CS342 ASSIGNMENT 4, Q2 REPORT

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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.

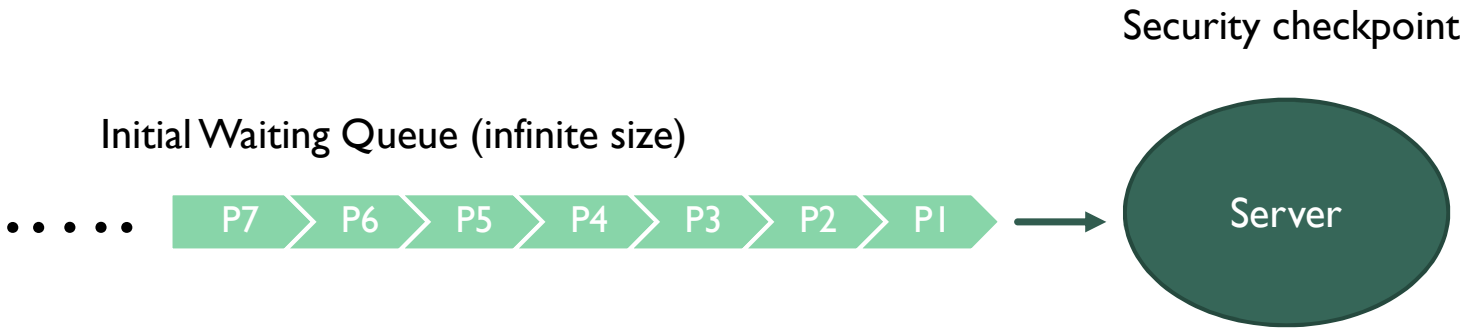
Inputs:

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

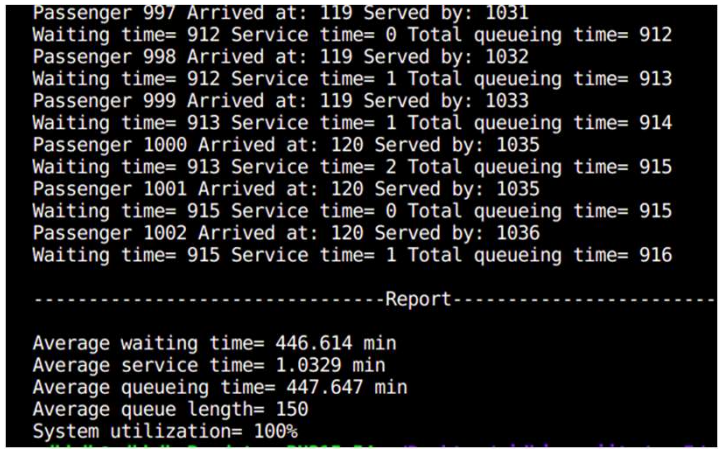
Parameters for analysis:

- **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

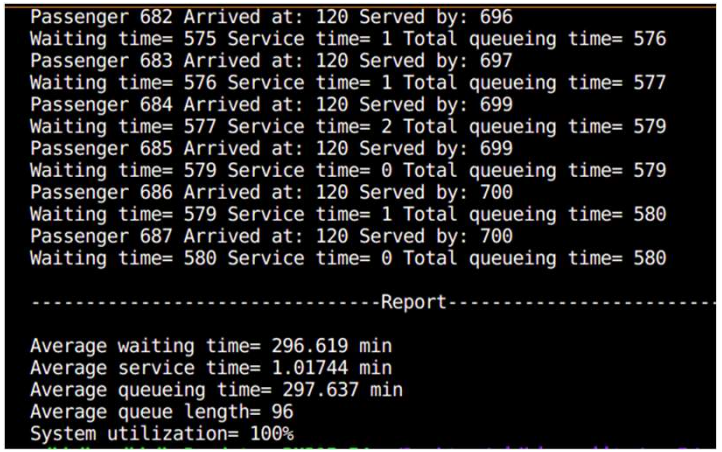
CASE 1: SINGLE SERVER, WITH INFINITE BUFFER



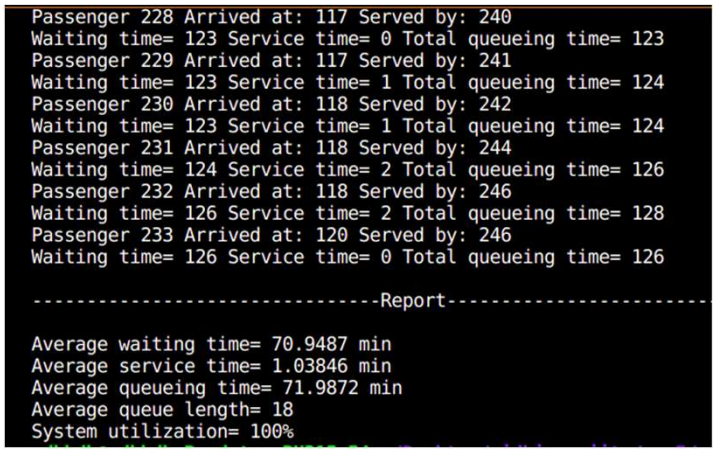
Arrival rate > Service rate



Input:
Arrival rate = 9 Service rate = 1



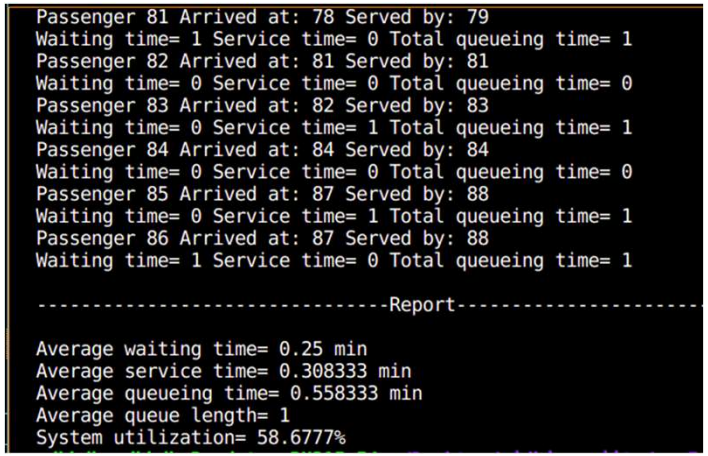
Input:
Arrival rate = 5 Service rate = 1



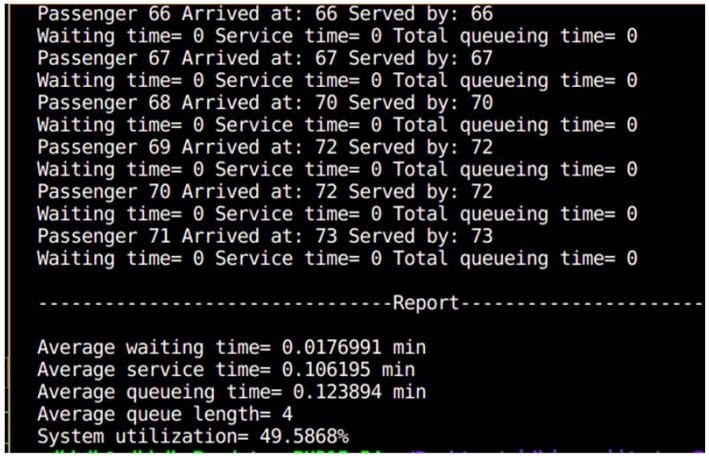
Input:
Arrival rate = 2 Service rate = 1

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).

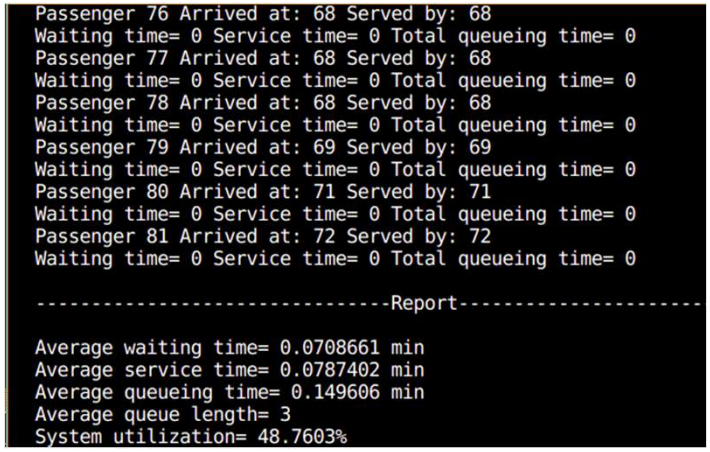
Arrival rate < Service rate



Input:
Arrival rate = 1 Service rate = 2



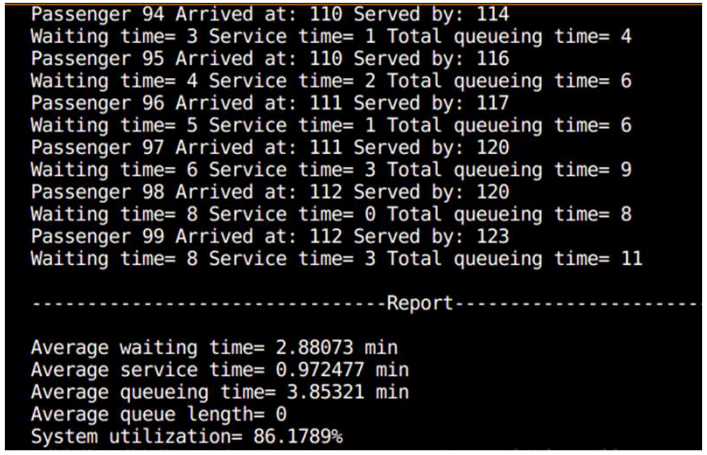
Input:
Arrival rate= 1 Service rate = 5



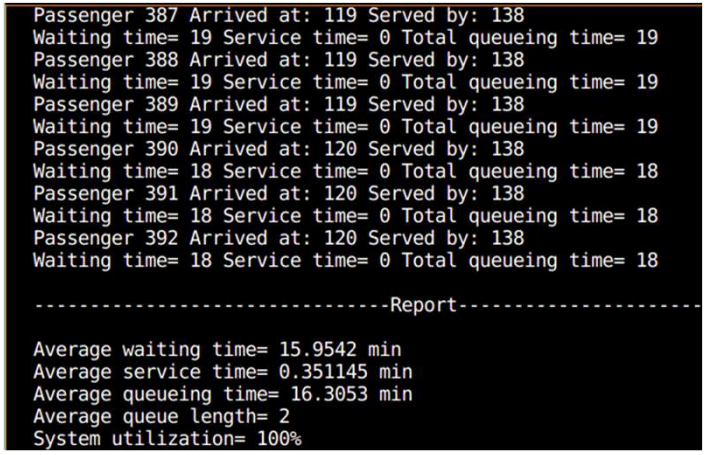
Input:
Arrival rate = 1 Service rate = 11

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).

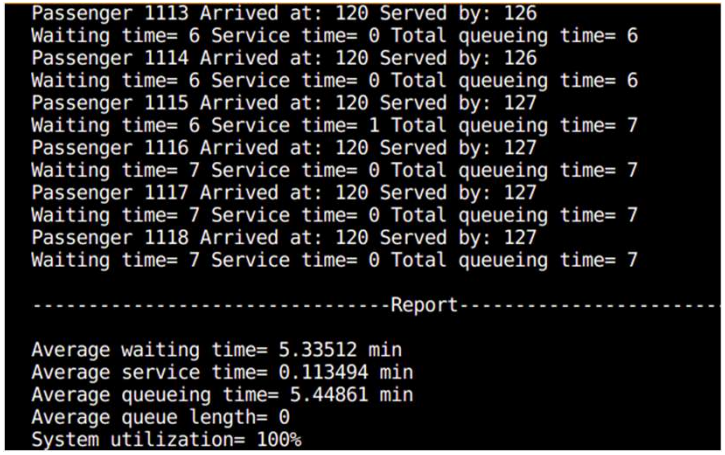
Arrival rate = Service rate



Input:
Arrival rate = 1 Service rate = 1



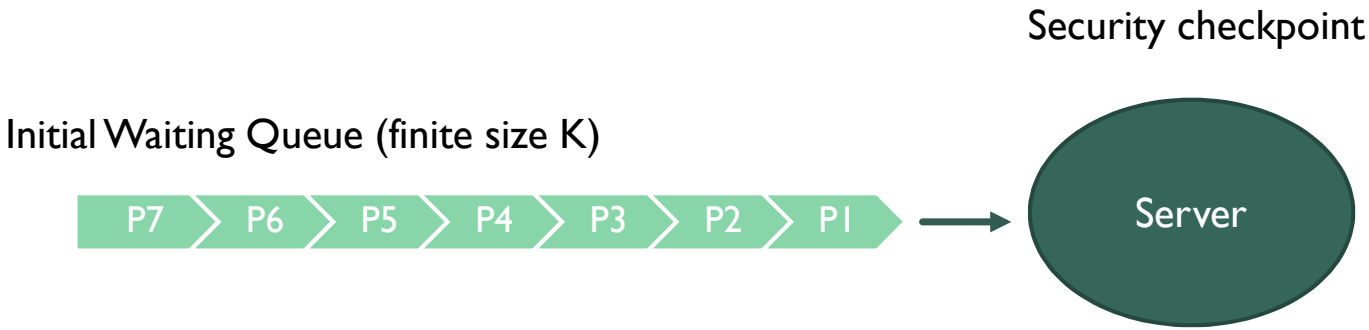
Input:
Arrival rate= 3 Service rate = 3



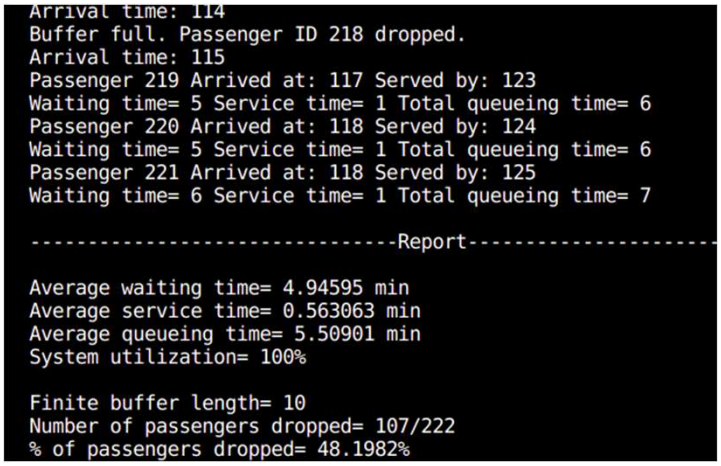
Input:
Arrival rate = 10 Service rate = 10

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.

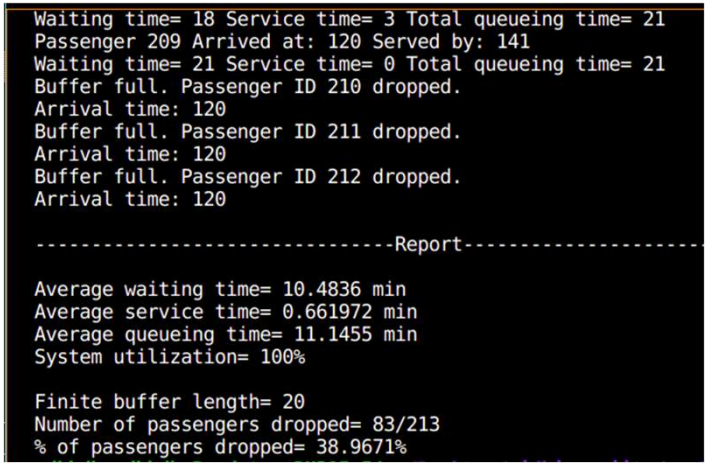
CASE 2: SINGLE SERVER, WITH FINITE BUFFER (K)



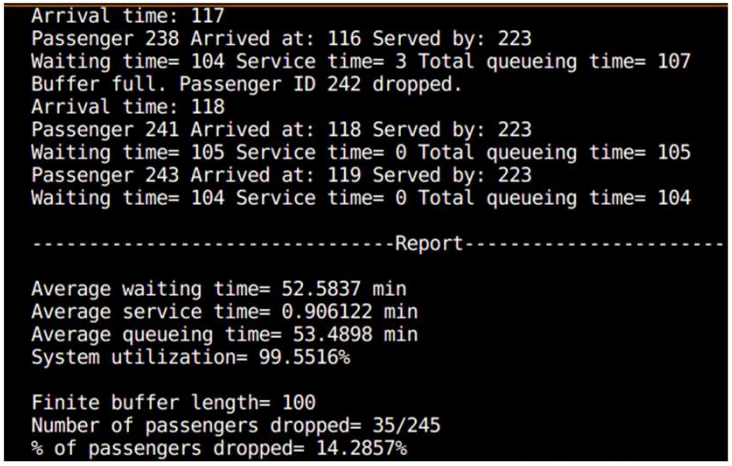
Arrival rate > Service rate



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



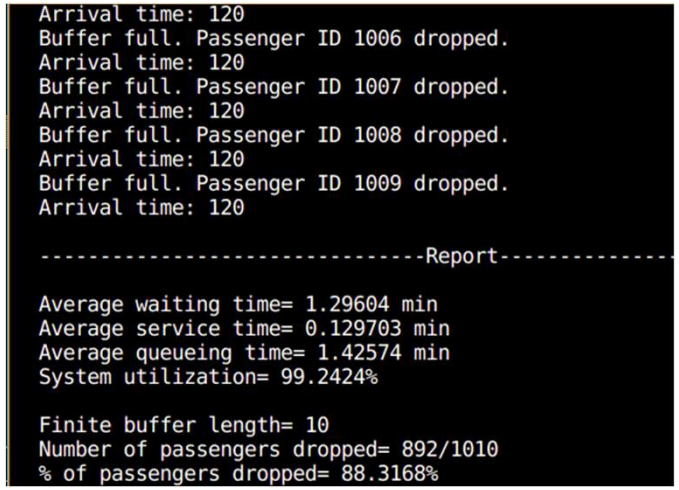
Input:
Arrival rate = 2 Service rate = 1
Buffer size = 20



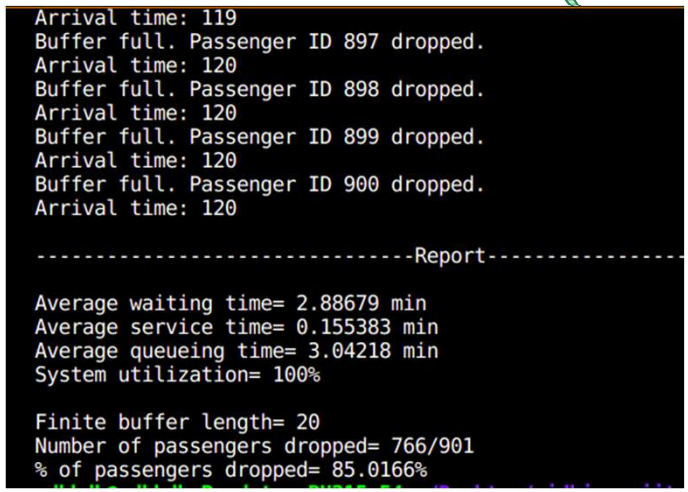
Input:
Arrival rate = 2 Service rate = 1
Buffer size = 100

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.

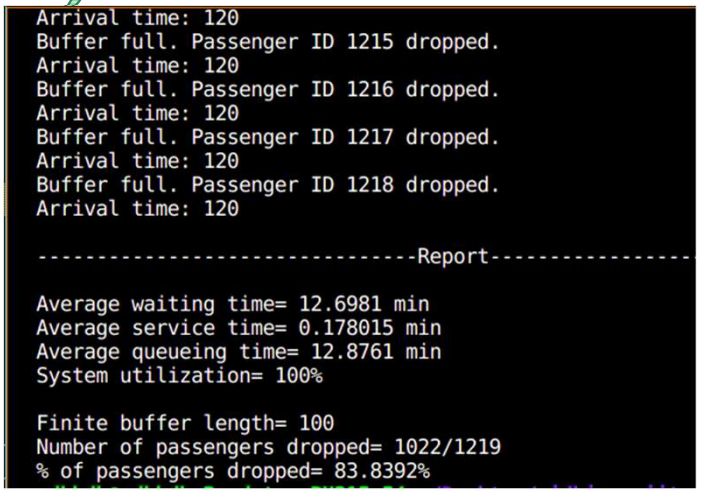
Arrival rate > Service rate (contd.)



Input:
Arrival rate = 9 Service rate = 1
Buffer size = 10



Input:
Arrival rate = 9 Service rate = 1
Buffer size = 20



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%
```

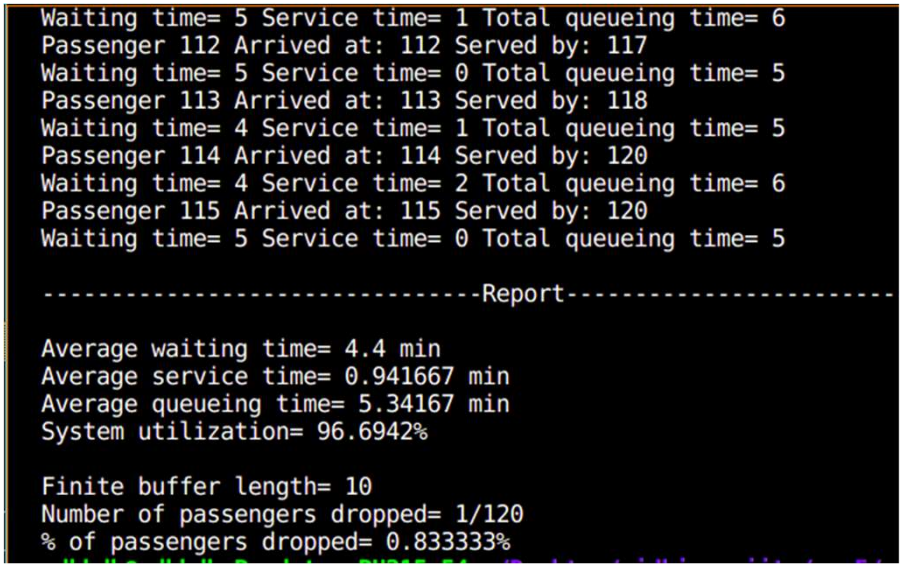
Arrival rate = 1 Service rate = 2 Buffer size = 10

```
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%
```

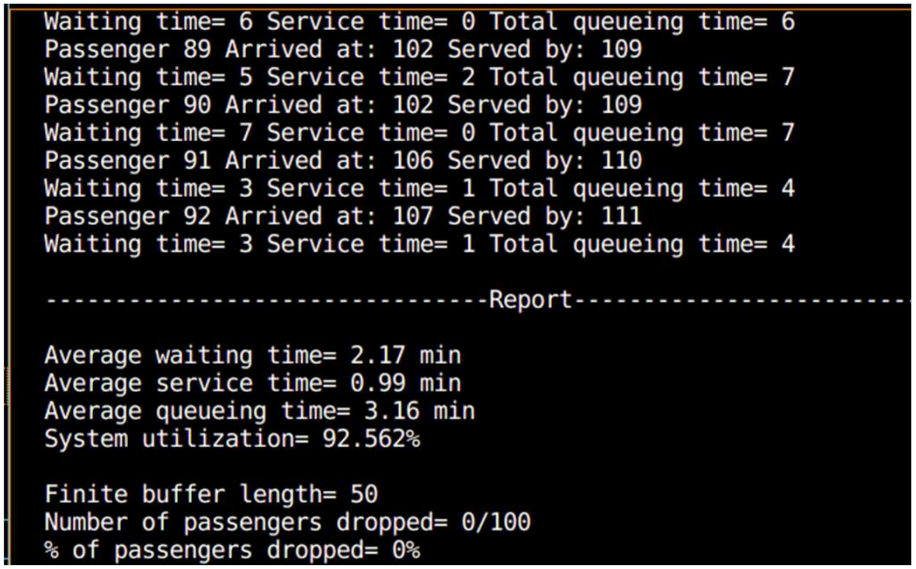
Arrival rate = 1 Service rate = 2 Buffer size = 50

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



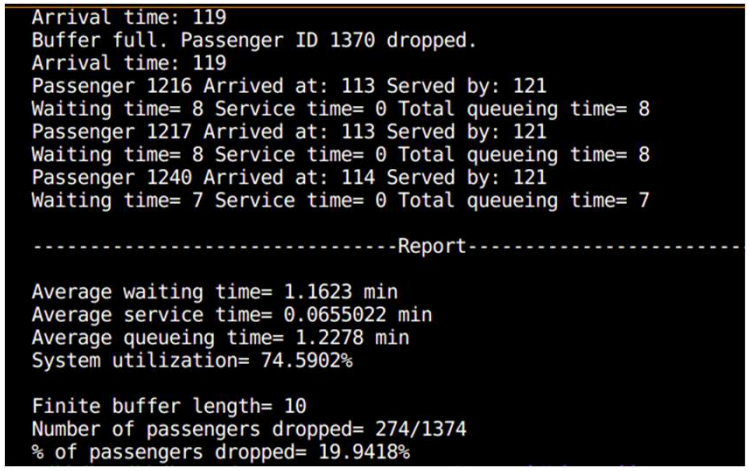
Arrival rate = 1 Service rate = 1 Buffer size = 10



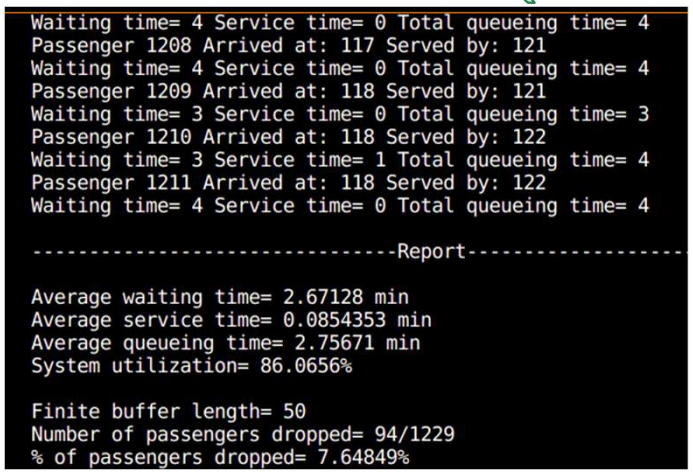
Arrival rate = 1 Service rate = 1 Buffer size = 50

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.

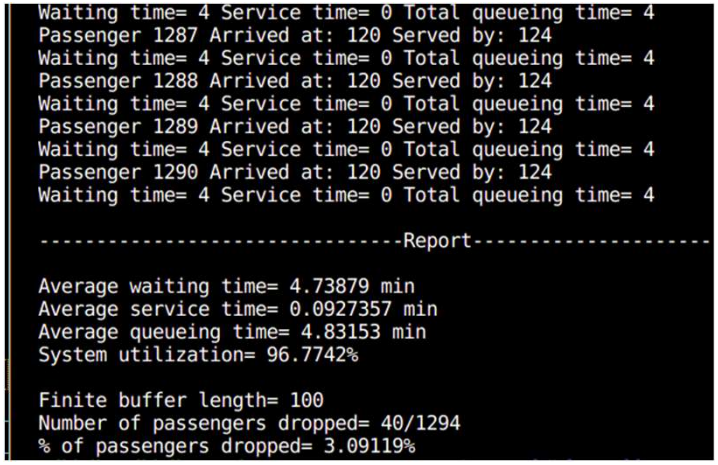
Arrival rate = Service rate (contd.)



Input:
Arrival rate = 10 Service rate = 10
Buffer size = 10



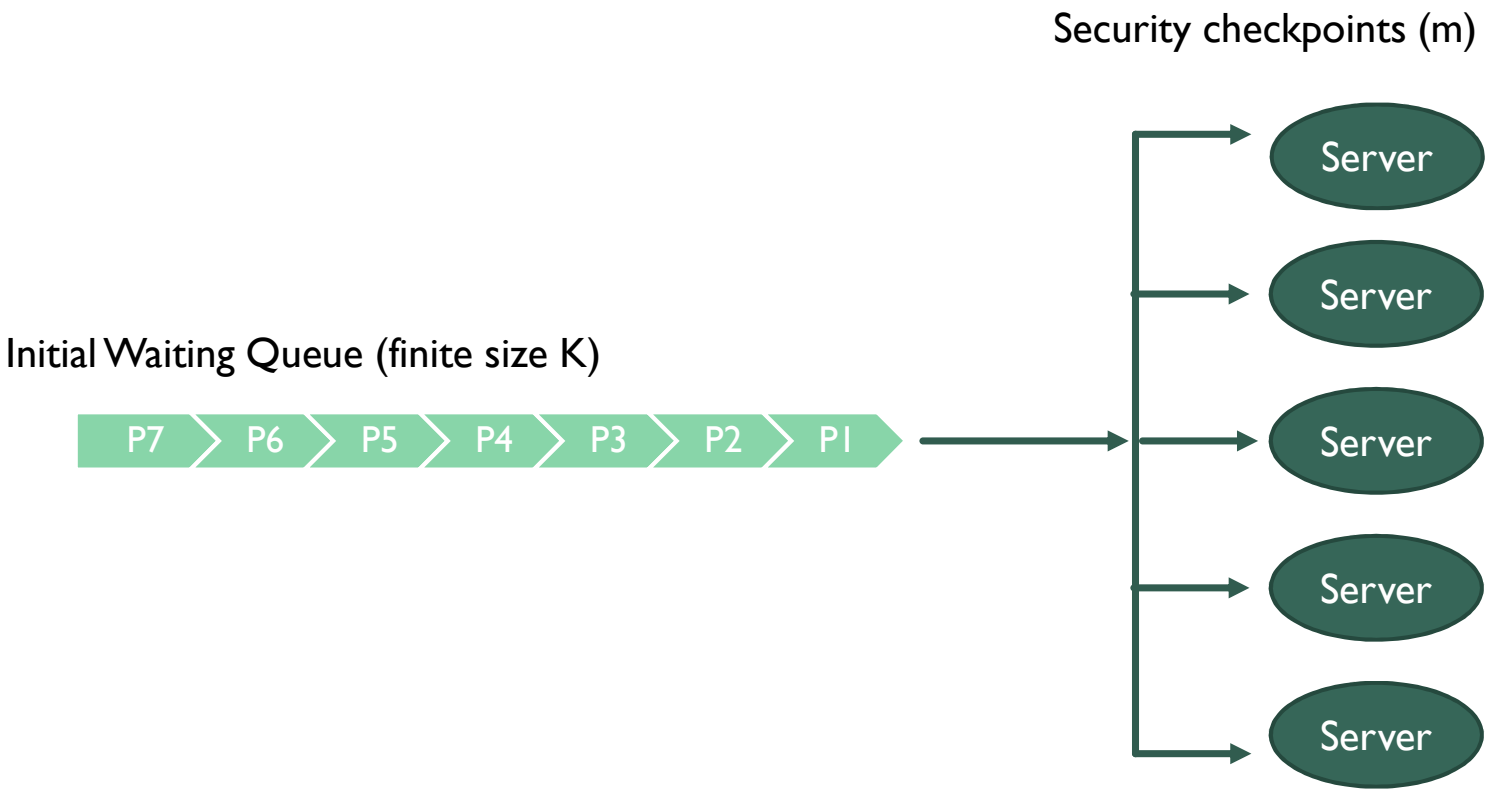
Input:
Arrival rate = 10 Service rate = 10
Buffer size = 50



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%
```

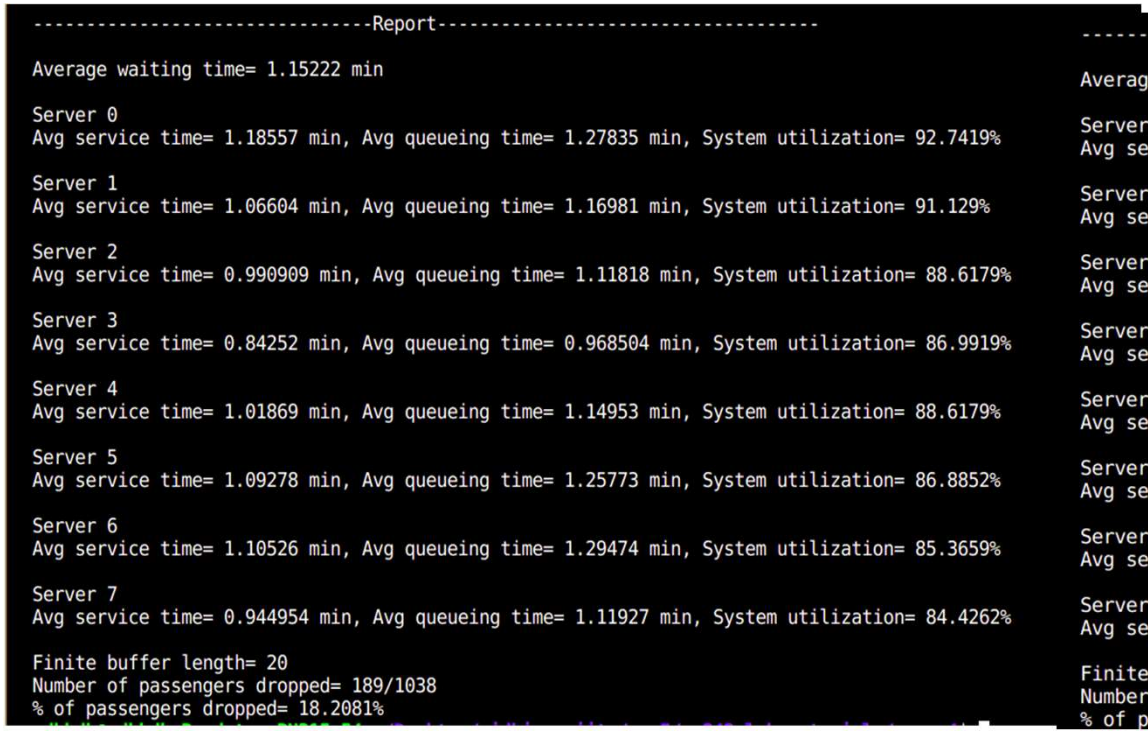
Arrival rate >= Service rate

Input:
Arrival rate = 9 Service rate = 1
Buffer size = 10 Servers = 2

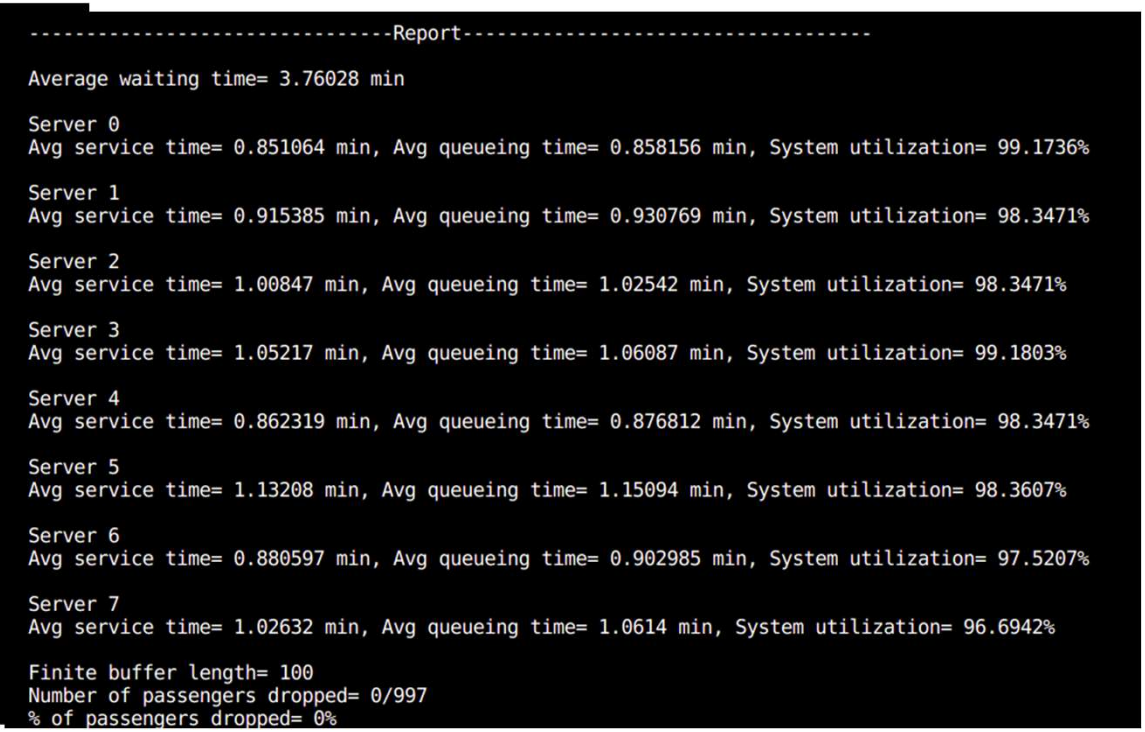
```
------------------------------Report-----------------------------------

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%
```

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.



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%
```

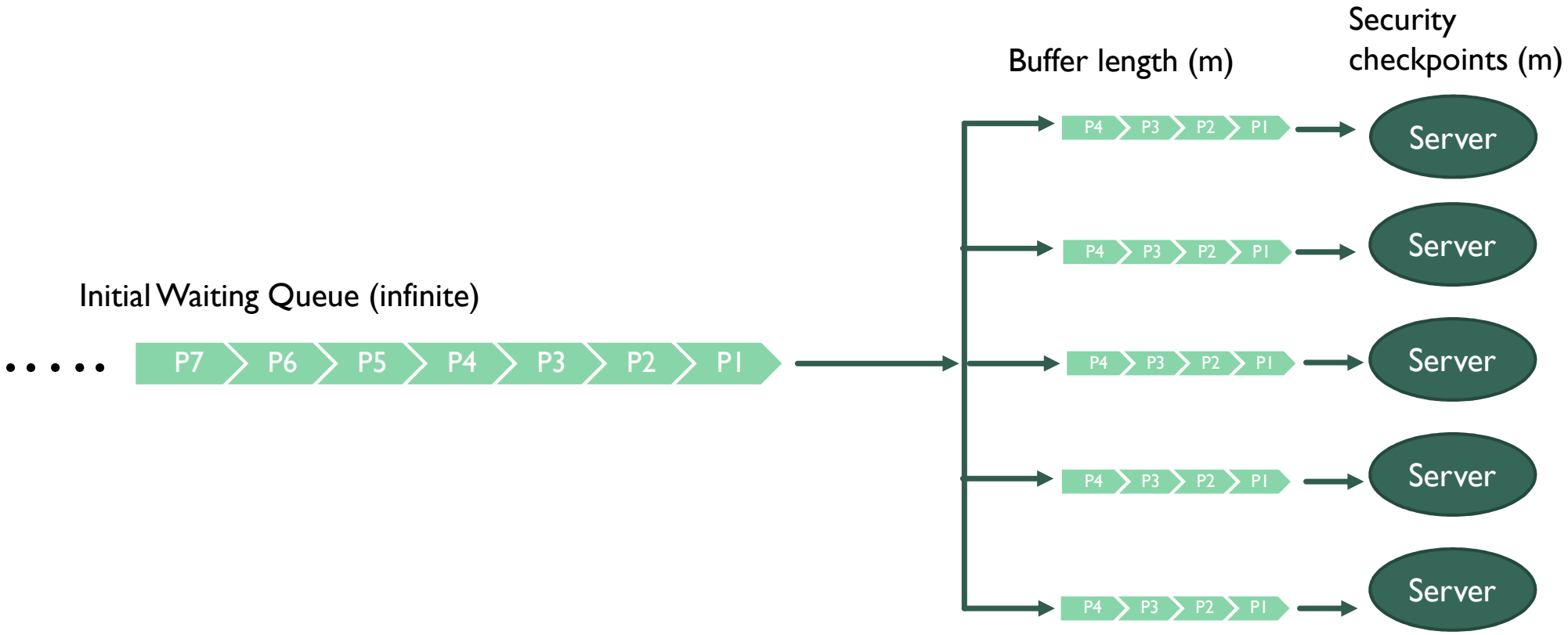
Input:
Arrival rate = 1 Service rate = 5
Buffer size = 10 Servers = 2

```
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 = 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)



```
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 >= 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

```
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%
```

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 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:

  Mean number in the system = Arrival rate × Mean response time => $(N = \lambda * T_w)$

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.