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Applications and Case Studies of Single-Server Retrieval Queuing Models with Batch Arrivals and Vacation

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Abstract: Where batch arrivals and server vacations are common occurrences, single-server retrieval queuing models find extensive use in contemporary service and industrial systems. Applying batch arrivals and server vacation rules to single-server retrieval queuing models, this study examines their applicability and case examples. We investigate situations in a variety of domains, including healthcare, communications networks, library management systems, and warehouse operations, where service requests occur in batches and servers sometimes go down for maintenance, upgrades, or breakdowns. To comprehend the behavior of the system under different configurations, analytical methods are used, such as steady-state analysis and stochastic modeling. To demonstrate how these models enhance service efficiency, decrease wait times, maximize resource utilization, and control customer happiness, real-world case studies are given. When it comes to building queuing systems that are more durable and efficient, our results show how important batch arrival patterns and vacation mechanisms are. Also included are suggestions for possible additions and upgrades to the model in the future.

Keywords: Single-Server Queuing Model, Batch Arrivals, Server Vacation, Retrieval Systems, Service Efficiency, Case Studies, Stochastic Modeling, Resource Optimization

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INTRODUCTION

For a long time, systems that involve customers or jobs waiting in line for service have been optimized using queueing models. Particularly applicable in situations where a single server handles several tasks or requests is the single-server retrieval queuing paradigm. These models play a vital role in systems such as healthcare services, telecommunication networks, data retrieval systems, and warehouse management. In these systems, waiting times, service efficiency, and resource utilization can be greatly impacted by both batch arrivals (groups of requests arriving at the same time) and server vacations (periods when the server is unavailable due to reasons like maintenance, breaks, or downtime).

Improving the overall efficiency of a single-server system relies on knowing how batch arrivals and server vacations interact with each other. In contrast to the continuous service and constant arrival rates assumed by traditional queuing models, real-world systems often have non-homogeneous arrival rates (e.g., batch arrivals) and server vacations. In order to properly evaluate and enhance the system's performance, it is crucial to design a suitable model that includes these components.

Examining their relevance and performance via real-world case studies, this study seeks to provide a thorough analysis of single-server retrieval queuing models with batch arrivals and server vacation rules. It

will also explore their applicability across varied industries.

OBJECTIVE

This study aims to examine the efficiency of batch arrival and server vacation rules in retrieval queuing models with a single server. While investigating practical uses and case studies from different sectors, it seeks to assess the effect of these variables on system performance measures like wait times, queue lengths, and server usage.

TECHNICAL APPROACH

The queuing system is modeled and studied in this work utilizing a mix of theoretical analysis and numerical simulations employing stochastic processes.

Kendall's Notation (Standard Format):

Written as **A/S/c/K/N/D**

- **A**: Arrival time distribution
- **S**: Service time distribution
- **c**: Number of servers
- **K**: Capacity of the system (optional)
- **N**: Size of population (optional)
- **D**: Queue discipline (optional)

Example: **M/M/1**

- Poisson arrivals (M), exponential service (M), 1 server
- **Arrival rate**: λ
- **Service rate**: μ
- **Utilization**: $\rho = \lambda / \mu$ (should be < 1 for a stable system)

Key Performance Measures:

- Average number in the system:
$$L = \frac{\lambda}{\mu - \lambda}$$
- Average time in the system:
$$W = \frac{1}{\mu - \lambda}$$
- Average number in queue:

$$L_q = \frac{\lambda^2}{\mu(\mu - \lambda)}$$

- Average waiting time in queue:

$$W_q = \frac{\lambda}{\mu(\mu - \lambda)}$$

In order to verify the usefulness and efficiency of the model, we will compare theoretical forecasts with actual data from real-world case studies in fields such as healthcare, telecommunications, and warehouse management.

LITERATURE REVIEW

Single-server queuing models have been a key area of research for analyzing service systems in diverse fields. These models typically assume that customers arrive at a service point individually, but real-world systems often exhibit **batch arrivals**, where multiple customers arrive simultaneously (Chakravarthy & Dhingra, 2014). The incorporation of batch arrivals in queuing models has proven to provide more realistic representations of scenarios such as bulk data processing and group services in telecommunication systems (Hernandez & Yamada, 2018). Chakravarthy and Dhingra (2014) extended traditional queuing models by integrating batch arrivals and demonstrated that such models could better predict performance in environments with clustered demands, leading to more efficient service management.

Additionally, the role of **server vacations**, a situation where the server becomes temporarily unavailable, has been extensively explored in queuing theory. Server vacation policies are crucial for modeling systems where the server undergoes breaks or maintenance periods, which is common in service industries and manufacturing settings (Jain & Kumar, 2017). These vacation models help optimize system performance during downtimes and reduce waiting times by ensuring the server's availability is maximized when needed (Sinha & Mathur, 2016). In their work, Jain and Kumar (2017) developed a generalized single-server model with vacations and demonstrated its application in a call center environment, where vacation periods reflect breaks or non-operational hours, improving the model's relevance to real-world scenarios.

Recent advancements in queuing models have focused on combining **batch arrivals** and **server vacations**, providing a comprehensive approach to studying systems where both factors are present. For instance, Bhat (2015) examined a single-server queuing model with batch arrivals and vacation periods in a manufacturing system, showing that vacation policies significantly reduce waiting times during non-peak hours. Similarly, Kumar and Verma (2019) integrated these two elements in a telecommunications network model, demonstrating that batch arrivals coupled with vacation policies could reduce network congestion and improve overall service quality by balancing server utilization and downtime efficiently.

Several studies have also highlighted practical applications of these models in different sectors. In **warehouse management**, the use of batch arrival queuing models helps optimize inventory management by handling large batches of stock arrivals (Patel & Sharma, 2020). In **healthcare**, queuing models with vacations have been applied to improve the efficiency of emergency departments where staff take breaks during shifts, and patients often arrive in groups (Sharma & Gupta, 2018). These applications showcase the

relevance of combining batch arrivals and server vacations to improve both operational efficiency and customer satisfaction in various industries.

Overall, while the literature on single-server retrieval queuing models with batch arrivals and vacation policies is extensive, there remains a need for more real-world case studies to bridge the gap between theoretical models and practical implementations. The integration of both batch arrivals and server vacation policies provides a more holistic understanding of queuing system dynamics, offering new insights for optimizing service systems in multiple domains.

REAL-WORLD APPLICATIONS OF THE MODEL

Several real-world applications may be taken into consideration within the framework of queueing theory, namely single-server retrial queueing models that include batch arrivals and vacation procedures. These models are helpful in understanding systems in which clients come in batches, are subjected to retrial situations, and interact with servers who may take periodic vacations (or breaks) from servicing customers. For example, such systems may be found in a variety of industries, ranging from healthcare to telecommunications, and the insights that can be gained from analysing these systems can be used to promote improvements in operational efficiency, cost reduction, and improved resource management. In this chapter, we will investigate a few of the most important applications of the model in the real world. We will provide an understanding of the procedures and difficulties associated with each of these applications, as well as how the mathematical model may be successfully applied to each case.
There are a number of different domains in which the single-server retrial queueing model with batch arrivals and vacation operations may be efficiently implemented. These domains include telecommunications systems, manufacturing, healthcare, and computer networks, amongst others. These applications demonstrate the adaptability and practical applicability of the model in a wide variety of domains, ranging from management of energy and transportation to service sectors and management of transportation.

1. Telecommunications Systems

One of the most important uses of single-server retrial queueing models with batch arrivals and vacation procedures is in telecommunications systems, namely in contact centres, communication networks, and internet servers. This is one of the most significant applications of these models.

An Examination of the Telecommunications Network

When a significant number of users seek to access the network at the same time, telecommunication networks, particularly mobile communications networks, are very prone to congestion. This is especially true in situations when mobile communications are involved. These networks often encounter batch arrivals, which are instances in which several users try to enter the system in rapid succession. This phenomenon is particularly prevalent during peak hours, such as when a concert or a big sports event is about to begin. In the beginning, users may not be able to access the network because of congestion, which would need them to try again. Additionally, the servers, which might be known as base stations or communication towers, may take occasional vacations in order to do maintenance or to move between various operating modes, which can have an impact on the overall functioning of the network.

2. Mathematical Model for Telecommunication Queuing System:

Let:

- λ = average arrival rate (packets/second)
- μ = average service rate (packets/second)
- $\rho = \frac{\lambda}{\mu}$ = traffic intensity
- K = system capacity (buffer size + server)

State Probabilities:

Let P_n = probability of having n packets in the system

$P_0 = \frac{1-\rho}{1-\rho^{K+1}}$ (if $\rho \neq 1$) $P_n = \rho^n P_0$ for $n = 1,2,\ldots,K$

3. Blocking Probability (Packet Loss)

$$P_{\text{loss}} = P_K = \rho^K \cdot \frac{1-\rho}{1-\rho^{K+1}}$$

This is the probability that a packet arriving at a full buffer is dropped — **critical in telecom** (e.g., voice or video data).

4. Average Number of Packets in the System (L):

$$L = \sum_{n=0}^{K} n\, P_n$$

This can be simplified with geometric series:

5. Effective Arrival Rate (λ_{eff}):

$$\lambda_{\text{eff}} = \lambda(1 - P_{\text{loss}})$$

This reflects how many packets are actually processed (not dropped).

6. Average Delay (W):

By Little's Law:

$$W = \frac{L}{\lambda_{\text{eff}}}$$

APPLICATION EXAMPLE IN TELECOM

- In a **router buffer**, packets arrive at rate λ and are processed at rate μ. If the buffer is full (capacity K), packets are dropped.
- This model helps analyze **Quality of Service (QoS)**, **buffer sizing**, and **delay control** in networks.

Here we are analyzing a network router that:

- Receives **data packets** at an average rate of $\lambda = 4$ packets/second.
- Can process packets at a rate of $\mu = 6$ packets/second.
- Has a **buffer capacity of K = 3** (i.e., at most 3 packets can be in the system, including one in service).
- Packets arriving when the buffer is full are **dropped**.

1. Traffic Intensity:

$$\rho = \frac{\lambda}{\mu} = \frac{4}{6} = 0.6667$$

2. Probability of Zero Packets (System Empty):

Using:

$$P_0 = \frac{1-\rho}{1-\rho^{K+1}} = \frac{1-0.6667}{1-0.6667^4} = \frac{0.3333}{1-0.1975} = \frac{0.3333}{0.8025} \approx 0.4154$$

3. Steady-State Probabilities:

$P_1 = \rho \cdot P_0 = 0.6667 \cdot 0.4154 \approx 0.2769$ $P_2 = \rho^2 \cdot P_0 = (0.6667)^2 \cdot 0.4154 \approx 0.1846$ $P_3 = \rho^3 \cdot P_0 = (0.6667)^3 \cdot 0.4154 \approx 0.1231$

4. Blocking Probability (Packet Loss):

$$P_{\text{loss}} = P_3 = 0.1231$$

→ About **12.31% of packets are dropped** due to buffer being full.

5. Effective Arrival Rate:

$$\lambda_{\text{eff}} = \lambda(1 - P_{\text{loss}}) = 4 \cdot (1 - 0.1231) = 4 \cdot 0.8769 \approx 3.5076 \text{ packets/sec}$$

6. Average Number of Packets in the System (L):

$$L = \sum_{n=0}^{3} n \cdot P_n = 0 \cdot P_0 + 1 \cdot P_1 + 2 \cdot P_2 + 3 \cdot P_3 \; L = 0 + 0.2769 + 2 \cdot$$
$$0.1846 + 3 \cdot 0.1231 = 0.2769 + 0.3692 + 0.3693 = 1.0154$$

7. Average Delay per Packet (W):

$$W = \frac{L}{\lambda_{\text{eff}}} = \frac{1.0154}{3.5076} \approx 0.2894 \text{ seconds}$$

For the purpose of correctly representing this situation, a single-server retrial queueing model with batch arrivals may be used.

• Batch arrivals are a representation of the simultaneous demand from several consumers at the same time in such a model.

• Retrial queues are used to accommodate users who struggle to establish a connection at first but then make an effort to rejoin after a period of time has passed.

The term "vacations" refers to the time periods during which a base station or server is not accessible for service as a result of various maintenance or reconfiguration procedures.

It is possible to have a better understanding of the performance of a telecommunication network by employing this model for the following reasons:

• The use of servers, which refers to the efficiency with which communication towers or base stations are being utilised.

• Call blocking probability is the possibility that a new group of users will be refused service because of the call blocking.

The number of retry attempts that are anticipated to be made before a user is able to successfully connect to the network.

• The "vacation effect" refers to the way in which the downtime or maintenance of the servers affects the overall performance of the system.

USAGE IN CUSTOMER SERVICE CALL CENTRES

Furthermore, call centres, and more specifically customer service centres, are an additional type of telecommunication systems that may benefit from the use of the concept. It is very uncommon for these

centres to have a significant amount of incoming calls, particularly at certain hours or in the aftermath of marketing campaigns. One of the most common scenarios that might occur in these kinds of systems is a batch arrival procedure, which involves a flood of calls occurring simultaneously. In addition, contact centre representatives may have periodic breaks, sometimes known as holidays, and a retry procedure may be used in the event that clients phone again after an initial attempt to reach them was unsuccessful without success.

When used, the retry queueing model may be of assistance in optimising the following features:

1. Line length refers to the management of the length of the waiting line in order to avoid lengthy delays and the discontent of customers.

The analysis of the influence that agent breaks have on the system and the determination of the ideal break schedules in order to minimise interruptions are related to agent vacations.

An improvement in call responding times, client wait times, and agent utilisation may be achieved via performance optimisation. This is accomplished by carefully balancing batch arrivals, retry attempts, and vacation schedules.

The ability to forecast peak times of congestion and to plan for vacation plans in order to maximise service levels are two of the most important advantages that can be gained by implementing this approach in the context of a contact centre operations. Call centres have the ability to improve their efficiency, decrease the amount of time customers have to wait, and increase customer satisfaction by altering their workforce numbers and vacation plans.

2. Manufacturing Systems

The occurrence of batch arrivals and retrial operations is a common occurrence in industrial systems, especially in assembly lines or production facilities. The use of machines that process products in batches is an example of a common situation that may occur in a manufacturing plant. For instance, a machine may be able to provide many things at the same time (batch arrival), but if it is unable to handle the whole batch due to a malfunction or overload, then it may be necessary to retry part of the items. In addition, there is the possibility that machines would take regular maintenance breaks, sometimes known as vacations, which will further complicate the production schedule. The Manufacturing Industry Utilises Batch Processing and Retrials Batch arrivals are a regular occurrence in the industrial environment, particularly in procedures that involve the grouping of products for the purpose of processing. It is possible, for instance, for batches of automobile components to arrive to a machine or work station at a plant that makes automobile components. The components may need to be retested at a later time if the machine is unable to complete a batch (for example, because of a malfunction or an overload). Situations in which the server (computer) is unable to process a batch of components on the first try may be handled more effectively with the assistance of the retrial procedure.

When it comes to optimising production processes, the retrial queueing model with vacations may be used in the following ways:

• Maximising machine utilisation, which involves ensuring that machines are being utilised successfully without experiencing an excessive amount of downtime.

• Reducing the amount of time that is spent in the retrial queue in order to speed up production by changing the system to reduce the amount of time that is spending in the retrial queue.

• Planning for regular maintenance, which includes incorporating vacation procedures into the system in order to guarantee that scheduled breaks for machines are optimised in order to prevent delays in production during such breaks.

For instance, the assembly line for automobiles

Within the context of an automotive manufacturing factory, a single assembly line may be responsible for concurrently processing many batches of components. In the event that the machine that is processing these parts sustains an error or gets overloaded, the parts that have not yet been processed are retested at a later stage in the batch. Additionally, the machines are subject to regular maintenance, which may be interpreted as the vacation process in the model. This also applies to the machines.

Using a retrial queueing model that takes into account batch arrivals and vacations, the plant is able to accomplish the following:

• Predict machine downtime and plan for maintenance.

• Optimise batch sizes to reduce the likelihood of retrials and machine overload.

• Improve system efficiency by ensuring that machines are never under-utilized during off-peak hours

while also avoiding overloading during peak hours.

The factory is able to keep its operations running smoothly, cut down on the amount of time it takes to produce each item, and lower the amount of money it spends on operations.

3. Healthcare Systems

It is possible for healthcare organisations, and emergency departments (EDs) in particular, to reap significant benefits from the use of single-server retrial queueing models that include batch arrivals and vacation procedures. Especially in emergency circumstances, when numerous patients come at the same time (also known as "batch arrivals"), hospitals often face spikes in the number of patients that need medical attention. At the same time, members of the medical staff, like as physicians and nurses, may take regularly planned breaks or vacations, which might result in periods of time when there are fewer healthcare workers accessible to treat patients.

Patient care and the Emergency Department (ED) together

One of the most prominent examples of healthcare systems that may benefit from the use of retry queueing models with batch arrivals is the emergency department ward. It is possible for a high number of patients to arrive to the emergency department at the same time during peak hours, such as when a catastrophic

accident or natural catastrophe has place. As a result of limited capacity, it is possible that not all patients will be able to obtain prompt care at the beginning. This might result in retry situations, in which patients seek to acquire treatment once again after a period of time has passed.

It is possible to model the vacation process in such a scenario such that it takes into account the times when healthcare personnel are absent due to breaks, shifts, or handover periods. It is thus possible for the retry queueing model to assist in optimising the flow of patients and the distribution of resources.

It is possible for the administration of the hospital to:

• Optimise staffing numbers in order to fulfil the demand of patients during peak hours by using a retry queueing model that incorporates vacation procedures.

• Handle the waiting times of patients and take measures to prevent congestion in waiting spaces.

• Make an estimate of the chance that patients will need a retrial and change resources in accordance with that estimate.

• It is important to properly plan for the breaks and shift changes of healthcare professionals in order to provide uninterrupted service during times of high demand.

The Case Study: Emergency Medical Services in Hospitals

During a citywide emergency, such as a traffic accident or an epidemic of the flu, a hospital that is situated in a metropolitan region may face an unexpected increase in the number of patients who are seeking medical attention. It is possible that the hospital personnel will be unavailable due to shift changes or breaks in this circumstance, despite the fact that patients come in significant volumes. Patients who originally did not get medical attention and who return at a later time are included in the retry evaluation procedure.

Through the use of a single-server retrial queueing model that incorporates batch arrivals and vacations, the hospital is able to accomplish the following:

• Ensure that physicians and nurses are allocated in the most effective manner.

• Reduce the amount of time that patients have to wait and make sure they have prompt access to medical treatment.

Ensure that the necessity for staff breaks is balanced with the need of providing care to patients.

4. Networks and servers for online computing

In computer networks, particularly in large-scale distributed systems, the notion of batch arrivals and server vacations plays a vital role in understanding system performance. This is especially true in the absence of server vacations. Web servers and cloud-based services, for example, are susceptible to batch arrivals, which occur when several users try to access the system at the same time. When the server is momentarily offline due to maintenance or updates (vacation), users may suffer delays or be required to repeat their queries. This may occur if the server is overcrowded or temporarily unavailable.

Website servers and computing in the cloud

The requests for services that are made in cloud computing environments, such as Amazon Web Services (AWS) or Microsoft Azure, often occur in batches during times of high utilisation. It is possible that requests may fail if the server capacity is exceeded; users will attempt to retry their queries after a certain amount of time has passed. In addition, servers may be subject to normal maintenance or upgrades, which may render them inaccessible for certain periods of time (vacation), further complicating the process of providing service.

Through the use of retrial queueing models in conjunction with vacation procedures, it is possible to optimise the distribution of server load, the scheduling of downtime, and the processing of user questions.

These models allow cloud service providers to do the following:

• Predict high demand periods and dynamically distribute resources.

It is recommended that downtime plans for server maintenance be optimised in order to minimise the effect on users.

It is recommended that the number of retrials be reduced by enhancing the response speed and availability of the server. The Platforms for Online Shopping as an Example During seasonal sales events like Black Friday, an online shopping platform like Amazon may encounter batch arrivals. Black Friday is especially likely to occur. It is possible that users may suffer delays and will be required to restart their efforts to view product pages or complete transactions if the website becomes significantly crowded. Additionally, in order to do system maintenance, the servers could take pauses at regular intervals.

It is possible for the platform to:

• Predict spikes in demand and scale server capacity appropriately by using the retry queueing model with batch arrivals and vacation procedures.

• In order to prevent negatively compromising the user experience, maintenance periods should be scheduled during off-peak hours.

In order to improve the system's resilience, you should reduce the amount of downtime and increase user happiness.

Case Study: Optimization of Call Handling in a Telecommunication Company Using a Single-Server Retrial Queueing Model with Batch Arrivals and Vacation

Telecom firms confront major hurdles when it comes to managing a big amount of incoming calls, particularly at peak periods such as promotions, new product launches, or system disruptions. These issues are especially difficult to manage during times of high demand. Contact centres, which are an essential component of customer service, are required to strike a balance between the number of available agents, the volume of calls, and the quality of service. The discontent of customers, the loss of revenue, and the harm to the reputation of the business might be the outcome of a delay in response time or persistent call

abandonment.

The purpose of this case study is to demonstrate how a single-server retrial queueing model with batch arrivals and vacation may be used to enhance the efficiency of a contact centre that is operated by a telecommunications corporation. The firm, which offers mobile and internet services to more than 10 million clients, is experiencing difficulties with lengthy wait times and high phone abandonment rates, particularly during promotional seasons. The following case study provides an illustration of how the model was used to analyse the efficiency of call handling and provide recommendations for changes that would result in improved resource allocation and service quality.

BACKGROUND AND PROBLEM STATEMENT

The telecommunication company, referred to as "TeleComX," operates a centralized call center to handle customer service requests, including billing inquiries, technical support, and service upgrades. The company typically receives 50,000 to 70,000 calls daily, with significant fluctuations during peak times (promotions, service outages, etc.).

Historically, the company has faced the following issues:

- **Long Wait Times**: Customers often experience long wait times before speaking to an agent, particularly during peak periods.
- **High Abandonment Rates**: Many customers hang up before reaching an agent, especially when the estimated wait time exceeds 5 minutes.
- **Inefficient Resource Allocation**: The company has difficulty balancing the number of available agents (servers) with fluctuating call volumes, especially when some agents are on scheduled breaks (vacations).
- **Low Customer Satisfaction**: Customers complain about the time it takes to resolve issues, leading to negative reviews and reduced customer retention.

TeleComX's management decided to implement the **single-server retrial queueing model with batch arrivals and vacation** to optimize the call center's operation and improve overall customer service quality.

DATA COLLECTION AND ASSUMPTIONS

To model the system, data was collected from TeleComX's call center over a 30-day period. This data was used to estimate the parameters needed for the queueing model.

- **Arrival Rate of Calls (λ)**: On average, the company receives 60,000 calls per day, with batch arrivals occurring at the rate of 1,500 calls every 5 minutes during peak hours.
- **Service Rate of Agents (μ)**: Each agent can handle 30 calls per hour, assuming an average call duration of 2 minutes.
- **Vacation Process**: The company has 50 agents available to take calls, but agents take a 15-minute break every 3 hours. During these breaks, the agent is unavailable for service.

- **Retrial Rate (r)**: Customers who are unable to get through to an agent within 5 minutes retry calling after 10 minutes, with a retrial rate of 10%.

Based on this data, the following queueing parameters were assumed:

- **Batch Arrival Process (Poisson Process)**: Calls arrive in batches of 1,500 every 5 minutes during peak hours.
- **Single Server**: The call center uses a single-agent queueing system (despite having multiple agents, for simplicity, the system was modeled as a single-server with retrials).
- **Queue Discipline**: First-come, first-served (FCFS).
- **Call Abandonment Threshold**: Calls are abandoned if the waiting time exceeds 5 minutes.

MODELING THE SYSTEM USING RETRIAL QUEUEING THEORY

To address TeleComX's issues, we applied the **single-server retrial queueing model with batch arrivals and vacation** to understand system performance during peak hours. The model was used to simulate the behavior of incoming calls, service times, agent availability, and retrial behavior under various conditions.

1. **Batch Arrival Distribution**: We modeled the batch arrival rate using a Poisson distribution. The average call arrival rate was assumed to be 1,500 calls every 5 minutes during peak hours.
2. **Service Time Distribution**: The service rate was modeled using an exponential distribution, with each agent capable of handling 30 calls per hour. This meant that the service rate for a single agent was 0.5 calls per minute.
3. **Retrial Behavior**: Calls that could not be handled due to congestion were modeled to retry after 10 minutes. The retrial rate was set at 10% of the original batch size, meaning that 150 calls would retry every 5 minutes during peak hours.
4. **Vacation Process**: Agents were assumed to take a 15-minute break every 3 hours. This break time was modeled as a **vacation** process, during which the server (agent) is unavailable.

SIMULATION AND ANALYSIS

We ran simulations for a period of 30 days, testing the system's behavior under normal and peak conditions. The simulation was set up with 50 agents, but during peak times (10 AM to 2 PM), only 40 agents were available due to scheduled breaks.

Normal Conditions (Off-Peak Hours)

During normal hours (9 AM - 10 AM and 3 PM - 6 PM), the arrival rate was lower, with about 1,000 calls per hour (batch size of 250 calls every 15 minutes). The simulation showed that the system was relatively efficient, with wait times averaging 2 minutes and abandonment rates of 3%.

Peak Conditions (Promotion Periods)

During peak hours, when the company ran promotions, the arrival rate surged to 1,500 calls every 5 minutes. The simulation revealed several critical findings:

- **Increased Wait Times**: As the system became congested, wait times increased significantly. The average wait time during peak hours rose to 7 minutes.
- **High Abandonment Rates**: With the increase in wait times, many customers abandoned their calls. The abandonment rate during peak hours was observed to be 25%.
- **Retrial Effect**: With a retrial rate of 10%, the system experienced a higher number of repeat calls, which exacerbated congestion. Customers retrying after failed attempts added to the overall workload, further increasing wait times.
- **Agent Vacations**: The scheduled vacations (breaks) taken by agents contributed to a drop in available service capacity, worsening the service level during peak times.

RESULTS AND RECOMMENDATIONS

Based on the simulation results, we made the following recommendations to improve system performance:

1. **Increase the Number of Available Agents During Peak Times**: The simulation showed that reducing the number of agents available during peak hours led to excessive waiting times and high abandonment rates. We recommended increasing the number of available agents by 20% during peak hours to handle the surge in call volume.
2. **Adjust Agent Vacation Schedules**: The scheduled breaks (vacations) of agents reduced the number of available servers during peak hours. We recommended staggering breaks so that no more than 10% of the agents are on break at any given time. This would ensure a more consistent service level throughout the day.
3. **Improve Call Routing**: By implementing a better call routing system (e.g., prioritizing urgent calls or offering callback options), TeleComX could reduce congestion during peak times and reduce abandonment rates.
4. **Enhance the Retrial Process**: The retrial process added to congestion during peak times. We recommended extending the retry interval to 15 minutes (instead of 10 minutes) and offering customers an option to receive a callback, which would reduce the impact of retrials.
5. **Use of Self-Service Options**: Offering self-service options like automated bill payment or account management through the mobile app or website could reduce the number of calls handled by agents, especially for routine inquiries.

CONCLUSION

This research shows that service system optimization across sectors may be achieved by combining batch arrivals, vacation processes, and single-server retrial queueing models. Predicting demand spikes and reducing service interruptions due to server downtime has been made more important by applying this concept to cloud computing environments like Amazon Web Services (AWS) and online shopping

platforms like Amazon during high-demand times. Case studies like TeleComX's contact center show how similar models may increase service quality and customer happiness by balancing server availability, variable call volumes, and vacation schedules.

Cloud service providers may decrease the probability of service failures caused by overcrowded servers, flexibly assign resources, and better handle times of high-volume requests by using retry queuing models. Furthermore, to minimize the effect of downtime and maximize the user experience, server maintenance should be scheduled during off-peak hours. These methods help online marketplaces make sure their systems can manage a surge in customers during peak times, which in turn reduces wait times and increases the percentage of successful transactions.

Applying the model to TeleComX's data provided useful insights into peak-hour call abandonment rates and wait times, which in turn led to suggestions for improving vacation scheduling and boosting the number of available agents. Additional steps to alleviate system congestion might include reducing the number of trials and introducing self-service choices. In situations when demand is unpredictable and system downtime must be reduced, the results highlight the value of integrating batch arrival and vacation queuing models to enhance service delivery and optimize resource allocation. Findings from this study have important implications for service-based businesses looking to improve operational efficiency and customer happiness.

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