CS1538 Homework 3 Report
https://github.com/Chris-Slade/CS1538-Team-Project

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Introduction

For our project we chose to simulate Hemingway's café, a bar and restaurant located on Forbes Avenue. Per the usual with simulations we were interested in matters of efficiency and optimality, in particular regarding the wait times endured by customers and the idle time enjoyed by servers and bartenders.

Our first and second questions concern just how much idle time (defined as time not spent interacting with customers or their immediate orders) servers and bartenders have on average. This will be of interest to the managers of the café for obvious reasons, as well as giving a rough idea how much time the servers and bartenders have to devote to other tasks, such as cleaning or organizing the café.

Our second and third questions regard the effect of the number of servers and number of bartenders on customer wait time. There are three ways in which customers can be forced to wait in the simulation—they can end up waiting for a seat (which customers require an available server to acquire), waiting for a drink order to be prepared by a bartender, or waiting for the finished drink order to be delivered by a server. We expect that wait times for seating are primarily a function of the number of servers and that wait times for drinks are primarily a function of the number of bartenders, so our questions are: how much do the numbers of those employees affect those corresponding types of wait times?

Approach

Because we were principally interested with three types of entities, namely customers, bartenders, and servers, they were the three most focused on in the design of the simulation. The simulation comprises a bar with an arbitrary number of seats, each treated equivalently. Customers enter the bar at a known average rate, estimated to be about 20 per hour following an exponential distribution. In reality, customers tended to arrive sporadically and with high variance in both time and number, so we were forced to smooth this out somewhat to get results that are more representative on average.

Data Collection

The particular bar we modeled has a fixed number of seats, servers, and bartenders, so we were able to collect data from there to parameterize our simulation. We did this by sitting at the bar and observing as people came and went, marking down the times when drink orders were placed, when they were completed by the bartender, and when the server would deliver the completed order to the customer. The ticket printer behind the counter proved invaluable for this task, since we could rely on the sound it produced as a signal for when an order was placed. The bartender would then prepare the drink and place it on top of the corresponding ticket, which we used as the signal for the end of the drink's preparation. Eventually a server would take the finished drink and deliver it to a table or seat. We performed these observations over the course of several days over the same two-hour Happy Hour periods each day, from 4 to 6 PM. We then collated our data to get average parameters over the course of the days we observed.

Input Modeling

Once customers arrive at the bar, they enter a seating queue, in which they remain until a server and a seat are available. Once so, the server seats the customer at the bar (taking on average 30 seconds to do so, distributed exponentially), and the customer will then place the first of some number of orders; on average customers want two drinks, distributed normally with a standard deviation of one. (In other words, roughly 16% of customers order one drink; 34% order two drinks; 34% order three drinks; and 16% order more than three drinks). Customers "make up their minds" as to how many drinks they want upon entering the bar, then order and consume that number of drinks (ordering one, drinking it, ordering another, etc.) and leave promptly afterward.

Servers and bartenders look around every thirty seconds to see if there are any customers in need of service; if there are none, they idle around for another thirty seconds before looking again (or do some other task, which is considered idling in our data). This is realistic because people are rarely truly "idle" — instead they occupy themselves with other tasks, some work-related (such as cleaning tables, glasses, or the floor), and some not work-related (such as checking one's phone or watching the football game on one of the televisions). An employer will want to minimize the latter form of idling while preserving the former, but crucially an employer would not want to eliminate all idling as we have defined it, since some is necessary to the operation of the café.

The time it takes for a server to deliver a finished drink to a customer is distributed normally with an average time of 50 seconds and a standard deviation of 25 seconds. We obtained this distribution and its parameters by putting the data into a histogram, estimating that it was approximately normal, and calculated the corresponding maximum likelihood estimates for the parameters of a normal distribution.

The time it takes for a bartender to prepare a drink is distributed normally with an average time of 20.1717 seconds and a standard deviation of 7.3048 seconds. This was taken from the collected data by computing the mean of all the data points, then taking the square root of the average of each data point minus the mean squared to calculate the standard deviation. The histogram for the data is shown below.

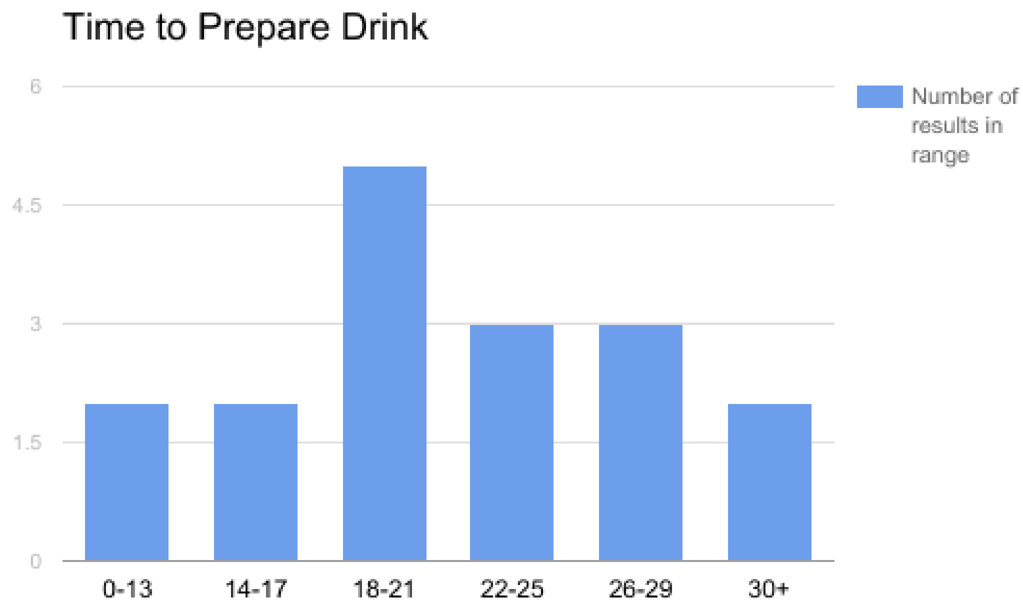

Figure 1: Histogram of drink preparation times

Experiment

Employee Idle Time

For our questions regarding server and bartender idle time, we simulated one hundred days for each of the nine configurations of one, two, or three servers or bartenders. The results are shown in Table 1 and Table 2.

Table 1: Server idle time in seconds by number of servers and bartenders

		Number of Bartenders		
		1	2	3
	1	2,293.03 (31.85%)	2,327.88 (32.33%)	2,234.24 (31.03%)
Number of Servers	2	4,718.18 (65.53%)	4,666.52 (64.81%)	4,657.58 (64.69%)
	3	5,546.97 (77.04%)	5,555.66 (77.16%)	5,503.64 (76.44%)

Simply by observing the tables it is apparent that the number of bartenders has a negligible effect on the idle time of servers and vice versa. This is counterintuitive in that one would expect a more effective server staff would mean bartenders would also have more customers to attend to and thus less idle time, or that more bartenders would mean customers would be in and out faster and thus there would be more opportunities for servers to be seating customers. However, the other parameters of the simulation, such as customer arrival time, drink preparation time, and the number of available seats dominate here; and the large amount of idle time both types of

Table 2: Bartender idle time in seconds by number of servers and bartenders

		Number of Bartenders		
		1	2	3
Number of Servers	1	5,683.03 (78.93%)	6,449.55 (89.58%)	6,700.30 (93.06%)
	2	5,684.55 (78.95%)	6,432.88 (89.35%)	6,687.68 (92.88%)
	3	5,685.15 (78.96%)	6,443.79 (89.50%)	6,689.80 (92.91%)

employee have in even the sparsest scenario (one server, one bartender) indicates that the system rarely becomes congested enough for an increase in the efficiency of one area to "spill over" into extra work in the other area.

Seating Wait Time

In our measurements we grouped together drink preparation and delivery time, and measured seating wait time separately.

To compute average wait times, we took the average wait time for all customers over each day, and then computed a weighted average (using the number of customers in a day as the weight) of those daily averages across one hundred days for each configuration of the simulation. As before, we tried each of the nine combinations of one, two, and three servers and bartenders.

The customer wait times to obtain seating as a function of the number of servers and bartenders is shown in Table 3. One can see that there is an insignificant difference in seating wait times based on the number of bartenders, but that having two servers is a significant improvement over having just one.

		Number of Bartenders		
		1	2	3
Number of Servers	1	117.58	114.40	113.24
	2	47.21	46.55	46.97
	3	40.68	39.49	40.12

Table 3: Customer wait times for seating in seconds by number of servers and bartenders

Testing these is rather difficult, since we only have daily averages and standard deviations. We were able to compute the overall average by using a weighted average, but overall standard deviation is trickier. Since the standard deviation for day i is $s_i = \sqrt{\frac{\sum(x_i-\bar{x})^2}{N-1}}$, we computed the overall sample standard deviation (over one hundred days) as

$$s = \sqrt{\frac{\sum\left(s_i^2 \times (N_i - 1)\right)}{\left(\sum N_i\right) - 1}}.$$

Using the weighted average and average standard deviation, we can apply hypothesis testing to confirm our suspicions. Looking only at scenarios with one bartender, we get the statistics shown in Table 4. Applying a two-sample t-test at the 95% confidence level shows that waiting times do indeed go down between one server and two servers ($p \approx 0.0000$), but that having three servers does not significantly improve seating wait times ($p \approx 0.0860$).

Table 4: Seating time statistics

Number of Servers	Average seating wait time	Std. dev. seating wait time
1	117.5795	106.1657
2	47.2096	35.4633
3	40.6848	31.7374

Drink Wait Time

Since it is quite clear from the results shown in Table 5 that our earlier assumption about the number of bartenders being the primary influence on drink wait time is inaccurate, we will instead see how the number of servers affects drink wait times.

Table 5: Customer wait times for drinks in seconds by number of servers and bartenders

		Number of Bartenders		
		1	2	3
Number of Servers	1	178.72	167.41	165.42
	2	103.16	96.78	94.65
	3	96.50	89.44	87.02

We use the same process described in Seating Wait Time to calculate the relevant statistics, shown in Table 6. Performing more paired t-tests shows that there is a significant decrease in waiting time for drinks when there are two servers instead of one ($p \approx 0.0000$), but that the decrease in wait time when a third server is added is not significant ($p \approx 0.0647$).

Table 6: Drink wait time statistics

Number of Servers	Average drink wait time	Std. dev. drink wait time
1	178.7223	92.2016
2	103.1641	32.8311
3	96.5016	28.9030

Conclusion

In order to minimize wait time for drinks, the café should consider having three servers on staff. The number of bartenders is largely irrelevant, provided there is at least one. To minimize seating time, the café should have at least two servers, but adding a third does not offer a significant advantage. Likewise, having two servers helps to minimize drink wait time, but the advantage of adding a third is insignificant.

Having three servers on staff results in servers being idle upwards of 75% of the time; having two results in around 65% idle time, and having only one results in only about 32% idle time. The café should balance its decision regarding how many servers to employ based on what percentage of their time the servers should be spending doing tasks not directly related to interacting with customers.

Having three bartenders on staff results in them being idle upwards of 92% of the time; having two results in around 90% idle time; having one results in about 79% idle time. The café likely does not need more than one bartender.

The large amount of idle time enjoyed by servers and bartenders indicates that the café should focus on increasing the customer arrival rate, perhaps by putting out advertisements.