Process simulation study of order processing at Starbucks University of Cincinnati (CCM Branch)

Submitted in partial fulfillment of the requirements of the course

BANA 7030 Simulation Modeling and Methods

By

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MS Business Analytics Candidate 2018

"On my honor, I have neither given nor received unauthorized aid in completing this academic work. This work has not been published/reported or submitted to any other university or institution for the award of any degree."

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I would also like to thank Starbucks University of Cincinnati CCM staff for granting permission to collect the data without them the project would not have been possible.

Abstract

Coffee is an important part of a student's life. It is estimated that Americans consume 3.1 kg of dry coffee per capita annually (ranking them 22nd globally), but the national coffee consumption is the highest at 971 tonnes. Coffee industry in United States is of 5.17 billion dollars. So, it should be important for any coffee outlet to carefully design their operations keeping customers at the center. During rush hours if a customer finds a long queue, and if he/she is in rush for work, they may opt to get coffee from the next outlet or may drop the idea for coffee altogether. For the outlet it means loss of business.

Contents

1. Introduction

1.1 Current Process

In this project, the attempt has been made to simulate the process of ordering coffee at a Starbucks inside the University of Cincinnati campus. The components of the system include customers who will place orders, cash counter queue where customer wait for their turn, cashier and food and beverage servers as resources processing the orders and servicing the customers. These are the components which mainly decide for how long a customer must stay in the Starbucks. Apart from these, 2 more components like the processes of (a) adding sugar/flavors to coffee (which is basically when a customer adds sugar/flavor in the coffee according to individual's taste in a nearby self-service counter) and (b) spending time in the sitting area are also added in the system, as they also prolong a customer's stay inside Starbucks.

1.2 Problem Statement

After closely observing the order processing system in Starbucks, it can be said that the easiest way in which a customer experience can be improved would be to make the customer wait for a lesser time. So, the goal of the simulation would be to come up with a simple suggestion to improve the customer overall waiting time.

1.3 Assumptions and Limitations

Limitations:

a. Since the true customer experience also depends on the overall quality of the service, thus the scope in the present project is to focus solely on operation and not on food/beverage quality. The improvement suggested in the project can't guarantee an increase in customer review ratings.
b. Only the peak hours (11:30 AM - 1:00 PM) of a weekday are considered in the model, as generally these are the times when queues are long and where the improvement can be made.

Assumptions:

Due to the limitations in simulating a system for a real world, certain assumptions were taken for making the model. Following are the assumptions:

a. Customers arrive either as individuals or in a group of size 2.
b. Customers order only once, and type of orders are limited to 4. In a real world a customer in the sitting area can come back and order again.
c. Cashier takes break in between for some time (to be considered as temporary failure of the system), so the uptime and the downtime have been assumed to be exponential distribution with mean of 33.5 minutes and 0.5 minutes respectively) and serves the customer later according to the failure rule “Wait”. Because in practice a cashier doesn’t leave the customer for his/her break. Failure duration was also recorded during data collection.

2. System and the components

2.1 System

System is described as follows: Customers arrive in Starbucks in groups of size 1 (which means customers arrive individually) or 2 and walk toward the cash counter. If the cashier is busy either taking the order of a customer ahead or is not available, customers will form queue. Upon reaching cash counter, a customer can be billed for 4 kinds of order (a) only food, (b) food with some beverages, (c) only beverages and last (d) only for the counter items. If a customer has been billed for counter items they quickly leave the Starbucks after billing and doesn't wait for any further process. Other customers then wait for their orders, upon receiving they either move towards the self-service counter where they can add sugars according to their taste (optional) or to the sitting area (optional). If a customer who wants to sit in the sitting area finds it to be full, they leave the Starbucks. Few customers who want to sit and find chairs available, spend some time (30 mins to 1 hour) in Starbucks before finally leaving.

2.2 Component Details

1. Entities: Customers arriving in groups of size 1 or 2
2. Resources: 1 cashier, 1 beverage server and 1 food server. 3 counters for self-service and 36 chairs to sit and enjoy coffee
3. Queues:
    a. Cash counter queue: FIFO; unlimited length; where customer waits for placing the order
    b. Beverage processing queue: FIFO; unlimited length; where customers' beverages are prepared by a server one by one
    c. Food processing queue: FIFO; unlimited length; where customers' food orders are processed by a server one by one
    d. Club food and beverage order queue: FIFO; unlimited length; where a customer who has ordered both food and beverage waits for his or her other order to arrive and only upon receiving both of the order he or she proceeds to the next area
    e. Self-service queue: FIFO; unlimited length; where customer waits for their turn to add sugars if all 3 of the self-service counters are occupied
    f. Chairs and table queue: 0 length limit; because generally customers don't wait or form queues for sitting area, they just leave and take their orders outside Starbucks if the sitting area is full.

3. About Data

3.1 Data Collection

The data was collected during rush hour between 11:30 – 1:00 pm at CCM Starbucks inside University of Cincinnati campus. The customers' arrival times, starting and ending times of their placing the orders, the time they received their order from the servers, their self-serving times and the time they left the system were all recorded in hh:mm:ss format. Only 30% come in groups of 2. Almost 77% order only beverages.

3.2 Fitting distribution in Input Analyzer

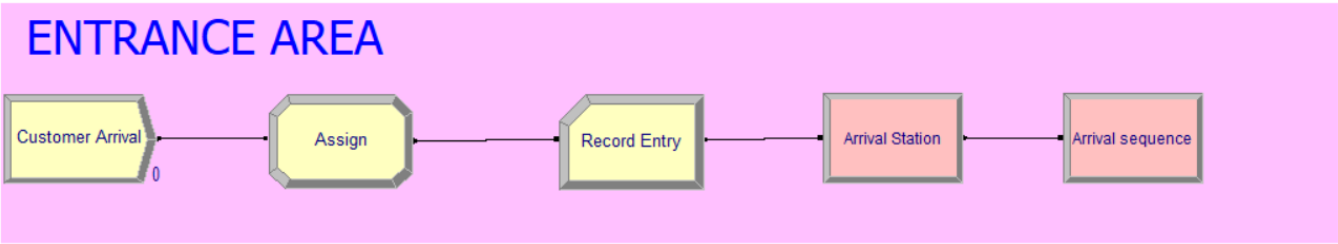
From the collected data the distribution for the different processing times were found either by using the Arena Input Analyzer or for the cases where the data points were too few (like only 3 food orders were recorded between the collection period), a Triangular distribution was used. Distribution which are used in the model are provided with more details in the appendix.

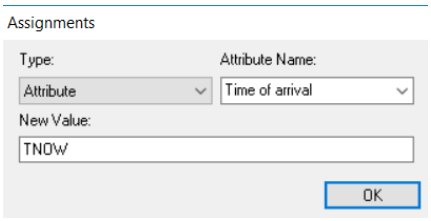
4. Arena Model

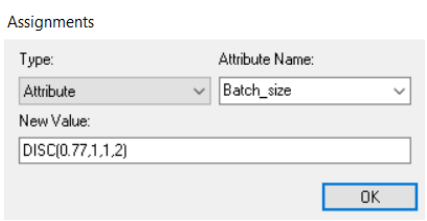
4.1 Modeling the system

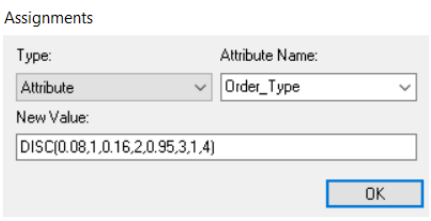
Based on the system and components discussed in section 2, below is the model in Arena which was used for simulating order processing.

I. ENTRANCE AREA: Model area where customers arrive as individuals or groups. This area records the entry time of the customers, assigns batch size and order type as their attributes.

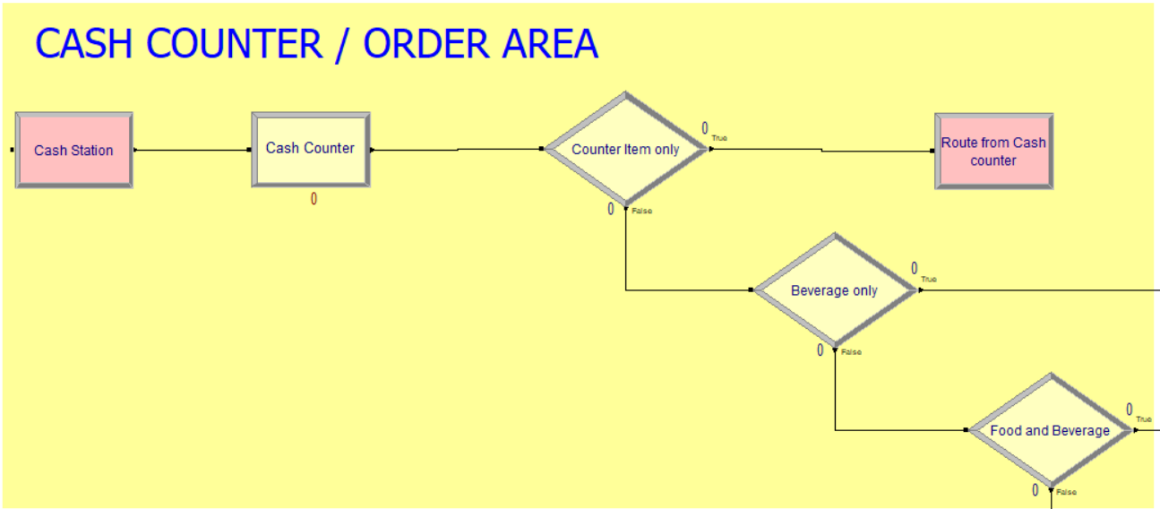


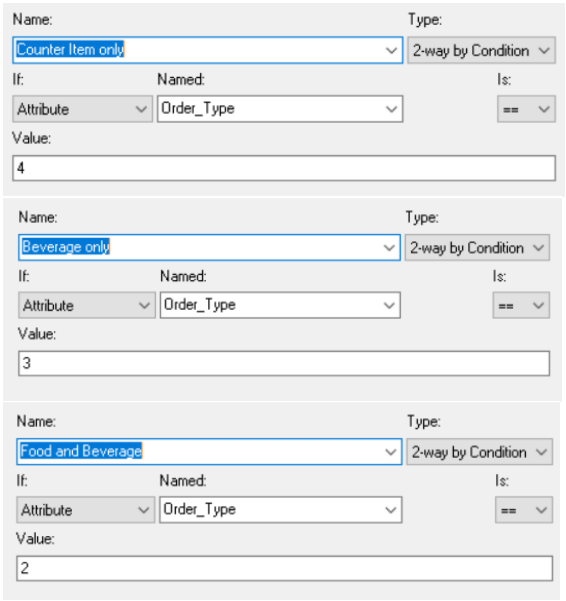


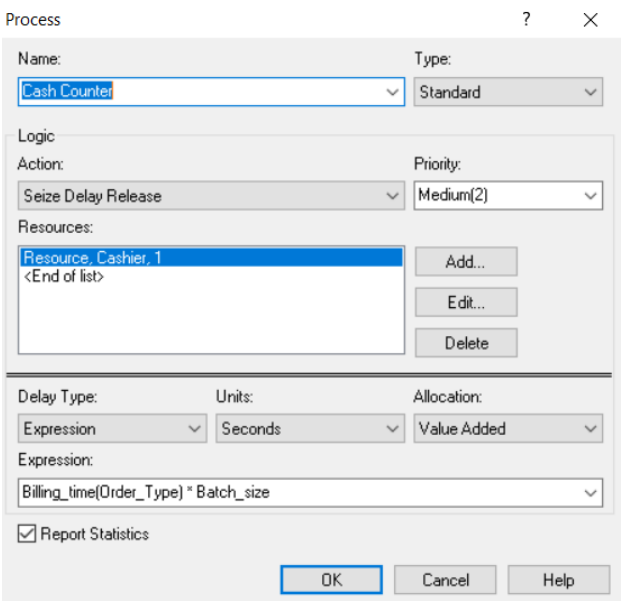




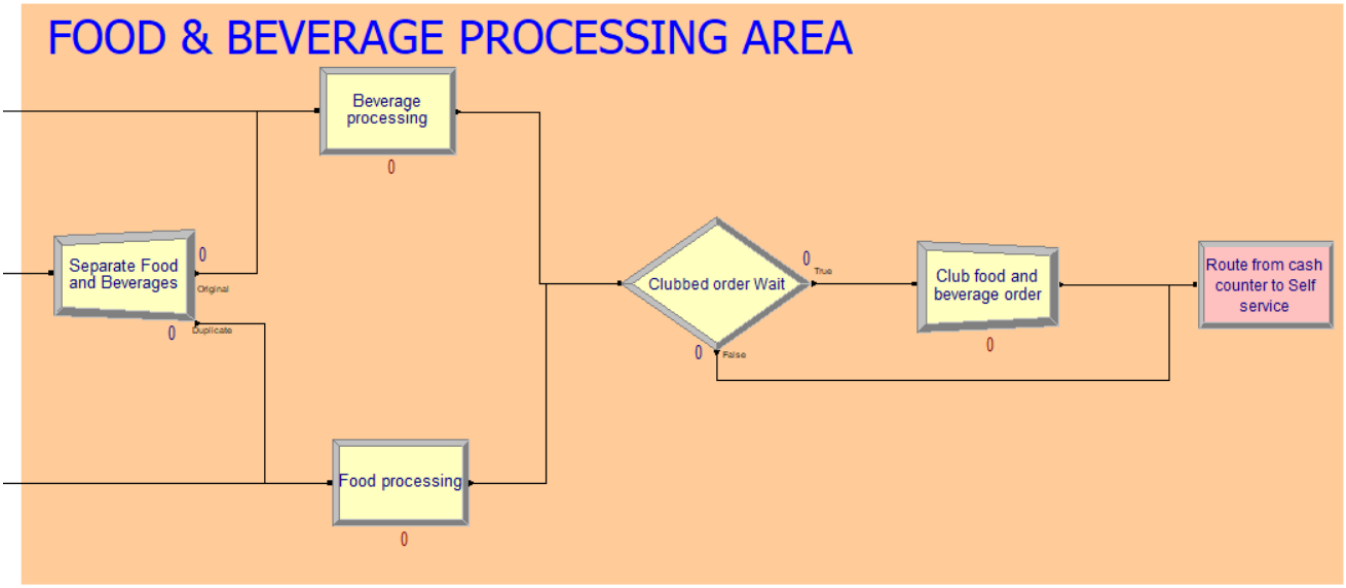
II. CASH COUNTER AREA: Here the customers arrive at the cash counter and their orders are processed by the cashier according to their order type. (For example food orders normally take a little longer and counter items are checked out quickly). Then based on the order type, they next go to Food and Beverage processing area. Processing time will be doubled if 2 customers have come together in a group.

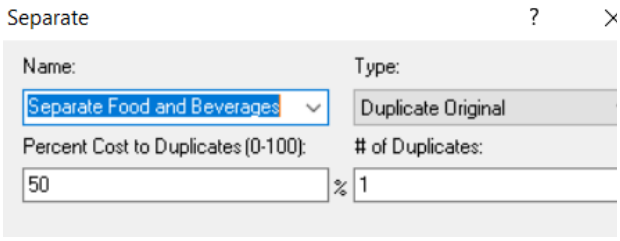


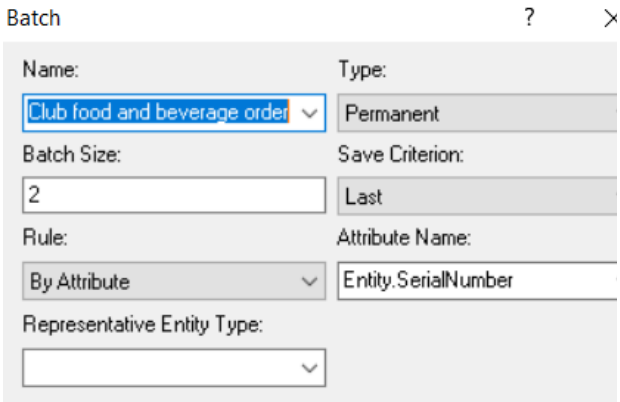


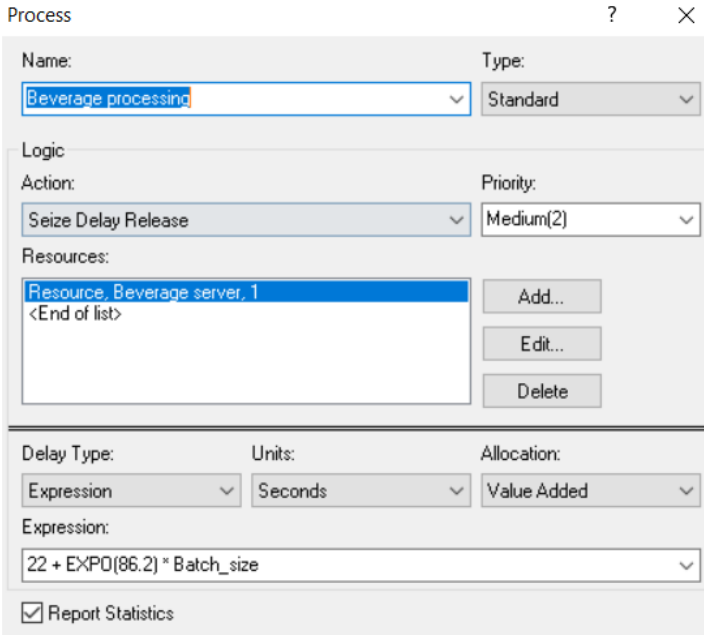


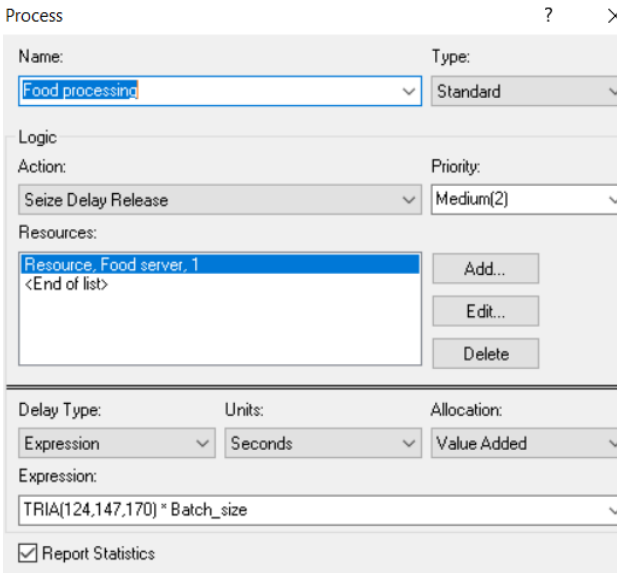
III. FOOD AND BEVERAGE PROCESSING AREA: Here the top line from the left is coming from orders which are only beverages. The next line is for orders which comprise both food and beverage and at the Separate module go to different processing units / servers because they take different amount of times in preparation. Beverage order customers directly move towards the self service station while customers having order type 2 (foor & beverage) have to wait for their 2nd order at the Batch module.

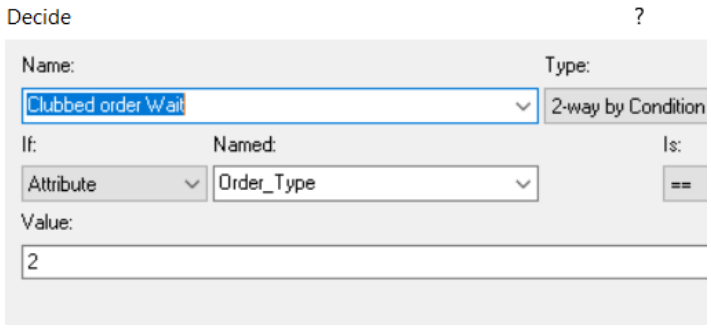




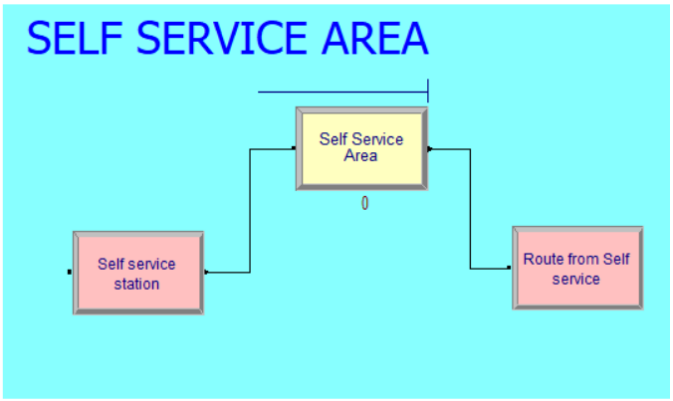


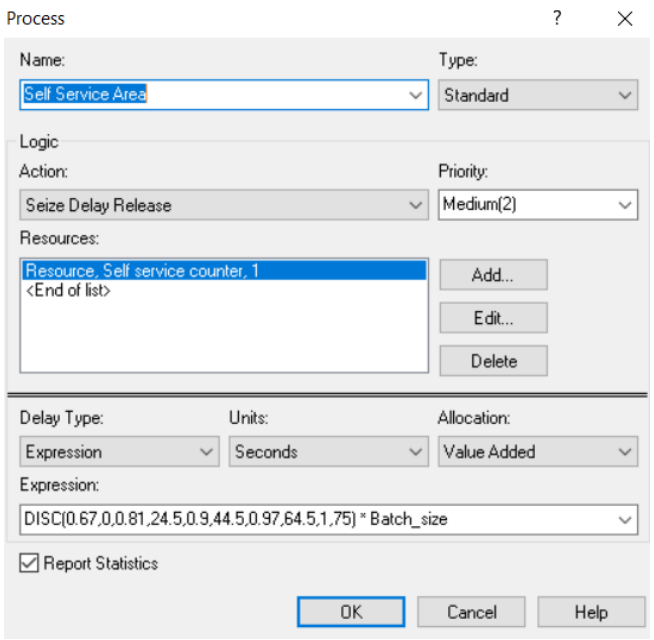




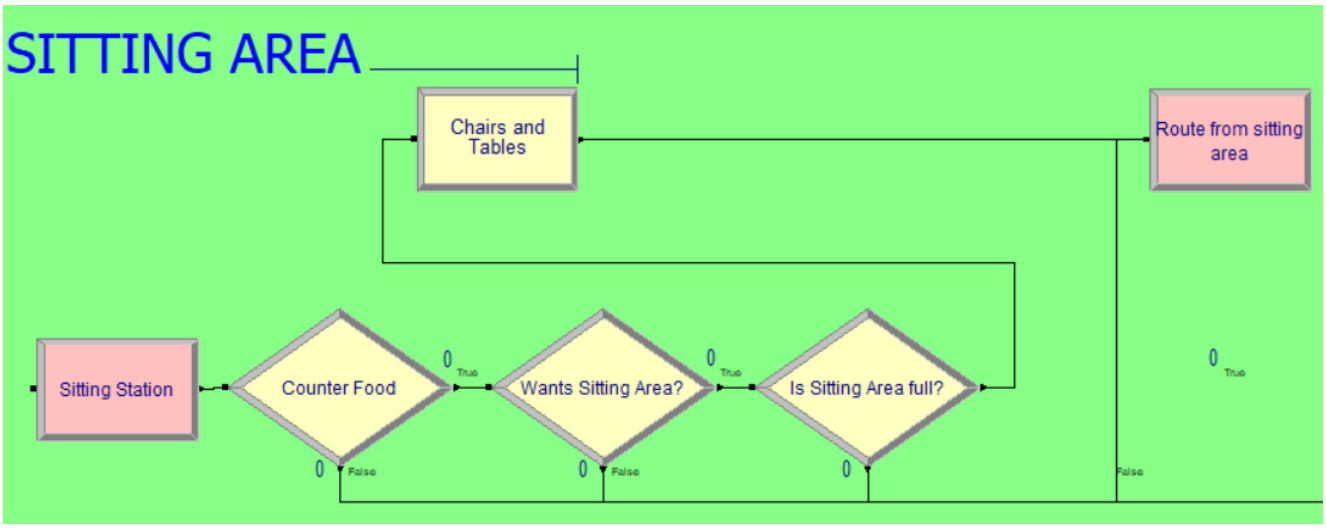


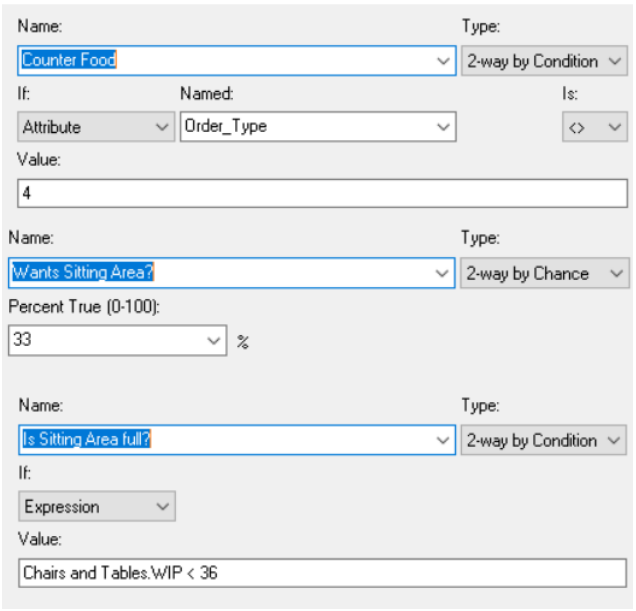
IV. SELF SERVICE AREA: In this area, customers wait in queue and then add sugars / flavors according to their taste and then proceed. Note that 67% of customers don't use this area.

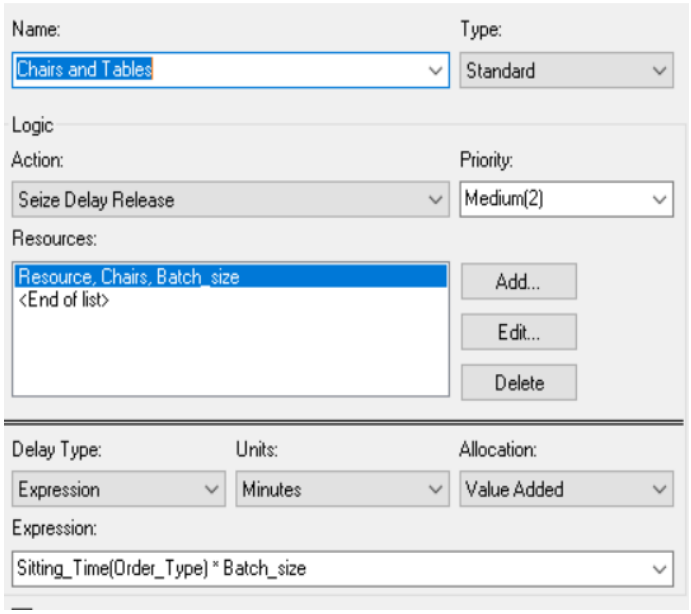




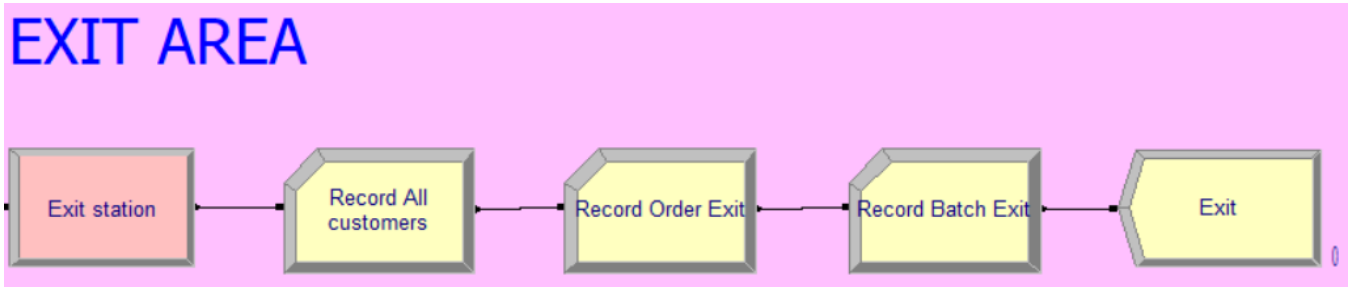
V. SITTING AREA: From the self-service station customer reaches the sitting station where they decide if they want to use the sitting area or must leave (according to the system description). Note that if the customer batch group size is 2 they are assumed to take double the time if they get to use the sitting area. If the capacity is full (customers in the sitting area = 36), the incoming customer with their coffee, leave the system.







VI. EXIT AREA: Customers from the sitting station arrives to the final exit station where their exit times are recorded.



4.2 Simulating the system

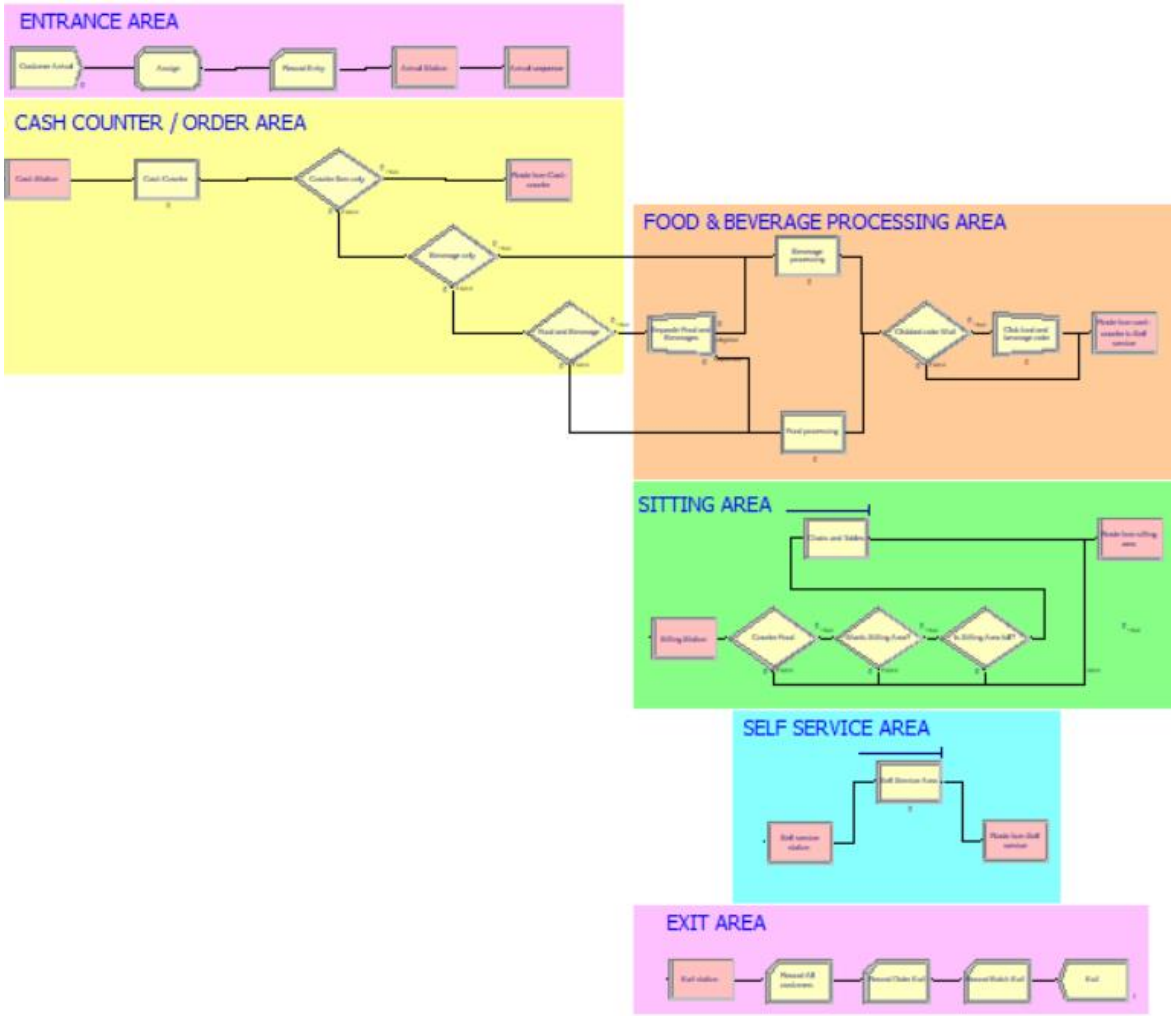
Simulation was run for the same time window of 1.50 hours for 10 replications. Half-width for customer waiting time was found to be 2.85 mins.

Wait Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Customers	7.1307	2.85	2.4057	13.9205	0.00	44.4253

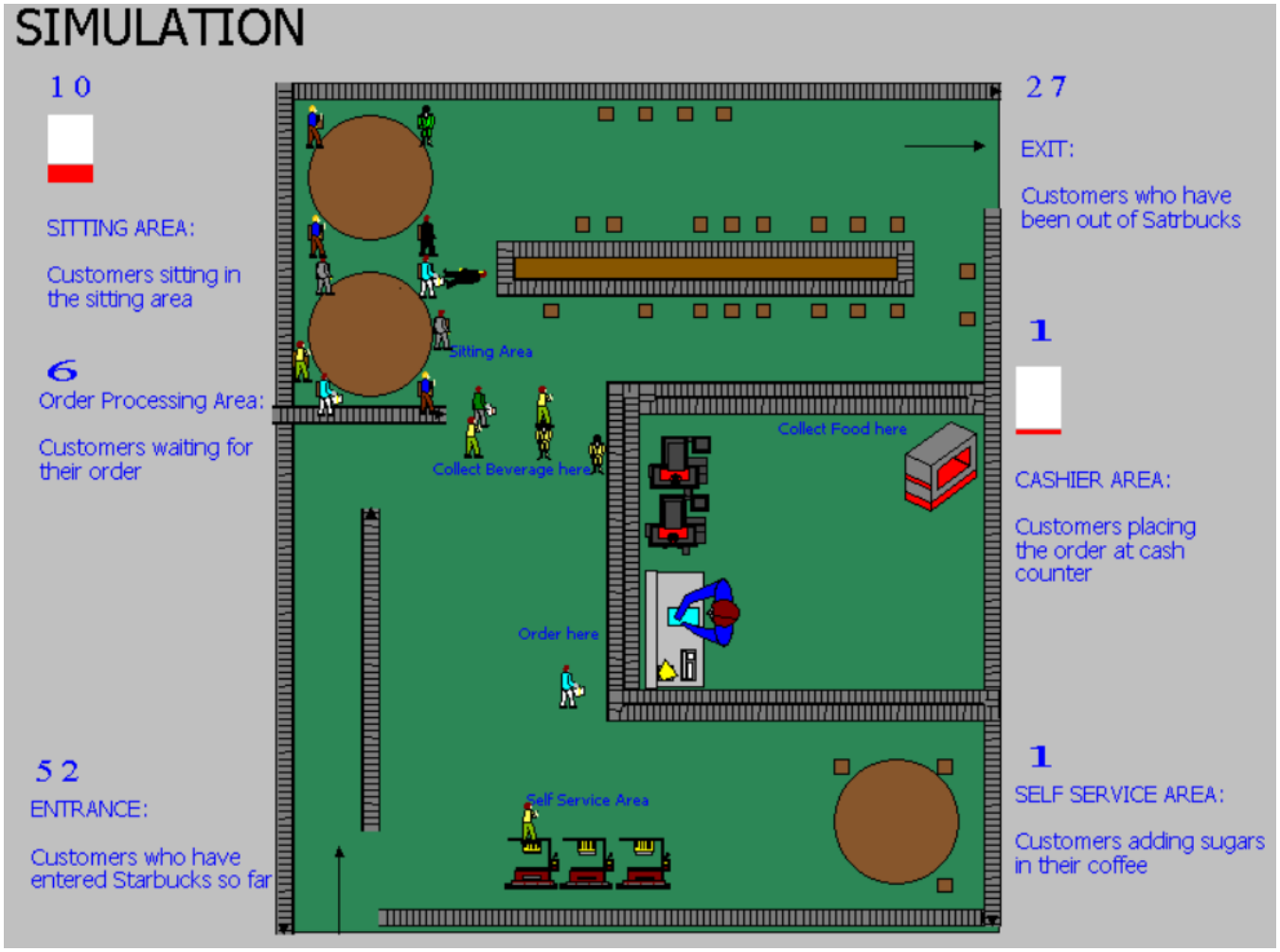
In order to improve accuracy and reduce the half-width to 0.5 mins we require:

$$n = 10 * \frac{2.85^2}{0.5^2} = 325\ replications$$

Rest of the outputs below will be for 325 replications.



Below is the snapshot of the animation where customers can be seen coming in and placing orders:



5. Analysis

5.1 Category Review report

The result of the simulation was obtained in the category overview report. All the output time units are in minutes. Following outputs were focused:

Project Starbucks Simulation

Replications: 325 Time Units: Minutes

Key Performance Indicators

System

	Average
Number Out	40

Waiting Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Beverage processing.Queue	10.8968	< 0.60	1.2593	29.0968	0.00	51.2782
Cash Counter.Queue	0.8751	< 0.05	0.1043	4.6626	0.00	12.3831
Chairs and Tables.Queue	0.00	< 0.00	0.00	0.00	0.00	0.00
Club food and beverage order.Queue	4.7110	< 0.38	0.00	16.9750	0.00	49.4103
Food processing.Queue	0.4922	< 0.06	0.00	2.5375	0.00	8.5327
Self Service Area.Queue	0.00	< 0.00	0.00	0.00	0.00	0.00

Below are the utilizations of different resources by %. We can observe that our beverage server is highly engaged during peak hours (busy 92% of the times).

Instantaneous Utilization	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Beverage server	0.9275	< 0.01	0.6491	0.9964	0.00	1.0000
Cashier	0.6012	< 0.01	0.3550	0.8252	0.00	1.0000
Chairs	0.1707	< 0.01	0.05847113	0.3111	0.00	0.6389
Food server	0.3179	< 0.01	0.02742020	0.5991	0.00	1.0000
Self service counter	0.04788841	< 0.00	0.01882716	0.08750000	0.00	1.0000

Below are the simulated Length of Stay (LOS) for each customer by their batch size and order type.

None	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Batch_Size_1_LOS	19.0305	< 0.56	8.0546	40.3309	0.6959	77.6182
Batch_Size_2_LOS	19.0066	< 0.82	5.1305	58.7471	1.1348	80.5596
Order_Type1_LOS	12.4350	< 1.15	0.00	58.0029	0.00	63.1434
Order_Type2_LOS	20.0774	< 1.55	0.00	73.1801	0.00	77.6182
Order_Type3_LOS	21.3174	< 0.65	8.5988	41.9677	1.0278	80.5596
Order_Type4_LOS	1.6739	< 0.12	0.00	12.2759	0.00	12.6511

Below is the average customer's length of stay in the system.

Interval	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Record All customers	19.0092	< 0.54	8.3948	36.9196	0.6959	80.5596
Record Entry	0.00	< 0.00	0.00	0.00	0.00	0.00

We can observe that according to our system a customer must wait for 10.8 minutes on an average for their beverage orders during rush hours. Our beverage server during rush hour is occupied 92% of the time, making him/her the busiest among all resources. Overall on an average a customer spends 19 minutes in our system (including the time spent in sitting area). If we want to improve the current system, our first option should be to improve the most time-consuming unit: beverage server, by increasing the capacity from 1 to 2 (during these rush hours).

5.2 Output Analyzer

So, 2 scenarios were created where we have only 1 Beverage server (Scenario 1) and another in which we have 2 beverage servers (Scenario 2). To check whether this change is significant or not, a paired t-test was performed on the customer's waiting time from 2 scenarios using the Arena Output Analyzer. Before doing the test, following changes were made in the Statistic module from Advanced Process panel.

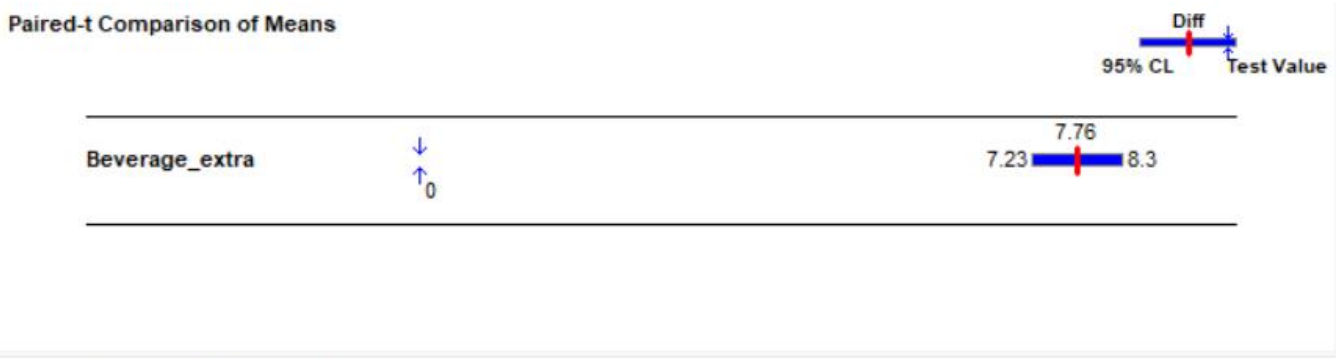
Statistic - Advanced Process

	Name	Type	Expression	Report Label	Output File
1	Beverage_normal	Output	TAVG(Customers.WaitTime)	Beverage_normal	Beverage_normal.dat

Statistic - Advanced Process

	Name	Type	Expression	Report Label	Output File
1 ▶	Beverage_extra	Output	TAVG(Customers.WaitTime)	Beverage_extra	Beverage_extra.dat

The final analysis results from the Output analyzer are below:



Paired-T Means Comparison :

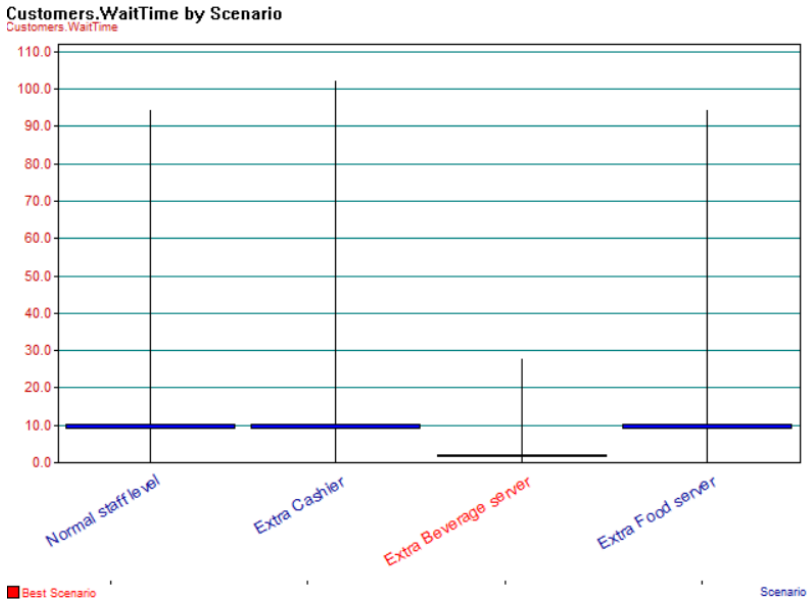
IDENTIFIER	ESTD. MEAN DIFFERENCE	STANDARD DEVIATION	0.950 C.I. HALF-WIDTH	MINIMUM VALUE	MAXIMUM VALUE	NUMBER OF OBS
Beverage_extra	7.76	4.92	0.537	1.77	25.1	325
				0.382	6.72	325

REJECT H0 => MEANS ARE NOT EQUAL AT 0.05 LEVEL

Since the zero is not in the 95% confidence interval, we reject the null hypothesis of scenarios being indifferent and can say that increasing the beverage server capacity had significant impact on the customer's waiting time.

5.3 Process Analyzer

In the Process Analyzer, 4 different scenarios were compared (including above mentioned scenario 2). Following were the results:



	Scenario Properties				Controls			Responses		
	S	Name	Program File	Reps	Cashier	Beverage server	Food server	Customers.WaitTime	Customers.TotalTime	Beverage server.Utilization
1		Normal staff level	26 : Model_	325	1.0000	1.0000	1.0000	9.652	19.009	0.928
2		Extra Cashier	26 : Model_	325	2.0000	1.0000	1.0000	9.641	19.027	0.936
3		Extra Beverage server	26 : Model_	325	1.0000	2.0000	1.0000	1.889	11.962	0.620
4		Extra Food server	26 : Model_	325	1.0000	1.0000	2.0000	9.668	19.163	0.932

6. Results

6.1 Conclusions

From the above results we can clearly see that an additional beverage server during peak hours can bring down the customer's total waiting time in the system from 9.6 minutes to 1.8 minutes (An improvement of 7.8 minutes). Moreover, our beverage servers are less busy (62%) than normal (92%), giving them some room to relax during rush hours. Adding other resources (like cashier or food server) have no valuable effect on the desired response.

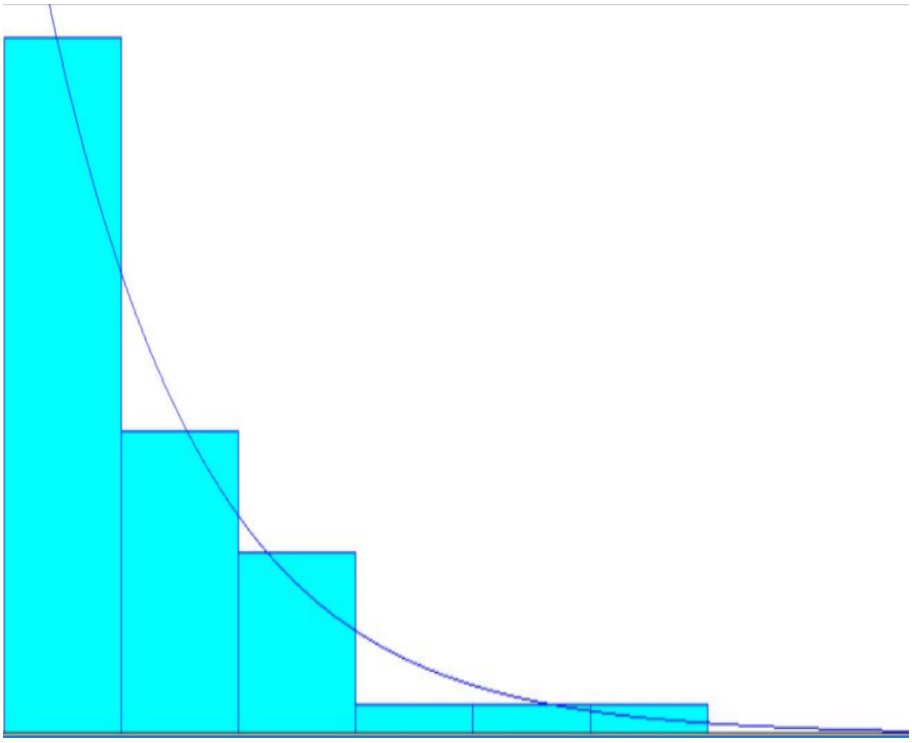
6.2 Suggestion for improvement

An additional beverage server between 11:30 AM – 1:00 PM on a weekday can decrease the customer average waiting time (includes time waited for placing and receiving the order) from current 9.6 minutes on an average to 1.8 minutes on an average. Saving almost 8 minutes of a customer during the rush hour.

7. Appendix

Time units are in seconds otherwise mentioned.

1. Customer inter-arrival time:

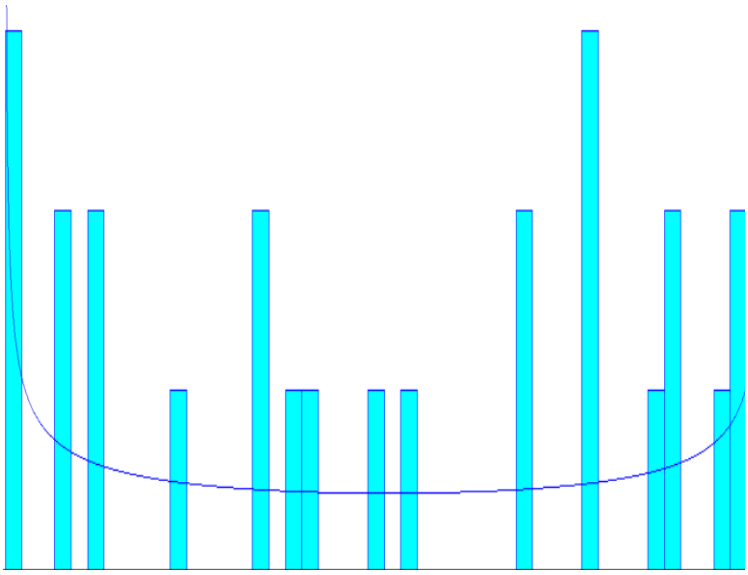


```
        Distribution Summary

Distribution:   Exponential
Expression:     -0.001 + EXPO(87.9)
Square Error:   0.002508

Chi Square Test
  Number of intervals   = 3
  Degrees of freedom    = 1
  Test Statistic        = 0.246
  Corresponding p-value = 0.648

Kolmogorov-Smirnov Test
  Test Statistic        = 0.148
  Corresponding p-value > 0.15

        Data Summary

Number of Data Points   = 43
Min Data Value          = 0
Max Data Value          = 593
Sample Mean             = 87.9
Sample Std Dev          = 113

        Histogram Summary

Histogram Range         = -0.001 to
Number of Intervals     = 9
```

2. Cashier billing time:

Type of Order	Distribution from Input Analyzer	Summary / Distribution (parameters in seconds)
Order 1: Only Food	Input Analyzer not used	TRIA (40,69,97)
Order 2: Food and Beverage	Input Analyzer not used	TRIA (60,82,90)

Order 3: Only Beverage



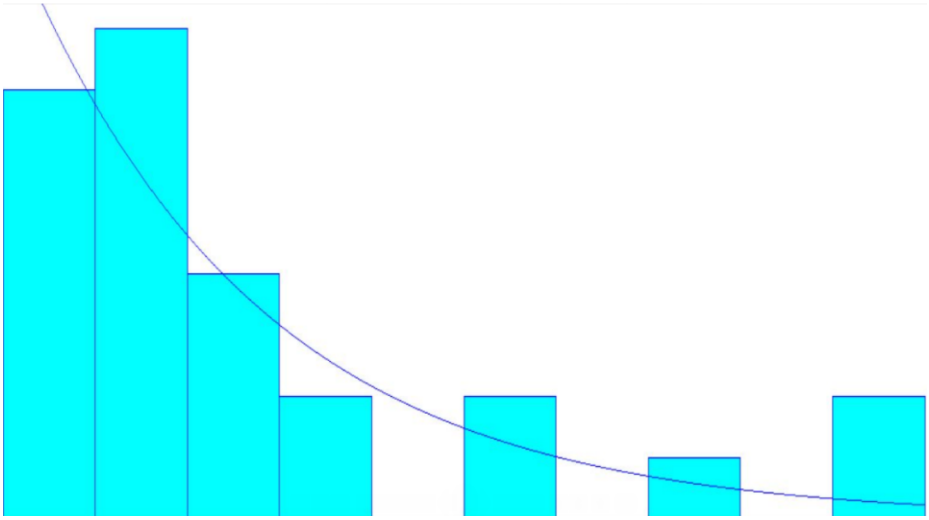
```
       Distribution Summary

Distribution:   Beta
Expression:     14.5 + 46 * BETA(0.633, 0.642)
Square Error:   0.044677

Chi Square Test
  Number of intervals   = 5
  Degrees of freedom    = 2
  Test Statistic        = 2.11
  Corresponding p-value = 0.37

       Data Summary

Number of Data Points   = 26
Min Data Value          = 15
Max Data Value          = 60
Sample Mean             = 38
Sample Std Dev          = 16.2

       Histogram Summary

Histogram Range         = 14.5 to 60.5
Number of Intervals     = 46
```

Order 4: Only counter items

Input Analyzer not used

TRIA (26,32,38)

3. Beverage Processing Time



```
       Distribution Summary

Distribution:   Exponential
Expression:     22 + EXPO(86.2)
Square Error:   0.022830

Chi Square Test
  Number of intervals   = 4
  Degrees of freedom    = 2
  Test Statistic        = 1.22
  Corresponding p-value = 0.55

Kolmogorov-Smirnov Test
  Test Statistic        = 0.113
  Corresponding p-value > 0.15

       Data Summary

Number of Data Points   = 26
Min Data Value          = 22
Max Data Value          = 350
Sample Mean             = 108
Sample Std Dev          = 92

       Histogram Summary

Histogram Range         = 22 to 350
Number of Intervals     = 10
```

4. Food Processing Time

Input Analyzer not used	TRIA (124,147,170)

5. Self Service Time

Input Analyzer not used. Based on empirical distribution.	DISC (0.67,0,0.81,24.5,0.9,44.5,0.97,64.5,1,75)

6. Sitting Area Time

Asked the customers and staff, and arrived at average timings for each order type (in minutes)	Order type 1	50
	Order type 2	60
	Order type 3	30
	Order type 4	0

8. Reference:

1. Book: SIMULATION WITH ARENA, Sixth Edition, International Edition 2015 - W. David Kelton/ Randall P. Sadowski/Nancy B. Zupick
2. Software used: Rockwell Arena Version 14.50.00002
3. Coffee usage stats: https://www.caffeineinformer.com/caffeine-what-the-world-drinks