PROJECT 3

QUEUES & SIMULATION

CSCI 220
DATA STRUCTURE 1

MAI PHAM

DEVELOPMENT ENVIRONMENT
MacOS – Xcode
Window 10 – MSVS 2017

TABLE OF CONTENTS

Mai Pham
CSCI 220 - Project 3
Prof. T. Vo

PROJECT NOTE

OBJECTIVE:

- Create a program that replicates a call line system at a calling center. Using a linked queue as a waiting line of customers that need to be serve, which call at a random time interval, and it takes a random time to serve each customer.

SUMMARY:

- The project is actually not that hard or time consuming once you understand the objective and the requirement. The project did provide the algorithm, so all I need to do is translate it into coding. As for the linked queue class, I reused the code from one of the lab assignment, "LinkedDequeue."

EXTRA CREDIT:

- I actually spent more time on the extra credit then the main project. First, I tried the multiple lines extra credit. However, I abandoned it once I realized I need to change/add a lot to my original code. Then I tried the 3rd extra credit option, which is input data from input file and estimate each customer wait time. For the estimate wait time, I don't know if the equation I came up with is correct or not. I think in theory, it should be right. But it may not be very partial.

CONCLUSION:

- Overall, my project is completed and successfully run the main project but I'm not sure if the extra credit part is corrected or not.

RESULT & DISCUSSION

	Numbers of Customers Served	Maximum Customers in Line	Longest Wait Time	Average Wait Time
Test Case 0	11	3	6	2.55
Test Case 1.1	280	15	32	13.44
Test Case 1.2	291	13	27	14.96
Test Case 1.3	276	10	23	8.19
Average	**283**	**114**	**28**	**12.20**
Test Case 2.1	297	50	89	42.92
Test Case 2.2	285	78	156	79.59
Test Case 2.3	286	72	151	73.96
Average	**290**	**67**	**132**	**65.49**
Test Case 3.1	243	5	13	2.55
Test Case 3.2	254	5	11	2.23
Test Case 3.3	239	4	9	1.31
Average	**246**	**5**	**11**	**2.03**

QUESTION:
Do the three sets of results seems reasonable? Explain.

I think my result seems reasonable. Because I know that if the call arrival rate is faster than the service rate (n < m), the line will grow indefinitely. If we take a look at test case 2, we notice that the number of customers wait in line grow very high compare to the test case 1 and test case 3. Therefore, causing a very long wait time as show in test case 2 longest wait time and average wait time.

I also know that even with (n = m), the line can still grow over a long period of time. For over 720 minutes, it did cause an average wait time of 12 minutes. It is in the test case 3 that we see with the rate of (n > m) that the wait time have decreased. Therefore, I think my result is reasonable.

QUESTION:
Provide a short explanation on how you come up with the estimate wait time.

I did some research on the estimate wait time and found out that there are many theories and researches on this topic like the M/M/1, M/M/c, etc. Each of those theories contain many symbols representing variety of scenario and factors into the calculation. Since our project is much smaller and simple down version, I don't know how to apply these formula into our project nor do I really understand those theories. Therefore, I decided to came up with my own equation that I think should provide the best estimate wait time. I concluded that:

Estimate wait time = (total served time/total customers got served) x customers in queue

I think that in order to get the current customer wait time, we should look into the previous calls. By calculate the amount of time spend on previous call and divide by amount of customer got served, we get the average served time for each customer. With the average served time for each customer and multiple by the amount of customer in line, we could predict that it is how long it takes to serve all the customers ahead before getting to the current customer. Therefore, providing us the estimate wait time for the current customer.

INPUT

*NOTE: Each test case input is in separate file. This is just to show what input for each test case.
Test Case 0:
1 30 4 4

Test Case 1:
1 720 4 4

Test Case 2:
1 720 3 4

Test Case 3:
1 720 5 4

OUTPUT

TEST CASE 0

```
Project 3: Queues & Simulation
By Mai Pham

Minute 1:
Minute 2:
Minute 3:
  => Customer 1 call.
  => Estimate wait time for customer 1 is 0.
  => Serving customer 1.
Minute 4:
  => Customer 2 call.
  => Estimate wait time for customer 2 is 2.
Minute 5:
  => Customer 3 call.
  => Estimate wait time for customer 3 is 4.
  => Customer 1 completed.
  => Serving customer 2.
Minute 6:
  => Customer 2 completed.
  => Serving customer 3.
Minute 7:
Minute 8:
  => Customer 4 call.
  => Estimate wait time for customer 4 is 2.
Minute 9:
Minute 10:
  => Customer 3 completed.
  => Serving customer 4.
Minute 11:
  => Customer 5 call.
  => Estimate wait time for customer 5 is 2.
  => Customer 4 completed.
  => Serving customer 5.
Minute 12:
  => Customer 5 completed.
Minute 13:
Minute 14:
  => Customer 6 call.
  => Estimate wait time for customer 6 is 0.
  => Serving customer 6.
Minute 15:
Minute 16:
Minute 17:
  => Customer 7 call.
  => Estimate wait time for customer 7 is 2.
Minute 18:
  => Customer 6 completed.
  => Serving customer 7.
Minute 19:
  => Customer 8 call.
  => Estimate wait time for customer 8 is 2.
Minute 20:
  => Customer 9 call.
  => Estimate wait time for customer 9 is 4.
Minute 21:
```

```
  => Customer 10 call.
  => Estimate wait time for customer 10 is 6.
Minute 22:
  => Customer 7 completed.
  => Serving customer 8.
Minute 23:
  => Customer 11 call.
  => Estimate wait time for customer 11 is 6.
Minute 24:
Minute 25:
  => Customer 8 completed.
  => Serving customer 9.
Minute 26:
  => Customer 12 call.
  => Estimate wait time for customer 12 is 6.
  => Customer 9 completed.
  => Serving customer 10.
Minute 27:
Minute 28:
Minute 29:
  => Customer 10 completed.
  => Serving customer 11.
Minute 30:
  => Customer 13 call.
  => Estimate wait time for customer 13 is 4.
  => Customer 11 completed.
  => Serving customer 12.

End of Program Report
================================================
Numbers of customers called:              13
Numbers of customers served:              11
Number of customers left in line:         1
Maximum number of customers in line:      3
Longest wait time for a customer:         6
Average wait time for customers:          2.54545
```

TEST CASE 1.1

```
Project 3: Queues & Simulation
By Mai Pham

Minute 1:
Minute 2:
  => Customer 1 call.
  => Estimate wait time for customer 1 is 0.
  => Serving customer 1.
Minute 3:
Minute 4:
Minute 5:
  => Customer 2 call.
  => Estimate wait time for customer 2 is 3.
  => Customer 1 completed.
  => Serving customer 2.
Minute 6:
  => Customer 3 call.
  => Estimate wait time for customer 3 is 2.
Minute 7:
  => Customer 2 completed.
  => Serving customer 3.
Minute 8:
  => Customer 4 call.
  => Estimate wait time for customer 4 is 2.
Minute 9:
Minute 10:
```

```
  => Customer 3 completed.
  => Serving customer 4.
Minute 11:
Minute 12:
  => Customer 5 call.
  => Estimate wait time for customer 5 is 3.
Minute 13:
Minute 14:
  => Customer 4 completed.
  => Serving customer 5.
Minute 15:
  => Customer 6 call.
  => Estimate wait time for customer 6 is 3.
...
...
...
Minute 705:
  => Customer 287 call.
  => Estimate wait time for customer 287 is 26.
  => Customer 274 completed.
  => Serving customer 275.
Minute 706:
Minute 707:
  => Customer 288 call.
  => Estimate wait time for customer 288 is 26.
Minute 708:
Minute 709:
  => Customer 275 completed.
  => Serving customer 276.
Minute 710:
  => Customer 289 call.
  => Estimate wait time for customer 289 is 26.
Minute 711:
  => Customer 290 call.
  => Estimate wait time for customer 290 is 28.
  => Customer 276 completed.
  => Serving customer 277.
Minute 712:
Minute 713:
Minute 714:
  => Customer 291 call.
  => Estimate wait time for customer 291 is 28.
  => Customer 277 completed.
  => Serving customer 278.
Minute 715:
  => Customer 278 completed.
  => Serving customer 279.
Minute 716:
Minute 717:
Minute 718:
  => Customer 292 call.
  => Estimate wait time for customer 292 is 26.
Minute 719:
  => Customer 293 call.
  => Estimate wait time for customer 293 is 28.
  => Customer 279 completed.
  => Serving customer 280.
Minute 720:
  => Customer 280 completed.
  => Serving customer 281.

End of Program Report
================================================
Numbers of customers called:              293
```

```
Numbers of customers served:              280
Number of customers left in line:         12
Maximum number of customers in line:      15
Longest wait time for a customer:         32
Average wait time for customers:          13.4393
```

TEST CASE 1.2

```
Project 3: Queues & Simulation
By Mai Pham

Minute 1:
Minute 2:
  => Customer 1 call.
  => Estimate wait time for customer 1 is 0.
  => Serving customer 1.
Minute 3:
Minute 4:
  => Customer 2 call.
  => Estimate wait time for customer 2 is 2.
  => Customer 1 completed.
  => Serving customer 2.
Minute 5:
Minute 6:
Minute 7:
  => Customer 2 completed.
Minute 8:
  => Customer 3 call.
  => Estimate wait time for customer 3 is 0.
  => Serving customer 3.
Minute 9:
Minute 10:
  => Customer 4 call.
  => Estimate wait time for customer 4 is 2.
Minute 11:
  => Customer 3 completed.
  => Serving customer 4.
Minute 12:
Minute 13:
Minute 14:
  => Customer 5 call.
  => Estimate wait time for customer 5 is 3.
Minute 15:
  => Customer 4 completed.
  => Serving customer 5.
...
...
...
Minute 705:
  => Customer 287 completed.
  => Serving customer 288.
Minute 706:
Minute 707:
  => Customer 289 call.
  => Estimate wait time for customer 289 is 2.
Minute 708:
Minute 709:
  => Customer 290 call.
  => Estimate wait time for customer 290 is 4.
  => Customer 288 completed.
  => Serving customer 289.
Minute 710:
Minute 711:
Minute 712:
```

```
Minute 713:
  => Customer 291 call.
  => Estimate wait time for customer 291 is 4.
  => Customer 289 completed.
  => Serving customer 290.
Minute 714:
Minute 715:
  => Customer 292 call.
  => Estimate wait time for customer 292 is 4.
Minute 716:
  => Customer 293 call.
  => Estimate wait time for customer 293 is 6.
Minute 717:
  => Customer 294 call.
  => Estimate wait time for customer 294 is 8.
  => Customer 290 completed.
  => Serving customer 291.
Minute 718:
  => Customer 291 completed.
  => Serving customer 292.
Minute 719:
  => Customer 295 call.
  => Estimate wait time for customer 295 is 6.
Minute 720:

End of Program Report
================================================
Numbers of customers called:              295
Numbers of customers served:              291
Number of customers left in line:         3
Maximum number of customers in line:      13
Longest wait time for a customer:         27
Average wait time for customers:          14.9588
```

TEST CASE 1.3

```
Project 3: Queues & Simulation
By Mai Pham

Minute 1:
Minute 2:
  => Customer 1 call.
  => Estimate wait time for customer 1 is 0.
  => Serving customer 1.
Minute 3:
  => Customer 2 call.
  => Estimate wait time for customer 2 is 1.
  => Customer 1 completed.
  => Serving customer 2.
Minute 4:
  => Customer 3 call.
  => Estimate wait time for customer 3 is 1.
  => Customer 2 completed.
  => Serving customer 3.
Minute 5:
  => Customer 3 completed.
Minute 6:
Minute 7:
Minute 8:
  => Customer 4 call.
  => Estimate wait time for customer 4 is 0.
  => Serving customer 4.
Minute 9:
Minute 10:
Minute 11:
```

```
  => Customer 5 call.
  => Estimate wait time for customer 5 is 1.
  => Customer 4 completed.
  => Serving customer 5.
Minute 12:
Minute 13:
  => Customer 6 call.
  => Estimate wait time for customer 6 is 2.
Minute 14:
  => Customer 7 call.
  => Estimate wait time for customer 7 is 4.
Minute 15:
  => Customer 8 call.
  => Estimate wait time for customer 8 is 6.
  => Customer 5 completed.
  => Serving customer 6.
...
...
...
Minute 705:
  => Customer 271 completed.
  => Serving customer 272.
Minute 706:
Minute 707:
  => Customer 279 call.
  => Estimate wait time for customer 279 is 14.
  => Customer 272 completed.
  => Serving customer 273.
Minute 708:
Minute 709:
  => Customer 273 completed.
  => Serving customer 274.
Minute 710:
  => Customer 280 call.
  => Estimate wait time for customer 280 is 12.
Minute 711:
Minute 712:
  => Customer 281 call.
  => Estimate wait time for customer 281 is 14.
Minute 713:
  => Customer 282 call.
  => Estimate wait time for customer 282 is 16.
  => Customer 274 completed.
  => Serving customer 275.
Minute 714:
Minute 715:
Minute 716:
  => Customer 275 completed.
  => Serving customer 276.
Minute 717:
  => Customer 283 call.
  => Estimate wait time for customer 283 is 14.
Minute 718:
  => Customer 284 call.
  => Estimate wait time for customer 284 is 16.
Minute 719:
  => Customer 285 call.
  => Estimate wait time for customer 285 is 18.
Minute 720:
  => Customer 276 completed.
  => Serving customer 277.

End of Program Report
================================================
```

```
Numbers of customers called:              285
Numbers of customers served:              276
Number of customers left in line:         8
Maximum number of customers in line:      10
Longest wait time for a customer:         23
Average wait time for customers:          8.18841
```

TEST CASE 2.1

```
Project 3: Queues & Simulation
By Mai Pham

Minute 1:
Minute 2:
Minute 3:
  => Customer 1 call.
  => Estimate wait time for customer 1 is 0.
  => Serving customer 1.
Minute 4:
Minute 5:
Minute 6:
  => Customer 2 call.
  => Estimate wait time for customer 2 is 3.
  => Customer 1 completed.
  => Serving customer 2.
Minute 7:
  => Customer 3 call.
  => Estimate wait time for customer 3 is 3.
Minute 8:
Minute 9:
  => Customer 2 completed.
  => Serving customer 3.
Minute 10:
  => Customer 4 call.
  => Estimate wait time for customer 4 is 2.
  => Customer 3 completed.
  => Serving customer 4.
Minute 11:
  => Customer 5 call.
  => Estimate wait time for customer 5 is 2.
Minute 12:
Minute 13:
  => Customer 6 call.
  => Estimate wait time for customer 6 is 4.
Minute 14:
  => Customer 4 completed.
  => Serving customer 5.
Minute 15:
  => Customer 7 call.
  => Estimate wait time for customer 7 is 4.
...
...
...
Minute 705:
  => Customer 292 completed.
  => Serving customer 293.
Minute 706:
  => Customer 340 call.
  => Estimate wait time for customer 340 is 94.
Minute 707:
Minute 708:
  => Customer 293 completed.
  => Serving customer 294.
Minute 709:
```

```
  => Customer 341 call.
  => Estimate wait time for customer 341 is 94.
Minute 710:
Minute 711:
Minute 712:
  => Customer 342 call.
  => Estimate wait time for customer 342 is 96.
  => Customer 294 completed.
  => Serving customer 295.
Minute 713:
  => Customer 295 completed.
  => Serving customer 296.
Minute 714:
  => Customer 343 call.
  => Estimate wait time for customer 343 is 94.
Minute 715:
  => Customer 344 call.
  => Estimate wait time for customer 344 is 96.
Minute 716:
  => Customer 296 completed.
  => Serving customer 297.
Minute 717:
  => Customer 345 call.
  => Estimate wait time for customer 345 is 96.
Minute 718:
  => Customer 346 call.
  => Estimate wait time for customer 346 is 98.
Minute 719:
Minute 720:
  => Customer 347 call.
  => Estimate wait time for customer 347 is 100.
  => Customer 297 completed.
  => Serving customer 298.

End of Program Report
================================================
Numbers of customers called:              347
Numbers of customers served:              297
Number of customers left in line:         49
Maximum number of customers in line:      50
Longest wait time for a customer:         89
Average wait time for customers:          42.9192
```

TEST CASE 2.2

```
Project 3: Queues & Simulation
By Mai Pham

Minute 1:
Minute 2:
Minute 3:
  => Customer 1 call.
  => Estimate wait time for customer 1 is 0.
  => Serving customer 1.
Minute 4:
  => Customer 2 call.
  => Estimate wait time for customer 2 is 2.
Minute 5:
  => Customer 3 call.
  => Estimate wait time for customer 3 is 4.
  => Customer 1 completed.
  => Serving customer 2.
Minute 6:
  => Customer 4 call.
  => Estimate wait time for customer 4 is 6.
```

```
Minute 7:
Minute 8:
  => Customer 5 call.
  => Estimate wait time for customer 5 is 9.
Minute 9:
  => Customer 6 call.
  => Estimate wait time for customer 6 is 12.
  => Customer 2 completed.
  => Serving customer 3.
Minute 10:
  => Customer 3 completed.
  => Serving customer 4.
Minute 11:
  => Customer 7 call.
  => Estimate wait time for customer 7 is 6.
Minute 12:
  => Customer 8 call.
  => Estimate wait time for customer 8 is 8.
Minute 13:
  => Customer 4 completed.
  => Serving customer 5.
Minute 14:
  => Customer 9 call.
  => Estimate wait time for customer 9 is 8.
Minute 15:
...
...
...
Minute 705:
Minute 706:
  => Customer 356 call.
  => Estimate wait time for customer 356 is 150.
Minute 707:
  => Customer 357 call.
  => Estimate wait time for customer 357 is 152.
  => Customer 281 completed.
  => Serving customer 282.
Minute 708:
Minute 709:
  => Customer 358 call.
  => Estimate wait time for customer 358 is 152.
Minute 710:
Minute 711:
  => Customer 359 call.
  => Estimate wait time for customer 359 is 154.
  => Customer 282 completed.
  => Serving customer 283.
Minute 712:
Minute 713:
  => Customer 360 call.
  => Estimate wait time for customer 360 is 154.
  => Customer 283 completed.
  => Serving customer 284.
Minute 714:
  => Customer 361 call.
  => Estimate wait time for customer 361 is 154.
Minute 715:
Minute 716:
  => Customer 362 call.
  => Estimate wait time for customer 362 is 156.
  => Customer 284 completed.
  => Serving customer 285.
Minute 717:
Minute 718:
```

```
Minute 719:
  => Customer 363 call.
  => Estimate wait time for customer 363 is 156.
Minute 720:
  => Customer 285 completed.
  => Serving customer 286.

End of Program Report
================================================
Numbers of customers called:              363
Numbers of customers served:              285
Number of customers left in line:         77
Maximum number of customers in line:      78
Longest wait time for a customer:         156
Average wait time for customers:          79.5895
```

TEST CASE 2.3

```
Project 3: Queues & Simulation
By Mai Pham

Minute 1:
Minute 2:
  => Customer 1 call.
  => Estimate wait time for customer 1 is 0.
  => Serving customer 1.
Minute 3:
Minute 4:
  => Customer 1 completed.
Minute 5:
  => Customer 2 call.
  => Estimate wait time for customer 2 is 0.
  => Serving customer 2.
Minute 6:
  => Customer 3 call.
  => Estimate wait time for customer 3 is 1.
  => Customer 2 completed.
  => Serving customer 3.
Minute 7:
Minute 8:
  => Customer 4 call.
  => Estimate wait time for customer 4 is 1.
  => Customer 3 completed.
  => Serving customer 4.
Minute 9:
  => Customer 5 call.
  => Estimate wait time for customer 5 is 2.
Minute 10:
Minute 11:
Minute 12:
  => Customer 6 call.
  => Estimate wait time for customer 6 is 4.
  => Customer 4 completed.
  => Serving customer 5.
Minute 13:
Minute 14:
  => Customer 5 completed.
  => Serving customer 6.
Minute 15:
  => Customer 7 call.
  => Estimate wait time for customer 7 is 2.
...
...
...
```

```
Minute 705:
  => Customer 351 call.
  => Estimate wait time for customer 351 is 144.
  => Customer 279 completed.
  => Serving customer 280.
Minute 706:
  => Customer 352 call.
  => Estimate wait time for customer 352 is 144.
  => Customer 280 completed.
  => Serving customer 281.
Minute 707:
Minute 708:
Minute 709:
  => Customer 353 call.
  => Estimate wait time for customer 353 is 144.
  => Customer 281 completed.
  => Serving customer 282.
Minute 710:
  => Customer 282 completed.
  => Serving customer 283.
Minute 711:
Minute 712:
  => Customer 354 call.
  => Estimate wait time for customer 354 is 142.
  => Customer 283 completed.
  => Serving customer 284.
Minute 713:
Minute 714:
  => Customer 284 completed.
  => Serving customer 285.
Minute 715:
  => Customer 355 call.
  => Estimate wait time for customer 355 is 140.
  => Customer 285 completed.
  => Serving customer 286.
Minute 716:
Minute 717:
Minute 718:
  => Customer 356 call.
  => Estimate wait time for customer 356 is 140.
Minute 719:
  => Customer 286 completed.
  => Serving customer 287.
Minute 720:
  => Customer 357 call.
  => Estimate wait time for customer 357 is 140.

End of Program Report
================================================
Numbers of customers called:              357
Numbers of customers served:              286
Number of customers left in line:         70
Maximum number of customers in line:      72
Longest wait time for a customer:         151
Average wait time for customers:          73.958
```

TEST CASE 3.1

```
Project 3: Queues & Simulation
By Mai Pham

Minute 1:
Minute 2:
Minute 3:
  => Customer 1 call.
```

```
  => Estimate wait time for customer 1 is 0.
  => Serving customer 1.
Minute 4:
Minute 5:
Minute 6:
Minute 7:
  => Customer 2 call.
  => Estimate wait time for customer 2 is 4.
  => Customer 1 completed.
  => Serving customer 2.
Minute 8:
  => Customer 2 completed.
Minute 9:
Minute 10:
Minute 11:
Minute 12:
  => Customer 3 call.
  => Estimate wait time for customer 3 is 0.
  => Serving customer 3.
Minute 13:
Minute 14:
Minute 15:
  => Customer 4 call.
  => Estimate wait time for customer 4 is 2.
  => Customer 3 completed.
  => Serving customer 4.
...
...
...
Minute 705:
  => Customer 238 completed.
  => Serving customer 239.
Minute 706:
  => Customer 243 call.
  => Estimate wait time for customer 243 is 8.
Minute 707:
Minute 708:
  => Customer 239 completed.
  => Serving customer 240.
Minute 709:
Minute 710:
Minute 711:
  => Customer 244 call.
  => Estimate wait time for customer 244 is 8.
Minute 712:
  => Customer 240 completed.
  => Serving customer 241.
Minute 713:
Minute 714:
  => Customer 245 call.
  => Estimate wait time for customer 245 is 8.
  => Customer 241 completed.
  => Serving customer 242.
Minute 715:
Minute 716:
  => Customer 242 completed.
  => Serving customer 243.
Minute 717:
  => Customer 246 call.
  => Estimate wait time for customer 246 is 6.
Minute 718:
Minute 719:
  => Customer 243 completed.
  => Serving customer 244.
```

```
Minute 720:
  => Customer 247 call.
  => Estimate wait time for customer 247 is 6.

End of Program Report
================================================
Numbers of customers called:              247
Numbers of customers served:              243
Number of customers left in line:         3
Maximum number of customers in line:      5
Longest wait time for a customer:         13
Average wait time for customers:          2.54733
```

TEST CASE 3.2

```
Project 3: Queues & Simulation
By Mai Pham

Minute 1:
Minute 2:
Minute 3:
Minute 4:
Minute 5:
  => Customer 1 call.
  => Estimate wait time for customer 1 is 0.
  => Serving customer 1.
Minute 6:
  => Customer 1 completed.
Minute 7:
Minute 8:
Minute 9:
Minute 10:
  => Customer 2 call.
  => Estimate wait time for customer 2 is 0.
  => Serving customer 2.
Minute 11:
  => Customer 2 completed.
Minute 12:
Minute 13:
Minute 14:
  => Customer 3 call.
  => Estimate wait time for customer 3 is 0.
  => Serving customer 3.
Minute 15:
  => Customer 4 call.
  => Estimate wait time for customer 4 is 2.
...
...
...
Minute 705:
Minute 706:
  => Customer 243 call.
  => Estimate wait time for customer 243 is 2.
Minute 707:
  => Customer 242 completed.
  => Serving customer 243.
Minute 708:
Minute 709:
Minute 710:
  => Customer 243 completed.
Minute 711:
  => Customer 244 call.
  => Estimate wait time for customer 244 is 0.
  => Serving customer 244.
```

```
Minute 712:
Minute 713:
Minute 714:
Minute 715:
  => Customer 245 call.
  => Estimate wait time for customer 245 is 2.
  => Customer 244 completed.
  => Serving customer 245.
Minute 716:
  => Customer 245 completed.
Minute 717:
Minute 718:
Minute 719:
  => Customer 246 call.
  => Estimate wait time for customer 246 is 0.
  => Serving customer 246.
Minute 720:
  => Customer 247 call.
  => Estimate wait time for customer 247 is 2.

End of Program Report
==================================================
Numbers of customers called:              247
Numbers of customers served:              245
Number of customers left in line:         1
Maximum number of customers in line:      5
Longest wait time for a customer:         11
Average wait time for customers:          2.22857
```

TEST CASE 3.3

```
Project 3: Queues & Simulation
By Mai Pham

Minute 1:
Minute 2:
Minute 3:
Minute 4:
Minute 5:
  => Customer 1 call.
  => Estimate wait time for customer 1 is 0.
  => Serving customer 1.
Minute 6:
  => Customer 2 call.
  => Estimate wait time for customer 2 is 4.
Minute 7:
Minute 8:
Minute 9:
  => Customer 3 call.
  => Estimate wait time for customer 3 is 8.
  => Customer 1 completed.
  => Serving customer 2.
Minute 10:
  => Customer 2 completed.
  => Serving customer 3.
Minute 11:
Minute 12:
Minute 13:
  => Customer 4 call.
  => Estimate wait time for customer 4 is 3.
Minute 14:
  => Customer 3 completed.
  => Serving customer 4.
Minute 15:
  => Customer 5 call.
```

```
  => Estimate wait time for customer 5 is 3.
...
...
...
Minute 705:
  => Customer 236 call.
  => Estimate wait time for customer 236 is 2.
  => Customer 235 completed.
  => Serving customer 236.
Minute 706:
Minute 707:
Minute 708:
Minute 709:
  => Customer 236 completed.
Minute 710:
  => Customer 237 call.
  => Estimate wait time for customer 237 is 0.
  => Serving customer 237.
Minute 711:
Minute 712:
Minute 713:
Minute 714:
  => Customer 237 completed.
Minute 715:
  => Customer 238 call.
  => Estimate wait time for customer 238 is 0.
  => Serving customer 238.
Minute 716:
  => Customer 239 call.
  => Estimate wait time for customer 239 is 2.
  => Customer 238 completed.
  => Serving customer 239.
Minute 717:
  => Customer 239 completed.
Minute 718:
Minute 719:
  => Customer 240 call.
  => Estimate wait time for customer 240 is 0.
  => Serving customer 240.
Minute 720:

End of Program Report
================================================
Numbers of customers called:              240
Numbers of customers served:              239
Number of customers left in line:         0
Maximum number of customers in line:      4
Longest wait time for a customer:         9
Average wait time for customers:          1.30962
```

SOURCE CODE

LINKED QUEUE TEMPLATE

```
//
//  LinkedQueue.h
//  Project 3
//
//  Created by Mai Pham on 10/28/17.
//  Copyright © 2017 Mai Pham. All rights reserved.
//
```

```
#ifndef LinkedQueue_h
#define LinkedQueue_h
#include <iostream>
using namespace std;

template <typename T>
class LinkedQueue
{
private:
    struct Node
    {
        T data;
        Node *next;
    };
    Node *head;
    Node *end;
    int count;

public:
    LinkedQueue()
    {
        head = end = NULL;
        count = 0;
    }
    void enqueue(T t)
    {
        Node *temp = new Node;
        temp->data = t;
        temp->next = NULL;
        if (head == NULL || end == NULL)
            head = end = temp;
        else
        {
            end->next = temp;
            end = temp;
        }
        count++;
    }
    void dequeue()
    {
        Node *temp = new Node;
        if (head != NULL)
        {
            temp = head;
            head = head->next;
            delete temp;
            count--;
        }
    }
    void printList()
    {
        Node *cur = head;
        int i = 1;
        while (cur != NULL)
        {
            cout << i << " " << cur->data << endl;
            cur = cur->next;
            i++;
        }
    }
    T front()
    {
        if(empty())
            cout << "Error!!!" << endl;
```

```
        return head->data;
    }
    int size()
    {
        return count;
    }
    bool empty()
    {
        return (count == 0);
    }
};

#endif /* LinkedQueue_h */
```

MAIN DRIVER

```
//
//  main.cpp
//  Project 3
//
//  Created by Mai Pham on 10/26/17.
//  Copyright © 2017 Mai Pham. All rights reserved.
//

#include "LinkedQueue.h"
#include <iostream>
#include <string>
#include <cstdlib>
#include <fstream>
using namespace std;

int main()
{
    //input data
    string fileName;
    int l;                              //# of line
    int t;                              //total run time
    int n;                              //max minutes between every call
    int m;                              //max minutes for serve time

    int nextCall;                       //next random call
    int servedTime = 0;                 //minutes to serve current call
    bool serving = false;               //on call or not
    int numOfCall = 0;                  //total # of customers called
    int customerServed = 0;             //total # of customers got served
    int totalServedTime = 0;            //total served time
    int estimated;                      //estimate wait time

    //end of program calculation
    int maxInLine = 0;                  //highest amount of customers wait in line
    int currentWaitTime = 0;            //current customer wait time
    int maxWaitTime = 0;                //longest wait time for 1 customers
    int totalWaitTime = 0;              //total wait time for all customers

    cout << "Please enter input file name: ";
    cin >> fileName;
    ifstream inputFile;
    inputFile.open(fileName);
    if (!inputFile)
    {
        cout << "Error opening file. \n";
        cout << "The file was not found" << endl;
        return 1;
    }
    while (!inputFile.eof())
```

```
    {
        inputFile >> l >> t >> n >> m;
    }

    LinkedQueue<int> callLine;
    srand(time(0));

    ofstream outFile;
    outFile.open("CallSimulation.txt");
    outFile << "Project 3: Queues & Simulation\n";
    outFile << "By Mai Pham\n\n";

    nextCall = rand() % n + 1;
    for (int i = 1; i <= t; i++)
    {
        outFile << "Minute " << i << ":";
        if (i == nextCall)
        {
            numOfCall++;
            outFile << "\n  => Customer " << numOfCall << " call.";

            callLine.enqueue(nextCall);
            if (maxInLine < callLine.size())
                maxInLine = callLine.size();

            if (serving == false)
                estimated = 0;
            else
                estimated = (totalServedTime/(customerServed+1))*callLine.size();
            outFile << "\n  => Estimate wait time for customer " << numOfCall << " is " <<
estimated << ".";

            nextCall += (rand() % n + 1);
        }
        if (i == servedTime)
        {
            customerServed++;
            serving = false;
            outFile << "\n  => Customer " << customerServed << " completed.";
        }
        if (serving == false && !callLine.empty())
        {
            currentWaitTime = i - callLine.front();
            totalWaitTime += currentWaitTime;
            if (maxWaitTime < currentWaitTime)
                maxWaitTime = currentWaitTime;

            callLine.dequeue();
            outFile << "\n  => Serving customer " << (customerServed+1) << ".";
            servedTime = (rand() % m + 1);
            totalServedTime += servedTime;
            servedTime += i;
            serving = true;
        }
        outFile << endl;
    }

    outFile << "\nEnd of Program Report\n";
    outFile << "================================================";
    outFile << "\nNumbers of customers called: \t\t\t" << numOfCall;
    outFile << "\nNumbers of customers served: \t\t\t" << customerServed;
    outFile << "\nNumber of customers left in line: \t\t" << callLine.size();
    outFile << "\nMaximum number of customers in line: \t" << maxInLine;
    outFile << "\nLongest wait time for a customer: \t\t" << maxWaitTime;
```

```
    outFile << "\nAverage wait time for customers: \t\t" <<
(double)totalWaitTime/customerServed;
    outFile << endl;
    return 0;
}
```