

## 2.1 Part1: How good is this current system?

Simulate the above scenario for an entire day starting at 8:00 am until store close at 1:00 am at a granularity of **1 minute**. Customers arrive with the aforesaid probability to a single queue. Each customer arrival is a call to the enqueue function. The dequeue process is assumed to be a steady stream of order processing: the chefs move onto the next order as soon as they process the current one; i.e., at every minute, we check to see if a customer is done so we can call the dequeue function.

After the simulation, provide answers for the following:

1. Average customer *wait time*. This is the mean wait time until they can place an order, i.e., time spent standing in line to get to the person behind the counter.
2. Average customer *service time*. This is the mean time to get the order in hand from the second they enter the store, i.e., wait time + service time.
3. Average *queue length*. The mean number of people in line at any given time averaged over the entire day.
4. The *best case* and *worst case* for each of the above and *at what time* did that occur: (i) wait time, (ii) service time, and (iii) queue length.

<pre>=====                 WELCOME TO BURGER KING                                 here are today's stats                    ===== =====  Total customer count: [ 266 ] Average wait time: [ 9.57143 ] minutes Best wait time: [ 1 ] minutes at time: 11 Worst wait time: [ 21 ] minutes at time: 377 Average service time: [ 13.406 ] minutes Best service time: [ 1 ] minutes at time: 3 Worst service time: [ 26 ] minutes at time: 487 Average queue size: [ 5.80098 ] Smallest queue length: [ 0 ] at time: 1 Largest queue length: [ 23 ] at time: 335 =====</pre>	<pre>=====                 WELCOME TO BURGER KING                                 here are today's stats                    ===== =====  Total customer count: [ 267 ] Average wait time: [ 5.77903 ] minutes Best wait time: [ 1 ] minutes at time: 5 Worst wait time: [ 19 ] minutes at time: 137 Average service time: [ 9.59925 ] minutes Best service time: [ 1 ] minutes at time: 1 Worst service time: [ 20 ] minutes at time: 357 Average queue size: [ 2.1902 ] Smallest queue length: [ 0 ] at time: 7 Largest queue length: [ 9 ] at time: 320 =====</pre>
<pre>=====                 WELCOME TO BURGER KING                                 here are today's stats                    ===== =====  Total customer count: [ 265 ] Average wait time: [ 8.82264 ] minutes Best wait time: [ 1 ] minutes at time: 15 Worst wait time: [ 25 ] minutes at time: 355 Average service time: [ 12.6755 ] minutes Best service time: [ 1 ] minutes at time: 2 Worst service time: [ 30 ] minutes at time: 525 Average queue size: [ 3.27647 ] Smallest queue length: [ 0 ] at time: 1 Largest queue length: [ 14 ] at time: 324 =====</pre>	<pre>=====                 WELCOME TO BURGER KING                                 here are today's stats                    ===== =====  Total customer count: [ 274 ] Average wait time: [ 5.90876 ] minutes Best wait time: [ 1 ] minutes at time: 5 Worst wait time: [ 17 ] minutes at time: 364 Average service time: [ 9.64599 ] minutes Best service time: [ 1 ] minutes at time: 1 Worst service time: [ 26 ] minutes at time: 557 Average queue size: [ 2.50098 ] Smallest queue length: [ 0 ] at time: 8 Largest queue length: [ 10 ] at time: 310 =====</pre>
<pre>=====                 WELCOME TO BURGER KING                                 here are today's stats                    ===== =====  Total customer count: [ 264 ] Average wait time: [ 8.92424 ] minutes Best wait time: [ 1 ] minutes at time: 6 Worst wait time: [ 28 ] minutes at time: 388 Average service time: [ 12.7879 ] minutes Best service time: [ 1 ] minutes at time: 5 Worst service time: [ 29 ] minutes at time: 510 Average queue size: [ 3.65 ] Smallest queue length: [ 0 ] at time: 1 Largest queue length: [ 20 ] at time: 330 =====</pre>	

As shown from the 5 different output images, the average wait time was about 7.5 minutes, the average service time was around 11.6 minutes and the average queue size was 3.5.

The smallest queue length is 0, which makes sense because the line can be empty, which is why the corresponding time is at the very beginning, where the queue is empty. The largest queue length is 23 at time 335 minutes, which makes sense, as this is during lunch time which has the highest customer arrival rate, and as a result, more customers will get in line.

The smallest wait time is 1 minute at a time of 6 minutes, which makes sense, as it relates to a customer joining an empty line, then ordering immediately and getting an order time of 1 minute. The largest wait time is 28 minutes at a time of 388 minutes, which makes sense, as this is during lunch time which has the highest customer arrival rate, and as a result, more customers will be waiting in line to order. Until the customer orders, their wait time continues to increase.

The smallest service time is 1 minute at a time of 3 minutes, which makes sense, as it relates to a customer joining an empty line, then ordering immediately and getting an order time of 1 minute. The largest service time is 30 minutes at a time of 525 minutes, which makes sense, as this is during dinner time which has a high customer arrival rate, and as a result, more customers will be waiting in line to order, and then ordering when at the front. From the moment they get in line until their order is received, a customer's service time continues to increase.

## 2.2 The Optimization

### Bonus Points (Extra Credit)

The store operations center realizes that during peak hours (breakfast/lunch/dinner), customers can be better served by having two people behind the counter, i.e., have two separate counters instead of one. There are two possibilities to make this happen: (i) customers form a single line, and are free to move to the next free server behind the counter when they are at the end of the queue, or (ii) form two separate queues, one each for the two counters. Customers are free to choose any queue they want to join as soon as they walk in. Customers typically pick a queue with the least number of people.

Simulate both the alternatives above by having two separate counters to serve customers at peak hours. Some helpful tips:

- For the first option, customers arrive at the store with the same probabilities and they join the single queue. When they get to the end of the queue, they pick the next free counter to go place their order.
- For the second option, a customer arrives at the store and notices two separate queues. The customer then picks the queue with lesser customers in it and joins the line.

For both these alternatives, calculate the parameters of interest: (i) average wait time, (ii) service time, and (iii) queue length. Suggest which alternative works better, and why?

## First Option:

```
=====
| WELCOME TO BURGER KING |
| here are today's stats |
=====
Total customer count: [ 335 ]
Average wait time: [ 1.26269 ] minutes
Best wait time: [ 1 ] minutes at time: 12
Worst wait time: [ 9 ] minutes at time: 94
Average service time: [ 5.40896 ] minutes
Best service time: [ 1 ] minutes at time: 1
Worst service time: [ 16 ] minutes at time: 553
Average queue size: [ 0.77549 ]
Smallest queue length: [ 0 ] at time: 2
Largest queue length: [ 4 ] at time: 90
=====
```

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=====
| WELCOME TO BURGER KING |
| here are today's stats |
=====
Total customer count: [ 292 ]
Average wait time: [ 5.27397 ] minutes
Best wait time: [ 1 ] minutes at time: 5
Worst wait time: [ 27 ] minutes at time: 305
Average service time: [ 10 ] minutes
Best service time: [ 1 ] minutes at time: 4
Worst service time: [ 31 ] minutes at time: 307
Average queue size: [ 1.93333 ]
Smallest queue length: [ 0 ] at time: 1
Largest queue length: [ 15 ] at time: 823
=====
```

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=====
| WELCOME TO BURGER KING |
| here are today's stats |
=====
Total customer count: [ 316 ]
Average wait time: [ 2.79114 ] minutes
Best wait time: [ 1 ] minutes at time: 24
Worst wait time: [ 16 ] minutes at time: 893
Average service time: [ 7.17722 ] minutes
Best service time: [ 1 ] minutes at time: 2
Worst service time: [ 20 ] minutes at time: 571
Average queue size: [ 1.00588 ]
Smallest queue length: [ 0 ] at time: 1
Largest queue length: [ 7 ] at time: 878
=====
```

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=====
| WELCOME TO BURGER KING |
| here are today's stats |
=====
Total customer count: [ 346 ]
Average wait time: [ 2.27746 ] minutes
Best wait time: [ 1 ] minutes at time: 8
Worst wait time: [ 14 ] minutes at time: 911
Average service time: [ 6.21387 ] minutes
Best service time: [ 1 ] minutes at time: 1
Worst service time: [ 18 ] minutes at time: 952
Average queue size: [ 0.940196 ]
Smallest queue length: [ 0 ] at time: 3
Largest queue length: [ 6 ] at time: 877
=====
```

```
=====
| WELCOME TO BURGER KING |
| here are today's stats |
=====
Total customer count: [ 347 ]
Average wait time: [ 2.9366 ] minutes
Best wait time: [ 1 ] minutes at time: 14
Worst wait time: [ 13 ] minutes at time: 220
Average service time: [ 6.85303 ] minutes
Best service time: [ 1 ] minutes at time: 12
Worst service time: [ 19 ] minutes at time: 513
Average queue size: [ 1.10196 ]
Smallest queue length: [ 0 ] at time: 1
Largest queue length: [ 6 ] at time: 748
=====
```

## Second Option:

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=====
| WELCOME TO BURGER KING |
| here are today's stats |
=====
Total customer count: [ 300 ]
Average wait time: [ 6.30667 ] minutes
Best wait time: [ 1 ] minutes at time: 8
Worst wait time: [ 29 ] minutes at time: 371
Average service time: [ 9.81667 ] minutes
Best service time: [ 1 ] minutes at time: 1
Worst service time: [ 32 ] minutes at time: 374
Average queue size: [ 2.18268 ]
Smallest queue length: [ 0 ] at time: 2
Largest queue length: [ 9 ] at time: 343
=====
```

```
=====
| WELCOME TO BURGER KING |
| here are today's stats |
=====
Total customer count: [ 279 ]
Average wait time: [ 5.71326 ] minutes
Best wait time: [ 1 ] minutes at time: 5
Worst wait time: [ 16 ] minutes at time: 166
Average service time: [ 9.56272 ] minutes
Best service time: [ 1 ] minutes at time: 1
Worst service time: [ 18 ] minutes at time: 168
Average queue size: [ 2.31742 ]
Smallest queue length: [ 0 ] at time: 7
Largest queue length: [ 11 ] at time: 319
=====
```

```
=====
| WELCOME TO BURGER KING |
| here are today's stats |
=====
Total customer count: [ 261 ]
Average wait time: [ 5.05747 ] minutes
Best wait time: [ 1 ] minutes at time: 19
Worst wait time: [ 14 ] minutes at time: 354
Average service time: [ 9.05364 ] minutes
Best service time: [ 1 ] minutes at time: 3
Worst service time: [ 17 ] minutes at time: 357
Average queue size: [ 1.76753 ]
Smallest queue length: [ 0 ] at time: 1
Largest queue length: [ 8 ] at time: 328
=====
```

```
=====
| WELCOME TO BURGER KING |
| here are today's stats |
=====
Total customer count: [ 286 ]
Average wait time: [ 5.79371 ] minutes
Best wait time: [ 1 ] minutes at time: 9
Worst wait time: [ 33 ] minutes at time: 359
Average service time: [ 9.51399 ] minutes
Best service time: [ 1 ] minutes at time: 1
Worst service time: [ 34 ] minutes at time: 360
Average queue size: [ 2.11992 ]
Smallest queue length: [ 0 ] at time: 2
Largest queue length: [ 12 ] at time: 329
=====
```

```
=====
| WELCOME TO BURGER KING |
| here are today's stats |
=====
Total customer count: [ 267 ]
Average wait time: [ 4.99625 ] minutes
Best wait time: [ 1 ] minutes at time: 17
Worst wait time: [ 26 ] minutes at time: 355
Average service time: [ 8.88389 ] minutes
Best service time: [ 1 ] minutes at time: 5
Worst service time: [ 30 ] minutes at time: 359
Average queue size: [ 1.75 ]
Smallest queue length: [ 0 ] at time: 1
Largest queue length: [ 9 ] at time: 329
=====
```

**Conclusion:**

The first alternative (two counters and one line) works much better than the latter (two lines and one counter for each line). This is perhaps because instead of having two queues running at a normal speed, it uses one queue that is faster than normal due to the extra counter, which works in conjunction with the queue's FIFO priority sequence. It essentially makes it "First two in, first two out" instead, which allows the different order times to be handled much more effectively because as soon as one of the two orders are done, the next customer can order, rather than two queues having to wait roughly the same amount of time as one queue with one counter.

With the first alternative, the average queue size was around 1, while the second alternative had an average queue size of 2. Also, the average wait time for the first alternative was around 2 minutes, which was significantly less than that of the second alternative having an average wait time of roughly 5.5 minutes, which was not much better than the average wait time of the unoptimized queue (7.5 minutes).

This pattern was no different with the average service time, with the first alternative having an average service time of about 7 minutes, compared to the average service time of the second alternative being 9.4 minutes.