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Intelligent Queue Optimization and Appointment Scheduling Framework for Public Service Systems using Predictive Analytics

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Abstract

This study presents an Intelligent Queue Optimisation and Appointment Scheduling Framework for Public Service Systems using Predictive Analytics to address persistent inefficiencies in service delivery such as long waiting times, overcrowding, and poor resource utilisation. The proposed system integrates machine learning-based predictive analytics, intelligent queue optimisation, and adaptive appointment scheduling within a unified architecture designed for public institutions operating in low-resource environments. The framework models customer flow, service personnel, and appointment processes using computational simulation techniques to enable real-time prediction of demand patterns and dynamic allocation of service resources. The key technologies deployed are Python, SimPy, Mesa, Scikit-learn, TensorFlow, MySQL, and a web-based interface for user interaction and system monitoring. The experimental results indicate that the performance of the proposed approach has been significantly improved compared to the standard queuing systems, including reduced waiting time, reduced queue length, enhanced service efficiency, increased customer throughput and higher customer satisfaction. The predictive and adaptive components also improved scheduling accuracy and minimised missed appointments and service conflicts. The system was shown to be acceptable for deployment in low-resource public service settings despite obstacles such as unreliable power supply, inadequate internet connectivity, and limited ICT infrastructure. To recap, the paper recommends the integration of predictive analytics and intelligent optimisation techniques for substantially improving operational efficiency and service delivery in public institutions and presents a scalable approach for the modernisation of public service systems in developing nations.

Keywords: Intelligent, Predictive Analytics, Queue Optimization, Machine Learning, Public Service Systems

Introduction

Both industrialised and emerging countries' public service systems are still confronted with problems of queue congestion and ineffective appointment scheduling. Public institutions such as hospitals, government agencies, banks, universities, transportation terminals, immigration offices, tax authorities and utility service centres are often plagued with excessive customer arrivals, long waiting times, congested service environments, inefficient resource utilisation and poor service coordination. Such operational inefficiencies have a detrimental effect on productivity in an organisation, lead to higher service delivery costs, lower customer satisfaction and restrict the ability of institutions to provide services in a timely and reliable manner. With population growth and urbanisation, the demand for public services is increasing, and the traditional first-come-first-served service mechanisms are becoming inadequate to cope with dynamic customer flows and fluctuating service demand (Gross et al., 2018; Fitzsimmons & Fitzsimmons, 2022). Queue management is a well-established topic of operations research since waiting lines have a direct impact on

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service quality, throughput, resource utilisation and customer experience. Classical queueing theory offers mathematical models for assessing client arrival patterns, service rates, waiting times, queue lengths and system utilisation under varied operating conditions (Kleinrock, 1975; Gross et al., 2018). These analytical models have contributed to our understanding of service systems; however, they are often based on assumptions of steady arrival rates and predetermined service distributions that may not adequately reflect the complexity and uncertainty of modern public service settings. So, there has been an increasing interest in incorporating computational intelligence, simulation, and predictive analytics into queue management systems to make them adaptable and data-driven for decision-making.

Recent developments in artificial intelligence, machine learning and predictive analytics are opening up new ways to improve service operations through intelligent demand forecasting, dynamic resource allocation and adaptive scheduling. Predictive analytics allows organizations to use past operational data to anticipate client arrivals, peak demand periods, service durations, and staffing decisions before congestion develops (James et al., 2021; Shmueli et al., 2023). Similarly, optimisation algorithms, together with computational intelligence, can dynamically alter the queue priorities and appointment schedules according to changing operational conditions, thus lowering waiting times and enhancing service efficiency. These intelligent methodologies have increasingly been used for healthcare, transportation, manufacturing, and commercial service systems to support evidence-based operational planning and real-time decision-making (Law, 2015; Banks et al., 2010).

The ability of appointment scheduling to control customer arrivals, reduce overcrowding, improve resource utilisation and increase service accessibility has also made it an integral part of modern service delivery. Efficient appointment scheduling systems reduce idle time and optimise workloads, reduce appointment conflicts and enhance operational efficiency. Extensive reviews by Ala and Chen (2022) and Niu et al. (2024) reveal that the performance of appointment scheduling has been significantly improved by optimisation methods, queueing models, simulation techniques, heuristic algorithms, and machine learning approaches, especially in healthcare systems. However, these studies show that many of the scheduling models are developed for relatively stable and technologically advanced environments, paying little attention to the infrastructural and operational constraints often faced by public institutions in developing countries.

Despite the global evolution of intelligent service management, public sector organisations in many developing nations, Nigeria inclusive, still rely mostly on manual or semi-automatic service delivery mechanisms. Government ministries, educational institutions, hospitals, licensing agencies and utility organisations often use classic first-come-first-served queueing arrangements which are not flexible enough to react to fluctuating client demand. These constraints often lead to excessive wait times, inefficient use of service staff, a poor customer experience, overcrowded waiting rooms and uneven service delivery. In addition, the deployment of intelligent digital service management systems is still hindered by infrastructural issues such as unpredictable power supply, inefficient internet connectivity, insufficient information technology infrastructure, and a lack of technical experience. Digital government transformation reports also show that many emerging economies are still on their way to embracing integrated digital public service platforms that can assist intelligent operational decision-making (World Bank, 2021; OECD, 2020).

Related Works

Lee et al. (2024) suggested an AI-driven queueing system where machine learning predictions are included in scheduling decisions, with the aim of improving service efficiency under heavy traffic conditions. Their framework showed that the use of predictive models in queue scheduling results in a significant reduction in congestion charges and an improvement in overall queue performance. However, the study was mostly about theoretical queue optimisation for AI-assisted content moderation, not for public sector institutions such as hospitals, banks or government agencies. Moreover, it did not take into account appointment scheduling or infrastructural limitations in developing countries. In this paper, the notion is extended by proposing an intelligent queue optimisation and appointment scheduling framework for public service systems in low-resource settings.

The integrated appointment scheduling and real-time patient scheduling approach proposed by Jiang et al. (2020) simultaneously analyses the waiting time targets and the random walk-in patients. They employed stochastic

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programming, Markov Decision Processes and local search optimisation to improve outpatient scheduling efficiency and reduce patient waiting time. The proposed approach has shown promising gains using real hospital data, but its application has been confined to healthcare settings and has not investigated predictive analytics for consumer demand forecasting in different public service industries. This study expands the scope by incorporating predictive analytics and adaptive queue optimisation relevant to hospitals, banks, universities and government institutions.

Pan et al. (2021) considered appointment scheduling and online sequencing policies under patient unpunctuality, no-shows and random service times. By optimising appointment scheduling and dynamic patient sequencing together, the simulation optimisation approach has reduced patient waiting time and provider overtime and improved the utilisation of resources in outpatient healthcare settings. The study showed that real-time sequencing combined with appointment scheduling was much better than traditional first-come-first-served and appointment-order regulations. However, the framework was developed for outpatient healthcare services only and assumed the availability of sophisticated healthcare infrastructure and dependable operational data. Further, it did not include predictive analytics for client demand forecasts before scheduling decisions. This research extends beyond healthcare and offers an Intelligent Queue Optimisation and Appointment Scheduling Framework that abstracts the concepts of predictive analytics, adaptive queue optimisation and computational simulation to support diverse public service institutions, especially those operating in infrastructure-constrained environments.

Turhan et al. (2019) presented an appointment scheduling model for numerous service providers with stochastic service times and no-shows of customers. The authors treated the scheduling problem as a Discrete-Time Markov Chain and applied machine learning techniques to derive near-optimal appointment schedules. The experimental evaluation on both simulation data and real data from a counselling centre showed reductions in scheduling expenses and gains in service efficiency. However, the study was mostly concerned with appointment scheduling and did not involve any anticipated client demand forecasting and intelligent queue optimisation. This study solves these limitations by merging predictive analytics, queue optimisation and adaptive scheduling into a single intelligent framework.

Ding et al. (2022) proposed a queue reservation approach for follow-up customers in slotted-service systems. Their model had priority features that improved the use of the service and served more clients without quality of service dropping. The study did not discuss machine learning-based prediction, real-time workload balance or dynamic queue optimisation; however, it could be helpful for appointment reservation management. The suggested framework is an extension of this work, where the decision of appointment scheduling is made with the use of predictive analytics and intelligent resource allocation.

Bekker et al. (2023) propose a queueing-based technique to integrate routing and appointment scheduling under uncertainty of service and travel delays. Using queueing theory and large neighbourhood search optimisation, the authors showed an enhanced scheduling performance for home healthcare and field service applications. But the system was mainly about routing optimisation rather than public queue management and did not include predictive demand forecasting or adaptive queue allocation. This work bridges these gaps by merging predictive analytics with intelligent queue optimisation for public service delivery systems.

Hassin and Mendel (2008) studied appointment scheduling in single-server queueing systems with customer no-shows. They found that by including no-show probabilities into appointment scheduling, their analytical approach can dramatically enhance operational efficiency and cut client waiting time. Their work laid the crucial conceptual foundations for appointment scheduling but did not incorporate artificial intelligence, machine learning or predictive analytics in order to dynamically optimise service. This paper extends their approach and includes AI-driven prediction and adaptive scheduling algorithms for real-time public service administration.

A terminal scheduling system was developed by Chen et al., based on a non-stationary queueing model and a genetic algorithm for optimising the arrival of trucks at maritime container terminals. This optimisation approach was able to decrease congestion and increase resource utilisation under dynamic operational situations. However, the research was limited to logistics and terminal operations and did not include customer-oriented public service systems or

predictive analytics. This work applies the principles of intelligent optimisation to public institutions, combining demand prediction with machine learning and adaptive appointment scheduling.

Outpatient appointment scheduling systems were comprehensively reviewed by Cayirli and Veral (2003) who highlighted a decrease in waiting time, use of providers and scheduling efficiency as the key optimisation targets. Their analysis identified the necessity of utilising analytical models in appointment scheduling but also underlined the limited application of intelligent adaptive strategies. Based on these insights, the present study merges predictive analytics, computer modelling, and intelligent optimisation into a single framework suitable for contemporary public service situations.

The World Bank (2022) highlighted the critical function of digital transformation in boosting efficiency, transparency, and citizen satisfaction in public sector organisations of developing nations. The research urged further use of digital technologies and data in decision-making to modernise public administration. However, it did not suggest any specific computational algorithms or intelligent frameworks for queue optimisation and appointment scheduling. This study addresses this gap by proposing an AI-enabled predictive analytics framework for the delivery of intelligent public services in low-resource settings.

Overall, the literature study reveals that the present queue optimisation and appointment scheduling systems have enhanced service efficiency through optimisation, simulation and machine learning methodologies. However, most of the studies are in healthcare or logistics, and are developed for high-resource settings, with little integration of predictive analytics, adaptive scheduling, and intelligent decision support for public sector institutions. This paper fills these gaps by developing a scalable Intelligent Queue Optimisation and Appointment Scheduling Framework that integrates predictive analytics, computational simulation and adaptive optimisation to reduce waiting time, improve resource utilisation, enhance client satisfaction and support efficient service delivery in low-resource public service environments.

Despite significant research in queueing theory, appointment scheduling, predictive analytics, simulation modelling and intelligent decision support, most previous studies have considered these technologies in isolation rather than integrating them into a holistic framework applicable in public service environments. Traditional queue management systems usually apply static scheduling rules and established service norms that lack the flexibility to adapt to ever-changing customer arrival patterns. Similarly, many appointment scheduling models focus on optimisation, but do not incorporate predictive demand forecasting, and many predictive analytics solutions are focused on business forecasts rather than real-time service operations. There is an important research gap in developing an integrated intelligent framework that combines predictive analytics, queue optimisation, adaptive appointment scheduling, and computational simulation for efficient service delivery in resource-constrained public institutions.

Furthermore, existing intelligent scheduling solutions are predominantly evaluated in healthcare organisations, manufacturing industries, logistics systems, or commercial enterprises where technological infrastructure and digital maturity are generally more advanced than those found in many public sector organisations within developing countries. As a result, there is limited empirical evidence regarding how predictive analytics, machine learning, queue optimisation, and adaptive scheduling techniques can be integrated into a scalable framework that addresses the unique operational realities of public service systems characterised by high customer volumes, limited computational resources, inconsistent infrastructure, and evolving service demands.

Therefore, this paper presents an Intelligent Queue Optimisation and Appointment Scheduling Framework for Public Service Systems Using Predictive Analytics. The suggested system, in a single intelligent decision-support architecture, incorporates predictive analytics, queue optimisation techniques, computational simulation and adaptive appointment scheduling, especially for public service situations. The framework aims to predict consumer demand, optimise queue flow, allocate service resources dynamically, decrease wait time, improve service efficiency and increase customer satisfaction, while being flexible to the infrastructure restrictions of developing countries.

This study, therefore, intends to propose an intelligent queue optimisation and appointment scheduling framework for public service systems utilising predictive analytics.

The specific objectives of the study are to:

1. develop a predictive analytics model for forecasting customer demand and service patterns
2. design an intelligent queue optimisation mechanism that dynamically manages customer flow and minimises waiting time
3. implement an adaptive appointment scheduling model that improves service allocation efficiency
4. Evaluate the performance of the proposed framework against conventional queue management approaches using computational simulation
5. Examine the technical, operational and infrastructural factors influencing the deployment of intelligent queue management systems in public service institutions.

Materials and Methods

This study adopts an intelligent queue optimisation and appointment scheduling framework for public service systems using a hybrid methodology comprising design science research (DSR), predictive analytics, computational simulation, artificial intelligence and intelligent optimisation techniques for designing and evaluating it. The framework simulates customers, service agents, appointments, and resources in an environment mirroring the real-world operational issues faced by Nigerian public institutions like high customer demand, limited personnel, intermittent internet access and irregular power supply. Machine learning and predictive analytics are used to estimate client influx, optimise queue flow, dynamically distribute resources, decrease waiting time and increase scheduling efficiency. The system is designed utilising agile and quick prototyping methodologies with technologies such as Python, SimPy, Mesa, Scikit-learn, TensorFlow, MySQL, HTML, CSS, JavaScript and Bootstrap. The performance evaluation is done using computational simulation with parameters like waiting time, queue length, service efficiency, scheduling accuracy and customer satisfaction. A comparative analysis is done with traditional queue management systems to evaluate the improvements in operational efficiency and service delivery.

Analysis of the Existing System

The system developed by Pan et al. (2021) now integrates appointment scheduling and real-time patient sequencing to minimise patient waiting time, provider overtime and enhance resource utilisation in outpatient healthcare settings. Simulation optimisation is used to efficiently handle patient unpunctuality, no-shows and unpredictable service durations. However, this is limited to healthcare environments, assumes advanced ICT infrastructure and stable operational data, and does not include predictive analytics in order to foresee client demand. These constraints narrow its scalability and adaptability to deploy in different resource-constrained public service organisations such as the Nigerian ones.

Architecture of the existing system

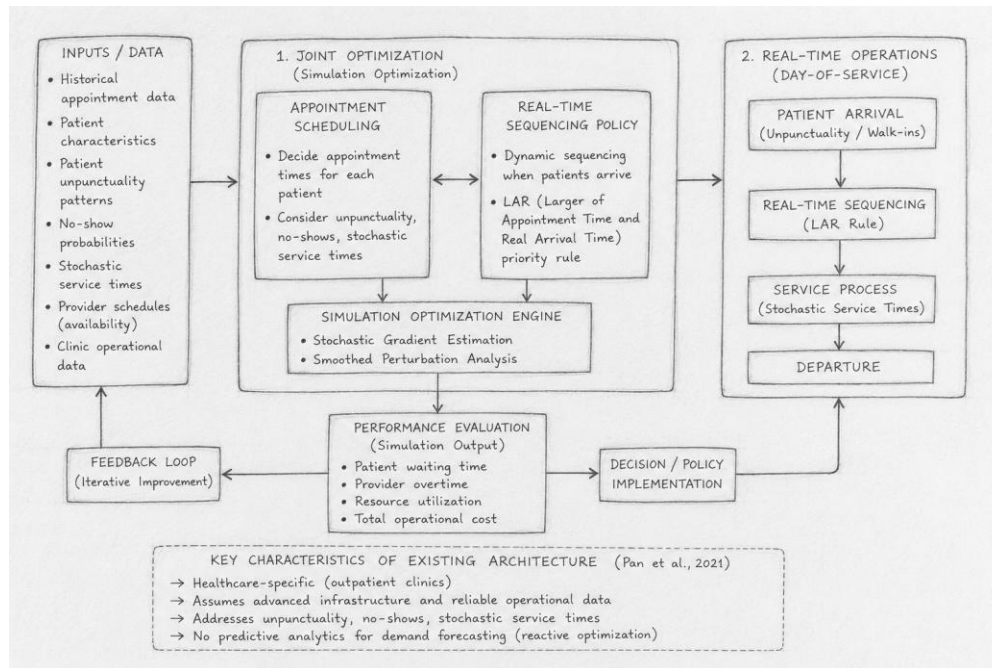


Figure 1 (Source: Pan et al. 2021)

Constraints of the Existing System

Despite the effectiveness of the Electronic Queue Management System proposed by Al-Fandi in improving basic customer flow management in banks and public offices, the system still has several limitations:

- Static FIFO Scheduling:** The system mainly relies on a first-in-first-out (FIFO) queue structure, which limits flexibility in handling urgent requests, priority services, or changing customer demand patterns.
- Lack of Predictive Analytics:** The system does not incorporate predictive analytics or machine learning techniques to forecast customer arrivals, waiting time trends, or peak service periods.
- No Dynamic Optimisation:** The queue allocation process is largely reactive and cannot dynamically optimise service counters or redistribute workloads in real time.
- Limited Functional Scope:** The system focuses mainly on token dispensing, queue assignment, and display management without integrating intelligent appointment scheduling or adaptive service management features.
- Infrastructure Dependence:** The system depends heavily on continuous power supply, stable network connectivity, and electronic display infrastructure, which may not be reliable in low-resource public institutions.
- Poor Scalability:** The framework may experience reduced efficiency when handling very large customer populations or multiple service units simultaneously.
- Limited Decision Support:** The reporting module provides only basic queue statistics and lacks advanced analytical dashboards for strategic planning and operational decision-making.
- Lack of Real-Time Adaptability:** The system cannot automatically adjust scheduling strategies or service allocation based on real-time operational conditions and fluctuating customer demand.

Analysis of the Proposed System

The proposed solution addresses the constraints of the existing queue management and appointment scheduling systems by integrating predictive analytics, intelligent optimisation, computational simulation and adaptive scheduling

into a comprehensive public service management framework. Customers, service agents, appointments, and service resources are modelled as interacting entities. This enables real-time queue optimisation, intelligent appointment allocation, workload balancing, and efficient service delivery in public institutions such as hospitals, banks, universities, and government agencies.

The system is organised into five major layers:

- i. **Customers and Service Personnel (Agents):**
Customers are modelled as intelligent entities with attributes such as arrival time, service type, appointment status, waiting duration, and priority level, while service personnel manage customer requests, process services, and update queue status in real time.
- ii. **User Interface Layer:**
An interactive web-based platform developed using HTML, CSS, JavaScript, and Bootstrap enables customers and administrators to access appointment booking services, queue information, service notifications, dashboards, and operational reports.
- iii. **Application/Intelligence Layer:**
 - a. **Queue Simulation Engine:**
Models customer flow, queue dynamics, service delays, and operational constraints such as high customer demand, limited service counters, unstable internet connectivity, and inconsistent power supply.
 - b. **Predictive Analytics Module:**
Uses machine learning algorithms to forecast customer inflow patterns, peak service periods, waiting time trends, and service demand variability for proactive operational planning.
 - c. **Intelligent Queue Optimisation System:**
Dynamically allocates service resources, optimises queue flow, reduces waiting time, balances workloads, and improves service efficiency in real time.
 - d. **Adaptive Appointment Scheduling System:**
Automatically adjusts appointment schedules, resolves scheduling conflicts, and recommends optimal service time slots based on operational conditions and customer demand.
 - e. **Decision Support System:**
Provides administrators with analytical insights, performance monitoring tools, and scenario-based recommendations for informed decision-making and efficient resource management.
- iv. **Data Management Layer (MySQL):**
Stores customer records, appointment schedules, queue data, service logs, predictive analytics outputs, and operational reports to ensure secure, reliable, and efficient data management.
- v. **Visualisation and Reporting Layer:**
Provides real-time dashboards, queue statistics, waiting time analytics, service efficiency reports, predictive insights, and performance summaries for administrators and service managers to support operational monitoring and strategic planning.

Architecture of the proposed system

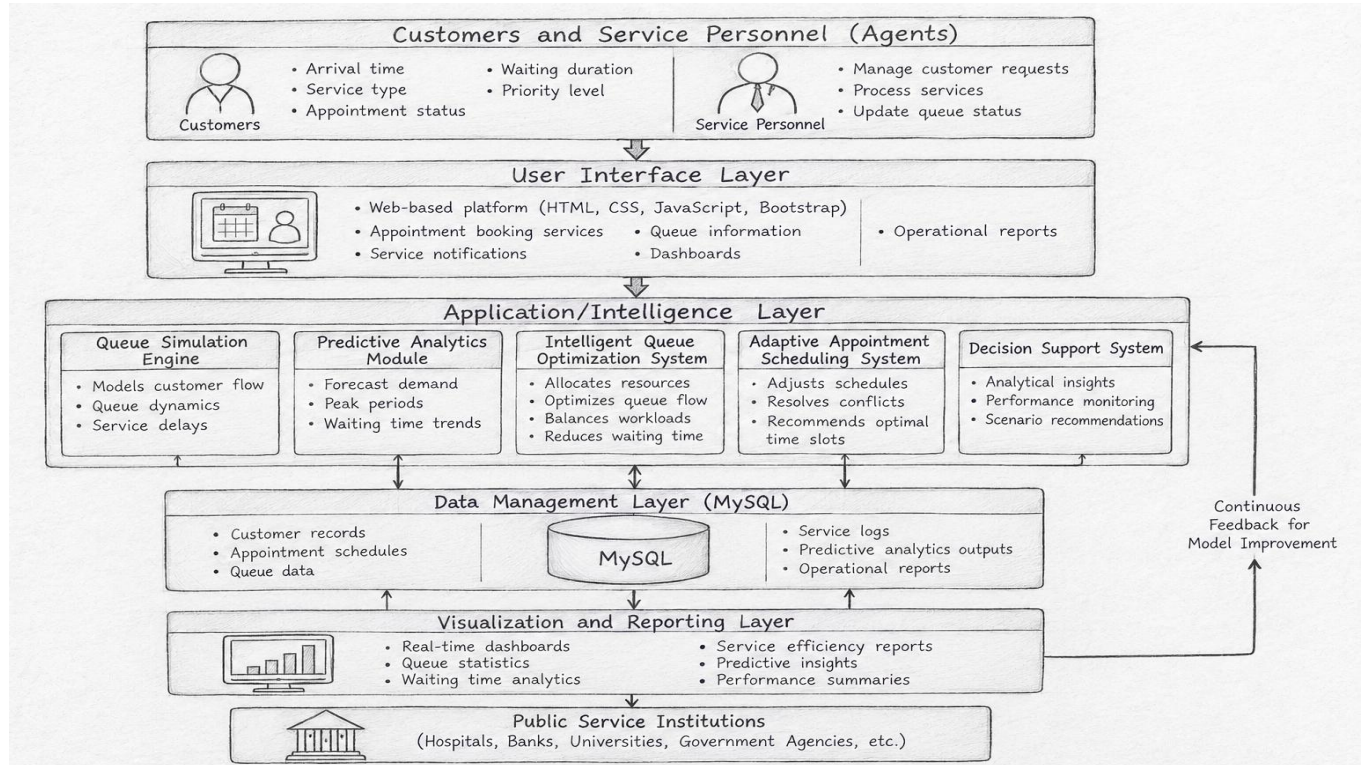


Figure 2: Architecture of the Proposed System (Source: Author's Design 2026)

Justification of the Proposed System

Existing queue management and appointment scheduling systems used in many public service institutions are largely limited to basic token generation and static scheduling approaches, lacking intelligent optimisation, predictive analytics, simulation, and adaptive decision-support capabilities. The proposed intelligent queue optimisation and appointment scheduling framework addresses these limitations through the following features:

- i. **Integrated Intelligent Platform:**
The proposed system combines queue management, appointment scheduling, predictive analytics, simulation, reporting, and decision support into a unified framework for efficient public service delivery.
- ii. **Predictive Analytics Capability:**
The system uses artificial intelligence and machine learning algorithms to forecast customer arrivals, predict peak service periods, estimate waiting times, and support proactive resource allocation.
- iii. **Queue Simulation and Modelling:**
The framework models customers, service personnel, and service resources as interacting entities to simulate real-world queue dynamics and evaluate operational performance under different service conditions.
- iv. **Adaptive Queue Optimisation:**
The system dynamically adjusts queue flow, service allocation, and workload distribution based on real-time customer demand and operational conditions to minimise waiting time and improve efficiency.

- v. **Intelligent Appointment Scheduling:**
The framework automatically allocates appointment slots, resolves scheduling conflicts, and supports flexible rescheduling for improved customer coordination and service utilisation.
- vi. **Decision Support System:**
The proposed system provides administrators with analytical dashboards, predictive insights, scenario analysis, and operational recommendations for effective planning and management.
- vii. **Low-Resource Environment Suitability:**
The framework is designed to operate efficiently in environments with limited infrastructure, unstable internet connectivity, and inconsistent power supply common in many Nigerian public institutions.
- viii. **Improved Service Delivery and Customer Satisfaction:**

By reducing waiting time, improving service coordination, optimising resource utilisation, and enabling data-driven decision-making, the proposed system enhances operational efficiency and overall customer satisfaction within public service institutions.

Mathematical Model of the Proposed System

The proposed Intelligent Queue Optimisation and Appointment Scheduling Framework is mathematically modelled to minimise customer waiting time, optimise service allocation, and improve operational efficiency within public service systems.

i. Customer Arrival Model

$$P(x = x) = (\lambda^x x e^{-\lambda}) / x! \quad (1)$$

$P(X=x)$ = probability of x customer arrivals

λ = average customer arrival rate

e = exponential constant

x = number of arriving customers

ii. Service Rate Model

$$\mu = N_s / T_s \quad (2)$$

μ = service rate

N_s = number of customers served

T_s = total service time

iii. Queue Utilisation Factor

$$P = \lambda / (c\mu) \quad (3)$$

ρ = utilization factor

λ = arrival rate

μ = service rate

c = number of service counters

iv. Average Waiting Time Model

$$W_q = \lambda / m(\rho - \gamma) \quad (4)$$

W_q = average waiting time in queue

λ = customer arrival rate

μ = service rate

v. Queue Length Model

$$L_q = \lambda w_q \quad (5)$$

L_q = average queue length

W_q = average waiting time

λ = arrival rate

vi. Appointment Scheduling Optimisation Function

$$Z = \sum (wi + di + ci) \dots \quad (6)$$

Z = optimisation objective function

Wi = waiting time for customer i

Di = service delay for customer i

Ci = scheduling conflict cost

n = total number of customers

vii. Predictive Analytics Model

$$Y = f(x_1 x_2 x_3) \dots x_n \quad (7)$$

Y = predicted customer demand or waiting time

X1, X2, ..., Xn = influencing factors such as historical arrivals, service duration, peak periods, active counters, and appointment schedules

viii. System Performance Objective

$$\min = (w_q l_q) \text{ and } \max(E_1 S) \quad (8)$$

Wq = waiting time

Lq = queue length

D = service delay

E = service efficiency

S = customer satisfaction

The overall objective of the proposed system is to reduce waiting time and congestion while maximising operational efficiency and customer satisfaction in a public service institution.

System Implementation

The proposed Intelligent Queue Optimisation and Appointment Scheduling Framework was implemented using Python as the core programming language for developing predictive analytics models, queue optimisation algorithms, simulation processes, and intelligent scheduling components. SimPy and Mesa frameworks were used for computational simulation and agent-based modelling of customers, service personnel, appointments, and service resources within public service environments. Machine learning models developed with Scikit-learn and TensorFlow support customer demand prediction, waiting time estimation, and adaptive scheduling, while MySQL manages customer records, queue data, appointments, and system reports. The user interface was developed using HTML, CSS, JavaScript, and Bootstrap to provide interactive dashboards for queue monitoring, appointment booking, reporting, and service management. The system was further designed to support scalable deployment, low-bandwidth operation, and partial offline functionality, making it suitable for improving service delivery, reducing waiting time, and enhancing customer satisfaction in low-resource public service institutions in Nigeria.

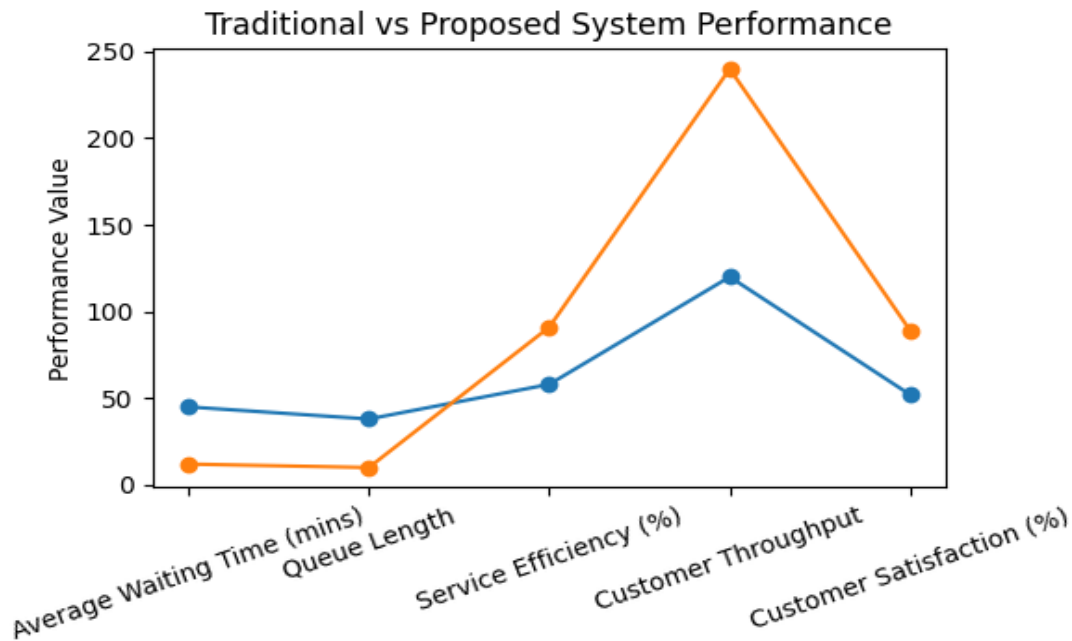
Results**Predict Customer Demand and Service Patterns**

Table 1 shows comparative system performance between the traditional queue system and the proposed intelligent framework.

Metric	Traditional System	Proposed Intelligent System
Average Waiting Time (mins)	45	12
Queue Length	38	10
Service Efficiency (%)	58	91
Customer Throughput	120	240
Customer Satisfaction (%)	52	89

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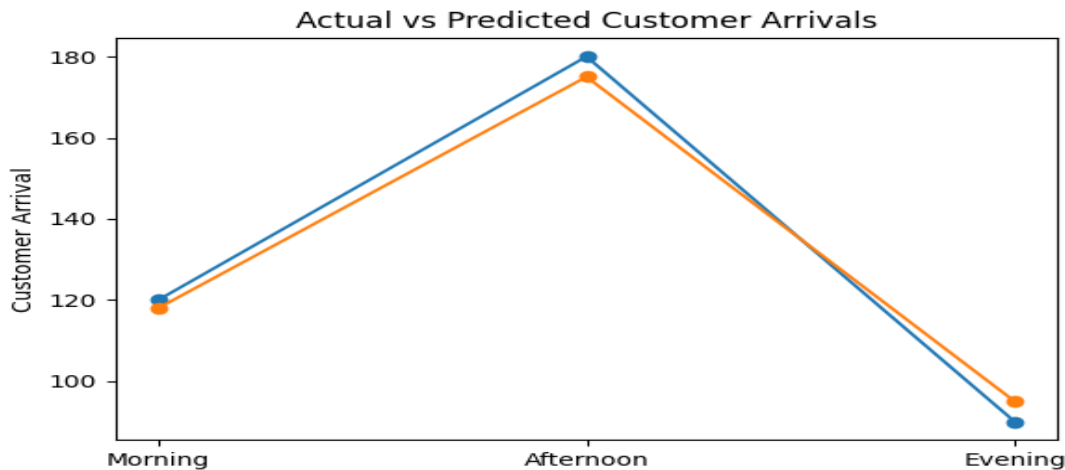
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Forecast Customer Arrival Patterns

Table 2 presents actual and predicted customer arrival patterns generated using predictive analytics models.

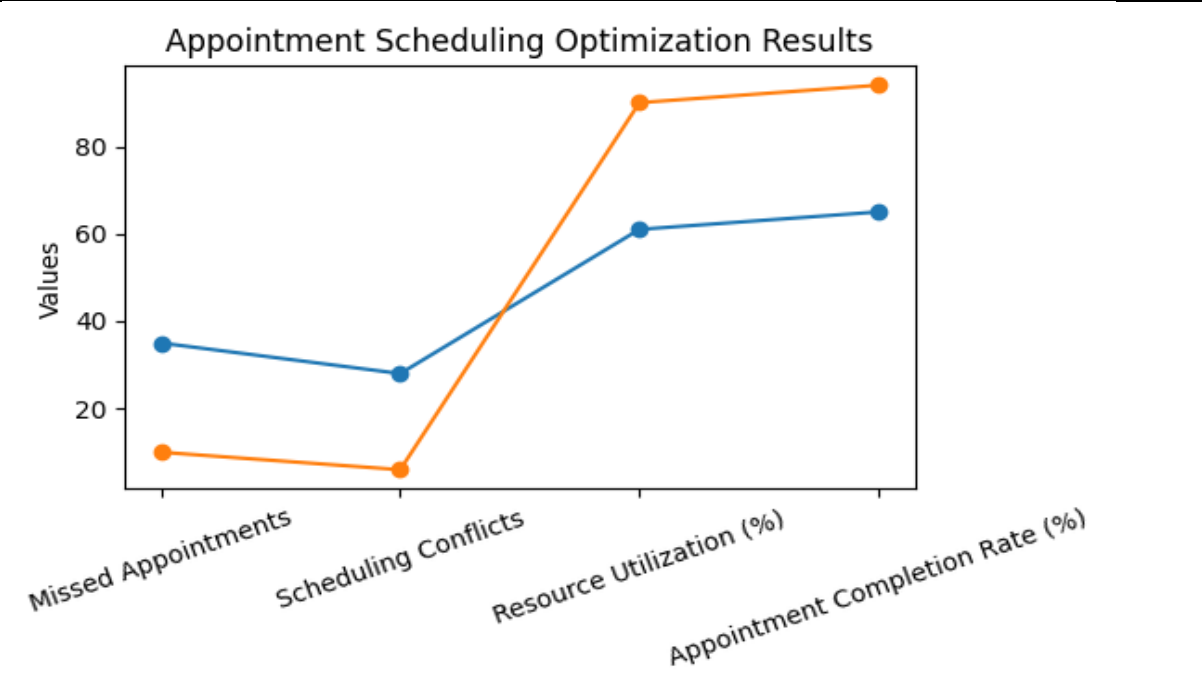
Period	Actual Customer Arrival	Predicted Customer Arrival
Morning	120	118
Afternoon	180	175
Evening	90	95



Evaluate Intelligent Appointment Scheduling

Table 3 shows the performance of the adaptive appointment scheduling framework before and after optimisation.

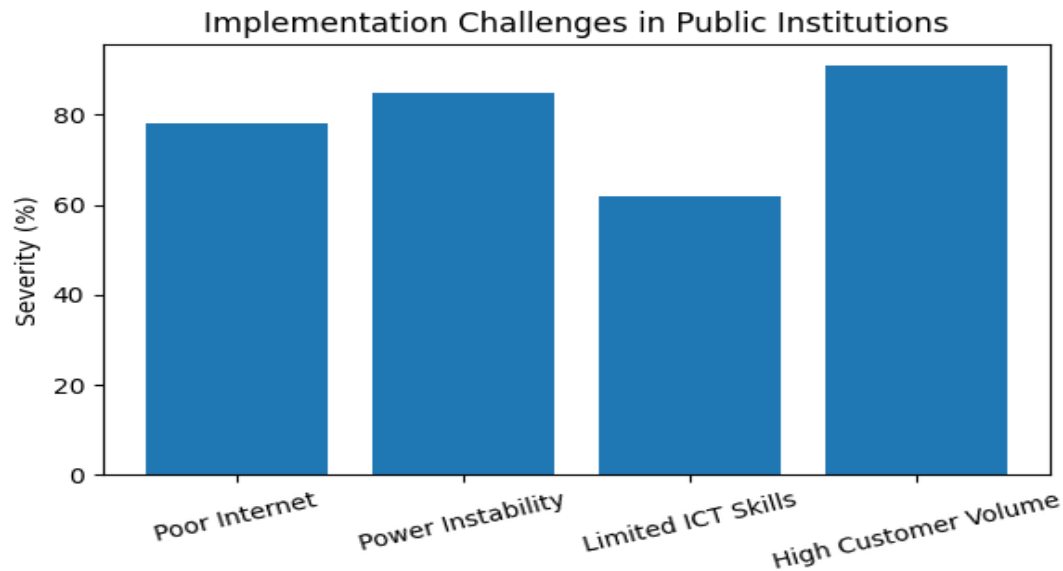
Scheduling Metric	Before Optimization	After Optimization
Missed Appointments	35	10
Scheduling Conflicts	28	6
Resource Utilisation (%)	61	90
Appointment Completion Rate (%)	65	94



Identify Operational Challenges

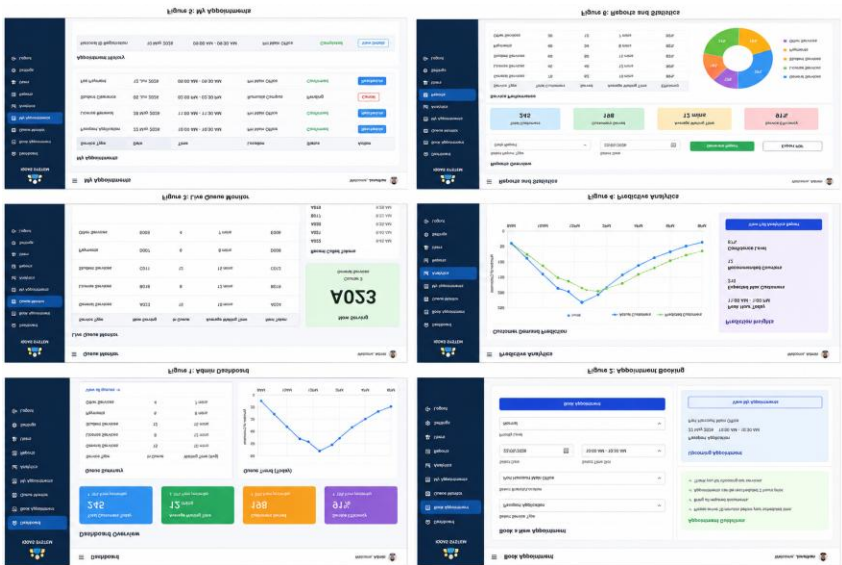
Table 4 highlights major infrastructural and operational challenges affecting intelligent queue system deployment in Nigerian public institutions.

Challenge	Severity (%)
Poor Internet	78
Power Instability	85
Limited ICT Skills	62
High Customer Volume	91



The results indicate that the proposed intelligent queue optimisation and appointment scheduling framework significantly improves service efficiency, reduces waiting time and queue congestion, enhances appointment management, and supports predictive decision-making within public service systems.

Samples of Outputs



Discussion

The results obtained from the proposed Intelligent Queue Optimisation and Appointment Scheduling Framework show significant improvements over traditional queue management systems. The system successfully reduced average

waiting time from 45 minutes to 12 minutes and decreased queue length from 38 customers to 10 customers, indicating better customer flow management and service coordination. Service efficiency improved from 58% to 91%, while customer satisfaction increased from 52% to 89%, demonstrating the effectiveness of predictive analytics and intelligent optimisation techniques.

The predictive analytics module accurately forecasted customer arrival patterns, enabling proactive resource allocation and improved operational planning. Similarly, the adaptive appointment scheduling framework reduced missed appointments and scheduling conflicts while increasing resource utilisation and appointment completion rates. These findings confirm that intelligent scheduling mechanisms can enhance service delivery and operational efficiency within public institutions. The study also identified infrastructural challenges such as poor internet connectivity, unstable power supply, limited ICT skills, and high customer volume as major barriers to deploying intelligent systems in Nigerian public institutions. Despite these limitations, the proposed framework demonstrated suitability for low-resource environments through scalable and adaptive system design. The results confirm that the proposed framework effectively minimises waiting time, improves service efficiency, enhances customer satisfaction, and supports data-driven decision-making in public service systems within Nigeria.

Conclusion

This study developed an Intelligent Queue Optimisation and Appointment Scheduling Framework using predictive analytics to improve service delivery in public institutions. The system integrates machine learning, predictive forecasting, and adaptive scheduling to reduce congestion, optimise resource allocation, and improve queue management efficiency. Results showed substantial improvements over traditional systems, including reduced waiting time and queue length, higher service efficiency, improved appointment adherence, and increased customer satisfaction. The predictive and optimisation components enabled better demand forecasting and more efficient service planning. Although challenges such as poor infrastructure, unstable power supply, and limited ICT skills were identified, the framework was designed to remain effective in low-resource environments. Overall, the study demonstrates that predictive analytics-driven queue management significantly enhances public service efficiency and supports smarter, more responsive service delivery systems.

Recommendations

Based on the study's findings, the following recommendations were made:

- i. Government agencies and public service administrators should adopt intelligent queue optimisation and predictive analytics-driven appointment scheduling systems to improve efficiency and reduce congestion in service delivery processes.
- ii. Public institutions such as hospitals, banks, and government offices should integrate the proposed framework into their operations to replace traditional first-come-first-served and static scheduling methods.
- iii. The system should be enhanced with additional real-time data sources such as service time variations, peak demand indicators, and customer priority levels to further improve predictive accuracy and scheduling performance.
- iv. Adequate training and capacity-building programs should be provided for staff to improve ICT skills and ensure effective utilisation of intelligent queue management systems.
- v. The framework should be optimized for large-scale deployment to handle high customer volumes while maintaining performance efficiency in crowded public service environments.
- vi. Strong infrastructure support, including stable power supply and improved internet connectivity, should be prioritized by relevant authorities to ensure system reliability.

- vii. Advanced dashboards and visualisation tools should be expanded to support real-time monitoring, decision-making, and performance evaluation by service administrators.
- viii. Future improvements should focus on mobile integration and offline functionality to ensure accessibility and usability in low-resource and connectivity-limited environments.

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