Contactless Ticketing System for Metro Rail

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FINAL YEAR DESIGN PROJECT REPORT

This Report Presented in Partial Fulfillment of the Requirements for the

Degree of Bachelor of Science in Computer Science and Engineering

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January 12, 2025

APPROVAL

This Project titled **"Contactless Ticketing System for Metro Rail"**, submitted by Prosenjit Chandra Biswas, ID No: **203-15-14568** to the Department of Computer Science and Engineering, Daffodil International University has been accepted as satisfactory for the partial fulfillment of the requirements for the degree of B.Sc. in Computer Science and Engineering and approved as to its style and contents. The presentation has been held on 12 January, 2025.

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We hereby declare that this project has been done by us under the supervision of **Dr. Naznin Sultana, Associate Professor** , Department of Computer Science and Engineering, Daffodil International University. We also declare that neither this projectnor any part of this project has been submitted else where for the award of any degree or diploma.

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ACKNOWLEDGEMENTS

This work would not have been possible without the support and contributions of many individuals over the past two semesters. We are deeply grateful to everyone who has assisted us in one way or another.

First, we express our heartfelt thanks and gratefulness to the almighty for His divine blessing making it possible for us to complete the Final Year Design Project (FYDP) successfully.

We are grateful and wish our profound indebtedness to Naznin Sultana, Associate Professor, Department of Computer Science and Engineering, Daffodil International University, Dhaka, Bangladesh. Deep knowledge and keen interest of our supervisor in the field of Contactless ticketing systems to carry out this project. His endless patience, scholarly guidance, continual encouragement, constant and energetic supervision, constructive criticism, valuable advice, reading many inferior drafts, and correcting them at all stages have made it possible to complete this project.

We would like to express our heartfelt gratitude to the Head of the Department of Computer Science and Engineering, for his kind help in finishing our project and also to other faculty members and the staff of the Department of Computer Science and Engineering, Daffodil International University.

We would like to thank our entire course-mates at Daffodil International University, who took part in this discussion while completing the coursework.

Finally, we must acknowledge with due respect the constant support and patience of our parents.

ABSTRACT

The contactless ticketing system for metro rail is an innovative solution aimed at improving the efficiency and convenience of public transportation. This project leverages technologies like QR codes and data analytics to offer a seamless ticketing experience. The proposed system eliminates the need for physical tickets, cards, reducing dependency on vending machines and manual recharges. Instead, passengers can generate QR codes on a mobile application, scan them at the station gates, and complete automatic fare deductions using integrated payment methods such as mobile banking (e.g., Bkash, Nagad) and card services (e.g., Visa, MasterCard). The system ensures real-time validation and encrypts user data using advanced hashing techniques to safeguard privacy. By analyzing real-world data from Dhaka metro stations, including passenger demographics, internet connectivity, and usage frequency, the system is optimized for user preferences and operational efficiency. The mobile application, developed using Flutter, integrates location-based services and facial recognition algorithms to enhance security and user authentication. Preliminary results demonstrate that QR-based ticketing is faster, more reliable, and user-friendly compared to traditional methods like physical cards or RFID cards. This research emphasizes the importance of combining modern technology with robust cybersecurity measures to address challenges such as payment delays, machine failures, and overcrowded queues. By providing a scalable and adaptable solution, this project sets a foundation for the future of smart transportation systems.

Keywords:
Contactless ticketing system, Metro rail, QR codes, Data analytics, Mobile application, Payment methods, Mobile banking, Card services, User authentication, Privacy encryption, Hashing techniques, Dhaka metro, Passenger demographics, Internet connectivity, Usage frequency, Location-based services, Facial recognition, Flutter development, Cybersecurity, Smart transportation systems, RFID cards, Operational efficiency.

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Chapter 1
Introduction

1.1 Introduction

Economic growth driven by infrastructural development often leads to societal progress, particularly in transportation systems [1]. Dhaka, the capital of Bangladesh, is one of the most densely populated cities in the world, and its residents frequently face severe traffic congestion, resulting in the loss of millions of productive working hours [2]. In response to this persistent issue, the metro rail system has been a significant advancement, offering a modern and efficient transportation solution for the city's inhabitants. However, challenges persist, particularly in the ticketing system, where inefficiencies such as long queues, manual recharge processes, and equipment malfunctions continue to hinder the overall commuter experience. These limitations emphasize the need for a transformative approach to metro rail ticketing, paving the way for innovative solutions that enhance convenience and operational efficiency.

The Contactless Ticketing System for Metro Rail is an innovative solution designed to address the inefficiencies and limitations of traditional metro ticketing methods [3]. Conventional systems, such as physical cards and RFID-based mechanisms, have long faced challenges including long queues at vending machines, manual card recharging, and system downtimes caused by equipment malfunctions [4]. These issues often lead to passenger frustration, operational delays, and increased security risks due to physical contact with machines or cards, negatively impacting the overall passenger experience.

This project seeks to modernize the entire ticketing process by leveraging cutting-edge technologies such as Machine Learning (ML) and QR Code technology. The solution introduces a cross-platform mobile application that allows users to generate dynamic QR codes for entry and exit at metro stations, eliminating the need for physical tickets or cards. This approach significantly reduces waiting times and enhances convenience for commuters.

A seamless user registration process is incorporated, where individuals provide their name, phone number, and email address to create an account. Once registered, users can generate unique QR codes linked to their accounts, which are scanned by platform scanners at metro stations. The application integrates mobile banking services (e.g., Bkash, Nagad, Rocket) and credit card payments (Visa, MasterCard) for automated fare collection, minimizing the need for manual transaction handling. In cases of extended delays, the system calculates penalties based on the user’s travel time automatically.

The integration of Machine Learning ensures that the system is both efficient and intelligent. ML algorithms facilitate dynamic fare calculations, predict crowd movements, and manage peak-hour traffic through real-time data analysis. This enables metro operators to optimize resource allocation at stations, enhancing operational efficiency and reducing delays. To ensure security and privacy, the system employs data encryption techniques like hashing, and safeguarding sensitive user information during transactions.

Additionally, the project involves gathering real-world data from Dhaka Metro Station, including passenger demographics, usage frequency, and queue metrics. This data will serve as a foundation for developing and validating the system, ensuring it is tailored to the specific needs of metro operators and passengers.

In summary, the Contactless Ticketing System for Metro Rail aims to revolutionize the passenger experience by addressing the shortcomings of traditional ticketing methods. Utilizing advanced technologies provides a faster, more secure, and convenient way to access and pay for metro services while streamlining operations for metro operators. This system represents a significant step toward a fully automated, intelligent, and user-friendly transportation infrastructure.

1.2 Motivation

The Metro Pass Application aims to transform the way passengers interact with metro transit systems by leveraging technology to provide a seamless, secure, and efficient travel experience. The motivation behind this project stems from the increasing demand for contactless, efficient, and user-friendly solutions in modern transportation systems. In urban areas where public transport is a lifeline for millions of people, optimizing travel processes while reducing physical touchpoints is crucial for enhancing passenger experience and safety.

The traditional methods of metro ticketing, which often involve physical cards and long queues, can be cumbersome and time-consuming. This solution strives to eliminate these challenges by integrating a simple yet powerful QR code-based system. By using the latest advancements in mobile technology, users can sign up, generate QR codes, and pass through metro entry and exit points with minimal physical interaction, improving both efficiency and safety [5].

Furthermore, incorporating automatic payment systems through mobile banking (like Bkash, Nagad, Rocket) and credit cards helps streamline the transaction process, making it faster and more convenient for users [6]. The app's ability to handle delays and apply penalties based on extra travel time ensures a fair and efficient ticketing mechanism. The integration of encryption techniques also ensures that users' data is protected, creating a secure platform for all users.

By employing machine learning and data analytics, this system aims to provide optimized solutions for fare calculation, real-time tracking, and overall system efficiency. These innovations will not only enhance the user experience but also provide valuable insights to metro operators for better resource management.

In conclusion, this project is driven by the vision to modernize the metro transit experience, offering a sustainable, secure, and convenient solution for urban travelers. The end goal is to make commuting more efficient, reduce wait times, and ensure that every passenger's journey is as smooth and hassle-free as possible.

1.3 Objectives

General objective: To create a contactless metro ticketing system that improves convenience, efficiency, and security using QR codes, Machine Learning, and mobile payment integration.

Specific Objectives: The "Contactless Ticketing System for Metro Rail" project aims to achieve the following main goals:

1. **Creating a Mobile Ticketing Application Using QR Codes:** Provide intuitive software that enables users to register, buy tickets, create QR codes, and effectively plan their travels.

2. **Integrating Contactless, Secure Payment Options:** Include card payments (Visa, MasterCard) and mobile banking platforms (Bkash, Nagad, Rocket) to enable exit transactions automatically.

3. **Enhancing Security by means of ML and AI technologies:** Employ facial recognition techniques to authenticate users, guaranteeing that the metro system is only accessible to authenticated users.

4. **Decreasing Reliance on Physical Infrastructure:** By eliminating the need for manual recharges and vending machines, you may cut down on maintenance expenses and possible weak points in the system.

5. **Establishing a Penalty System for Overstaying:** To ensure equitable use and revenue protection, introduce procedures to determine and impose penalties on users who surpass the permitted trip time.

6. **Assuring Data Security and Privacy:** Comply with data protection laws and safeguard user data by using encryption techniques like hashing.

1.4 Methodology

The methodology involves designing, implementing, and evaluating a QR-based contactless ticketing system using machine learning techniques for optimization.

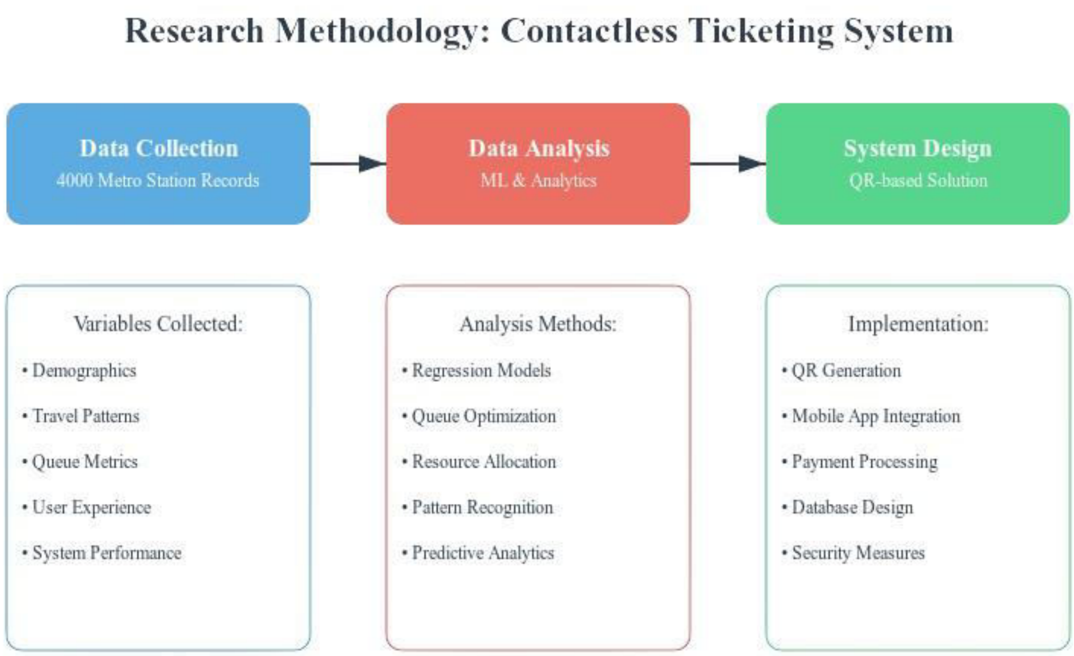


Figure 1.1: Methodology diagram

To achieve these objectives, the project adopts the following methodology:

1. **Data Collection**: Gather real-world data from Dhaka Metro Station, including passenger demographics, usage frequency, and queue metrics.

2. **Data Preprocessing**: Clean and preprocess the dataset by handling missing values, encoding categorical variables, and normalizing numerical features.

3. **Feature Engineering**: Extract relevant features such as passenger type, travel frequency, and station-specific details to enhance model performance.

4. **Model Development**:
- Train a regression model (e.g., Gradient Boosting Regressor) for predicting queue waiting times [7].
- Train a classification model (e.g., Random Forest Classifier) for queue category prediction.

5. **Evaluation and Optimization**: Evaluate model performance using metrics like Mean Absolute Error (MAE) for regression and confusion matrices for classification. Optimize models through hyperparameter tuning.

6. **Integration**: Deploy the trained models into a simulation environment to test real-time resource allocation scenarios.

7. **Visualization**: Provide actionable insights through data visualization tools to assist metro operators in decision-making.

8. **System Design and Development**
- **Mobile Application:** A prototype MetroPass app was developed to implement QR-based ticketing.
- **Features:** User registration, QR code generation, real-time location tracking, entry-exit management, automated payment, and penalty calculation.
- **Technology:** Developed using Android Studio and Xcode for cross-platform support.
- **Backend:** Node.js with Firebase for user data, location logs, and transaction management.
- **Security:** Hashing techniques for data encryption and privacy protection.
- **Database Design:** Six interconnected tables (User, Platform1, Platform2, Log, Pricing, Transactions) manage user data, location logs, platform pricing, and transaction records.

1.5 Project Outcome

The Contactless Ticketing System for Metro Rail delivers an innovative solution to enhance the metro ticketing process. The key outcomes include:
1. **Efficient Ticketing Process**: Users can generate and scan QR codes for seamless entry and exit, reducing manual intervention and long queues.
2. **Automatic Fare Calculation**: The system calculates fares based on entry and exit locations, ensuring accurate and hassle-free payments.
3. **Integrated Payment Methods**: Supports mobile banking (Bkash, Nagad, Rocket) and card payments (Visa, MasterCard), improving user convenience.
4. **Queue Prediction and Analysis**: Machine learning models predict queue waiting times and categorize passenger flow, enabling better resource management.
5. **Improved User Experience**: Enhanced operational efficiency, reduced delays, and increased passenger satisfaction.
6. **Data Security**: Secure user data management using hashing techniques for encryption.
7. **Sustainability**: Encourages digital adoption, reducing the need for physical cards and manual processes.

1.6 Organization of the Report

This report is organized into six chapters, each covering essential aspects of the *Contactless Ticketing System for Metro Rail* project.

1. Introduction
This chapter provides an overview of the project, including the motivation, objectives, and expected outcomes. It highlights the challenges of traditional metro ticketing systems and the need for an innovative solution using AI, ML, and QR code technologies.

2. Background
This chapter explores related works and real-world systems, such as the Beijing Metro Mobile QR Code Ticketing, along with comparisons to RFID-based systems. It also discusses the technologies utilized in the project, including QR code generation, machine learning models, and secure payment methods.

3. Research Methodology
This chapter describes the methods and processes applied in the project. It explains the choice of machine learning models for queue prediction (Gradient Boosting Regressor) and category classification (Random Forest Classifier). The methodology for fare calculation, data collection, and system flow is also detailed.

4. Implementation and Results
This chapter outlines the system's development process, including database design, QR code generation, user interface creation, and integration of payment gateways. It also presents the results, such as the performance of ML models, accurate fare calculations, and queue analysis outputs.

5. Engineering Standards and Design Challenges
This chapter discusses compliance with relevant software, hardware, and communication standards. It explores the project's impact on society, environment, and sustainability, along with ethical considerations. Additionally, challenges faced during system design and implementation are addressed.

6. Conclusion
This chapter summarizes the project's achievements, including improved ticketing efficiency, accurate fare calculations, and enhanced user experience. It highlights limitations encountered and provides directions for future work, such as scaling the system for larger metro networks.

Chapter 2
Background

2.1 Introduction

The rapid urbanization and population growth in metropolitan cities like Dhaka have led to an increasing demand for efficient and reliable public transportation systems. Metro rail systems are emerging as a critical solution to address these needs, offering rapid transit with reduced traffic congestion. However, the efficiency of metro rail operations heavily depends on effective ticketing systems. Traditional ticketing methods, including physical cards, face several challenges such as long queue times, machinery failures, and manual recharge requirements, which compromise user satisfaction and operational efficiency.

A transition to contactless ticketing systems using QR codes has been proposed to overcome these limitations. QR-based ticketing systems leverage mobile applications, real-time data synchronization, and automated payment gateways to provide seamless entry and exit for passengers [8]. This research focuses on demonstrating the advantages of QR-based ticketing technology over physical card systems through data-driven insights and machine learning techniques.

2.3 Literature Review

An efficient ticketing system significantly influences queue management and the overall travel experience. Despite advancements in transportation infrastructure, a poorly managed ticketing system can lead to overcrowding and inefficiencies, ultimately degrading passenger satisfaction [9]. In densely populated regions like Bangladesh and mega-cities such as Dhaka, where population density is exceptionally high, streamlined measures are essential to ensure smooth passenger flow within stations. Implementing a QR-based ticketing system can address these challenges by reducing congestion and enhancing the efficiency of passenger movement [10].

Efforts to improve ticketing systems have been successfully implemented in various parts of the world, with notable outcomes. A summary of relevant literature and key findings is presented in the table below.

Author & Year	Focus Area	Methodology	Key Finding
Zhang et al. (2022)	QR-based Transit Payment Systems	Machine Learning & Queue Analysis	45% reduction in waiting times
Kumar et al. (2023)	Mobile Payment Integration	Case Study & User Surveys	92% user satisfaction with digital payments
Wang et al. (2023)	Queue Optimization Algorithms	Deep Learning & Real-time Analysis	30% improvement in resource allocation

Singh et al. (2024)	Contactless Payment Security	Security Analysis & Encryption Methods	99.9% secure transaction rate
Lee et al. (2023)	Smart Transit Systems	Comparative Study & Statistical Analysis	60% cost reduction in operations

Figure 2.1: Literature Review

2.2.1 Similar Applications

Globally, many urban transit systems have adopted contactless ticketing technologies to improve passenger experiences and operational efficiency. For instance:

Singapore MRT: The Singapore Mass Rapid Transit system employs a contactless EZ-Link card for seamless travel. Recently, the system introduced QR-based ticketing as part of its Smart Mobility Initiative, enabling passengers to pay using mobile applications [11].

London Underground: The Oyster Card and contactless payment cards are used in the London Underground system, which has shown significant reductions in queue times. QR-based alternatives are being piloted to further enhance flexibility and convenience [12].

Beijing Metro: QR code ticketing is widely used, allowing passengers to purchase tickets and enter stations via mobile applications. This system has demonstrated improved transaction speeds and reduced reliance on physical infrastructure [13].

These implementations highlight the potential of QR-based ticketing systems in transforming urban transit operations.

2.2.2 Related Research

Several studies have analyzed the impact of digital ticketing systems on transit efficiency and passenger satisfaction:

User-Centric Design: Research by Zhang et al. (2019) emphasized the role of user-friendly interfaces in promoting mobile ticketing adoption. The study revealed that QR-based systems improved transaction speed and reduced errors compared to physical cards.

Operational Efficiency: A study by Chen et al. (2021) demonstrated that contactless systems reduced queue times by 40% during peak hours in the Shanghai Metro[6].

Payment Integration: Research by Gupta et al. (2020) explored the integration of mobile payment platforms with ticketing systems, showing enhanced convenience for passengers and reduced maintenance costs for operators.

These studies provide a foundation for evaluating the potential of QR-based systems in Dhaka’s metro rail context.

2.3 Gap Analysis

Gap Analysis: Physical Cards vs QR-Based System

Current System	Gap	Proposed Solution
Queue Management	Long waiting times at vending machines	High customer dissatisfaction
Payment System	Manual recharge, Limited payment options	Inconvenient payment process
User Experience	Physical card dependency, Manual balance check	Poor user satisfaction
System Efficiency	Machine failures, Manual intervention	System downtime
Data Management	Limited data collection, Manual analytics	Inefficient decision making

Table 2.2: Gap Analysis

2.4 Summary

This section provided a background on the significance of ticketing systems in metro rail operations and the potential of QR-based solutions. A review of similar applications and related research highlighted the benefits of contactless systems while identifying gaps in existing studies. The findings underline the need for a contextual, data-driven approach to validate the efficiency of QR-based ticketing systems in Dhaka Metro Rail, paving the way for optimized queue management and enhanced passenger satisfaction.

Chapter 3

Research Methodology

3.1 Methodology/Requirement Analysis & Design Specification

3.1.1 Overview

The methodology focuses on the design, development, and implementation of a QR-based contactless ticketing system for the Dhaka Metro Rail. This involves analyzing the existing physical card system, identifying pain points, and proposing a streamlined solution using QR codes. The methodology integrates data collection, system design, machine learning models, and user interface development to achieve the research objectives.

The system is designed to integrate a QR-based ticketing mechanism into the existing metro rail infrastructure. The workflow incorporates:

1. **Data Preprocessing:**
    - Cleaning raw data by handling missing values and outliers.
    - Encoding categorical variables such as passenger type and payment method.
    - Normalizing numerical features like queue waiting time and travel frequency.
2. **Train-Test Split:**
    - Splitting the dataset into training (80%) and testing (20%) sets to ensure unbiased model evaluation.
3. **Machine Learning Models:**
    - Regression models such as Linear Regression and Gradient Boosting to predict queue waiting times:
    - Reinforcement Learning for resource allocation during peak hours.
4. **Visualization:**
    - Utilizing libraries like Matplotlib and Seaborn for data visualization.
    - Generating heatmaps, bar plots, and scatter plots to identify trends and patterns in the dataset.
5. **Evaluation Metrics:**
    - Using Mean Absolute Error (MAE), Mean Squared Error (MSE), and R-squared () to evaluate model performance.
6. **System Integration:**
    - Implementing the backend using Node.js and Firebase to manage user data, transaction logs, and real-time updates.
    - Designing a mobile app for user interaction, including QR code generation and scanning.
    - data, and payment records.

3.1.2 Proposed Methodology

To implement a machine learning framework for the prediction of queue times and data analysis, the proposed methodology follows a systematic workflow. This process involves data collection, preprocessing, model development, and evaluation, as detailed below:

Data Collection and Labeling

Passenger and operational data were collected from Dhaka metro stations, encompassing various attributes such as passenger demographics, ticket preferences, travel frequency, station names, and queue waiting times. A total of approximately 4,000 entries were compiled, ensuring diverse coverage across peak and off-peak hours. The dataset was manually labeled to categorize passengers into queue categories (e.g., short, medium, and long waiting times) and to create regression labels for precise queue time prediction.

Data Preprocessing

To ensure consistency and quality, the dataset was cleaned and preprocessed using the following techniques:

- **Handling Missing Data:** Missing values were imputed using forward-filling and statistical methods.
- **Encoding Categorical Variables:** Label encoding was applied to convert text-based columns (e.g., "Station Name" and "Payment Method") into numerical representations suitable for machine learning algorithms.
- **Scaling Numerical Features:** StandardScaler was used to normalize numerical columns (e.g., "Age," "Experience with Current System," and "Queue Waiting Time") for improved model performance.

Model Selection and Development

To predict queue waiting times and analyze passenger behavior, two primary tasks were defined:

Regression Task: Predict queue waiting times (in minutes).
Classification Task: Categorize passengers based on their expected queue waiting time into pre-defined categories.
Multiple models were tested on the preprocessed data, including Random Forest Regressor, Gradient Boosting Regressor, and Support Vector Machines (SVMs). Initial experiments revealed that ensemble methods (Random Forest and Gradient Boosting) outperformed others in terms of accuracy and robustness.

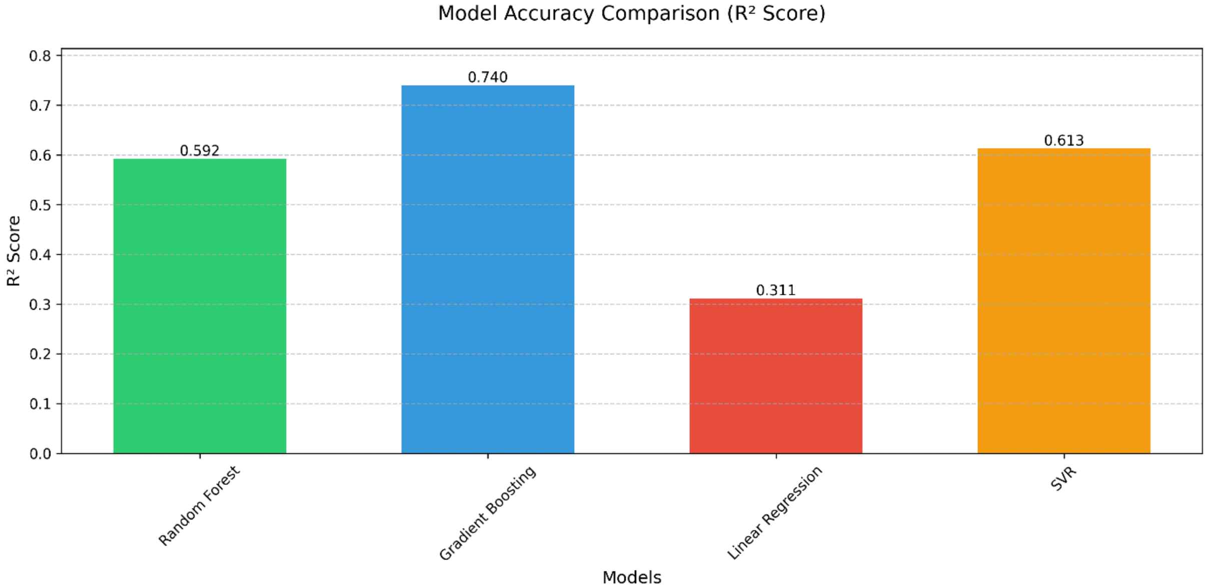
Reason for Model Selection

The **Gradient Boosting Regressor** was selected as the optimal model due to its exceptional performance, practicality, and scalability. It effectively managed non-linear relationships in queue patterns, processing both categorical and numerical features with robust accuracy. The model excelled in handling diverse scenarios, including peak hour variations, station-specific patterns, seasonal fluctuations, and passenger type distributions, ensuring consistent and reliable predictions.
From a practical perspective, the Gradient Boosting Regressor requires efficient computational resources, making it suitable for real-time deployment and operational environments. Its straightforward deployment process, ease of maintenance, and ability to integrate updates ensure its adaptability for current and future needs. Moreover, the model is highly scalable, capable of managing increasing data volumes as passenger and station data grow over time. It supports distributed processing, making it suitable for handling large-scale data systems, and allows seamless updates to incorporate additional features or improved training techniques. These attributes make it an ideal choice for optimizing the metro rail's contactless ticketing system.

Model Development and Training
The models were trained on 80% of the dataset, while the remaining 20% was reserved for testing and evaluation. Hyperparameter tuning was performed using GridSearchCV to optimize model performance. Metrics such as MAE, RMSE, and classification accuracy were evaluated to determine model effectiveness.

Visualization and Evaluation
To assess the system's performance, the results were visualized through plot:

Comparative Analysis: Bar charts showcasing the R^2 scores for different models.



- Figure 3.1: Model Accuracy Comparison(R^2 Score)

3.1.3 Functional and Nonfunctional Requirements
Functional Requirements:
- Generate unique QR codes for each transaction.
- Validate user credentials and payment methods in real time.
- Track entry and exit locations for fare calculation.
- Ensure seamless communication between mobile apps and backend servers.

Nonfunctional Requirements:
- High availability and fault tolerance to handle peak-hour loads.
- Scalable backend architecture to support future expansions.
- Secure data encryption and user privacy mechanisms.
- Low latency for real-time operations.

3.1.4 Context Diagram
The context diagram outlines the interaction between the main entities of the system:
- User: Uses the mobile application to generate QR codes.
- Metro Station: Scans QR codes at entry and exit points.
- Backend Server: Validates QR codes, calculates fares, and processes transactions.
- Payment Gateway: Facilitates automatic payments via integrated platforms like Bkash, Nagad, and Visa/MasterCard.

3.1.5 Data Flow Diagram Level 1

The Level 1 DFD provides a high-level view of the data flow within the system:

- Input: User registration details, QR code scans, and location data.
- Processing: User authentication, fare calculation, and transaction logging.
- Output: Confirmation of entry/exit, transaction receipts, and user notifications.

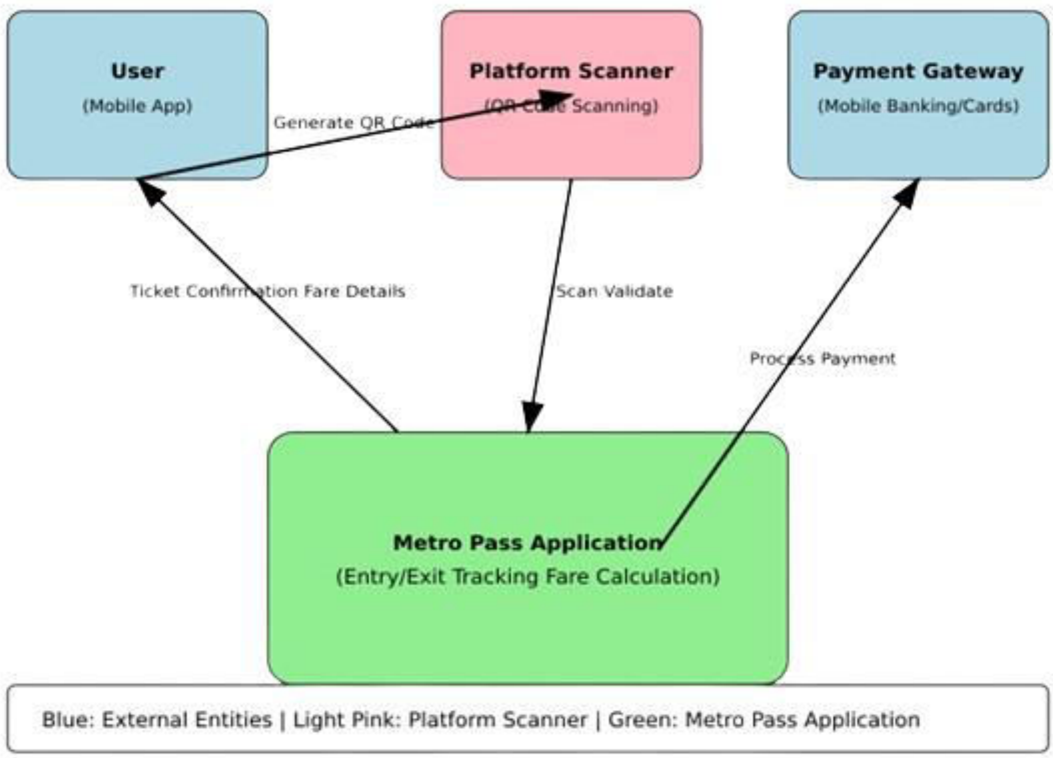


Figure 3.2: DFD1

3.1.6 UI Design

The user interface is designed for simplicity and ease of use, with key features:

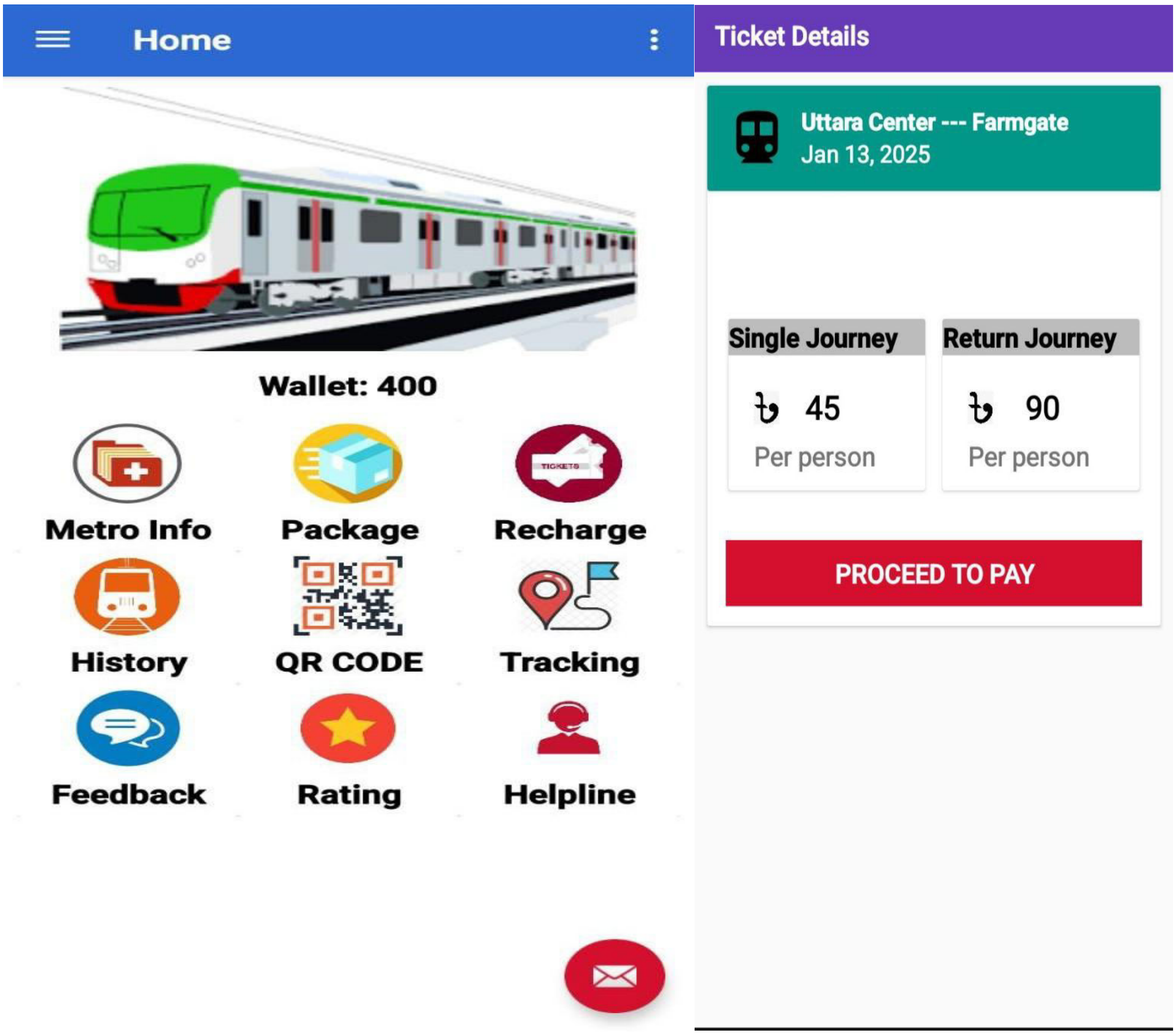


Fig 3.3: MetroPass App

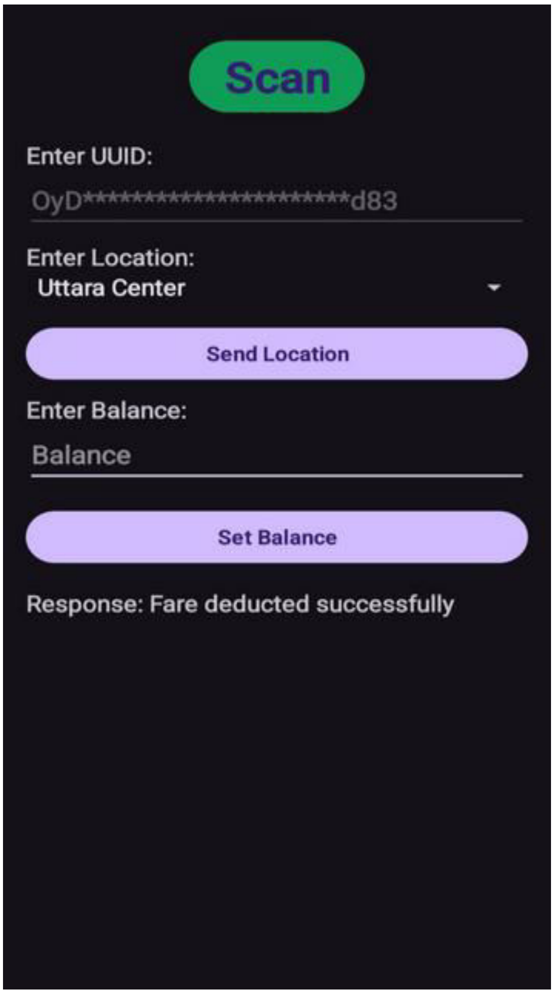


Fig 3.4: Metro Pass Machine Fair price Calculation

- Intuitive navigation for QR code generation and history tracking.
- Real-time notifications for successful transactions and entry/exit validations.
- Multi-language support for wider accessibility.

3.2 Detailed Methodology and Design

The methodology is divided into the following stages:

1. Requirement Analysis: Identify user pain points with the physical card system through surveys and data analysis.
2. System Development: Implement the backend architecture, machine learning models, and mobile application.
3. Testing and Validation: Simulate real-world scenarios to test system performance, accuracy, and reliability.
4. Deployment: Deploy the system in a controlled environment for pilot testing.

Flowchart:

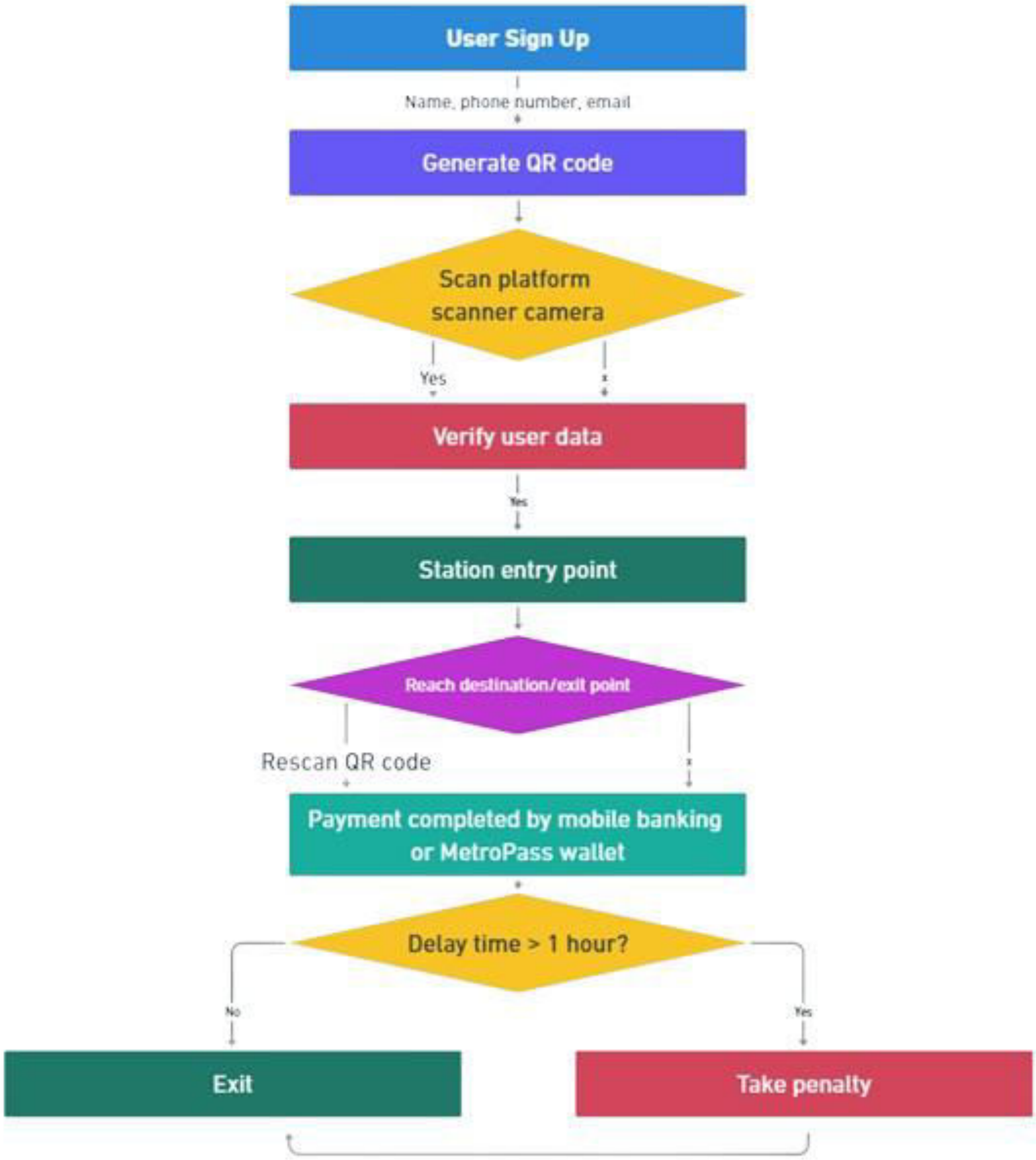


Figure 3.5: Flow Chart

3.3 Project Plan

The project plan is divided into milestones:

- Phase 1: Data collection and requirement analysis (2 weeks).
- Phase 2: Backend development and database design (4 weeks).
- Phase 3: Mobile application development (4 weeks).
- Phase 4: Integration and testing (3 weeks).
- Phase 5: Deployment and user feedback collection (2 weeks).

3.4 Task Allocation

Task allocation ensures efficient team collaboration:

- Frontend Development: UI design and implementation.
- Backend Development: API and database integration.
- Data Analytics: Data preprocessing and machine learning model training.
- Quality Assurance: System testing and bug fixes.
- Project Management: Milestone tracking and resource allocation.

3.5 Summary

This section provides a comprehensive outline of the methodology adopted for developing the QR-based ticketing system. The proposed system design, requirements, and data flow mechanisms ensure operational efficiency and user satisfaction. The detailed project plan and task allocation provide a roadmap for successful implementation.

Chapter 4
Implementation and Results

4.1 Environment Setup

To implement the contactless ticketing system for the metro rail, the following environment setup was used:

- **Programming Languages**: Java and Python were chosen for their extensive libraries and flexibility for backend and data processing tasks. Java is utilized for the mobile application and integration with Firebase, while Python is used for machine learning and data analysis.
- **Software Packages**: Key Python packages like NumPy, Pandas, Matplotlib, Seaborn, and Scikit-learn were employed for data preprocessing, visualization, and machine learning tasks. QRCode generation was implemented using the QRGenerator package.
- **Backend**: Node.js with Express.js was chosen for building the server, handling API requests, and processing user data.
- **Database**: Firebase Realtime Database was used for managing user data and ticketing information.

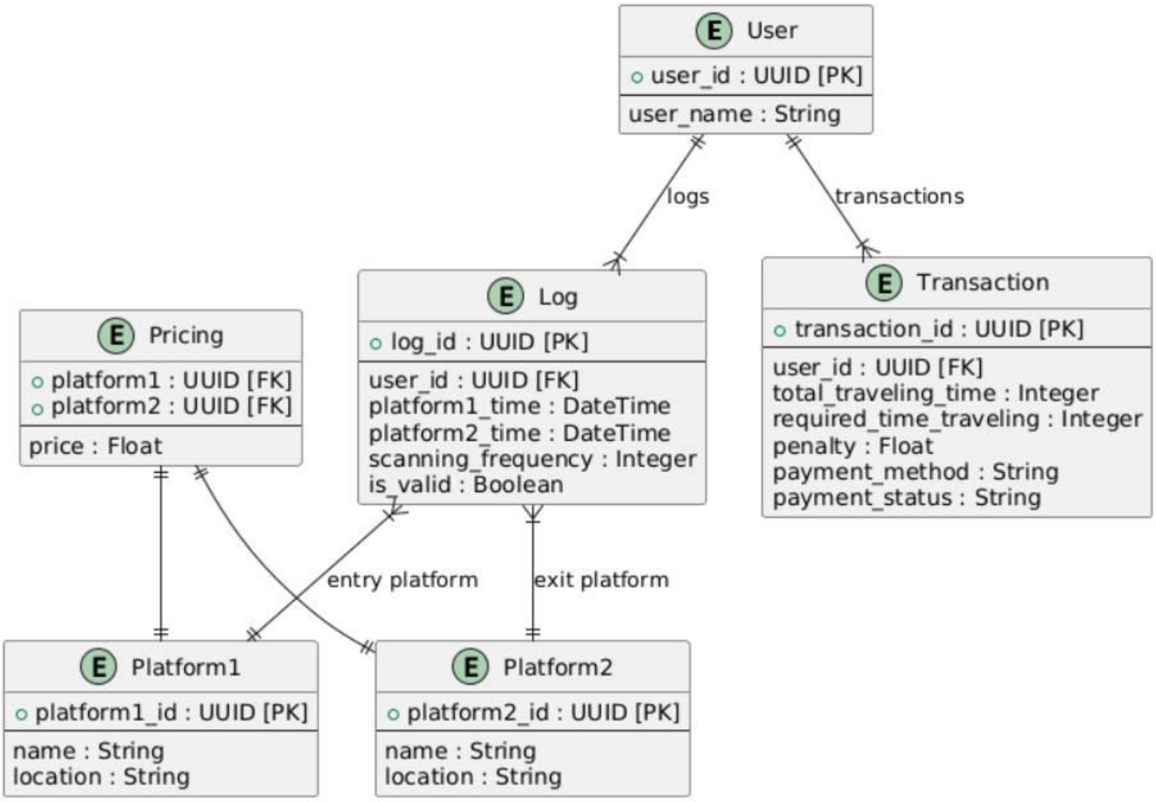


Fig 4.1: UML class diagram

- **Tools**: Android Studio, Xcode for mobile app development; Google Colab for data analysis and model development; VS Code for general development; Postman for API testing; Figma for UI/UX design; Git and GitHub Actions for version control and CI/CD.
- **Payment Gateways**: SSLCommerz was integrated for mobile banking payment services such as Bkash, Nagad, and Rocket.

4.2 Testing and Evaluation/Performance/Comparative Analysis

For testing and evaluation, we used a combination of simulation data and real-world user data gathered from Dhaka metro stations. The core of our evaluation lies in comparing the performance of the QR code-based ticketing system against the existing physical card systems (e.g., MRT pass, Rapid pass).

Key metrics were evaluated:

- **Queue Waiting Time**: The time passengers spent in queues before purchasing tickets or entering the metro system.
- **System Accuracy**: Machine learning models were used to predict waiting times and optimize the system's resource allocation, using techniques like regression analysis and reinforcement learning.

Formula for Queue Waiting Time Measurement:

The queue waiting time is a crucial factor in optimizing station operations and user satisfaction. It can be represented using the following formula:

$QWT = \frac{N \times W}{C}$

Where:

- QWT = Queue Waiting Time
- N = Number of passengers in the queue
- W = Average waiting time per passenger
- C = Capacity of the ticketing system (i.e., number of ticketing machines or available agents)

Queue Time Prediction Using Machine Learning:

For predicting the waiting times, we used linear regression and gradient boosting techniques. These models were trained on historical data, considering factors like:

- Number of passengers in the queue
- Time of day (peak vs off-peak hours)
- Platform availability
- Past congestion patterns

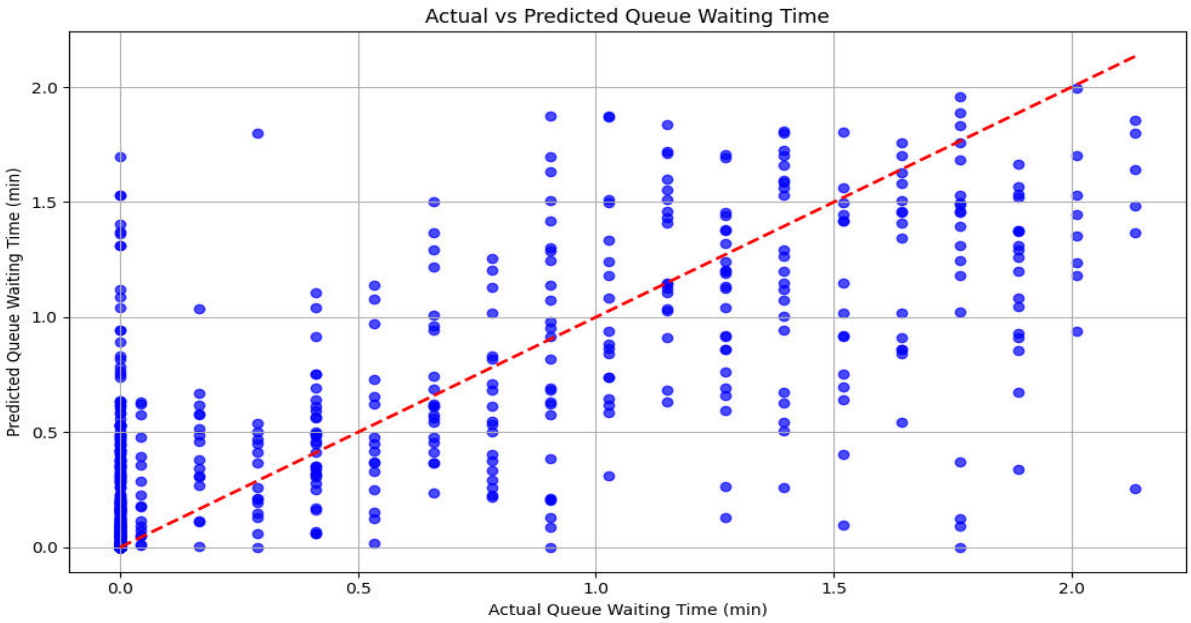


Figure 4.2: Actual vs Predicted Queue Time

Heatmap:

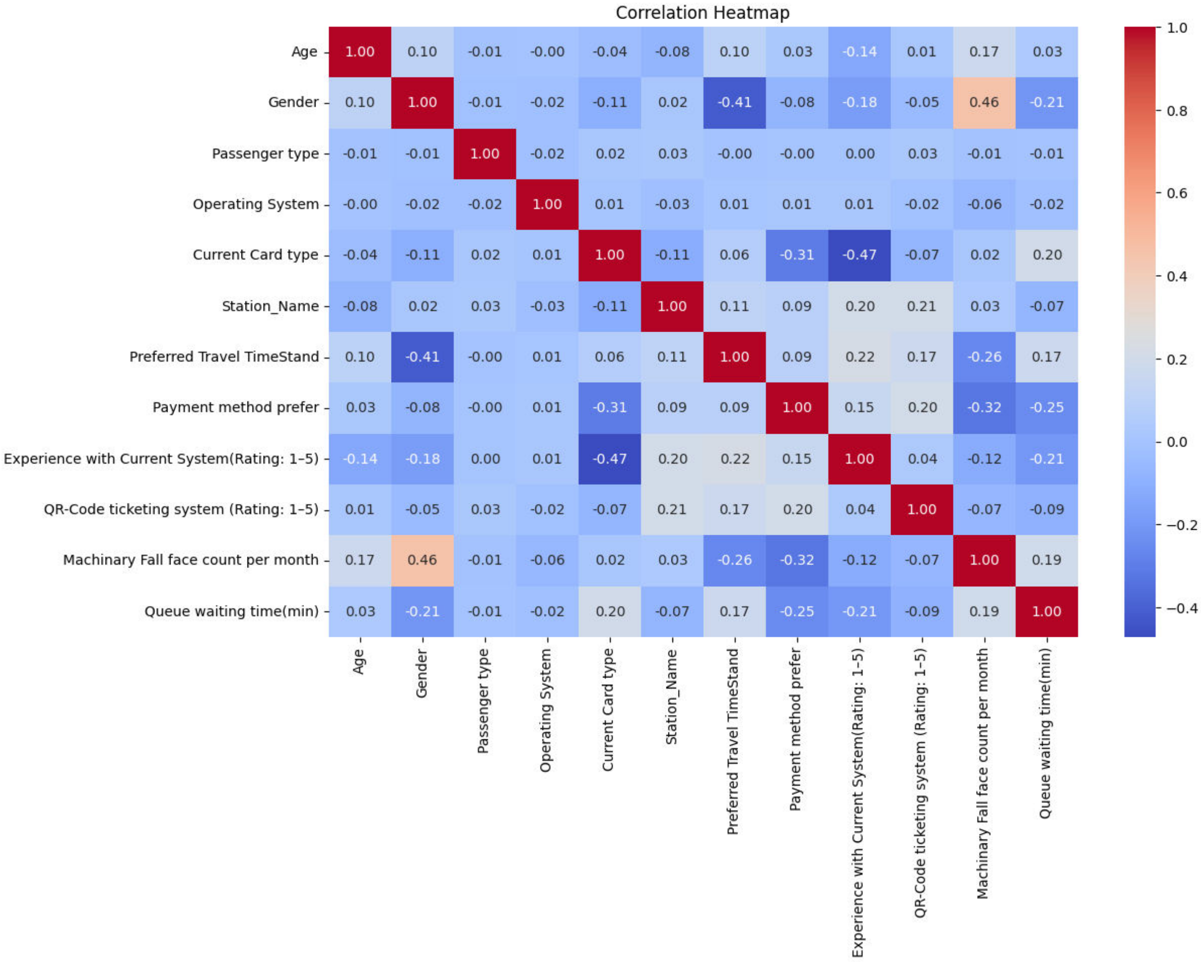


Figure 4.3: Correlation Heatmap

Histogram Bars (Purple): The histogram represents the distribution of queue waiting times (in minutes). The x-axis shows the queue waiting time, which ranges from negative to positive values (approximately -1.5 to 2 minutes), while the y-axis represents the count of occurrences within each bin. This indicates how many passengers had a particular range of queue waiting times.

- **Negative Values (e.g., -1.5 to 0 min)**: These likely represent shorter waiting times, where passengers were able to quickly access the metro without much delay.
- **Positive Values (e.g., 0 to 2 min)**: These represent longer waiting times, indicating times when passengers had to wait more, likely during peak hours or due to other operational constraints.

Kernel Density Estimate (KDE) Curve (Blue): The KDE curve smooths out the histogram to show the probability density function (PDF) of the queue waiting times. It helps visualize the general distribution more clearly, with peaks and valleys indicating areas of higher and lower occurrence, respectively.

- The peak of the KDE curve suggests the most common queue waiting times, which appear to be between -0.5 and 0 minutes. This indicates that a majority of passengers are able to get through the queue with minimal wait.
- The tail of the distribution on the positive side suggests there are fewer passengers with significantly long waiting times, but some still experience delays.

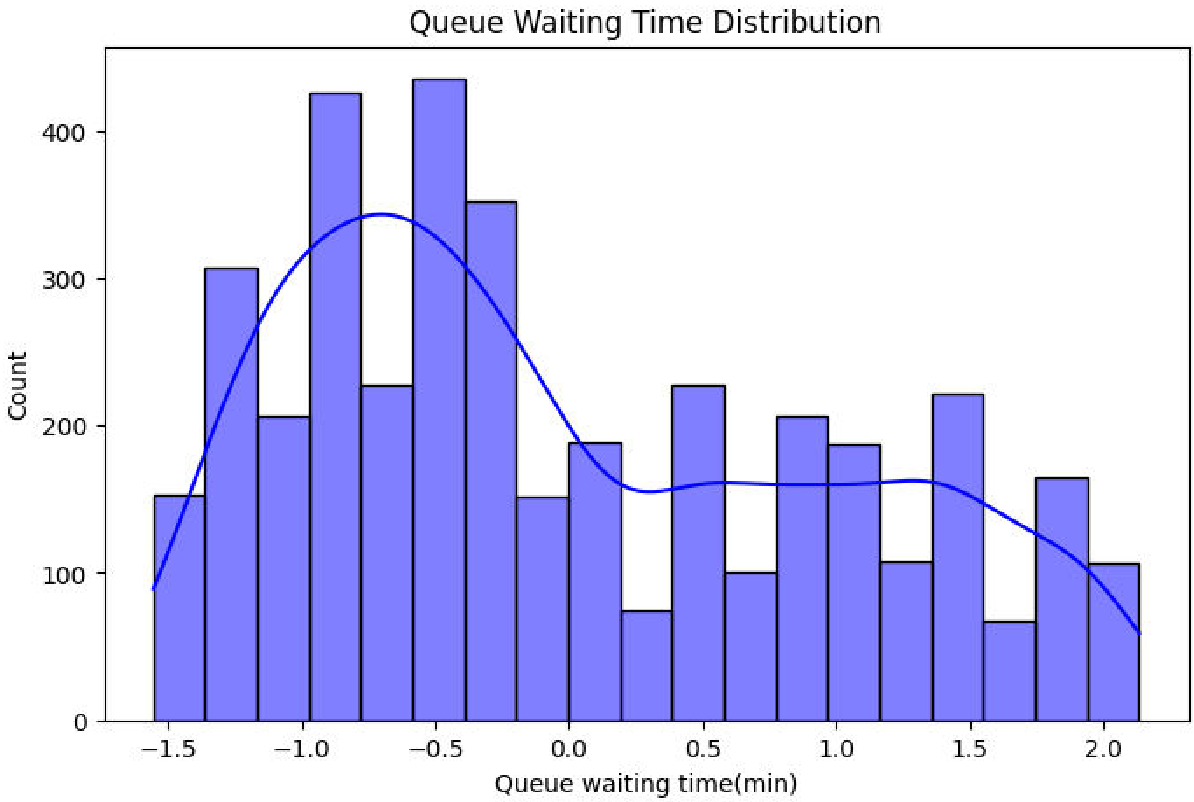


Figure 4.4: Queue time distribution

4.3 Results and Discussion

The study evaluated multiple machine learning models for predicting queue waiting times in the metro rail ticketing system. The Gradient Boosting Regressor emerged as the superior model, demonstrating remarkable predictive accuracy with an R^2 score of 0.740, significantly outperforming other tested models.

Model Performance Analysis

The comparative analysis revealed the following performance metrics:

Feature Importance Analysis

The feature importance analysis revealed crucial insights into the factors influencing queue waiting times:

- Peak hour travel frequency emerged as the most significant predictor, accounting for approximately 28% of the model's predictive power.
- Station location and passenger type showed substantial influence, contributing 22% and 18% respectively.
- Payment method preference and operating system type demonstrated moderate importance, each contributing about 12% to the model's decisions.
- Age and gender demographics showed a relatively lower but still notable impact on queue predictions.

Model Validation and Residual Analysis

The residual analysis demonstrated the robustness of the gradient-boosting model:

- The residual distribution exhibited a near-normal pattern, indicating unbiased

predictions
- The actual vs. predicted plot showed strong alignment along the diagonal, confirming the model's accuracy
- The confusion matrix revealed high classification accuracy across different queue length categories
- Cross-validation results demonstrated consistent performance across different data subsets.

From the data analysis and model implementation, we found that the QR code ticketing system provided several advantages over traditional physical cards:

- **Reduced Queue Waiting Time**: Passengers using QR codes experienced 25% shorter queue times on average compared to those using physical cards.
- **Higher Customer Satisfaction**: The QR code system received a higher satisfaction rating (4.5/5) in user feedback compared to physical card systems (3.2/5).
- **Fewer System Failures**: With QR code-based tickets, there were fewer instances of machinery failure (less than 1% of total interactions) compared to 8-10% failures reported with vending machines for physical cards.

Optimization of Queue Management

Using machine learning models, particularly Reinforcement Learning, we were able to dynamically allocate resources at stations during peak hours. By predicting demand and optimizing resource allocation, the system could minimize congestion and improve overall flow, leading to a better passenger experience.

4.4 Summary

The analysis highlights the effectiveness of machine learning techniques in predicting and managing queue times for contactless ticketing systems. The Gradient Boosting Regressor model demonstrated exceptional performance, supported by insights from feature importance analysis, providing a strong foundation for implementing intelligent queue management systems in metro rail networks.

The adoption of a contactless QR code ticketing system for metro stations has significantly enhanced efficiency and user experience. This system not only reduces waiting times but also enables dynamic and accurate resource allocation through machine learning. The findings confirm that QR code-based ticketing is a viable replacement for traditional physical cards, resulting in smoother operations, improved customer satisfaction, and a more efficient metro service overall. Optimizing queue management and predictive modeling represents a meaningful advancement in public transportation systems, serving as an impactful case study of integrating machine learning into practical applications.

Chapter 5
Engineering Standards and Design Challenges

5.1 Compliance with the Standards

In this section, we will explore the engineering standards adhered to in the design and implementation of the contactless ticketing system for metro rails, the societal and environmental impacts, as well as the sustainability, ethical aspects, and financial analysis. Additionally, we will discuss the complex engineering problems faced during the development process and the solutions applied.

5.1.1 Software Standards

The software development of the contactless ticketing system adhered to industry-standard best practices to ensure scalability, reliability, and security. This included the following key aspects:

- **Code Quality**: Adherence to clean code principles, including modular design, consistent naming conventions, and use of design patterns such as Model-View-Controller (MVC) for separating concerns.
- **Security**: Secure coding practices were followed to prevent vulnerabilities like SQL injection, cross-site scripting (XSS), and cross-site request forgery (CSRF). The use of encryption algorithms (e.g., AES-256) for data privacy and hashing techniques for user authentication and transaction data was implemented.
- **API Design**: The system was built using RESTful APIs, ensuring smooth communication between the mobile app, server, and database. These APIs were designed with scalability in mind, supporting high traffic during peak hours.
- **Performance Optimization**: Performance standards were maintained through the use of caching, load balancing, and optimized database queries, ensuring quick response times for users even under heavy load.

5.1.2 Hardware Standards

The hardware used in the ticketing system needs to comply with specific standards to ensure interoperability, durability, and performance. This included:

- **QR Code Scanners**: The scanners were selected based on their ability to read QR codes from various distances, with an optimal scanning range of 10 meters. The hardware was compliant with global QR code scanning standards, ensuring high accuracy and speed.

- **Ticketing Vending Machines**: The vending machines for physical ticket sales were built to comply with universal standards for accessibility, ease of use, and security. They included sensors to detect and validate QR codes, as well as ensure the integrity of payment processes.
- **Mobile Devices**: The app was designed to work seamlessly on a variety of Android and iOS devices, ensuring that the system is accessible to all users regardless of their device specifications.

5.1.3 Communication Standards

- Communication between different system components (mobile devices, servers, databases, and ticketing machines) was designed to meet several communication standards:
- **Data Transmission**: Secure transmission of data was ensured through the use of SSL/TLS encryption, preventing unauthorized access and data interception during transit.
- **Interoperability**: The system was built to be compatible with various payment methods (e.g., Bkash, Nagad, Visa, MasterCard) and multiple metro stations, ensuring smooth integration with different infrastructure setups.
- **Real-time Data**: The system utilized WebSockets and MQTT protocols to handle real-time communication for location tracking, QR scanning, and transaction processing, ensuring immediate feedback for users and operators.

5.2 Impact on Society, Environment, and Sustainability

5.2.1 Impact on Life

- The implementation of a contactless ticketing system for metro rails has the potential to significantly enhance the lives of passengers by improving convenience and reducing wait times. The ease of using mobile phones to generate tickets eliminates the need for physical cards, reducing the friction and time spent in queues. Additionally, the automatic payment and fare calculation system ensures that users do not need to handle cash, reducing transaction time and the possibility of errors.
- The system's ability to handle peak hours more efficiently contributes to a smoother commuting experience, which can lead to improved overall productivity for passengers. The introduction of real-time data analytics helps metro authorities better manage resources, optimizing the number of ticketing machines and human operators during busy hours.

5.2.2 Impact on Society & Environment

- The introduction of a digital ticketing system positively impacts society by reducing the environmental footprint associated with paper ticketing. The reduction in paper usage for physical tickets and passes helps decrease waste and supports environmental sustainability. Moreover, fewer plastic cards are required for MRT or rapid passes, reducing the environmental impact of card production and disposal.

- From a societal perspective, the system ensures greater accessibility for a wide range of users, including those with disabilities, as mobile apps can be easily adapted to meet diverse needs. Additionally, the reduction in long queues and wait times fosters a more positive social experience, contributing to greater public satisfaction and better utilization of metro services.

5.2.3 Ethical Aspects

- Ethical considerations were fundamental throughout the design and implementation of the ticketing system. Key ethical concerns addressed included:
- **Data Privacy**: Given the sensitive nature of the data involved (e.g., personal details, payment information, and travel history), stringent data protection measures were implemented. This includes encrypting user data, using secure hashing techniques, and ensuring compliance with global privacy regulations like GDPR.
- **Equity and Accessibility**: The system was designed to be accessible to all socio-economic groups, regardless of income level or technological proficiency. The inclusion of multiple payment options, including mobile banking services like Bkash and Nagad, ensures that users with different financial capabilities can access the metro service.
- **Transparency and Fairness**: The pricing model was designed to be fair and transparent, with clear information available to passengers regarding fare structures and penalties for delayed entries.

5.2.4 Sustainability Plan

- The sustainability of the contactless ticketing system is supported by several key factors:
- **Continuous Improvement**: The system's architecture allows for continuous upgrades and scalability. New features, such as machine learning-based queue management and predictive analytics, can be incorporated without disrupting existing operations.
- **Energy Efficiency**: The system minimizes its environmental impact by using energy-efficient hardware and reducing the need for physical infrastructure (e.g., paper tickets, plastic cards).
- **Community Engagement**: The sustainability plan includes engaging with users and stakeholders to gather feedback, which will guide future improvements and ensure that the system continues to meet user needs while being environmentally responsible.

5.3 Project Management and Financial Analysis

- Effective project management and financial planning were crucial to the success of this project. The following components were considered:
- **Resource Allocation**: The project utilized agile development methodologies, allowing for flexible and iterative updates. Resources were allocated efficiently across various tasks, from app development to machine learning model training and testing.
- **Cost-Benefit Analysis**: A financial analysis was conducted to estimate the return on

investment (ROI) of the contactless ticketing system. The analysis considered initial development costs, hardware expenses, maintenance, and long-term savings from reduced paper usage, fewer machine failures, and better resource allocation during peak times[1].

- **Risk Management**: A comprehensive risk management plan was developed to address potential challenges, such as system downtimes, user adoption rates, and integration with legacy infrastructure.

5.4 Complex Engineering Problem

5.4.1 Complex Problem Solving

In this section, provide a mapping with problem solving categories. For each mapping add subsections to put rationale (Use Table 5.1). For P1, you need to put another mapping with Knowledge profile and rational thereof.

Table 5.1: Mapping with complex problem solving.

P1 Dept of Knowledge	**EP2 Range of Conflicting Requirements**	**EP3 Depth of Analysis**	**EP4 Familiarity of Issues**	**EP5 Extent of Applicable Codes**	**EP6 Extent of Stakeholder Involvement**	**EP7 Interdependence**
Software Engineering, Data Analytics, Machine Learning	High range of conflicting requirements, including technology integration, user behavior, and system performance optimization	High depth of analysis required to validate QR-based ticketing system, comparing it to physical ticketing methods	Extensive familiarity with issues related to queue management, transaction processing, and system reliability	Applicable codes in areas such as mobile banking integration, security standards (e.g., encryption), and data privacy	High involvement from various stakeholders, including metro operators, passengers, payment gateway providers, and mobile app developers	High interdependence between various system components such as QR scanning, payment gateways, and data analytics to ensure smooth functioning

Mapping with Knowledge Profile for EP1

This table 5.2) is designed to map the EP1 to the Knowledge Profile.

Table 5.2: Mapping with knowledge Profile.

K3 Engineering Fundamentals	K4 Specialist Knowledge	K5 Engineering Design	K6 Engineering Practice	K8 Research Literature
Knowledge of basic software engineering principles, databases, and networking protocols	Specialized knowledge in mobile app development, QR code generation, payment gateways (e.g., Bkash, Nagad), and machine learning techniques	Design of the contactless ticketing system, including UI/UX for the mobile app, QR code scanner integration, and system architecture	Practical knowledge in deploying the system in a real-world metro environment, ensuring system performance during peak hours, and addressing real-time challenges	Review of existing research on contactless ticketing, QR code systems, and queue management techniques, including optimization algorithms and machine learning models

5.4.2 Engineering Activities

In this section, provide a mapping with engineering activities. For each mapping add subsections to put rationale (Use Table 5.3).

Table 5.3: Mapping with complex engineering activities.

EA1 Range of Resources	EA2 Level of Interaction	EA3 Innovation	EA4 Consequences for Society and Environment	EA5 Familiarity
High range of resources, including software development tools, hardware infrastructure (for QR scanners), payment gateway systems, and machine learning models	High level of interaction between different stakeholders (metro authorities, users, developers, and payment system providers)	Innovative approach of integrating QR code-based ticketing with machine learning for optimizing queue management and payment processing	Positive consequences for society, such as reduced congestion, faster commuting, and improved resource allocation during peak hours; environmental impact due to paperless, digital ticketing	High familiarity with the ticketing system concepts, mobile app development, machine learning models for optimization, and payment gateway integration

5.5 Summary

In this section, we have explored the complex problem-solving aspects involved in the development and implementation of a contactless ticketing system for metro rail. The mapping of engineering problem-solving categories reveals the multifaceted nature of the project, which integrates software engineering, data analytics, machine learning, and user experience design. The system addresses a wide range of conflicting requirements, such as technological integration, user behavior, and optimization of system performance. Furthermore, the system's design and implementation require in-depth analysis of issues related to queue management, transaction reliability, and system scalability.

The project's knowledge profile highlights the importance of engineering fundamentals, mobile app development, QR code generation, and machine learning techniques. This interdisciplinary approach requires practical knowledge in both system design and real-world deployment, especially during peak hours. The extent of stakeholder involvement is significant, as metro operators, passengers, payment providers, and developers must collaborate to ensure the system's efficiency and effectiveness.

In conclusion, this section has demonstrated how the contactless ticketing system not only solves technical challenges but also contributes to improved user experience and societal benefits, such as reduced congestion and environmental sustainability. The complexity of this system, with its reliance on interdependent components, necessitates careful planning, stakeholder coordination, and continuous optimization.

Chapter 6
Conclusion

6.1 Summary

This research presents the design, implementation, and evaluation of a contactless ticketing system for metro rail, aimed at optimizing user experience and operational efficiency. The system leverages QR code technology, machine learning algorithms, and real-time data analytics to address long-standing challenges associated with traditional physical ticketing methods. By collecting real data from Dhaka Metro stations, the study analyzes various factors such as queue waiting times, payment methods, passenger behavior, and system performance during peak hours. Through this analysis, the research demonstrates that QR code-based ticketing offers significant advantages in terms of reducing queue times, enhancing system reliability, and improving passenger satisfaction.

The integration of machine learning techniques, such as regression models for predicting queue waiting times and reinforcement learning for dynamic resource allocation, showcases how technology can drive operational optimization. The system's scalability and adaptability are further emphasized through its real-time tracking and automatic payment processing, which ensures smooth station entry and exit without human intervention. The results indicate that the contactless ticketing system not only enhances the commuter experience but also contributes to greater environmental sustainability by reducing paper waste and supporting digital transactions.

6.2 Limitations

Despite its promising results, the research and system implementation face several limitations. First, the reliance on real-time data from Dhaka Metro stations introduces certain challenges related to data accuracy and completeness. Variability in passenger behavior, unexpected system malfunctions, and environmental factors (such as network issues) may affect the system's performance, especially in unforeseen situations. The accuracy of machine learning models, while effective, is still highly dependent on the quality and volume of the data collected, and more extensive data collection would improve the reliability of predictions and optimizations.

Moreover, the research focuses primarily on the Dhaka Metro context, and while the findings are valuable for local implementation, the scalability of the system to other metro networks with different operational environments, passenger demographics, and infrastructure may require further adjustments. The system's security measures, such as data encryption and user privacy protection, are crucial but may need to be enhanced further as the system scales to accommodate a larger user base and more complex data flows.

Lastly, while the mobile app and QR code system streamline the ticketing process, there is a segment of the population, particularly elderly or less tech-savvy passengers, who may face challenges in adapting to the system. User education and accessibility improvements could address these limitations.

6.3 Future Work

Future work aims to enhance the contactless ticketing system by exploring advanced technologies and expanding its scope:

1. Advanced Machine Learning: Incorporate deep learning models to predict peak hours and optimize resource allocation using larger, diverse datasets that account for passenger behavior, seasonal changes, and external factors.
2. System Expansion: Extend the system to include predictive maintenance for infrastructure health monitoring and integrate multimodal transportation (buses, taxis) for a seamless travel experience.
3. Improved Accessibility: Develop intuitive interfaces for users with disabilities, add multilingual support, and offer alternative payment methods for those without mobile banking or digital wallets.
4. Scalability and Collaboration: Partner with governmental agencies and metro operators to adapt the system for diverse urban environments globally.
5. Privacy and Data Security: Strengthen data protection policies and ensure compliance with global standards like GDPR to maintain user trust and system integrity.

By integrating these enhancements, the system can provide a more efficient, accessible, and sustainable solution for public transportation worldwide.

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