INTELLIGENT METHODS AND TOOLS FOR PATIENT QUEUE MANAGEMENT IN HEALTHCARE SYSTEMS

Fotima Toshbadalovna Egamberdieva
Master's student at the University of Information Technologies and Management

Abstract: *The growing demand for healthcare services causes long waiting times, uneven staff workload, and inefficient resource use. This study proposes an artificial intelligence–based patient queue management framework using machine learning and data-driven decisions. Simulation results show reduced waiting times, improved resource utilization, and higher service efficiency, demonstrating the system's importance for digital healthcare transformation and sustainable operational performance globally today.*

Keywords: *healthcare system, patient queue management, intelligent systems, artificial intelligence, machine learning, workload optimization, digital healthcare.*

INTRODUCTION

Healthcare systems worldwide are experiencing rapid growth in service demand due to population increase, aging societies, and the rising prevalence of chronic diseases. These factors have intensified pressure on healthcare institutions, resulting in long patient queues, overloaded medical staff, and reduced service quality. Efficient patient queue management has therefore become a critical issue for healthcare administrators and policymakers.

Conventional queue management systems are typically based on fixed schedules, first-come-first-served principles, or manual prioritization. Such approaches are limited in their ability to respond to real-time fluctuations in patient arrivals, emergency cases, and resource availability. Consequently, they often lead to suboptimal decision-making and inefficiencies in healthcare delivery.

Recent advances in artificial intelligence and data analytics provide new opportunities to address these challenges. Intelligent methods enable predictive analysis, adaptive decision-making, and automation of complex management processes. This study aims to develop and evaluate intelligent methods and tools for patient queue management in healthcare systems, focusing on improving efficiency, adaptability, and service quality.

METHODS

The research methodology combines system analysis, intelligent modeling, and experimental evaluation to develop and validate an intelligent patient queue management system for healthcare institutions. The overall methodological framework is designed to address the dynamic and stochastic nature of patient arrivals, service processes, and resource availability within healthcare systems. The study follows a structured, multi-stage approach to ensure methodological rigor and reproducibility.

The first stage focuses on the analysis of patient flow characteristics and service processes in healthcare institutions. This includes examining patient arrival patterns, service pathways, and interaction points within outpatient departments, diagnostic units, and specialized medical services. Patient flow data are characterized by high variability due to factors such as time of day, type of medical service, emergency cases, and seasonal effects. System analysis techniques are applied to identify bottlenecks, service delays, and inefficiencies in existing queue management practices. This stage provides a conceptual understanding of how queues are formed and how operational constraints affect service performance.

The second stage involves the identification and formalization of key factors influencing queue formation and system performance. These factors include patient arrival rates, service time distributions, priority levels (e.g., emergency versus non-emergency cases), availability of medical staff, and capacity constraints of medical equipment and facilities. Both deterministic and stochastic elements are considered to reflect real-world healthcare conditions. The identified factors are represented as system variables and parameters, forming the basis for subsequent intelligent modeling. This step ensures that the proposed system accurately captures the complexity and interdependencies inherent in healthcare service delivery.

In the third stage, an intelligent queue management model is developed using artificial intelligence and machine learning techniques. The proposed model integrates predictive analytics with adaptive decision-making mechanisms. Machine learning algorithms are employed to forecast patient arrivals and service demand in real time based on historical data and current operational conditions. These predictive models enable the system to anticipate workload fluctuations and proactively adjust queue management strategies. In addition, decision rules for prioritization and resource allocation are embedded within the model to support dynamic scheduling of medical staff and services. The intelligent model is designed to be adaptive, allowing it to learn from new data and continuously refine its predictions and decisions over time.

The fourth stage focuses on the experimental evaluation of the proposed intelligent system. A simulation-based environment is used to replicate healthcare service processes under various workload scenarios, including normal operation, peak demand periods, and emergency situations. Simulation experiments allow for controlled comparison between the intelligent queue management system and conventional queue management approaches, such as first-come-first-served and static scheduling. Key performance indicators include average patient waiting time, resource utilization rates, service throughput, and system stability. Statistical analysis is applied to assess performance differences and validate the effectiveness of the proposed approach.

Throughout the methodology, the intelligent system operates in a closed feedback loop, continuously collecting real-time data, updating predictive models, and refining decision-making strategies. This self-improving mechanism ensures robustness and adaptability in dynamic healthcare environments. The methodological framework not only supports performance optimization but also provides a scalable foundation for integration into real-world healthcare information systems. As a result, the proposed methods offer a comprehensive and practical approach to intelligent patient queue management in modern healthcare systems.

RESULTS

The proposed intelligent queue management system was evaluated using a simulation-based experimental setup designed to reflect realistic operational conditions in healthcare institutions. Multiple workload scenarios were generated to assess system behavior under varying levels of demand and resource availability. These scenarios included (i) normal operating conditions with moderate patient arrivals, (ii) peak-demand periods characterized by high arrival rates and increased service requests, and (iii) stress-test conditions that incorporated emergency cases, temporary staff shortages, and limited capacity of diagnostic equipment. The results were compared against conventional queue management baselines, such as first-come-first-served (FCFS) and static appointment scheduling models.

Waiting Time Reduction

Across all simulated scenarios, the intelligent system consistently reduced average patient waiting time compared to traditional methods. Under normal workload conditions, the predictive component of the system enabled proactive scheduling and prevented queue accumulation by forecasting short-term patient inflow. During peak-demand periods, the adaptive prioritization mechanism dynamically re-ranked patients based on urgency, predicted service duration, and current queue states, which reduced prolonged delays for high-priority cases. Importantly, the reduction in waiting time was not limited to urgent cases; non-emergency patients also benefited from smoother flow and less congestion due to improved resource distribution and bottleneck prevention.

Improved Resource Utilization

The intelligent approach increased utilization efficiency for both medical personnel and infrastructure resources (e.g., consultation rooms, diagnostic units, and equipment). Traditional systems often produce uneven workload distribution—some staff become overloaded while others remain underutilized due to rigid scheduling or lack of real-time coordination. In contrast, the proposed system continuously monitored operational indicators (queue length, service rate, and available capacity) and redistributed tasks accordingly. As a result, idle time for key resources was reduced, and staff allocation became more balanced across service points. The simulation results also indicated that equipment usage became more consistent, minimizing periods of underuse while avoiding excessive overload that can cause delays or service interruptions.

Stability Under Stress and Emergency Conditions

A major advantage of the proposed system was its operational stability under extreme and unpredictable conditions. In stress-test simulations with sudden surges of patient arrivals or emergency incidents, traditional queue management models showed sharp increases in waiting times and a tendency toward bottleneck formation at critical service nodes. By contrast, the intelligent system maintained stable performance by rapidly adjusting priorities and rerouting patient flow toward available service capacity. Even when resources were constrained—such as during a simulated temporary reduction in staff availability—the adaptive decision rules allowed the system to preserve throughput and prevent queue collapse. This indicates that the proposed framework is resilient and can support continuity of healthcare services during high-pressure situations.

Bottleneck Minimization and Workflow Balance

Detailed analysis of simulation logs demonstrated that the intelligent system effectively minimized bottlenecks by identifying congestion points early and applying corrective actions. For example, when diagnostic services became overloaded, the system adjusted upstream scheduling by temporarily slowing referrals, reallocating staff, or redirecting patients to alternative service channels where possible. This created a smoother distribution of patient flow across the entire healthcare process. Consequently, the system improved overall workflow balance, reduced queue oscillations (rapid growth and sudden drops), and enabled more predictable service delivery.

Overall Operational Efficiency

Collectively, the experimental results confirm that the intelligent queue management system enhances operational efficiency in healthcare institutions by reducing waiting times, improving resource utilization, and ensuring stable service performance across different workload conditions. The results also indicate that intelligent queue management is not merely an incremental improvement but a structural enhancement to healthcare operations, supporting real-time decision-making and adaptive optimization. These outcomes underscore the practical value of the proposed approach for healthcare institutions seeking to improve patient satisfaction, reduce operational stress, and strengthen service resilience in the context of increasing demand and limited resources.

DISCUSSION

The findings highlight the advantages of applying intelligent methods to patient queue management in healthcare systems. By leveraging real-time data and predictive analytics, the proposed system enables proactive decision-making and flexible resource management. This contributes to improved service quality and patient satisfaction while reducing operational stress on healthcare personnel.

However, successful implementation of intelligent queue management systems requires careful consideration of data quality, system integration, and information security. Additionally, healthcare staff must be adequately trained to interact with intelligent tools and interpret system recommendations.

CONCLUSION

This study demonstrates that intelligent methods and tools provide an effective solution for patient queue management in healthcare systems. The proposed approach enhances service efficiency, optimizes resource utilization, and reduces patient waiting times. Intelligent queue management systems represent a key component of digital healthcare transformation and offer significant potential for improving the sustainability and resilience of healthcare services. Future research will focus on real-world implementation and integration with electronic health record systems and hospital information platforms.

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