
CS342 ASSIGNMENT 4, Q2 REPORT

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Group CS-18:

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ANALYZING AIRPORT SECURITY LINES

We have created a simulation that replicates and improves security screening processes in a busy airport environment. As in real-life airports, passengers arrive at irregular intervals and undergo varying durations of security checks. This simulation scenario mirrors the actual challenges of queuing in airport scenarios, emphasizing the need to optimize security lines for heightened passenger satisfaction and overall airport efficiency.

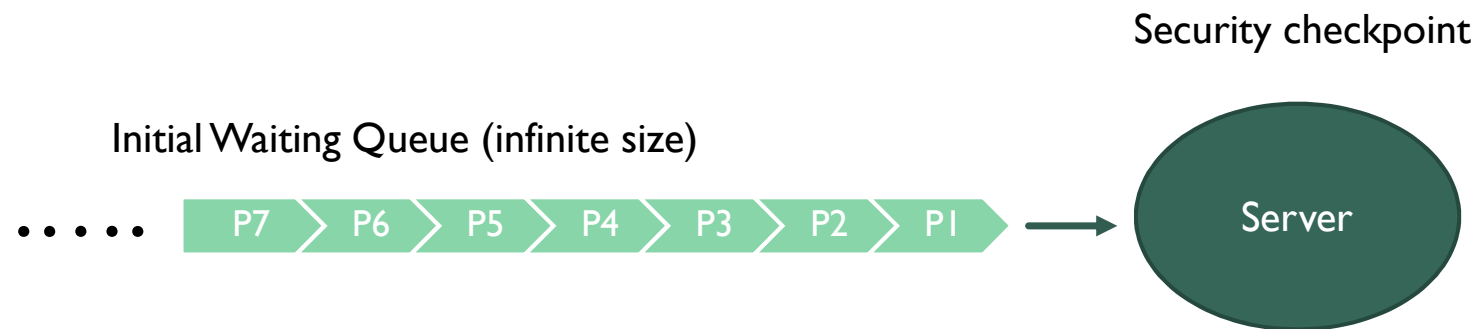
Inputs:

- Arrival rate (λ)
- Service rate (μ)
- Buffer size (k)
- Number of servers (m)

Parameters for analysis:

- **Average waiting time (T_w):** The average time passengers spend waiting in line before their security checks
- **Average service time (T_s)**
- **Average queuing time ($T_q = T_w + T_s$)**
- **Average queue length:** The average number of passengers in the queue at any given time
- **System Utilization:** The percentage of time the security scanner is actively processing passengers

CASE I: SINGLE SERVER, WITH INFINITE BUFFER



Arrival rate > Service rate

```
Passenger 997 Arrived at: 119 Served by: 1031
Waiting time= 912 Service time= 0 Total queueing time= 912
Passenger 998 Arrived at: 119 Served by: 1032
Waiting time= 912 Service time= 1 Total queueing time= 913
Passenger 999 Arrived at: 119 Served by: 1033
Waiting time= 913 Service time= 1 Total queueing time= 914
Passenger 1000 Arrived at: 120 Served by: 1035
Waiting time= 913 Service time= 2 Total queueing time= 915
Passenger 1001 Arrived at: 120 Served by: 1035
Waiting time= 915 Service time= 0 Total queueing time= 915
Passenger 1002 Arrived at: 120 Served by: 1036
Waiting time= 915 Service time= 1 Total queueing time= 916
```

```
-----Report-----
Average waiting time= 446.614 min
Average service time= 1.0329 min
Average queueing time= 447.647 min
Average queue length= 150
System utilization= 100%
```

Input:
Arrival rate = 9 Service rate = 1

```
Passenger 682 Arrived at: 120 Served by: 696
Waiting time= 575 Service time= 1 Total queueing time= 576
Passenger 683 Arrived at: 120 Served by: 697
Waiting time= 576 Service time= 1 Total queueing time= 577
Passenger 684 Arrived at: 120 Served by: 699
Waiting time= 577 Service time= 2 Total queueing time= 579
Passenger 685 Arrived at: 120 Served by: 699
Waiting time= 579 Service time= 0 Total queueing time= 579
Passenger 686 Arrived at: 120 Served by: 700
Waiting time= 579 Service time= 1 Total queueing time= 580
Passenger 687 Arrived at: 120 Served by: 700
Waiting time= 580 Service time= 0 Total queueing time= 580
```

```
-----Report-----
Average waiting time= 296.619 min
Average service time= 1.01744 min
Average queueing time= 297.637 min
Average queue length= 96
System utilization= 100%
```

Input:
Arrival rate = 5 Service rate = 1

```
Passenger 228 Arrived at: 117 Served by: 240
Waiting time= 123 Service time= 0 Total queueing time= 123
Passenger 229 Arrived at: 117 Served by: 241
Waiting time= 123 Service time= 1 Total queueing time= 124
Passenger 230 Arrived at: 118 Served by: 242
Waiting time= 123 Service time= 1 Total queueing time= 124
Passenger 231 Arrived at: 118 Served by: 244
Waiting time= 124 Service time= 2 Total queueing time= 126
Passenger 232 Arrived at: 118 Served by: 246
Waiting time= 126 Service time= 2 Total queueing time= 128
Passenger 233 Arrived at: 120 Served by: 246
Waiting time= 126 Service time= 0 Total queueing time= 126
```

```
-----Report-----
Average waiting time= 70.9487 min
Average service time= 1.03846 min
Average queueing time= 71.9872 min
Average queue length= 18
System utilization= 100%
```

Input:
Arrival rate = 2 Service rate = 1

When **arrival rate > service rate**, it means that number of passengers arriving is more than the service capacity of the server. This results in longer queues, longer waiting times and therefore longer queueing times. The system utilization is 100%, since the system is over-loaded – more passengers than service capacity. In the above cases we can observe that as arrival rate is increasing over same service rate, the waiting time is increasing considerably, from 70min to 296min to 446min. Similarly the queue lengths are also increasing with arrival rate (18, 96, 150).

Arrival rate < Service rate

```
Passenger 81 Arrived at: 78 Served by: 79
Waiting time= 1 Service time= 0 Total queueing time= 1
Passenger 82 Arrived at: 81 Served by: 81
Waiting time= 0 Service time= 0 Total queueing time= 0
Passenger 83 Arrived at: 82 Served by: 83
Waiting time= 0 Service time= 1 Total queueing time= 1
Passenger 84 Arrived at: 84 Served by: 84
Waiting time= 0 Service time= 0 Total queueing time= 0
Passenger 85 Arrived at: 87 Served by: 88
Waiting time= 0 Service time= 1 Total queueing time= 1
Passenger 86 Arrived at: 87 Served by: 88
Waiting time= 1 Service time= 0 Total queueing time= 1
```

-----Report-----

```
Average waiting time= 0.25 min
Average service time= 0.308333 min
Average queueing time= 0.558333 min
Average queue length= 1
System utilization= 58.6777%
```

Input:

Arrival rate = 1 Service rate = 2

```
Passenger 66 Arrived at: 66 Served by: 66
Waiting time= 0 Service time= 0 Total queueing time= 0
Passenger 67 Arrived at: 67 Served by: 67
Waiting time= 0 Service time= 0 Total queueing time= 0
Passenger 68 Arrived at: 70 Served by: 70
Waiting time= 0 Service time= 0 Total queueing time= 0
Passenger 69 Arrived at: 72 Served by: 72
Waiting time= 0 Service time= 0 Total queueing time= 0
Passenger 70 Arrived at: 72 Served by: 72
Waiting time= 0 Service time= 0 Total queueing time= 0
Passenger 71 Arrived at: 73 Served by: 73
Waiting time= 0 Service time= 0 Total queueing time= 0
```

-----Report-----

```
Average waiting time= 0.0176991 min
Average service time= 0.106195 min
Average queueing time= 0.123894 min
Average queue length= 4
System utilization= 49.5868%
```

Input:

Arrival rate= 1 Service rate = 5

```
Passenger 76 Arrived at: 68 Served by: 68
Waiting time= 0 Service time= 0 Total queueing time= 0
Passenger 77 Arrived at: 68 Served by: 68
Waiting time= 0 Service time= 0 Total queueing time= 0
Passenger 78 Arrived at: 68 Served by: 68
Waiting time= 0 Service time= 0 Total queueing time= 0
Passenger 79 Arrived at: 69 Served by: 69
Waiting time= 0 Service time= 0 Total queueing time= 0
Passenger 80 Arrived at: 71 Served by: 71
Waiting time= 0 Service time= 0 Total queueing time= 0
Passenger 81 Arrived at: 72 Served by: 72
Waiting time= 0 Service time= 0 Total queueing time= 0
```

-----Report-----

```
Average waiting time= 0.0708661 min
Average service time= 0.0787402 min
Average queueing time= 0.149606 min
Average queue length= 3
System utilization= 48.7603%
```

Input:

Arrival rate = 1 Service rate = 11

When **arrival rate < service rate**, it means that the service capacity of the server is much more than the number of passengers arriving, i.e. server can serve passengers much faster than they're arriving. This means that as the service rate increases, the service times decrease (0.3min, 0.1min, 0.07min). The difference is more prominent when there is greater difference between service rates. It can also be noted that system utilization is much lower than 100% and decreases as the service rate increases, because the system is not being used to full capacity (capacity keeps increasing). The queue lengths are also small (<5).

Arrival rate = Service rate

```
Passenger 94 Arrived at: 110 Served by: 114
Waiting time= 3 Service time= 1 Total queueing time= 4
Passenger 95 Arrived at: 110 Served by: 116
Waiting time= 4 Service time= 2 Total queueing time= 6
Passenger 96 Arrived at: 111 Served by: 117
Waiting time= 5 Service time= 1 Total queueing time= 6
Passenger 97 Arrived at: 111 Served by: 120
Waiting time= 6 Service time= 3 Total queueing time= 9
Passenger 98 Arrived at: 112 Served by: 120
Waiting time= 8 Service time= 0 Total queueing time= 8
Passenger 99 Arrived at: 112 Served by: 123
Waiting time= 8 Service time= 3 Total queueing time= 11
```

-----Report-----

```
Average waiting time= 2.88073 min
Average service time= 0.972477 min
Average queueing time= 3.85321 min
Average queue length= 0
System utilization= 86.1789%
```

Input:

Arrival rate = 1 Service rate = 1

```
Passenger 387 Arrived at: 119 Served by: 138
Waiting time= 19 Service time= 0 Total queueing time= 19
Passenger 388 Arrived at: 119 Served by: 138
Waiting time= 19 Service time= 0 Total queueing time= 19
Passenger 389 Arrived at: 119 Served by: 138
Waiting time= 19 Service time= 0 Total queueing time= 19
Passenger 390 Arrived at: 120 Served by: 138
Waiting time= 18 Service time= 0 Total queueing time= 18
Passenger 391 Arrived at: 120 Served by: 138
Waiting time= 18 Service time= 0 Total queueing time= 18
Passenger 392 Arrived at: 120 Served by: 138
Waiting time= 18 Service time= 0 Total queueing time= 18
```

-----Report-----

```
Average waiting time= 15.9542 min
Average service time= 0.351145 min
Average queueing time= 16.3053 min
Average queue length= 2
System utilization= 100%
```

Input:

Arrival rate= 3 Service rate = 3

```
Passenger 1113 Arrived at: 120 Served by: 126
Waiting time= 6 Service time= 0 Total queueing time= 6
Passenger 1114 Arrived at: 120 Served by: 126
Waiting time= 6 Service time= 0 Total queueing time= 6
Passenger 1115 Arrived at: 120 Served by: 127
Waiting time= 6 Service time= 1 Total queueing time= 7
Passenger 1116 Arrived at: 120 Served by: 127
Waiting time= 7 Service time= 0 Total queueing time= 7
Passenger 1117 Arrived at: 120 Served by: 127
Waiting time= 7 Service time= 0 Total queueing time= 7
Passenger 1118 Arrived at: 120 Served by: 127
Waiting time= 7 Service time= 0 Total queueing time= 7
```

-----Report-----

```
Average waiting time= 5.33512 min
Average service time= 0.113494 min
Average queueing time= 5.44861 min
Average queue length= 0
System utilization= 100%
```

Input:

Arrival rate = 10 Service rate = 10

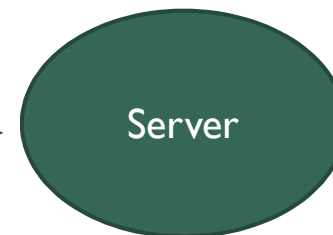
When **arrival rate = service rate**, it means that the service capacity of the server is equal to the number of passengers arriving, i.e. server can serve passengers at the same rate as they're arriving. Here, the queue lengths can be seen to be negligible (<3). System utilization increases with arrival/service rate and gradually reaches 100%. Service times decrease with increase in service rate.

CASE 2: SINGLE SERVER, WITH FINITE BUFFER (K)

Initial Waiting Queue (finite size K)



Security checkpoint



Arrival rate > Service rate

```
Arrival time: 114
Buffer full. Passenger ID 218 dropped.
Arrival time: 115
Passenger 219 Arrived at: 117 Served by: 123
Waiting time= 5 Service time= 1 Total queueing time= 6
Passenger 220 Arrived at: 118 Served by: 124
Waiting time= 5 Service time= 1 Total queueing time= 6
Passenger 221 Arrived at: 118 Served by: 125
Waiting time= 6 Service time= 1 Total queueing time= 7
```

-----Report-----

```
Average waiting time= 4.94595 min
Average service time= 0.563063 min
Average queueing time= 5.50901 min
System utilization= 100%
```

```
Finite buffer length= 10
Number of passengers dropped= 107/222
% of passengers dropped= 48.1982%
```

Input:

Arrival rate = 2 Service rate = 1

Buffer size = 10

```
Waiting time= 18 Service time= 3 Total queueing time= 21
Passenger 209 Arrived at: 120 Served by: 141
Waiting time= 21 Service time= 0 Total queueing time= 21
Buffer full. Passenger ID 210 dropped.
Arrival time: 120
Buffer full. Passenger ID 211 dropped.
Arrival time: 120
Buffer full. Passenger ID 212 dropped.
Arrival time: 120
```

-----Report-----

```
Average waiting time= 10.4836 min
Average service time= 0.661972 min
Average queueing time= 11.1455 min
System utilization= 100%
```

```
Finite buffer length= 20
Number of passengers dropped= 83/213
% of passengers dropped= 38.9671%
```

Input:

Arrival rate = 2 Service rate = 1

Buffer size = 20

```
Arrival time: 117
Passenger 238 Arrived at: 116 Served by: 223
Waiting time= 104 Service time= 3 Total queueing time= 107
Buffer full. Passenger ID 242 dropped.
Arrival time: 118
Passenger 241 Arrived at: 118 Served by: 223
Waiting time= 105 Service time= 0 Total queueing time= 105
Passenger 243 Arrived at: 119 Served by: 223
Waiting time= 104 Service time= 0 Total queueing time= 104
```

-----Report-----

```
Average waiting time= 52.5837 min
Average service time= 0.906122 min
Average queueing time= 53.4898 min
System utilization= 99.5516%
```

```
Finite buffer length= 100
Number of passengers dropped= 35/245
% of passengers dropped= 14.2857%
```

Input:

Arrival rate = 2 Service rate = 1

Buffer size = 100

When **arrival rate > service rate**, it means that number of passengers arriving is more than the service capacity of the server. This results in longer queues, longer waiting times and therefore longer queueing times. The system utilization is 100% (or nearly 100%), since the system is over-loaded – more passengers than service capacity. In the above cases we can observe that keeping the arrival and service rates same, as we increase the finite buffer size, the percentage of passengers dropped decreases (48%, 39%, 14%). This is because there is more capacity to handle passengers in the waiting stage when queue length is long. But a drawback can be noticed too, as the buffer length becomes too long, the waiting times become very long too (5min, 10min, 52min). This decreases passenger satisfaction.

Arrival rate > Service rate (contd.)

```
Arrival time: 120
Buffer full. Passenger ID 1006 dropped.
Arrival time: 120
Buffer full. Passenger ID 1007 dropped.
Arrival time: 120
Buffer full. Passenger ID 1008 dropped.
Arrival time: 120
Buffer full. Passenger ID 1009 dropped.
Arrival time: 120
```

-----Report-----

```
Average waiting time= 1.29604 min
Average service time= 0.129703 min
Average queueing time= 1.42574 min
System utilization= 99.2424%
```

```
Finite buffer length= 10
Number of passengers dropped= 892/1010
% of passengers dropped= 88.3168%
```

Input:

Arrival rate = 9 Service rate = 1

Buffer size = 10

```
Arrival time: 119
Buffer full. Passenger ID 897 dropped.
Arrival time: 120
Buffer full. Passenger ID 898 dropped.
Arrival time: 120
Buffer full. Passenger ID 899 dropped.
Arrival time: 120
Buffer full. Passenger ID 900 dropped.
Arrival time: 120
```

-----Report-----

```
Average waiting time= 2.88679 min
Average service time= 0.155383 min
Average queueing time= 3.04218 min
System utilization= 100%
```

```
Finite buffer length= 20
Number of passengers dropped= 766/901
% of passengers dropped= 85.0166%
```

Input:

Arrival rate = 9 Service rate = 1

Buffer size = 20

```
Arrival time: 120
Buffer full. Passenger ID 1215 dropped.
Arrival time: 120
Buffer full. Passenger ID 1216 dropped.
Arrival time: 120
Buffer full. Passenger ID 1217 dropped.
Arrival time: 120
Buffer full. Passenger ID 1218 dropped.
Arrival time: 120
```

-----Report-----

```
Average waiting time= 12.6981 min
Average service time= 0.178015 min
Average queueing time= 12.8761 min
System utilization= 100%
```

```
Finite buffer length= 100
Number of passengers dropped= 1022/1219
% of passengers dropped= 83.8392%
```

Input:

Arrival rate = 9 Service rate = 1

Buffer size = 100

When **arrival rate > service rate**, it means that number of passengers arriving is more than the service capacity of the server. The system utilization is 100% (or nearly 100%), since the system is over-loaded – more passengers than service capacity. In the above cases we can observe that when arrival rate is much higher than service rate, the % of passengers dropped is also much higher and doesn't get affected too much by increase in buffer length (88%, 85%, 83%). The same drawback can be noticed - as the buffer length becomes too long, the waiting times become very long as well (1min, 2.8min, 12min). This decreases passenger satisfaction.

Arrival rate < Service rate

```
Waiting time= 0 Service time= 0 Total queueing time= 0
Passenger 96 Arrived at: 85 Served by: 85
Waiting time= 0 Service time= 0 Total queueing time= 0
Passenger 97 Arrived at: 85 Served by: 85
Waiting time= 0 Service time= 0 Total queueing time= 0
Passenger 98 Arrived at: 86 Served by: 87
Waiting time= 0 Service time= 1 Total queueing time= 1
Passenger 99 Arrived at: 88 Served by: 88
Waiting time= 0 Service time= 0 Total queueing time= 0
```

-----Report-----

```
Average waiting time= 0.514925 min
Average service time= 0.30597 min
Average queueing time= 0.820896 min
System utilization= 61.157%
```

```
Finite buffer length= 10
Number of passengers dropped= 0/134
% of passengers dropped= 0%
```

Arrival rate = 1 Service rate = 2 Buffer size = 10

```
Waiting time= 1 Service time= 0 Total queueing time= 1
Passenger 101 Arrived at: 86 Served by: 86
Waiting time= 0 Service time= 0 Total queueing time= 0
Passenger 102 Arrived at: 88 Served by: 90
Waiting time= 0 Service time= 2 Total queueing time= 2
Passenger 103 Arrived at: 88 Served by: 93
Waiting time= 2 Service time= 3 Total queueing time= 5
Passenger 104 Arrived at: 88 Served by: 94
Waiting time= 5 Service time= 1 Total queueing time= 6
```

-----Report-----

```
Average waiting time= 1.09375 min
Average service time= 0.453125 min
Average queueing time= 1.54688 min
System utilization= 70.2479%
```

```
Finite buffer length= 50
Number of passengers dropped= 0/128
% of passengers dropped= 0%
```

Arrival rate = 1 Service rate = 2 Buffer size = 50

When **arrival rate < service rate**, it means that the service capacity of the server is much more than the number of passengers arriving, i.e. server can serve passengers much faster than they're arriving. In the above cases it can be observed that keeping the arrival and service rate same, the system utilization increases as buffer size increases, since more passengers can be accommodated in the waiting queue. In all cases the percentage of passengers dropped is 0% as the passengers are always arriving slower than the rate at which server is serving them. So the queue never fills up to its maximum capacity, and hence no passengers are dropped.

Arrival rate = Service rate

```
Waiting time= 5 Service time= 1 Total queueing time= 6
Passenger 112 Arrived at: 112 Served by: 117
Waiting time= 5 Service time= 0 Total queueing time= 5
Passenger 113 Arrived at: 113 Served by: 118
Waiting time= 4 Service time= 1 Total queueing time= 5
Passenger 114 Arrived at: 114 Served by: 120
Waiting time= 4 Service time= 2 Total queueing time= 6
Passenger 115 Arrived at: 115 Served by: 120
Waiting time= 5 Service time= 0 Total queueing time= 5
```

-----Report-----

```
Average waiting time= 4.4 min
Average service time= 0.941667 min
Average queueing time= 5.34167 min
System utilization= 96.6942%
```

```
Finite buffer length= 10
Number of passengers dropped= 1/120
% of passengers dropped= 0.833333%
```

Arrival rate = 1 Service rate = 1 Buffer size = 10

```
Waiting time= 6 Service time= 0 Total queueing time= 6
Passenger 89 Arrived at: 102 Served by: 109
Waiting time= 5 Service time= 2 Total queueing time= 7
Passenger 90 Arrived at: 102 Served by: 109
Waiting time= 7 Service time= 0 Total queueing time= 7
Passenger 91 Arrived at: 106 Served by: 110
Waiting time= 3 Service time= 1 Total queueing time= 4
Passenger 92 Arrived at: 107 Served by: 111
Waiting time= 3 Service time= 1 Total queueing time= 4
```

-----Report-----

```
Average waiting time= 2.17 min
Average service time= 0.99 min
Average queueing time= 3.16 min
System utilization= 92.562%
```

```
Finite buffer length= 50
Number of passengers dropped= 0/100
% of passengers dropped= 0%
```

Arrival rate = 1 Service rate = 1 Buffer size = 50

When **arrival rate = service rate**, it means that the service capacity of the server is equal to the number of passengers arriving, i.e. server serves passengers at same rate as they're arriving. In the above cases it can be observed that when the queue length is less, a small number of passengers are dropped (1 or 2) and as the queue length increases, the percentage of passengers dropped reduces to 0. This is because in that situation the queue never fills up to its maximum capacity, and hence no passengers are dropped.

Arrival rate = Service rate (contd.)

```
Arrival time: 119
Buffer full. Passenger ID 1370 dropped.
Arrival time: 119
Passenger 1216 Arrived at: 113 Served by: 121
Waiting time= 8 Service time= 0 Total queueing time= 8
Passenger 1217 Arrived at: 113 Served by: 121
Waiting time= 8 Service time= 0 Total queueing time= 8
Passenger 1240 Arrived at: 114 Served by: 121
Waiting time= 7 Service time= 0 Total queueing time= 7
```

-----Report-----

```
Average waiting time= 1.1623 min
Average service time= 0.0655022 min
Average queueing time= 1.2278 min
System utilization= 74.5902%
```

```
Finite buffer length= 10
Number of passengers dropped= 274/1374
% of passengers dropped= 19.9418%
```

Input:

Arrival rate = 10 Service rate = 10

Buffer size = 10

```
Waiting time= 4 Service time= 0 Total queueing time= 4
Passenger 1208 Arrived at: 117 Served by: 121
Waiting time= 4 Service time= 0 Total queueing time= 4
Passenger 1209 Arrived at: 118 Served by: 121
Waiting time= 3 Service time= 0 Total queueing time= 3
Passenger 1210 Arrived at: 118 Served by: 122
Waiting time= 3 Service time= 1 Total queueing time= 4
Passenger 1211 Arrived at: 118 Served by: 122
Waiting time= 4 Service time= 0 Total queueing time= 4
```

-----Report-----

```
Average waiting time= 2.67128 min
Average service time= 0.0854353 min
Average queueing time= 2.75671 min
System utilization= 86.0656%
```

```
Finite buffer length= 50
Number of passengers dropped= 94/1229
% of passengers dropped= 7.64849%
```

Input:

Arrival rate = 10 Service rate = 10

Buffer size = 50

```
Waiting time= 4 Service time= 0 Total queueing time= 4
Passenger 1287 Arrived at: 120 Served by: 124
Waiting time= 4 Service time= 0 Total queueing time= 4
Passenger 1288 Arrived at: 120 Served by: 124
Waiting time= 4 Service time= 0 Total queueing time= 4
Passenger 1289 Arrived at: 120 Served by: 124
Waiting time= 4 Service time= 0 Total queueing time= 4
Passenger 1290 Arrived at: 120 Served by: 124
Waiting time= 4 Service time= 0 Total queueing time= 4
```

-----Report-----

```
Average waiting time= 4.73879 min
Average service time= 0.0927357 min
Average queueing time= 4.83153 min
System utilization= 96.7742%
```

```
Finite buffer length= 100
Number of passengers dropped= 40/1294
% of passengers dropped= 3.09119%
```

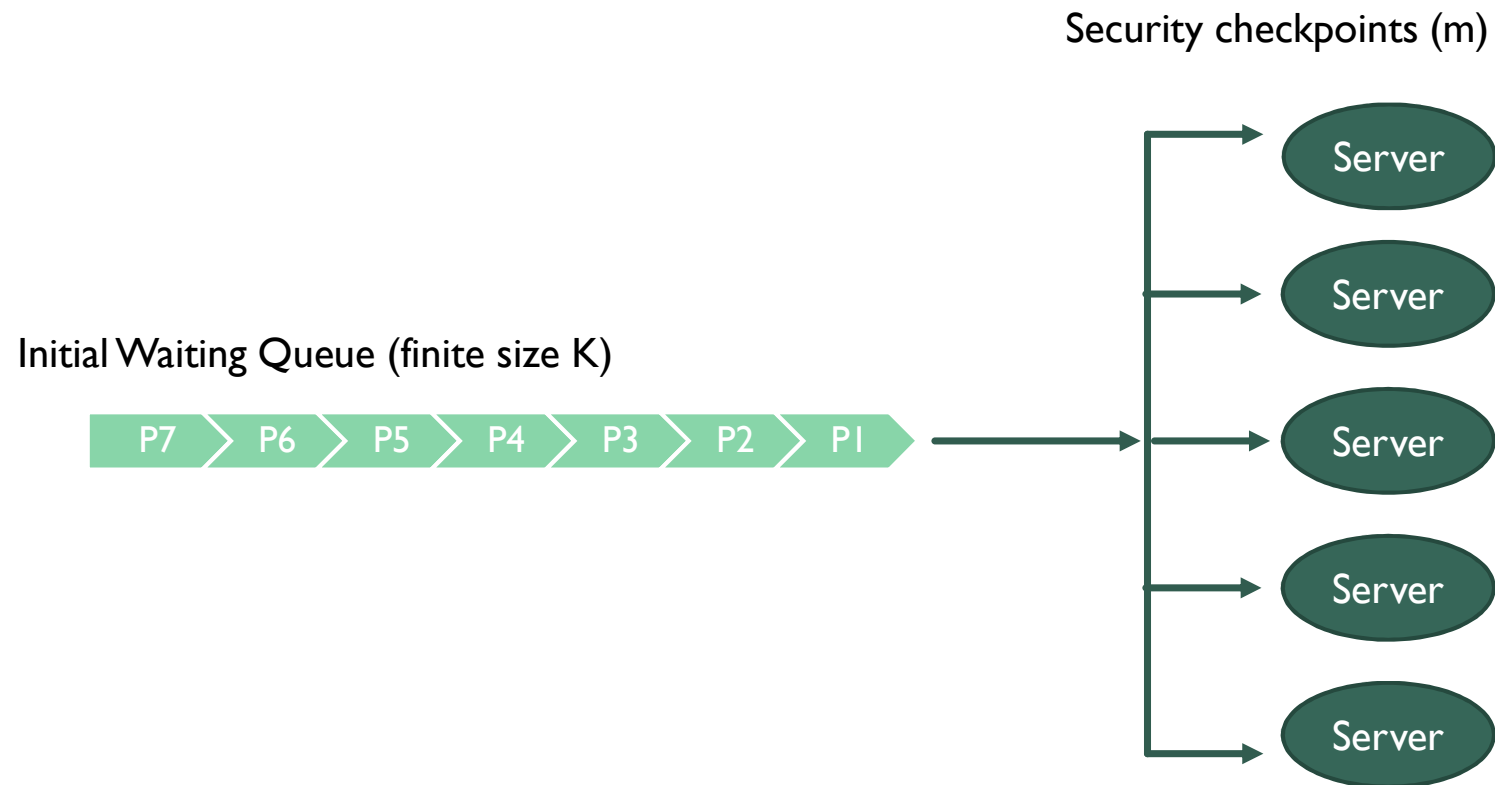
Input:

Arrival rate = 10 Service rate = 10

Buffer size = 100

When **arrival rate = service rate**, it means that the service capacity of the server is equal to the number of passengers arriving, i.e. server serves passengers at same rate as they're arriving. In the above cases it can be observed that as the queue length increases, the percentage of passengers dropped decreases (19%, 7%, 3%). The system utilization also increases with increase in buffer size (74%, 86%, 96%).

CASE 3: MULTI SERVER (M), WITH ONE FINITE BUFFER (K)




```
Arrival time: 120
Buffer full. Passenger ID 1216 dropped.
Arrival time: 120
```

```
-----Report-----
```

```
Average waiting time= 0.974528 min
```

```
Server 0
```

```
Avg service time= 1.18349 min, Avg queueing time= 1.18349 min, System utilization= 100%
```

```
Server 1
```

```
Avg service time= 1.01587 min, Avg queueing time= 1.01587 min, System utilization= 100%
```

```
Finite buffer length= 10
```

```
Number of passengers dropped= 981/1217
```

```
% of passengers dropped= 80.6081%
```

```
-----Report-----
```

```
Average waiting time= 0.544527 min
```

```
Server 0
```

```
Avg service time= 1.08411 min, Avg queueing time= 1.14019 min, System utilization= 95.082%
```

```
Server 1
```

```
Avg service time= 1.03774 min, Avg queueing time= 1.13208 min, System utilization= 91.6667%
```

```
Server 2
```

```
Avg service time= 1.02804 min, Avg queueing time= 1.1215 min, System utilization= 91.6667%
```

```
Server 3
```

```
Avg service time= 0.868852 min, Avg queueing time= 0.991803 min, System utilization= 87.6033%
```

```
Server 4
```

```
Avg service time= 0.954128 min, Avg queueing time= 1.10092 min, System utilization= 86.6667%
```

```
Server 5
```

```
Avg service time= 1.00952 min, Avg queueing time= 1.14286 min, System utilization= 88.3333%
```

```
Server 6
```

```
Avg service time= 1.11828 min, Avg queueing time= 1.30108 min, System utilization= 85.9504%
```

```
Server 7
```

```
Avg service time= 1.09783 min, Avg queueing time= 1.30435 min, System utilization= 84.1667%
```

```
Finite buffer length= 10
```

```
Number of passengers dropped= 236/1078
```

```
% of passengers dropped= 21.8924%
```

Arrival rate \geq Service rate

Input:

Arrival rate = 9 Service rate = 1

Buffer size = 10 Servers = 2

Input:

Arrival rate = 9 Service rate = 1

Buffer size = 10 Servers = 8

Effect of changing number of servers (2, 8), keeping buffer size same (10):

With more number of servers, % of passengers dropped decreases. With less number of servers, individual server utilizations increase.

-----Report-----

Average waiting time= 1.15222 min

Server 0
Avg service time= 1.18557 min, Avg queueing time= 1.27835 min, System utilization= 92.7419%

Server 1
Avg service time= 1.06604 min, Avg queueing time= 1.16981 min, System utilization= 91.129%

Server 2
Avg service time= 0.990909 min, Avg queueing time= 1.11818 min, System utilization= 88.6179%

Server 3
Avg service time= 0.84252 min, Avg queueing time= 0.968504 min, System utilization= 86.9919%

Server 4
Avg service time= 1.01869 min, Avg queueing time= 1.14953 min, System utilization= 88.6179%

Server 5
Avg service time= 1.09278 min, Avg queueing time= 1.25773 min, System utilization= 86.8852%

Server 6
Avg service time= 1.10526 min, Avg queueing time= 1.29474 min, System utilization= 85.3659%

Server 7
Avg service time= 0.944954 min, Avg queueing time= 1.11927 min, System utilization= 84.4262%

Finite buffer length= 20

Number of passengers dropped= 189/1038

% of passengers dropped= 18.2081%

-----Report-----

Average waiting time= 3.76028 min

Server 0
Avg service time= 0.851064 min, Avg queueing time= 0.858156 min, System utilization= 99.1736%

Server 1
Avg service time= 0.915385 min, Avg queueing time= 0.930769 min, System utilization= 98.3471%

Server 2
Avg service time= 1.00847 min, Avg queueing time= 1.02542 min, System utilization= 98.3471%

Server 3
Avg service time= 1.05217 min, Avg queueing time= 1.06087 min, System utilization= 99.1803%

Server 4
Avg service time= 0.862319 min, Avg queueing time= 0.876812 min, System utilization= 98.3471%

Server 5
Avg service time= 1.13208 min, Avg queueing time= 1.15094 min, System utilization= 98.3607%

Server 6
Avg service time= 0.880597 min, Avg queueing time= 0.902985 min, System utilization= 97.5207%

Server 7
Avg service time= 1.02632 min, Avg queueing time= 1.0614 min, System utilization= 96.6942%

Finite buffer length= 100

Number of passengers dropped= 0/997

% of passengers dropped= 0%

Arrival rate = 9 Service rate = 1
Buffer size = 20 Servers = 8

Arrival rate = 9 Service rate = 1
Buffer size = 100 Servers = 8

Effect of changing buffer size (10, 20, 100), keeping number of servers same (8):

Waiting times increase (0.5, 1, 3.7 min) with increase in buffer size, but % of passengers dropped decreases (21%, 18%, 0%).

Arrival rate < Service rate

```
Server no. 0 Service end time: 112
Server no. 1 Service end time: 118
Passenger 123 Arrived at: 119Server idle time= 104 Service time= 0 Total queueing time= 0
Server no. 1 Service end time: 118
Server no. 0 Service end time: 119
Passenger 124 Arrived at: 120Server idle time= 106 Service time= 0 Total queueing time= 0
Server no. 0 Service end time: 119
Server no. 1 Service end time: 120
```

-----Report-----

Average waiting time= 0 min

Server 0
Avg service time= 0.197368 min, Avg queueing time= 1.56579 min, System utilization= 12.605%

Server 1
Avg service time= 0.291667 min, Avg queueing time= 2.5 min, System utilization= 11.6667%

Finite buffer length= 10
Number of passengers dropped= 0/125
% of passengers dropped= 0%

```
Passenger 125 Arrived at: 120Server idle time= 106 Service time= 0 Total queueing time= 0
Server no. 1 Service end time: 116
Server no. 0 Service end time: 118
Passenger 109 Arrived at: 119Server idle time= 113 Service time= 1 Total queueing time= 1
Server no. 0 Service end time: 118
Server no. 1 Service end time: 120
Passenger 110 Arrived at: 120Server idle time= 105 Service time= 0 Total queueing time= 0
Server no. 0 Service end time: 120
Server no. 1 Service end time: 120
```

-----Report-----

Average waiting time= 0.00900901 min

Server 0
Avg service time= 0.238095 min, Avg queueing time= 1.90476 min, System utilization= 12.5%

Server 1
Avg service time= 0.148936 min, Avg queueing time= 2.55319 min, System utilization= 5.83333%

Finite buffer length= 20
Number of passengers dropped= 0/111
% of passengers dropped= 0%

Input:

Arrival rate = 1 Service rate = 5

Buffer size = 10 Servers = 2

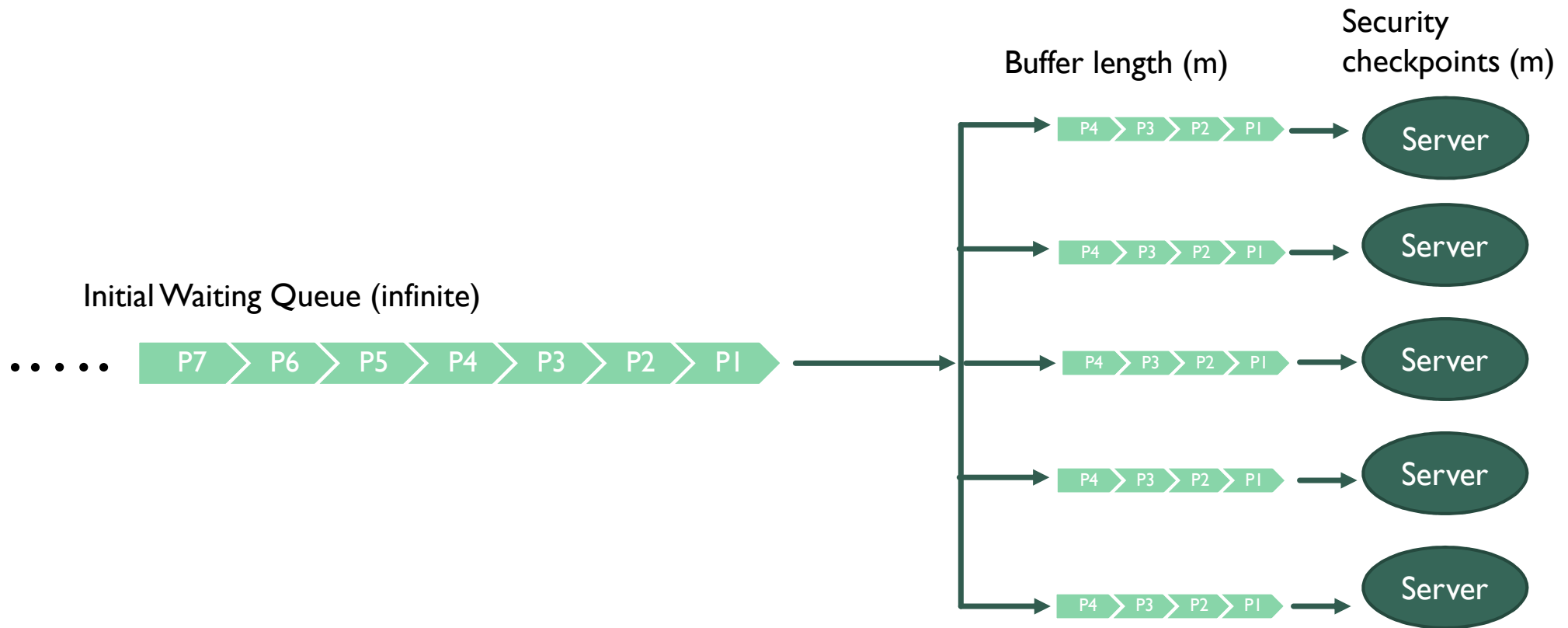
Input:

Arrival rate = 1 Service rate = 5

Buffer size = 20 Servers = 2

When **arrival rate < service rate**, it means that the server serves passengers at faster rate than they're arriving. Hence % of passengers dropped is 0, and remains so even on increasing buffer size, or number of servers. Waiting time increases with increase in buffer size, but still remains a negligible value.

CASE 3: MULTI SERVER (M), WITH MULTIPLE FINITE BUFFERS (M)




```

125 120
Passenger 1282 Arrived at: 120 Served by - 0
Waiting time= 5 Service time= 0 Total queueing time= 133
126 126
Buffer full. Passenger ID 1283 dropped.
Arrival time: 120
Buffer full. Passenger ID 1284 dropped.
Arrival time: 120
Buffer full. Passenger ID 1285 dropped.
Arrival time: 120

-----Report-----

Average waiting time= 0.883359 min

Server 0
avg service time= 0.942308min avg queueing time= 0.948718min System utilization= 99.3243%

Server 1
avg service time= 1.03871min avg queueing time= 1.05161min System utilization= 98.773%

Finite buffer length= 10
Number of passengers dropped= 974/1286
% of passengers dropped= 75.7387%

```

Arrival rate \geq Service rate

Input:

Arrival rate = 9 Service rate = 1

Buffer size = 10 Servers = 2

```

-----Report-----

Average waiting time= 0 min

Server 0
Avg service time= 0.953488 min, Avg queueing time= 1.20349 min, System utilization= 79.2271%

Server 1
Avg service time= 1.03529 min, Avg queueing time= 1.25882 min, System utilization= 82.243%

Server 2
Avg service time= 0.969697 min, Avg queueing time= 1.27273 min, System utilization= 76.1905%

Server 3
Avg service time= 0.924528 min, Avg queueing time= 1.28302 min, System utilization= 72.0588%

Server 4
Avg service time= 0.873418 min, Avg queueing time= 1.17722 min, System utilization= 74.1935%

Server 5
Avg service time= 0.828025 min, Avg queueing time= 1.19108 min, System utilization= 69.5187%

Server 6
Avg service time= 1.04762 min, Avg queueing time= 1.38095 min, System utilization= 75.8621%

Server 7
Avg service time= 0.993007 min, Avg queueing time= 1.39161 min, System utilization= 71.3568%

Finite buffer length= 10
Number of passengers dropped= 0/1272
% of passengers dropped= 0%

```

Input:

Arrival rate = 9 Service rate = 1

Buffer size = 10 Servers = 8

Effect of changing number of servers (2, 8), keeping buffer size same (10):

With more number of servers, % of passengers dropped decreases. And this value is lesser than that in case with no individual buffers. With less number of servers, individual server utilizations increase. Buffers reduce load on each server.


```

-----Report-----
Average waiting time= 0 min

Server 0
Avg service time= 0.89172 min, Avg queueing time= 1.23567 min, System utilization= 72.1649%

Server 1
Avg service time= 1.15333 min, Avg queueing time= 1.58667 min, System utilization= 72.6891%

Server 2
Avg service time= 0.971831 min, Avg queueing time= 1.44366 min, System utilization= 67.3171%

Server 3
Avg service time= 0.873239 min, Avg queueing time= 1.39437 min, System utilization= 62.6263%

Server 4
Avg service time= 0.878571 min, Avg queueing time= 1.42857 min, System utilization= 61.5%

Server 5
Avg service time= 0.907143 min, Avg queueing time= 1.45 min, System utilization= 62.5616%

Server 6
Avg service time= 1.10145 min, Avg queueing time= 1.57246 min, System utilization= 70.0461%

Server 7
Avg service time= 0.954545 min, Avg queueing time= 1.46212 min, System utilization= 65.285%

Finite buffer length= 20
Number of passengers dropped= 0/1142
% of passengers dropped= 0%

```

Arrival rate = 9 Service rate = 1
 Buffer size = 20 Servers = 8

```

-----Report-----
Average waiting time= 0 min

Server 0
Avg service time= 1.0398 min, Avg queueing time= 1.41294 min, System utilization= 73.5915%

Server 1
Avg service time= 0.95 min, Avg queueing time= 1.365 min, System utilization= 69.5971%

Server 2
Avg service time= 0.955 min, Avg queueing time= 1.44 min, System utilization= 66.3194%

Server 3
Avg service time= 1.0443 min, Avg queueing time= 1.70886 min, System utilization= 61.1111%

Server 4
Avg service time= 1.06 min, Avg queueing time= 1.43 min, System utilization= 74.1259%

Server 5
Avg service time= 1.1 min, Avg queueing time= 1.61 min, System utilization= 68.323%

Server 6
Avg service time= 0.94 min, Avg queueing time= 1.65 min, System utilization= 56.9697%

Server 7
Avg service time= 0.98 min, Avg queueing time= 1.81 min, System utilization= 54.1436%

Finite buffer length= 100
Number of passengers dropped= 0/1160
% of passengers dropped= 0%

```

Arrival rate = 9 Service rate = 1
 Buffer size = 100 Servers = 8

Effect of changing buffer size (10, 20, 100), keeping number of servers same (8):
 Waiting times are 0 or negligible since individual buffers mean passengers are removed from initial queue almost immediately. The % of passengers dropped is also 0 as each passenger is accommodated in server's individual buffer.

Arrival rate < Service rate

```
-----Report-----  
  
Average waiting time= 0 min  
  
Server 0  
Avg service time= 0.366667 min, Avg queueing time= 3.56667 min, System utilization= 10.2804%  
  
Server 1  
Avg service time= 0.1 min, Avg queueing time= 3.8 min, System utilization= 2.63158%  
  
Server 2  
Avg service time= 0.153846 min, Avg queueing time= 4.57692 min, System utilization= 3.36134%  
  
Server 3  
Avg service time= 0.25 min, Avg queueing time= 4.35 min, System utilization= 5.74713%  
  
Server 4  
Avg service time= 0.15 min, Avg queueing time= 4.75 min, System utilization= 3.15789%  
  
Finite buffer length= 10  
Number of passengers dropped= 0/127  
% of passengers dropped= 0%
```

Input:

Arrival rate = 1 Service rate = 5

Buffer size = 10 Servers = 5

Input:

Arrival rate = 1 Service rate = 5

Buffer size = 20 Servers = 2

```
Server idle time= 111 Service time= 0 Total queueing time= 0  
82 100  
Passenger 124 Arrived at: 120 Served by: 0  
Server idle time= 111 Service time= 0 Total queueing time= 0  
83 100
```

```
-----Report-----  
  
Average waiting time= 0 min  
  
Server 0  
Avg service time= 0.15625 min, Avg queueing time= 1.89062 min, System utilization= 8.26446%  
  
Server 1  
Avg service time= 0.116667 min, Avg queueing time= 1.96667 min, System utilization= 5.9322%  
  
Finite buffer length= 20  
Number of passengers dropped= 0/125  
% of passengers dropped= 0%
```

When **arrival rate < service rate**, it means that the server serves passengers at faster rate than they're arriving. Hence % of passengers dropped is 0, and remains so even on increasing buffer size, or number of servers. Waiting times are 0 too.

OPTIMIZATION STRATEGIES

- Comparing all models, the multi server model performs better than single server in terms of lesser % of passengers dropped and more efficient system utilization. The system is not overloaded, and work is divided amongst the m servers.
- The buffered multi server system is most optimal as it reduces waiting time to a minimum and therefore increases passenger satisfaction. No passengers are dropped since several buffers are present and therefore a large number of passengers can be accommodated. This performs well for most realistic arrival rates at airports.
- This is because the mean number of people in the initial queue is controlled by Little's Law as follows:

$$\text{Mean number in the system} = \text{Arrival rate} \times \text{Mean response time} \quad \Rightarrow \quad (N = \lambda * T_w)$$

Therefore lesser is the waiting time, lesser passengers in queue, and therefore lesser is the probability of buffer overflow. Hence % of passengers dropped is less.