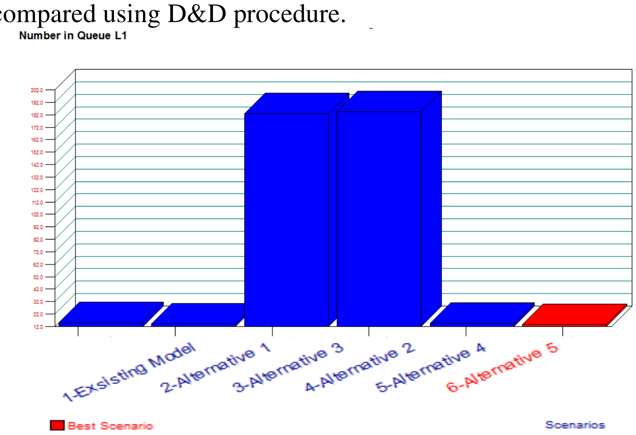

Fig. 10 Average Number Waiting in Line1

C2 D&D procedure

We ranked the alternatives and select the best alternative using the D&D procedures.

For k = 4; n0 = 60; P* = 0.90; d* = 0.5; h1=2.583; and t=2.00288

- Step 1: Define the first-stage Sample Means and Variances:

$$\bar{X}_i^{(1)}(n_0) = \frac{\sum_{j=1}^{n_0} X_{ij}}{n_0}\ ; \qquad S_i{}^2(n_0) = \frac{\sum_{j=1}^{n_0}(X_{ij} - \bar{X}_i^{(1)}(n_0))^2}{n_0 - 1}$$

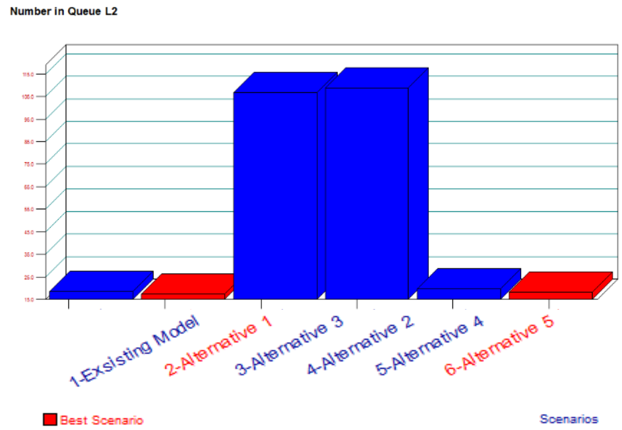

Fig. 11 Average Number Waiting in Line2

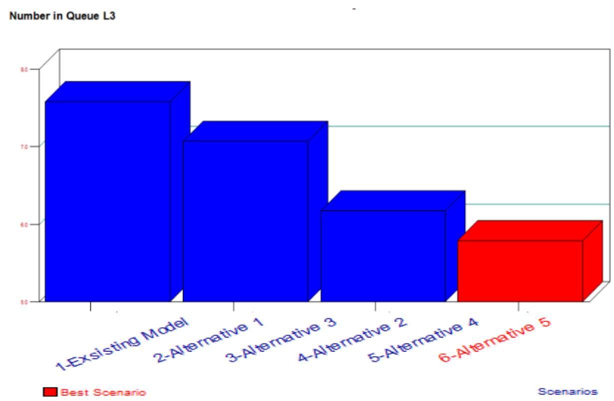

Fig. 12 Average Number Waiting in Line3

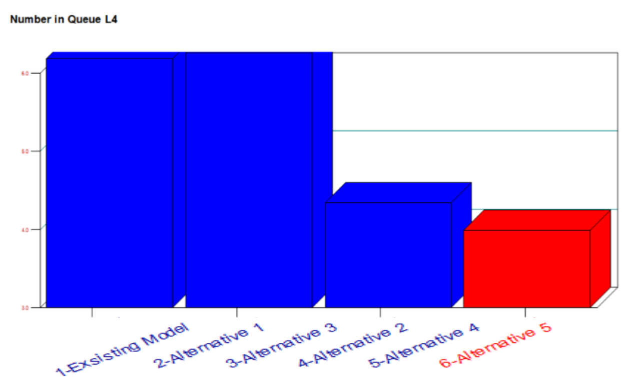

Fig. 13 Average Number Waiting in Line4

- Step 2: Compute the total sample size Ni needed for each alternative '*i*':

$$N_i = max\left\{n_0 + 1, \left\lceil \frac{h_1^2 S_1^2(n_0)}{(d*)^2} \right\rceil \right\}$$

- Step 3: We make (Ni – no) more replications of each alternative 'i' and obtain the second-stage Sample Means

$$\bar{X}_i^{(2)}(N_i - n_0) = \frac{\sum_{j=n_0+1}^{n_i} X_{ij}}{N_i - n_0}$$

- Step 4: Define the weights

$$W_{i1} = \frac{n_0}{N_i}\left[1 + \sqrt{1 - \frac{N_i}{n_0}\left(1 - \frac{(N_i - n_0)(d*)^2}{h_1^2 S_1^2(n_0)}\right)}\right]$$

$$W_{i2} = 1 - W_{i1} \ , for\ i = 1,2,\ldots,k$$

- Step 5: Define the weighted Sample Means and select the alternative with the smallest weighted mean

$$\tilde{X}_i(N_i) = W_{i1}\bar{X}_i^{(1)}(n_0) + W_{i2}\bar{X}_i^{(2)}(N_i - n_0)$$

For each alternative developed, the model was run to obtain two types of data, which are time in system and number in queue. The initial number of run is 60. The calculation results are in Table II.

- Time in system

TABLE II

D&D RESULTS FOR TIME IN SYSTEM

k	$X_i^{(1)}$ (n_0)	S_i^2 (n_0)	N_i	$X_i^{(2)}$ (N_i-n_0)	W_{i1}	W_{i2}	X
Existing	6.632	0.862	61	6.387	1.334	-0.334	6.713
Alt. 1	5.92	0.935	61	4.625	1.318	-0.318	6.331
Alt.4	6.296	0.791	61	6.994	3.95	-2.95	4.237
Alt.5	**5.596**	**1.011**	**61**	**6.125**	**3.62**	**-2.62**	**4.21**

The calculation result for time in system shows that the fifth alternative has the smallest X value. It also can be seen from the average time in system that the fifth alternative has the smallest time in system. So that, we can choose the fifth alternative, which is removing second self-service, and make line three and four operate on two hours is the best alternative to reduce customer time in system.

- Number in queue

The comparison was done by comparing each queue. The calculation results are in tables (III - VI).

TABLE III

D&D RESULTS FOR NUMBER IN QUEUE 1

k	$X_i^{(1)}$ (n_0)	S_i^2 (n_0)	N_i	$X_i^{(2)}$ (N_i-n_0)	W_{i1}	W_{i2}	X
Existing	15.155	20.826	172	14.159	0.373	0.627	14.531
Alt. 1	13.983	13.499	112	13.897	0.578	0.422	13.947
Alt. 4	14.808	16.806	139	14.389	0.856	0.144	14.748
Alt. 5	**13.751**	**16.806**	**139**	**13.757**	**0.862**	**0.138**	**13.752**

TABLE IV

D&D RESULTS FOR NUMBER IN QUEUE 2

k	$X_i^{(1)}$ (n_0)	S_i^2 (n_0)	N_i	$X_i^{(2)}$ (N_i-n_0)	W_{i1}	W_{i2}	X
Existing	18.58	14.659	121	18.059	0.519	0.481	18.329
Alt. 1	18.478	12.115	100	18.058	0.622	0.378	18.319
Alt. 4	19.506	12.936	107	18.925	1.111	-0.111	19.57
Alt. 5	**18.322**	**15.561**	**129**	**18.041**	**0.926**	**0.074**	**18.301**

From the whole calculation results in tables (II - VI), it can be seen that the fifth alternative is the best alternatives to reduce time in either system or number in queue.

TABLE V

D&D RESULTS FOR NUMBER IN QUEUE 3

k	$X_i^{(1)}$ (n_0)	S_i^2 (n_0)	N_i	$X_i^{(2)}$ (N_i-n_0)	W_{i1}	W_{i2}	X
Existing	7.578	12.66	105	4.092	0.613	0.387	6.228
Alt. 1	7.066	11.321	94	7.234	0.681	0.319	7.12
Alt. 4	6.171	9.813	81	5.72	1.466	-0.466	6.381
Alt. 5	**5.789**	**10.057**	**83**	**4.968**	**1.435**	**-0.435**	**6.145**

TABLE VI

D&D RESULTS FOR NUMBER IN QUEUE 4

k	$X_i^{(1)}$ (n_0)	S_i^2 (n_0)	N_i	$X_i^{(2)}$ (N_i-n_0)	W_{i1}	W_{i2}	X
Existing	6.186	12.66	105	5.948	0.613	0.387	6.094
Alt. 1	6.259	11.847	98	5.971	0.644	0.356	6.156
Alt. 4	4.337	5.936	61	1.899	2.06	-1.06	6.921
Alt. 5	**3.987**	**5.936**	**61**	**4.816**	**2.066**	**-1.066**	**3.104**

VIII. CONCLUSION AND RECOMMENDATIONS

The research at the main KSU restaurant finally reaches the following conclusions:

- The system consists of five lines, which is four lines are regular food menu type and one line is combo food menu.
- There is a problem in four regular food menu lines, which are big queue at rush hour at lunchtime from 12-3 pm on Saturday to Wednesday and from 1-3 pm on Friday.
- There are five alternatives developed to obtain solution for the queue problem which is:
    - Remove second self-service (Move cold drink to first self-service; move spoon and adds after cashier)
    - Combines the line one and two to be one line and line three and four to be one line based on main model.
    - Combines the line one and two to be one line and line three and four to be one line based on first alternatives.
    - Make line three and four operate on two hours based on main model.
    - Make line three and four operate on two hours based on first alternatives.
- The best alternative are the fifth alternative, which is removing second self-service and make line three and four operate on two hours. And the second best alternative is the first alternative which is removing second self-service.

- The easiest alternative is the first alternative that can be applied with the minimum effort to obtain the real result.

The recommendations for next research are:

- While doing the research, we faced limitations. Some of the limitations were:
    - The time to prepare the food
    - The lines providing technique

  In addition, maybe if we can improve one of these limitations we will get better results.
- Considering to calculation the economic factor while decide the best alternative.
- Applied the best alternatives.

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