Queue Management Optimization: A Multi-Scenario Simulation Analysis of Call Handling Dynamics and Operator Efficiency in Customer Service Centers

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Objective:

The overarching goal of this project is to explore, simulate, and analyze varying queue management policies and operator configurations within customer service call centers. The intention is to discern the implications and efficiency of different structures and policies on average waiting times and overall service delivery.

Initial Problem Framework:

The foundational layer of this project is built upon the simulation of a system where the time between incoming phone calls follows an Exponential distribution with a mean of 14 minutes. Call durations are governed by a Triangular distribution, with parameters set at min=5, max=20, and most likely=10 minutes.

Primary Scenarios:

Scenario A:

- **System Structure:** Two operators managing a single queue.
- **Objective:** To investigate the average waiting time in a single-queue system and report the histogram and mean, thereby analyzing the effectiveness of such a configuration.

Scenario B:

- **System Structure:** Two operators, each equipped with its own queue, and incoming calls are allocated based on a "random" policy.
- **Objective:** To explore the dynamics of a dual-queue system and analyze the operational impact through the evaluation of the histogram and mean of the average waiting time.

Advanced Problem Revision:

This project extends its scope by revisiting the initial problem with alterations, wherein the average time between incoming phone calls is reduced to an Exponential mean of 5 minutes. The system is now evaluated with three operators, each with distinct service time distributions and individual queues.

- **Operators 1 and 2:** Have Uniformly distributed service times between 5 to 20 minutes.
- **Operator 3:** The service time is Normally distributed, with a mean of 15 minutes and a standard deviation of 3 minutes, representing prolonged engagement with the callers.

Extended Scenarios Objectives:

- **Objective a:** Develop and analyze a utilization plot for each operator, extracting insights about their operational efficiency and capacity.
- **Objective b:** Determine and discuss the individual waiting times for each operator to understand the customer wait experiences and service delivery under varied operator characteristics.
- **Objective c:** Calculate and interpret a 95% confidence interval for the average waiting time for each operator, assessing the reliability and consistency of the waiting times observed.

Methodology:

Each scenario, primary and advanced, will be simulated for a duration of 6 hours with 50 replications to authenticate the derived insights and to ensure the comprehensive and reliable depiction of real-world implications.

Solution.

In this Layer of the problem, we aim to simulate a call center environment with two operators handling incoming phone calls. The time between incoming phone calls follows an exponential distribution with a mean of 14 minutes. The duration of each call follows a triangular distribution with a minimum of 5 minutes, a maximum of 20 minutes, and a most likely duration of 10 minutes.

We will analyze two different queue management scenarios:

1. Both operators share a single queue.
2. Each operator has their own queue, and incoming calls are randomly assigned to one of the two queues. For both scenarios, we will run simulations for 6 hours with 50 replications. Our objective is to compare the average waiting times in each scenario and determine if there are any meaningful differences between them.

Using the simmer package, we set up and run the simulations, collecting the results in a data frame. We calculate the mean average waiting times for both scenarios and create histograms to visualize the distribution of average waiting times.

By comparing the results, we will be able to determine which queue management strategy leads to a better customer experience in terms of waiting times.

Scenario A.

In this simulation study, we analyze a call center's performance with two operators handling incoming calls. We explore the case where there is only a single queue for both operators, and the operators attend to calls on a first-come, first-served basis. The main objective of the study is to assess the efficiency of the call center in terms of average waiting time for customers in this single queue scenario.

```
set.seed(123)
library(simmer)
library(simmer.plot)
```

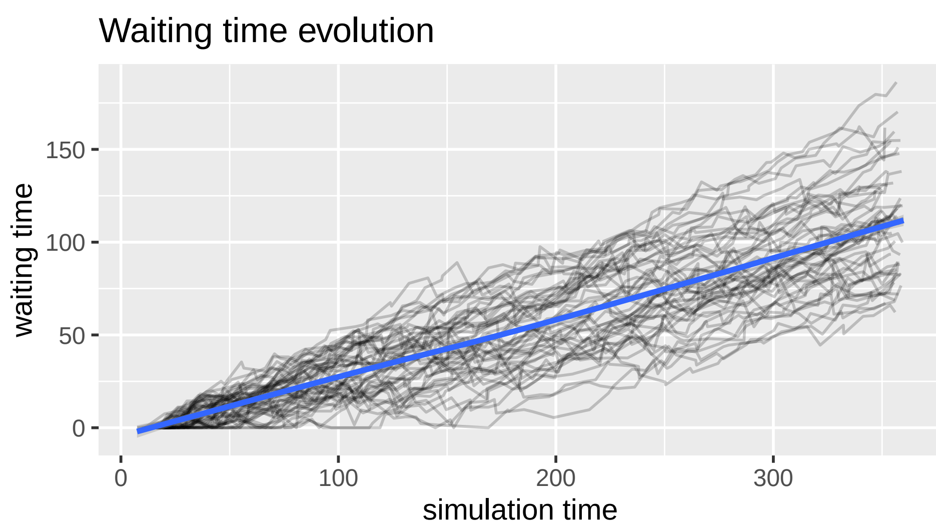
```
## Loading required package: ggplot2
```

```
##
## Attaching package: 'simmer.plot'
```

```
## The following objects are masked from 'package:simmer':
##
##     get_mon_arrivals, get_mon_attributes, get_mon_resources
```

```r
library(triangle)

set.seed(123)
calls <- trajectory("Call's path") %>%
  seize("operator", 1) %>%
  timeout(function() rtriangle(1, 5, 20, 10)) %>%
  release("operator", 1)

#create our environment and run the simulation
envs1 <- lapply(1:50, function(i) {
  simmer("Call Center") %>%
    add_resource("operator", 2) %>%
    add_generator("calls", calls, function() rexp(1, 1/4)) %>%
    run(360)
})

# Collect and plot the results

call <- get_mon_arrivals(envs1)
plot(call, metric = "waiting_time")
```

```
## `geom_smooth()` using method = 'gam' and formula = 'y ~ s(x, bs = "cs")'
```




```r
# Calculate the average waiting time
waiting_time <- (call$end_time - call$start_time) - call$activity_time
average_waiting_time <- round(mean(waiting_time, na.rm = TRUE), 2)
cat("Mean waiting time:", average_waiting_time, "\n")
```

```
## Mean waiting time: 54.93
```

The mean waiting time of approximately 54.93 minutes indicates that customers are waiting for a significant amount of time before their calls are attended to. This can be problematic as long wait times can lead to customer dissatisfaction and potential loss of business.

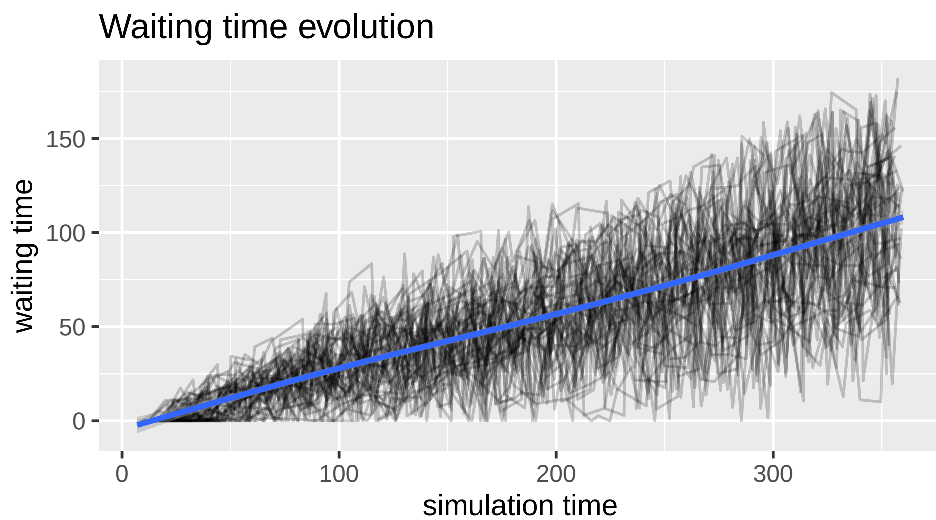
Scenario B.

In this simulation study, we also analyze a call center's performance with two operators handling incoming calls, but in this case, each operator has their own queue. The call center follows a random policy, directing incoming calls to either of the queues randomly. The primary goal of this study is to evaluate the efficiency of the call center in terms of average waiting time for customers in this dual-queue scenario.

We simulate the system based on exponential call arrival distribution with a mean interarrival time of 14 minutes and triangular service time distribution with minimum, maximum, and most likely service times of 5, 20, and 10 minutes, respectively. By running the simulation for 6 hours with 50 replications, we aim to identify patterns in waiting times and assess the overall effectiveness of the two-queue approach with a random policy in managing the call center's workload. The results from this scenario will be compared to the single queue case to determine if there is any meaningful difference in performance and customer waiting times.

```r
set.seed(123)
library(simmer)
library(simmer.plot)
library(triangle)

set.seed(123)
calls_ramdon <- trajectory("Call's path") %>%
  select(c("operator1", "operator2"), policy = "random") %>%
  seize_selected() %>%
  timeout(function() rtriangle(1, 5, 20, 10)) %>%
  release_selected()

#create our environment and run the simulation
envs2 <- lapply(1:50, function(i) {
  simmer("Call_Center") %>%
    add_resource("operator1", capacity = 1) %>%
    add_resource("operator2", capacity = 1) %>%
    add_generator("calls", calls_ramdon, function() rexp(1, 1/4)) %>%
    run(360)
})

# Collect and plot the results

callsr <- get_mon_arrivals(envs2)
plot(callsr, metric = "waiting_time")
```

```
## `geom_smooth()` using method = 'gam' and formula = 'y ~ s(x, bs = "cs")'
```




```
# Calculate the average waiting time
waiting_time_r <-(callsr$end_time - callsr$start_time) - callsr$activity_time
average_waiting_time_r <- round(mean(waiting_time_r, na.rm = TRUE), 2)
cat("Mean waiting time:", average_waiting_time_r, "\n")
```

```
## Mean waiting time: 54.14
```

In the case of 1 queue, the hairs being closer to the line indicate that the waiting times are more consistent and concentrated around the mean waiting time. This suggests that the single queue system is maintaining relatively steady waiting times as the calls are processed.

However, in the case of 2 queues, the fact that the hairs are more open and spread out as the simulation time increases indicates that the waiting times are more varied. This could be due to the random assignment of calls to the queues, which can result in an uneven distribution of calls between the two operators. In some cases, one operator may be handling a call with a long duration, while the other operator is idle, leading to longer waiting times for some calls.

The shape of the plot remaining similar in both cases suggests that the overall distribution of waiting times is not drastically different between the two scenarios. However, the wider spread of waiting times in the 2 queue system may indicate that the random assignment of calls to the queues is not as efficient as having a single queue where operators can take the next call as soon as they are available.

Comparative Insights:

In the case of a single queue system, the mean waiting time is 54.93 minutes. Comparing this to the mean waiting time of 54.14 minutes in the two-queue system with a random policy, we can observe a slight decrease in the average waiting time. However, the difference is not significant, suggesting that the call center's performance is quite similar in both scenarios.

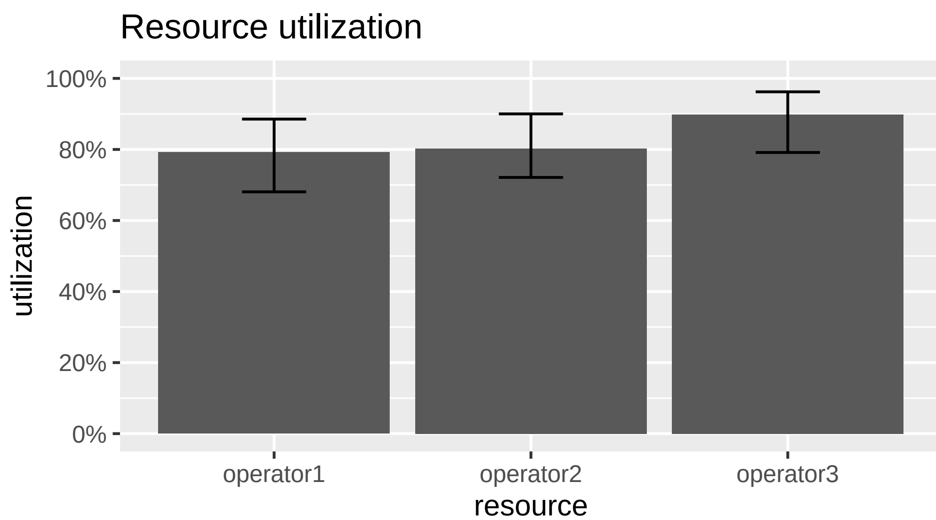
In summary, having two separate queues with a random policy does not provide a substantial advantage in terms of reducing the average waiting time compared to having a single queue.

Advanced Problem Revision

The objectives of this analysis are to: a) Report and interpret the utilization plot for each operator. b) Report the waiting time for each operator and discuss the findings. c) Calculate a 95% confidence interval for the average waiting time for each operator.

a) Based on the simulation results, we will provide insights into the call center's performance, identify potential areas of improvement, and suggest possible strategies to optimize resource utilization and enhance customer satisfaction.

```
library(simmer)
library(simmer.plot)

# Set up the simulation environment and create a trajectory for the phone calls

phone_call <- trajectory("Phone Call's Path") %>%

  branch(option = function() sample(1:3, 1, replace = TRUE), continue = c(T, T, T),
    trajectory("Operator 1") %>%
      seize("operator1", 1) %>%
      timeout(function() runif(1, min = 5, max = 20)) %>%
      release("operator1", 1),
    trajectory("Operator 2") %>%
      seize("operator2", 1) %>%
      timeout(function() runif(1, min = 5, max = 20)) %>%
      release("operator2", 1),
    trajectory("Operator 3") %>%
      seize("operator3", 1) %>%
      timeout(function() rnorm(1, mean = 15, sd = 3)) %>%
      release("operator3", 1)
  )

set.seed(123)

# Run the simulation for 6 hours with 50 replications
envs <- lapply(1:50, function(i) {
  simmer("Call_Center") %>%
    add_resource("operator1", capacity = 1) %>%
    add_resource("operator2", capacity = 1) %>%
    add_resource("operator3", capacity = 1) %>%
    add_generator("phone call", phone_call, function() rexp(1, 1 / 5)) %>%
    run(360)
})

# Generate the utilization plot for each operator
resources <- get_mon_resources(envs)
plot(resources, metric = "utilization")
```



From the utilization plot, we can observe that operators 1 and 2 have a utilization rate of around 80%, while operator 3 has a higher utilization rate of around 90%. This indicates that operator 3 is busier and more occupied compared to operators 1 and 2.

In the context of this call center, this difference in utilization rates can be attributed to the fact that operator 3 takes more time to handle calls (normally distributed with a mean of 15 minutes and a standard deviation of 3 minutes) compared to operators 1 and 2 (uniformly distributed between 5 and 20 minutes). This chattier behavior of operator 3 leads to a higher workload and utilization rate.

The implications of these findings could be:

Operator 3 might be at a higher risk of burnout or reduced performance due to their increased workload. Callers assigned to operator 3 might experience longer waiting times, leading to potential dissatisfaction.

b) To calculate the waiting time for each operator, we proceed as follows.

```
# Calculate waiting time
arrivals <- get_mon_arrivals(envs, per_resource = T)
waitingTime = (arrivals$end_time - arrivals$start_time) - arrivals$activity_time
arrivals2 = cbind(arrivals, waitingTime)

# Calculate the mean waiting time for each operator
mean_waiting_time <- aggregate(arrivals2$waitingTime, by = list(arrivals2$resource),
    FUN = mean)
colnames(mean_waiting_time) <- c("Operator", "Mean_Waiting_Time")
mean_waiting_time
```

```
##    Operator Mean_Waiting_Time
## 1 operator1          15.97817
## 2 operator2          18.48356
## 3 operator3          24.76400
```

Based on the calculated mean waiting times for each operator, we can make the following observations:

1. Operator 1 has the lowest mean waiting time (15.98 minutes), which indicates that this operator is relatively efficient at handling incoming phone calls.

2. Operator 2 has a slightly higher mean waiting time (18.48 minutes) compared to operator 1. This could be due to various factors, such as the operator taking slightly longer to address customer concerns or being less efficient in managing their workload.
3. Operator 3 has the highest mean waiting time (24.76 minutes) among all operators. As we know from the problem description, this operator is chattier and takes more time to handle calls (Normally distributed with a mean of 15 and a standard deviation of 3 minutes). This longer service time is likely the primary reason for the higher waiting time for this operator. The waiting times for each operator show that operator 3's chattiness has a significant impact on their efficiency in handling customer calls, leading to longer waiting times for customers assigned to this operator. On the other hand, operators 1 and 2 have relatively lower waiting times, indicating better efficiency in managing incoming phone calls.

c) Below we calculate the 95% confidence interval for the average waiting time for each operator.

```r
library(knitr)
# Calculate a 95% confidence interval for the average waiting time for each
# operator

# Separate the arrivals by operator
operator1_arrivals <- subset(arrivals2, resource == "operator1")
operator2_arrivals <- subset(arrivals2, resource == "operator2")
operator3_arrivals <- subset(arrivals2, resource == "operator3")

# Calculate the average waiting time per replication for each operator
average_waiting_per_replication_op1 <- aggregate(operator1_arrivals$waitingTime,
    by = list(operator1_arrivals$replication), FUN = mean)
average_waiting_per_replication_op2 <- aggregate(operator2_arrivals$waitingTime,
    by = list(operator2_arrivals$replication), FUN = mean)
average_waiting_per_replication_op3 <- aggregate(operator3_arrivals$waitingTime,
    by = list(operator3_arrivals$replication), FUN = mean)

# Calculate the 95% Confidence Interval for each operator
CI_op1 <- quantile(average_waiting_per_replication_op1$x, c(0.025, 0.975))
CI_op2 <- quantile(average_waiting_per_replication_op2$x, c(0.025, 0.975))
CI_op3 <- quantile(average_waiting_per_replication_op3$x, c(0.025, 0.975))

# Print the results
results_table <- data.frame(Operator = c("Operator 1", "Operator 2", "Operator 3"),
    Lower_Bound = c(CI_op1[1], CI_op2[1], CI_op3[1]), Upper_Bound = c(CI_op1[2],
        CI_op2[2], CI_op3[2]))

# Print the results table
kable(results_table, caption = "95% Confidence Intervals for Average Waiting Time")
```

Table 1: 95% Confidence Intervals for Average Waiting Time

Operator	Lower_Bound	Upper_Bound
Operator 1	3.170336	39.47033
Operator 2	2.674783	54.92529
Operator 3	5.485284	57.34474

Table 1 shows the confidence intervals for the average waiting time differ among the three operators. Operator 1 has the narrowest interval, ranging from approximately 3.17 to 39.47 minutes. Operator 2 has a slightly wider interval, from around 2.67 to 54.93 minutes. Operator 3, who is chattier and takes more time to respond to calls, has the widest interval, ranging from approximately 5.49 to 57.34 minutes. These results provide an estimate of the average waiting time for each operator, taking into account the uncertainty associated with the simulation.

Conclusions:

Summary of Findings:

The meticulous examination of differing queue management strategies and operator configurations has unveiled several pivotal insights regarding operational efficiency within the call center. A singular observation is the marginal difference in mean waiting times between a single queue and a dual-queue system, with the latter exhibiting a minutely reduced waiting time. The extended examination, incorporating three operators with distinctive service time characteristics, rendered more pronounced disparities in operational outcomes.

Implications of Observations:

Significant Waiting Times: The substantial mean waiting time of approximately 54.93 minutes reflects potential challenges, emphasizing the exigency for strategic modifications to enhance customer satisfaction and retention.

Consistency and Variability: The single queue system demonstrated a more consistent and concentrated waiting time around the mean, indicating relative stability. In contrast, the dual-queue system portrayed greater variability, attributed to the randomized call assignments, potentially leading to uneven call distributions and sporadic idle times.

Operator Utilization and Efficiency: Varied utilization rates were observed among the operators, with operator 3 exhibiting elevated levels due to chattier interactions. The implications extend to potential risks of burnout for operator 3 and heightened dissatisfaction among customers experiencing extended waiting times.

Operational Insights:

Efficiency Analysis: The differential mean waiting times among the operators underline inherent disparities in efficiency levels, with operator 3's prolonged interactions contributing to extended waiting times, contrasting the relatively efficient call handling by operators 1 and 2.

Confidence Intervals and Uncertainty: The established confidence intervals illuminate the probable ranges of average waiting times, offering insights into the uncertainty inherent in the simulation and aiding in the nuanced understanding of operational dynamics.

Strategic Recommendations:

System Refinement: Given the relative ineffectiveness of the dual-queue system in enhancing operational efficiency, a holistic review and refinement of the existing queue management strategies are crucial. Incorporation of advanced allocation policies and customer prioritization protocols can offer more substantive improvements.

Operator Training and Support: Tailored training programs and supportive measures can be initiated to augment the efficiency levels of the operators, especially focusing on managing service times and ensuring customer satisfaction.

Final Reflections:

In conclusion, the exploration of varied queue management strategies and operator configurations has served as a lens through which the intricate dynamics of call center operations can be understood. The insights derived form a foundational basis for the conceptualization and implementation of innovative strategies, aiming to optimize operational efficacy and enhance customer experiences. While the observed differences in this study were somewhat inconsequential, the nuanced understanding acquired provides a stepping stone towards the continual refinement of call center operational strategies.

Future Directions:

The findings of this study prompt further exploration into innovative queue management policies and varied operator configurations, delving into the potential incorporation of customer prioritization and differing operator skill levels. Additionally, more in-depth studies focusing on operator well-being and its correlation with operational efficiency can present a holistic perspective, aligning organizational objectives with employee welfare. The perpetual evolution of call center operations necessitates ongoing research endeavors to adapt to the ever-changing customer service landscape, ensuring the sustained delivery of exemplary service experiences.