A Study on Waiting Time of Customers in Petrol Bunks in Madurai District

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ABSTRACT

Waiting in line has become an unavoidable aspect of modern life, and petrol bunks are no exception. Long queues not only inconvenience customers but also reduce operational efficiency and damage service reputation. This study examines customer waiting times at petrol bunks in Madurai District using a queuing theory approach. Data were collected during peak hours over two days from a stratified sample of four stations, covering 959 customer arrivals. Arrival and service times were analysed under the M/M/c model, which assumes Poisson arrivals, exponential service times, and multiple service channels. Key performance measures such as traffic intensity, idle probability, average queue length, and waiting times were computed. The findings show that both high arrival intensity and service inefficiency contribute to delays. Bunk 1 demonstrated relatively efficient performance, while Bunks 3 and 4 exhibited slower service rates and Bunk 2 was more constrained by demand. Although average waiting times in queue were short in absolute terms, their cumulative effect during peak hours is significant. The study recommends improving service efficiency, optimising pump allocation, and adopting technology-enabled queue management to minimise waiting. These insights highlight how queuing models can guide petrol bunk managers in balancing customer satisfaction with operational efficiency.

Keywords: queuing theory; M/M/c; petrol stations; waiting time; service efficiency; traffic intensity.

INTRODUCTION

Queuing is a familiar experience in everyday life. Whether waiting to refuel a vehicle, collect groceries, or process a transaction at a bank, individuals routinely encounter situations where demand temporarily exceeds service capacity. At its core, a queuing system consists of customers arriving for a service and servers attending to them in sequence. When the number of arrivals surpasses available resources, waiting becomes inevitable. This phenomenon is not confined to people alone—machines wait for tasks to be processed, aircraft circle in the sky before receiving clearance to land, and digital requests queue in computer networks. In each case, the experience of waiting introduces both inconvenience and inefficiency. Understanding and managing waiting time is therefore essential, not only for improving customer satisfaction but also for enhancing operational effectiveness across service systems.

Delays and Queuing problems are most common features not only in our day to day situations. They play an essential role for business process re-engineering purposes in administrative tasks. Queuing models provide the analyst with a powerful tool for designing and evaluating the performance of queuing systems. Whenever customers arrive at a service facility, some of them have to wait before they receive the desired service. It means that the customer has to wait for his/her turn may be in a line. Customers arrive at a service facility with several queues, each with one server. The customers choose a queue of a server according to some mechanism (e.g. shortest queue or shortest workload). In some queuing systems customers arrive according to some stochastic process (e.g. a Poisson Process) and immediately upon arrival must join one of the queues, thereafter to be served on a first-come first served basis, with no jockeying or defections allowed. The service times are independent and identically distributed with a known distribution. Moreover, the service times are independent of the arrival process and the customer decisions.

Sometimes fuel supply to consumers in Madurai District may be intermittent fuel supply occasionally leads to scarcity, thereby creating fuel scarcity resulting in long queues of vehicles at filling stations. However, it was observed that even when there was no fuel scarcity, long queues were still prominent in most of the filling stations in Madurai.

REVIEW OF LITERATURE

Waiting time at petrol bunks is a critical factor influencing customer satisfaction and operational efficiency. With increasing vehicle density and demand for fuel, petrol stations often face challenges related to long queues and customer dissatisfaction. The study of waiting times at petrol bunks involves analysing customer flow, service rates, and the application of queuing models to optimize service delivery. Various research studies have been conducted to understand and mitigate the impact of waiting times, focusing on queuing theory applications, simulation models, customer satisfaction, and technological interventions.

One of the earliest significant studies on the topic was conducted by Akinnuli et al. (2015), who applied queuing theory to analyze the waiting time of customers at fuel stations. The study emphasized that long waiting lines at petrol bunks negatively impact customer satisfaction and the performance of the fuel station. To mitigate these issues, the research recommended increasing the number of service points during peak hours and optimizing staff deployment. In the same year, Moazzami et al. (2015) utilized a discrete-event simulation model to study the behavior of petrol stations under varying demand conditions. Their findings demonstrated that simulation-based approaches could accurately predict waiting times and identify peak load periods, leading to recommendations for optimizing pump allocation and enhancing cashier efficiency.

In subsequent years, researchers began to focus on integrating technology into queue management. Yang et al. (2019) developed a smart queue management system that integrated digital displays and mobile notifications, resulting in a reported 30% reduction in waiting times and improved customer satisfaction. This technological innovation demonstrated the potential of using smart systems to manage customer flow efficiently. The focus on technology continued with Rai and Rajan (2020), who explored the impact of automated payment systems, digital pump availability displays, and pre-payment methods on reducing queue lengths. They found that these solutions significantly minimized wait times and improved the overall customer experience.

Yi and Win (2021) contributed to the field by conducting a comprehensive study on applying queuing models to minimize waiting times at fuel stations. Their study highlighted that adopting multi-server models, such as M/M/1 and M/M/c, could significantly reduce waiting time compared to traditional single-server setups, especially when accommodating fluctuating customer arrival rates. In the same year, Anggraeni et al. (2021) performed a simulation study focusing on customer waiting times and worker utilization at an Indonesian petrol station. By simulating various operational scenarios, they identified that increasing the number of pumps and cash registers during peak hours could significantly reduce waiting times.

Customer satisfaction also emerged as a critical area of research, as actual waiting times and perceived waiting experiences were both found to influence customer perceptions. Lovelock and Wirtz (2016) discussed the importance of informing customers about anticipated waiting times and providing amenities during waits, which positively impacted satisfaction levels. Later, Palawatta (2021) emphasized that perceived waiting time is a key determinant of customer satisfaction. The study found that providing real-time information about expected waiting duration and ensuring a comfortable waiting environment, such as shaded areas and digital boards, improved customer satisfaction.

Statement of the Problem

Waiting time at petrol bunks has become a critical issue affecting customer satisfaction and operational efficiency. In today's fast-paced world, customers value quick and efficient service, and prolonged waiting times can significantly damage the reputation and goodwill of service providers. As vehicle density and fuel demand continue to rise, petrol bunks frequently face challenges in managing customer flow, especially during peak hours.

Many previous studies have examined how waiting in line within a service system impacts customer goodwill and overall satisfaction. It has been observed that queues form when there is an imbalance between the demand for service and the capacity of the available service facilities. This imbalance arises in two primary scenarios:

Excess Demand Leading to Long Queues:

When the number of customers seeking fuel exceeds the capacity of the petrol bunk, the service facilities become overwhelmed. This situation results in long queues, where customers experience extended waiting times. The service staff becomes occupied with serving a limited number of customers, leaving others to wait for their turn. Consequently, customers become dissatisfied, and the reputation of the petrol bunk suffers. In addition to dissatisfaction, such scenarios can lead to operational inefficiencies as employees are pressured to serve faster, potentially compromising service quality.

Low Demand Leading to Idle Facilities:

On the other hand, problems also arise when the demand for service is lower than anticipated. In such cases, service facilities remain underutilized, resulting in idle time for both the infrastructure and the employees. This underutilization not only leads to financial losses but also affects employee productivity and motivation. Customers who arrive during these periods may still encounter confusion or inefficiencies if the bunk's layout and queue management systems are not optimized.

Finding the right balance between service demand and facility capacity is crucial to maintaining customer satisfaction and minimizing operational waste. The primary challenge for petrol bunks lies in effectively managing fluctuating customer demand without compromising service quality or causing significant downtime.

This study aims to investigate the factors contributing to long waiting times at petrol bunks and to identify strategies for optimizing queue management. By analyzing customer arrival patterns, service rates, and the effectiveness of existing queuing systems, the study will develop insights into minimizing waiting times and enhancing customer experiences. Addressing these challenges is essential for petrol bunks to remain competitive and maintain customer loyalty in an increasingly demanding environment.

Description of the model and the data

The Two days data collection from four Petrol bunks during peak hours was very useful to initiate this paper. The arrival time of customers was calculated by the help of stop-watch. Analysis of this type is more supportive in the calculation of inter-arrival time and service time. A simple activity of the queuing system is given below:

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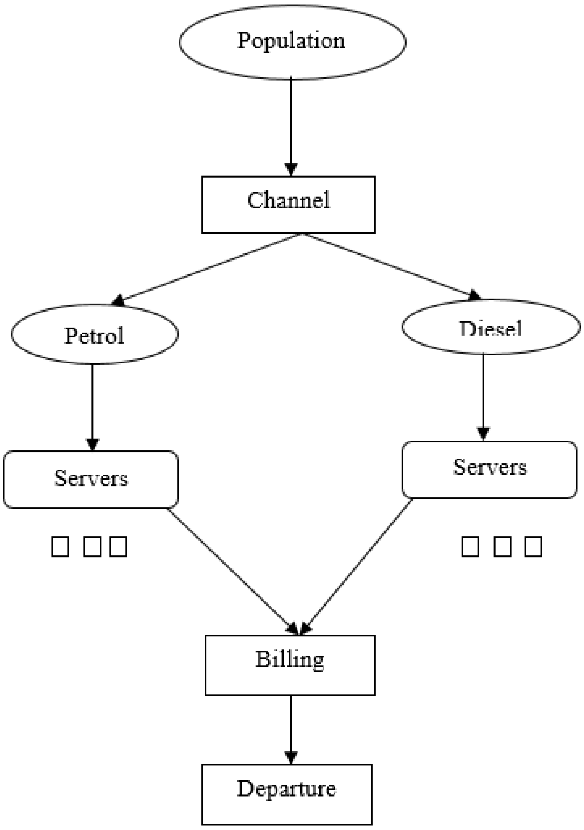
Figure 1 Activity Flow of the Queuing System in Petrol Bunks



System Analysis and Problem Identification

System analysis plays an important role in understanding the queuing dynamics at petrol bunks. It aims to identify problem areas and deliver prompt solutions to minimize customer waiting times. By carefully analyzing the flow of vehicles and the service mechanisms, management can implement strategies to enhance operational efficiency and customer satisfaction.

Queuing System or Process

Service Facility Design

The design of a service facility plays a decisive role in determining the efficiency of customer flow and the quality of the service experience. In facilities such as petrol bunks, arriving customers are usually required to form either a single queue or multiple queues, depending on the operational setup. A single-channel facility directs vehicles into a single line to access one service point, whereas a multi-channel facility involves several service points, each served by a separate queue. The choice between these models is not only an operational matter but also a determinant of customer satisfaction, waiting time, and fairness in service delivery.

Single-Channel Queues

In a single-channel queue, the entire facility operates through one service station, such as a petrol bunk with a single fuel pump. Vehicles line up sequentially, and only one customer can be served at any given moment. Once the service is completed, the next vehicle advances to the service zone. Although this system appears simple, it enforces discipline and ensures order among waiting customers.

The single-channel queue can be further divided into single-phase and multi-phase structures. In a single-channel single-phase queue, the process is straightforward: a vehicle enters the premises, joins the line, receives service, and departs. By contrast, when the demand for service intensifies, the single channel may become a bottleneck. Managers often respond by introducing additional service stations, which may convert the facility into a multi-

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channel setup. This decision directly influences congestion levels, reduces perceived waiting time, and helps prevent dissatisfaction among customers. Thus, even modest changes in service facility design have significant implications for operational efficiency.

Queue Discipline or Service Discipline

Queue discipline defines the principle by which waiting customers are selected for service. It is essentially the protocol governing fairness, order, and transparency in the system. Several types of queue discipline are observed in practice:

First-In-First-Out (FIFO) or First-Come-First-Served (FCFS)

This is the most common arrangement in petrol bunks. Customers are served strictly in the order in which they arrive. Such a method is widely accepted because it promotes fairness and predictability. If this principle is violated, for instance by allowing later arrivals to bypass earlier ones, customer dissatisfaction may arise. Managers must therefore ensure adherence to this discipline as part of their responsibility to maintain trust.

Last-In-First-Out (LIFO) or Last-Come-First-Served (LCFS)

Under this approach, the most recent arrival receives service before those who have been waiting. Although not suitable for service environments such as petrol bunks, LIFO is sometimes used in inventory control systems, where the most recently added stock is withdrawn first.

Service in Random Order (SIRO)

In this discipline, customers are selected at random rather than by order of arrival. While this may be rare in structured service operations, it may be observed in social or religious gatherings where service order is less formalised.

Service by Priority

Customers are categorised based on specific criteria and served according to their priority level. Priority rules can be either preemptive or non-preemptive. In preemptive priority, a high-priority customer may displace one who is currently being served. Emergency services often employ this model. In non-preemptive priority, higher-priority customers are served before others waiting in line, but without disturbing ongoing service.

The discipline chosen has a direct bearing on customer perceptions of fairness and the smooth functioning of the service environment. Clear communication of the adopted system is essential to prevent disputes and manage expectations effectively.

The M/M/C Queue Model: (FCFS/∞/∞)

Queuing theory provides a mathematical foundation for analysing service facility performance. Among its models, the M/M/C system is frequently applied in environments with multiple service points operating simultaneously. In petrol bunks, where several pumps may be active, this model provides a framework for predicting queue lengths, waiting times, and server utilisation.

The notation M/M/C has specific interpretations. The first M indicates that arrivals occur according to a Poisson distribution, which assumes random and independent customer arrivals over time. The second M denotes that service times follow an exponential distribution, reflecting the variability and memoryless nature of the service process. The parameter C represents the number of servers, in this case the fuel pumps available to customers.

The extended notation (FCFS/∞/∞) conveys three further assumptions. Customers are served on a first-come-first-served basis, the system allows for an unlimited queue length, and the potential customer base is considered infinite. These assumptions make the model analytically tractable and suitable for approximation of real-world conditions in busy service facilities.

By applying the M/M/C model, managers can evaluate the adequacy of the number of pumps in relation to arrival rates, predict average waiting times, and identify when additional service channels should be introduced. Its use therefore supports evidence-based decision-making in service facility design and management.

METHODOLOGY

This study employed a quantitative research design grounded in queuing theory. The analytical framework was the M/M/c model, which assumes Poisson arrivals, exponential service times, and multiple parallel service channels. This model is particularly suitable for petrol bunks, where customer arrivals occur randomly and fuelling times vary across vehicles, while several pumps operate simultaneously.

Data Collection

Data were collected over two consecutive peak days from four petrol bunks in Madurai District, selected through stratified sampling to ensure geographical representation. The observation period covered both morning and evening peaks, when congestion is typically at its highest. A stopwatch was used to record inter-arrival times, defined as the time between two successive vehicle arrivals, and service times, defined as the duration from the start of fuelling to its completion. In total, 959 customer arrivals were observed: 242 at Bunk 1, 261 at Bunk 2, 236 at Bunk 3, and 220 at Bunk 4.

System Classification

In the queuing framework, each petrol pump is considered an independent server. Thus, a station with three pumps is modelled as an M/M/3 system, where each server can handle one customer at a time, and all servers work in parallel. Customers are assumed to arrive according to a Poisson process and are served on a First-Come, First-Served (FCFS) basis.

Methodological Framework

It is important to distinguish between single-server and multi-server queuing models. The M/M/1 model is commonly introduced in the literature and includes a simplified expression for waiting time, $1/(\mu - \lambda)$, which illustrates the principle that the service rate must exceed the arrival rate for a system to remain stable. In this study, the reference to M/M/1 serves only this conceptual purpose.

The actual computations were carried out using the M/M/c model, which is appropriate for multi-channel service environments such as petrol bunks. The model parameters included the probability of an idle system (P_0), traffic intensity ($\rho = \lambda / c\mu$), expected number of customers in the system (Ls), expected number of customers in the queue (Lq), mean waiting time in the queue (Wq), and mean total time in the system (Ws). These were derived using standard M/M/c formulations.

Understanding the Formula

In queuing theory, the formula

$$1/ (\mu-\lambda)$$

is used to calculate the **average waiting time in the queue** when the system is stable. Let’s break down the components:

λ (Lambda): The **arrival rate**, which represents the average number of vehicles arriving per unit of time.

μ (Mu): The **service rate**, which indicates the average number of vehicles served per unit of time by a single pump.

The expression **(μ−λ)** indicates the difference between the service rate and the arrival rate. This difference must be positive for the system to be stable, meaning that the service capacity must exceed the arrival rate.

The inverse of this difference, **1/(μ−λ)**, gives the **average waiting time** in the queue. This waiting time is crucial for petrol bunk management, as prolonged waiting negatively affects customer satisfaction and operational efficiency.

By optimizing these parameters, petrol bunks can significantly reduce customer waiting times and enhance overall service quality.

In this M/M/C: (FCFS/∞/∞)model, the number of service channel is C(that is C > 1)

The formulae used in this model are listed below:

The probability that the system is empty or idle,

$$P_o = \left[\sum_{n=0}^{s-1} \frac{1}{n!} \left(\frac{\lambda}{\mu} \right)^n + \frac{1}{s!} \left(\frac{\lambda}{\mu} \right)^s \left(\frac{s\mu}{s\mu - \lambda} \right) \right]^{-1}$$

Average number of customers in the queue

$$L_s = \quad L_q = \left[\frac{1}{(s-1)!} \left(\frac{\lambda}{\mu} \right)^s \left(\frac{\lambda\mu}{(s\mu - \lambda)^2} \right) \right] .P_o + \frac{\lambda}{\mu}$$

Expected number of customers in the queue

$$L_q = \left[\frac{1}{(s-1)!} \left(\frac{\lambda}{\mu} \right)^s \left(\frac{\lambda\mu}{(s\mu - \lambda)^2} \right) \right] .P_o$$

Average time a customer spends in the system

$$W_s = \frac{L_q}{\lambda} + \frac{1}{\mu}$$

Average waiting time of a customer in the queue

$W_q = \frac{L_q}{\lambda}$ Average waiting time of a customer in the queue

$$P\ (n \geq s) = \left[\frac{1}{s!} \left(\frac{\lambda}{\mu} \right)^s \left(\frac{s\mu}{(s\mu - \lambda)} \right) \times po \right]$$

Traffic intensity or Utilization rate

$$\rho = \frac{\lambda}{s\mu}$$

The probability that a customer enters the service without waiting is given by

$1 - \rho$; ($n \geq C$)

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Major Findings

The performance of the selected petrol bunks was assessed using the M/M/c queuing model to capture variations in arrival rates, service rates, and customer waiting times. Table 1 presents the estimated parameters for each bunk, including the probability of idle time, traffic intensity, expected number of customers in the system and queue, as well as average waiting times. These measures provide a comparative view of operational efficiency, highlighting differences in how each station manages demand during peak hours.

Table 1 Queue Performance Measures of Petrol Bunks in Madurai District

Bunk	λ (cust/min)	μ (cust/min)	c	P_0	$\rho = \lambda/(c\mu)$	Ls	Lq	Wq (min)	Ws (min)
1	1.01	0.95	3	0.3403	0.3544	1.1211	0.05795	0.0574	1.1100
2	1.09	0.90	3	0.2906	0.4037	1.1551	0.06598	0.0606	1.1719
3	0.98	0.85	3	0.3094	0.3843	1.2331	0.08011	0.0817	1.2582
4	0.92	0.80	3	0.3103	0.3833	1.2293	0.07930	0.0862	1.3362

The empirical analysis employed the M/M/c queuing framework to evaluate customer waiting times at four petrol bunks in Madurai District. Key parameters estimated include the arrival rate (λ), service rate (μ), number of servers (c), probability of idle system (P_0), traffic intensity (ρ), the average number of customers in the system (Ls), the average number in queue (Lq), the mean waiting time in queue (Wq), and the total time spent in the system (Ws). The results provide critical insights into the operational dynamics of service delivery in petrol bunks.

Arrival and Service Dynamics

The analysis highlights significant variation in arrival and service rates across bunks. Bunk 2 reported the highest arrival intensity (λ = 1.09 customers/minute) combined with a comparatively low service rate (μ = 0.90 customers/minute), thereby exerting greater pressure on its service system. Conversely, Bunk 4 registered the lowest arrival rate (λ = 0.92 customers/minute) but also the lowest service efficiency (μ = 0.80 customers/minute). Despite receiving fewer vehicles, its service limitations resulted in outcomes comparable to more congested bunks. Across all four stations, arrival rates approached or exceeded service rates, suggesting a consistent risk of congestion during peak hours.

System Utilisation and Idle Probability

Traffic intensity values ranged between 0.3544 (Bunk 1) and 0.4037 (Bunk 2). These levels indicate that the facilities were not operating under extreme strain; however, they remained sufficiently burdened to generate persistent queues. The highest utilisation rate recorded at Bunk 2 illustrates its vulnerability to extended waiting times should demand increase further.

The probability of an idle system (P_0) was estimated between 0.29 and 0.34, implying that petrol bunks remained idle for nearly one-third of the observation period, even during peak demand. This counterintuitive outcome suggests inefficiencies in queue discipline and customer distribution across pumps, where some pumps remained underutilised while others accumulated queues.

Customers in Queue and System Occupancy

The expected number of customers within the system (Ls) varied marginally, ranging from 1.1211 in Bunk 1 to 1.2331 in Bunk 3. Similarly, the mean number of customers waiting in the queue (Lq) was highest in Bunk 3 (0.08011) and lowest in Bunk 1 (0.05795). Although the magnitude of these values appears small, they reflect operational inefficiencies that, over time, can influence throughput and customer perceptions of service quality. The consistently higher Lq values in Bunk 3 suggest that its service delivery was less efficient relative to the other stations.

Waiting Times in Queue and System

The findings demonstrate a clear relationship between service rate efficiency and waiting times. Bunk 1 recorded the lowest waiting time in queue (Wq = 0.0574 minutes, approximately 3.4 seconds) and the shortest total system time (Ws = 1.1100 minutes). In contrast, Bunk 4 exhibited the highest waiting and system times, with Wq = 0.0862 minutes (5.2 seconds) and Ws = 1.3362 minutes respectively. Although the numerical differences in Wq across bunks may appear marginal, they are operationally significant. Small increments in service time accumulate rapidly during congested periods, producing substantial delays and undermining customer satisfaction.

Comparative Efficiency of Petrol Bunks

A comparative evaluation reveals that Bunk 1 demonstrated the most efficient performance, as reflected in its lower utilisation rate, reduced queue length, and shorter system time. Bunk 2, despite higher demand, maintained moderate system performance, though it remains vulnerable to service bottlenecks under rising demand pressure. Bunk 3 consistently reported higher Ls, Lq, and Wq values, suggesting structural inefficiencies in managing arrivals. Bunk 4, despite experiencing relatively low arrival rates, recorded the longest system times due to service inefficiency, underscoring that slower service rates can be equally detrimental as excess demand.

Managerial Implications

The analysis offers several implications for management practice. First, improving service efficiency (μ) in Bunks 3 and 4 is imperative, as service rate inadequacy is the primary driver of longer waiting times. Second, the significant idle probability values highlight the need for optimised queue allocation mechanisms, ensuring that vehicles are distributed evenly across available pumps. Third, capacity augmentation during peak hours may be necessary for Bunk 2, either through temporary staff allocation or additional pumps. Finally, adopting technology-enabled queue management solutions, such as digital pump availability displays and real-time allocation systems, could mitigate idle capacity and improve customer flow.

CONCLUSION

The results confirm that waiting times in petrol bunks are shaped by the dual influence of arrival intensity and service efficiency. While absolute waiting times were short in duration, their cumulative effect during peak hours is non-trivial, with significant implications for customer satisfaction and service reliability. Among the four bunks, Bunk 1 emerged as the most efficient, while Bunks 3 and 4 require immediate operational improvements. The study demonstrates that application of the M/M/c model is not only analytically robust but also practically useful in diagnosing inefficiencies and recommending targeted interventions for service optimisation.

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