

CM2605 - Simulation and Modelling Techniques

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```
library(magrittr)
library(simmer)
library(ggplot2)
library(dplyr)
```

```
##
## Attaching package: 'dplyr'
```

```
## The following object is masked from 'package:simmer':
##
##      select
```

```
## The following objects are masked from 'package:stats':
##
##      filter, lag
```

```
## The following objects are masked from 'package:base':
##
##      intersect, setdiff, setequal, union
```

```
set.seed(2022)
env <- simmer("bank")
```

```
customer <- trajectory("Customer") %>%
  seize("counter", 1) %>%
  timeout(function() rexp(1, 1/5)) %>%
  release("counter", 1)
```

```
env %>%
  add_resource("counter", 2) %>%
  add_generator("customer", customer, function() rexp(1, 10/60)) %>%
  run(until = 480)
```

```
## simmer environment: bank | now: 480 | next: 485.617310260069
## { Monitor: in memory }
## { Resource: counter | monitored: TRUE | server status: 2(2) | queue status: 1(Inf) }
## { Source: customer | monitored: 1 | n_generated: 84 }
```

```

arrivals <- get_mon_arrivals(env)
resources <- get_mon_resources(env) %>% filter(resource == "counter")

arrivals <- arrivals %>%
  mutate(waiting_time = end_time - start_time - activity_time,
         time_in_system = end_time - start_time)

avg_waiting_time <- mean(arrivals$waiting_time, na.rm = TRUE)
avg_time_in_system <- mean(arrivals$time_in_system, na.rm = TRUE)
avg_queue_length <- mean(resources$queue)

busy_time <- sum(diff(c(resources$time, 480)) * head(resources$server, -1))

## Warning in diff(c(resources$time, 480)) * head(resources$server, -1): longer
## object length is not a multiple of shorter object length

```

```

total_server_time <- 480 * 2
utilization <- busy_time / total_server_time

cat("Average Waiting Time:", round(avg_waiting_time, 2), "mins\n")

```

Average Waiting Time: 0.48 mins

```

cat("Average Time in System:", round(avg_time_in_system, 2), "mins\n")

```

Average Time in System: 5.34 mins

```

cat("Server Utilization:", round(utilization * 100, 2), "%\n")

```

Server Utilization: 40.99 %

Simulation with 3 counters

```

set.seed(2022)
env_3 <- simmer("bank_3")

env_3 %>%
  add_resource("counter", 3) %>%
  add_generator("customer", customer, function() rexp(1, 10/60)) %>%
  run(until = 480)

```

```

## simmer environment: bank_3 | now: 480 | next: 486.257242131862
## { Monitor: in memory }
## { Resource: counter | monitored: TRUE | server status: 1(3) | queue status: 0(Inf) }
## { Source: customer | monitored: 1 | n_generated: 83 }

```

```

arrivals_3 <- get_mon_arrivals(env_3)
resources_3 <- get_mon_resources(env_3) %>% filter(resource == "counter")

arrivals_3 <- arrivals_3 %>%
  mutate(waiting_time = end_time - start_time - activity_time,

```

```

        time_in_system = end_time - start_time)

avg_waiting_time_3 <- mean(arrivals_3$waiting_time, na.rm = TRUE)
avg_time_in_system_3 <- mean(arrivals_3$time_in_system, na.rm = TRUE)
avg_queue_length_3 <- mean(resources_3$queue)

busy_time_3 <- sum(diff(c(resources_3$time, 480)) * head(resources_3$server, -1))

```

```

## Warning in diff(c(resources_3$time, 480)) * head(resources_3$server, -1):
## longer object length is not a multiple of shorter object length

```

```

total_server_time_3 <- 480 * 3
utilization_3 <- busy_time_3 / total_server_time_3

cat("3 Counters - Average Waiting Time:", round(avg_waiting_time_3, 2), "mins\n")

```

```

## 3 Counters - Average Waiting Time: 0 mins

```

```

cat("3 Counters - Average Time in System:", round(avg_time_in_system_3, 2), "mins\n")

```

```

## 3 Counters - Average Time in System: 4.81 mins

```

```

cat("3 Counters - Server Utilization:", round(utilization_3 * 100, 2), "%\n")

```

```

## 3 Counters - Server Utilization: 27.19 %

```

Simulation of the bank system was mimicked for an 8 hour (480 minutes) using M/M/2 model. Customer arrivals are poisson while the service times follow exponential distribution with 2 counters. System calculated the below metrics for evaluation

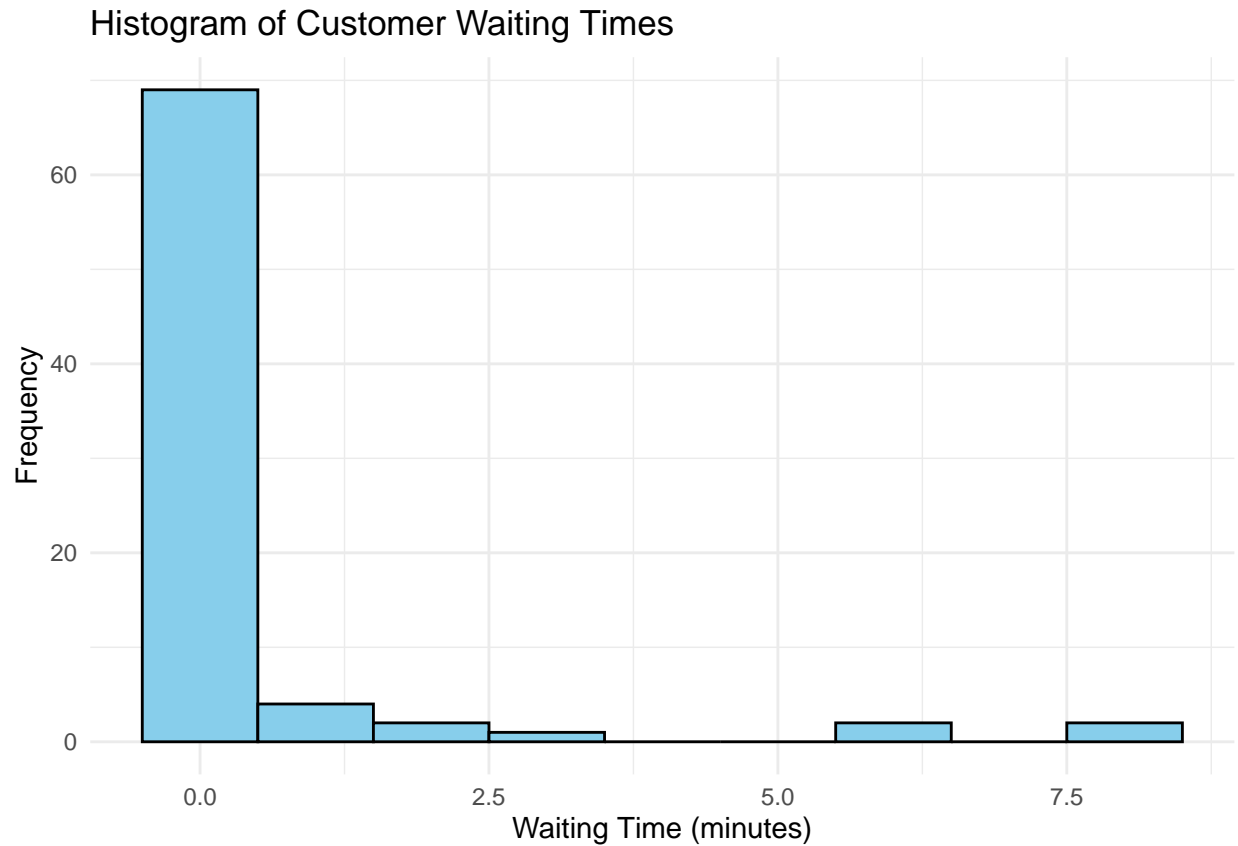
Average Waiting Time: 0.48 mins Average Time in System: 5.34 mins Server Utilization: 40.99 %

Average waiting time is 0.48 minutes (28.8 seconds), which is lower than the bank manager's considered limit 15 from a huge margin. This indicates under this configuration 2 counters are not only enough but it also has very low waiting time where customers are served immediately with a really low wait. Total time a customer spends in the queue and the counter have been averaged into 5.34 minutes. That number aligns very closely with the given 5 minutes average service time which suggests Most of the time spent by customers in the service. Server utilization was given as 40.99% presents which means on average each counter was on work at around 41% of the total time. This says that banks current resources are not being used to their full capacity and the counters may have experience idle times in between. This also reflects the fact that the current system is comfortably handling the customer load without any bottlenecks.

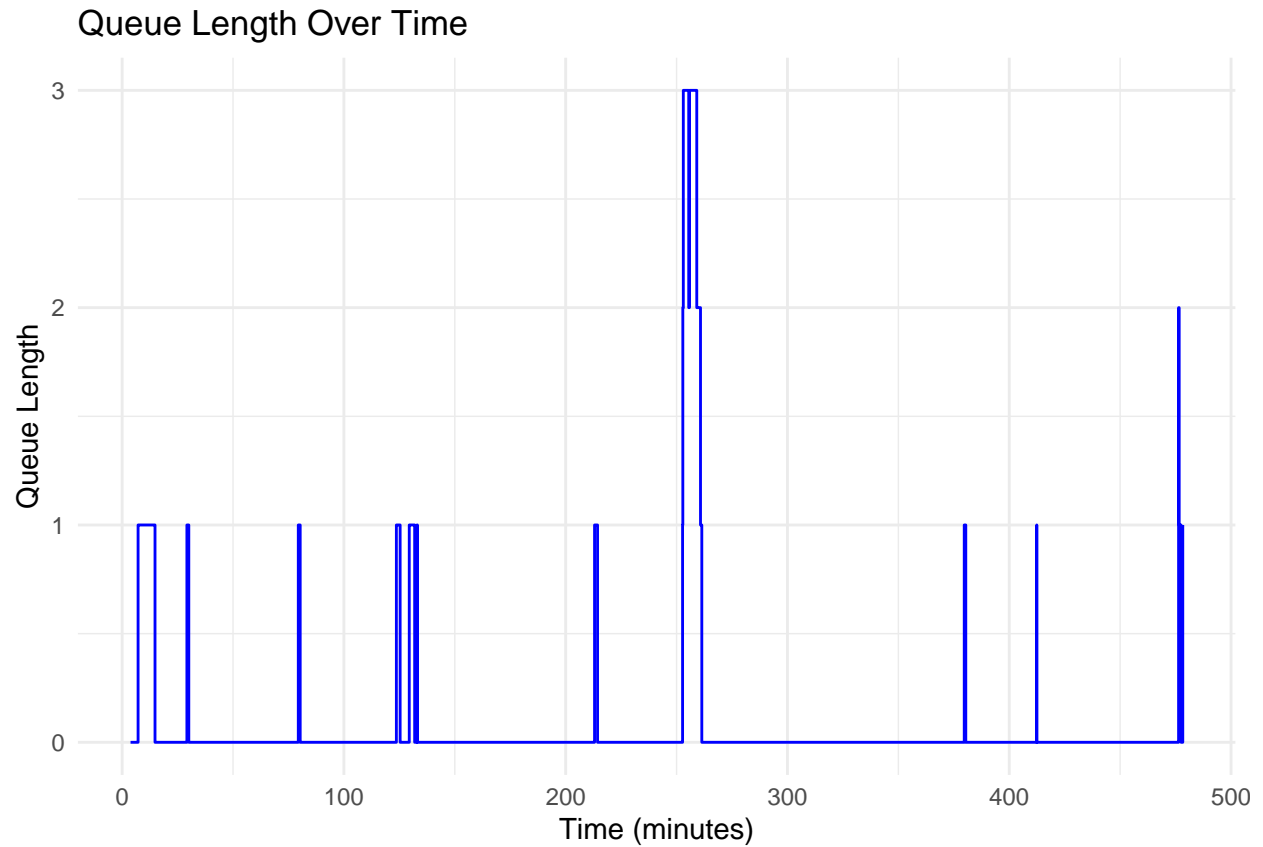
But adding 3 counters reduce the average waiting time to 0 minutes, total time in the system into 4.81 minutes and reduce the server utilization into 27.19%

Taking all of this to consideration with the above metrics it reflects the fact that the current system in the bank with 2 counters is already over performing and adding a third counter may increase the idle time in service counters. Also 2 counter system is way lower than the limits which was given by the bank manager. With that fact currently there is no need to add a third counter it may only increase the operational cost but not a significant improvement to the bank.

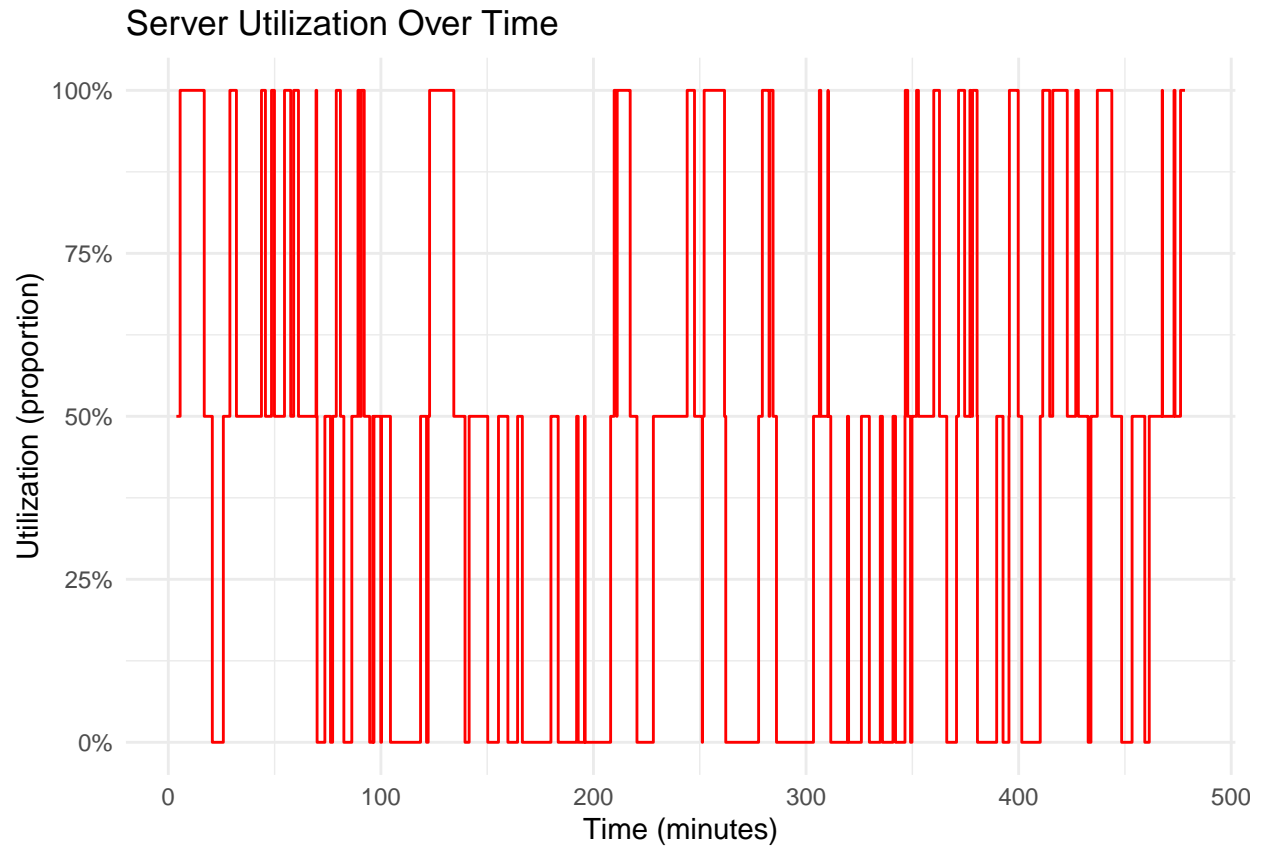
```
ggplot(arrivals, aes(x = waiting_time)) +
  geom_histogram(binwidth = 1, fill = "skyblue", color = "black") +
  labs(title = "Histogram of Customer Waiting Times",
       x = "Waiting Time (minutes)",
       y = "Frequency") +
  theme_minimal()
```



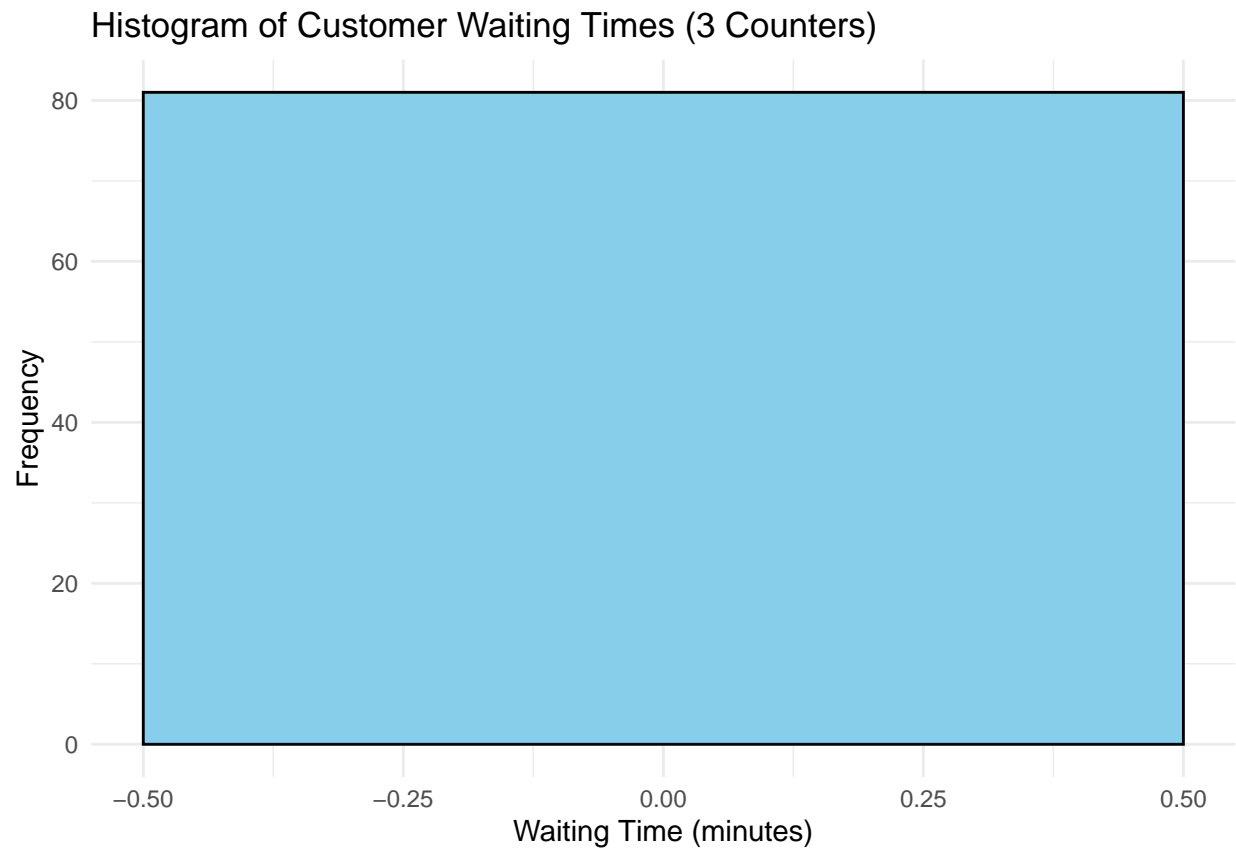
```
ggplot(resources, aes(x = time, y = queue)) +
  geom_step(color = "blue") +
  labs(title = "Queue Length Over Time",
       x = "Time (minutes)",
       y = "Queue Length") +
  theme_minimal()
```



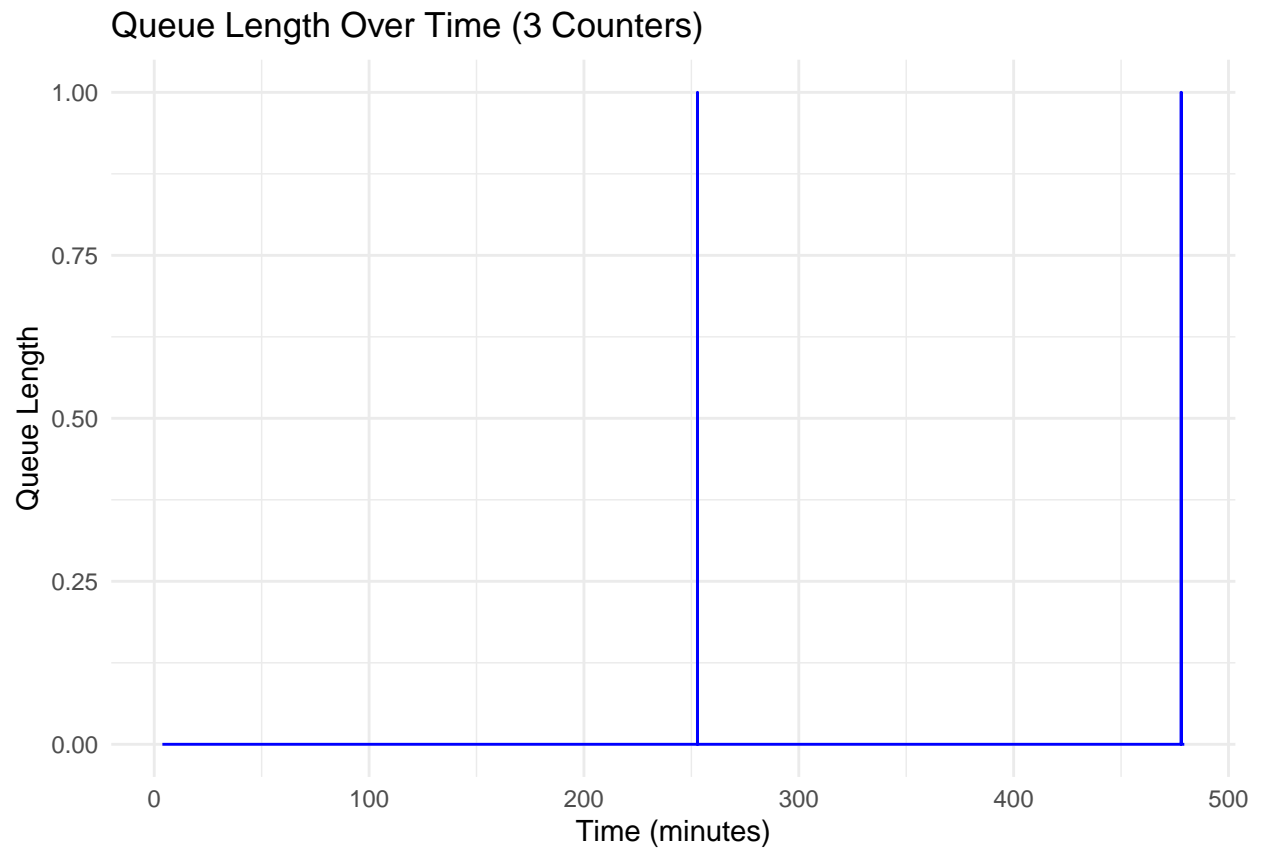
```
resources <- resources %>%  
  mutate(utilization = server / 2) # 2 counters, so max capacity is 2  
  
ggplot(resources, aes(x = time, y = utilization)) +  
  geom_step(color = "red") +  
  labs(title = "Server Utilization Over Time",  
        x = "Time (minutes)",  
        y = "Utilization (proportion)") +  
  scale_y_continuous(limits = c(0, 1), labels = scales::percent) +  
  theme_minimal()
```



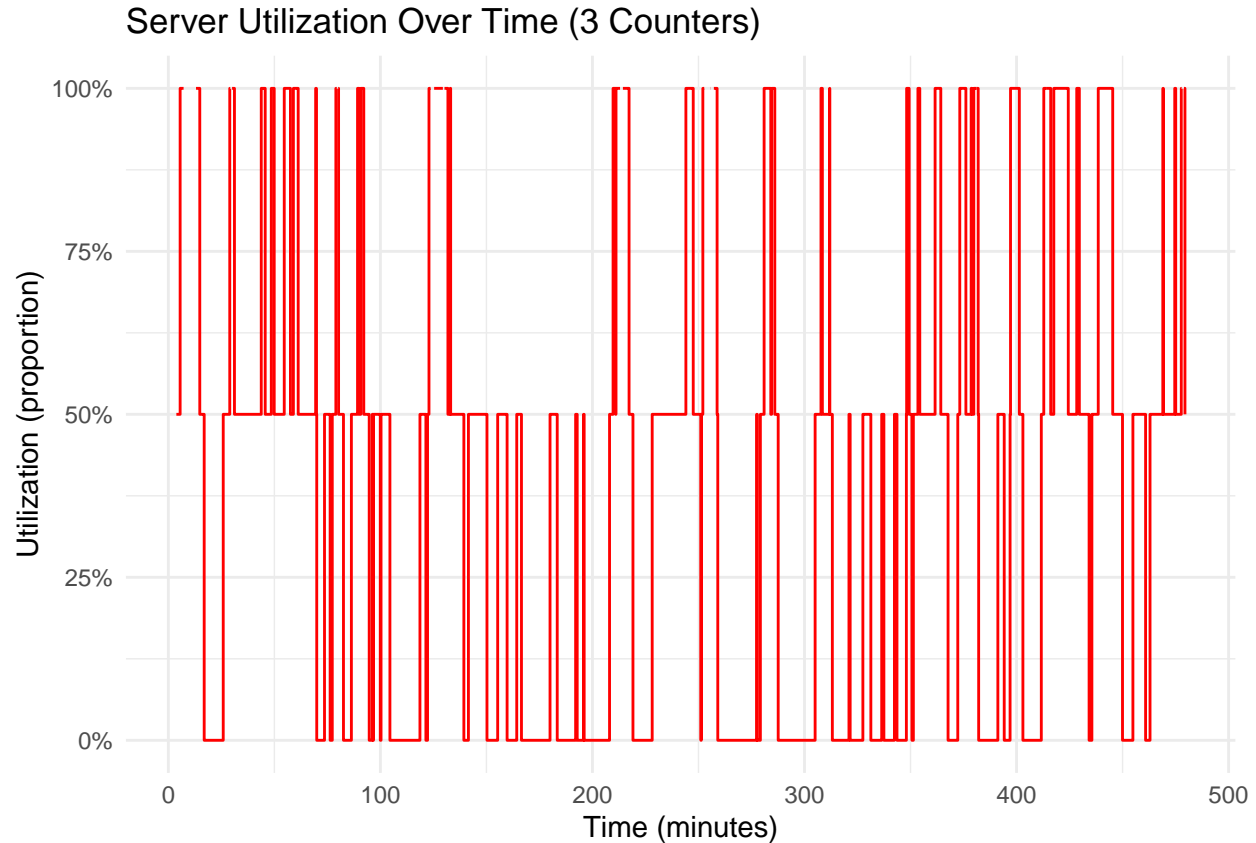
```
ggplot(arrivals_3, aes(x = waiting_time)) +  
  geom_histogram(binwidth = 1, fill = "skyblue", color = "black") +  
  labs(title = "Histogram of Customer Waiting Times (3 Counters)",  
        x = "Waiting Time (minutes)",  
        y = "Frequency") +  
  theme_minimal()
```



```
ggplot(resources_3, aes(x = time, y = queue)) +  
  geom_step(color = "blue") +  
  labs(title = "Queue Length Over Time (3 Counters)",  
        x = "Time (minutes)",  
        y = "Queue Length") +  
  theme_minimal()
```



```
resources_3 <- resources_3 %>%  
  mutate(utilization = server / 2) # 2 counters, so max capacity is 2  
  
ggplot(resources_3, aes(x = time, y = utilization)) +  
  geom_step(color = "red") +  
  labs(title = "Server Utilization Over Time (3 Counters)",  
        x = "Time (minutes)",  
        y = "Utilization (proportion)") +  
  scale_y_continuous(limits = c(0, 1), labels = scales::percent) +  
  theme_minimal()
```

There are 3 types of charts namely, Histogram of Customer Waiting Times, Queue Length Over Time, Server Utilization Over Time. Each one of them for 2 scenarios of 2 counters and 3 counters making it all 6 charts.

First chart shows the Customer Waiting Times for 2 counters where vast majority of the customers have less than 1-minute wait time on the other hand in 3 counters all customers are in the less than 1-minute range. With the 2 counter system, a really small amount of customers has been waited for 7.5 to 8 minutes but yet it is almost 2 times less than the bank manages limit of 15 minutes.

Second chart shows the evaluation of the queue length overtime. With 2 counters, queue has been expanded maximum to 3 people in very rare instances. But with 3 counters queue is almost 0 for most parts but in very few instances it has been expanded up to a person. Considerable queues cannot be seen in 2 counter scenario where not only the largest queue was only 3 people which is not a large queue but also with the very low waiting time those queues have been vanished very quickly.

Lastly the line chart shows the server utilization over time. It can be seen that the 2 counter system also counter has not been fully occupied 100% all the time with some times it is not occupied at all with 0% utilization. Adding a 3rd counter has decreased the utilization further more by increasing the idles too.

With all that into consideration adding a 3rd counter is not recommended. Not only the current system does not satisfy the average time limitation of 15 minutes that the manager gave but also looking at other factors such as queue length and server utilization, adding another counter is not recommended. The current is more than enough to handle the current customer load. Even if the customer load is increased in current distributions it can handle up to a good certain limit.

Final Conclusion: There is no need to add a third counter to handle the current customer load.