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Automatic Bus Fare Collection System using RFID

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Abstract

Public transportation systems in developing regions often depend on manual fare collection methods that are inefficient, more prone to human error and vulnerable to fare evasion and revenue leakage. This research implements an Automatic Bus Fare Collection System which uses Radio Frequency Identification (RFID) and Global Positioning System (GPS) technologies to manage these challenges. The objective of this system is to automate fare collection based on real-time passenger tracking and distance traveled, helping in improving passenger experience. The system is built with an ESP32 microcontroller at the center, RFID readers installed at bus entry and exit points and a GPS NEO-6M module for real-time location tracking. A database records details of fare transaction, whereas a web-based interface enables users to manage accounts and view payment history. Integration with the eSewa digital payment gateway facilitates remote balance recharge. The system experimental testing confirmed accurate fare calculation, reduced boarding time, and minimized dependency on conductors. The system also improves security through encrypted communication and user authentication. Identified challenges include misplacement of the RFID card, initial infrastructure costs, and the need to adapt to the user. Despite these, the system shows strong potential as a reliable, scalable and cost-effective alternative to traditional fare collection systems. It sets a practical foundation for the adoption of intelligent transport infrastructure in urban environments, particularly in the context of developing nations.

Keywords— *RFID, GPS, Automatic Fare Collection, Public Transport, ESP32, Real-Time Tracking, Contactless Payment, Intelligent Transport System*

1. INTRODUCTION

Public transportation is an important part of urban transport. The highly populated cities like Kathmandu mostly relies in it. The local transports system still relies on the manual, cash-based fare collection system handled by human conductors. This method leads to the long boarding queues, repeated human error during fare calculation and untraceable revenue leakage. With the rapid growth of digital infrastructure in Nepal, there is a growing need to modernize fare collection systems to make them faster, more transparent, and more accountable.

To address these issues, this system presents an Automatic Bus Fare Collection System that combines Radio Frequency Identification (RFID), Global Positioning System (GPS) tracking and digital wallet integration through eSewa. The system detects passenger entry and exits after scanning the RFID card, calculates the traveled distance in real time and deducts the correct fare from the card of the users. Thus, this system improves efficiency, enhance security, reduce dependency on conductors and provide transport operators with the overall data for route management and other improvements.

2. LITERATURE REVIEW

Previously, different projects and researches were done on topics related to use of RFID and GPS in public transport. They used different methods to improve the transport system. Al-Mutairi and Khokhar [1] designed an RFID-based fare collection model which replaced manual ticketing method with contactless smart cards. Their work reduced boarding delays but lacked a GPS module, making it unsuitable for distance-based fare calculation.

Zhao et al. [2] reviewed RFID applications in Intelligent Transport Systems (ITS) and identified operational benefits, yet they emphasized that integration with real-time tracking was still limited.

Jang et al. [3] focused on tracking passenger entry and exit using RFID to compute dynamic fares. Their simulation showed improved transparency, although they acknowledged the need for robust system architecture to handle large transaction volumes.

Zhang and Li [4] proposed combining GPS and RFID to support fleet monitoring and dynamic routing, but their work remained mostly conceptual.

Similarly, Kumar and Pradhan [5] studied GPS–RFID convergence in Asian cities and reported a 25 % improvement in fare processing speed, yet they also noted persistent problems such as high cost, interoperability, and weak data security.

Although previous research has demonstrated the individual benefits of RFID and GPS, very few systems have incorporated digital wallet payment gateways or tailored their solutions to the unique constraints of developing countries. To the best of our knowledge, there is no such existing system in Nepal which combines RFID, GPS, and eSewa in a unified platform that supports distance-based fare calculation, secure transactions, and real-time data analytics or can say that in Nepal all the transport operators still follow traditional method for fare collection. This system fills that gap by implementing distance-based fare collection system which is low in cost, scalable and adjusted according to the needs of Nepal's public transport sector.

3. METHODOLOGY

This system was built with the combination of hardware and software modules. The central module is the ESP32 microcontroller. It was used in this system because it has Wi-Fi and Bluetooth capability. Every passenger/user receives an RFID card which is linked to a personal account and has a certain amount loaded in it. In addition, the cards are categorized into student/elderly and regular types, since student/elderly cards have discounts available for them according to the rate. While boarding the bus, the RFID reader scans the card and logs the entry time and GPS coordinates. Similarly, upon leaving the bus, the RFID reader scans the card and calculates the distance traveled based on GPS information and then deducts the fare according to the rate determined accordingly from the account balance.

On the software side, Arduino IDE was used for microcontroller programming and MySQL was used to maintain the backend database. WordPress was used as a content management system for the web interface. And Visual Studio was used for the development of the user interface. The database has user information, transactions details and distance traveled by users. Security measures were taken to encrypt user data and offer safe transactions. The system was tested in a controlled environment with the fixed bus routes and performance metrics such as transaction time, system reliability and data accuracy were evaluated.

Error Handling: Since GPS signals may be lost in dense urban streets or due to hardware glitches, fallback mechanisms were implemented. When GPS coordinates are unavailable, the system temporarily logs the last known valid position and calculates fare based on the closest fixed distance fare. If the signal remains lost beyond 3 minutes, the system defaults to a minimum base fare to avoid passenger overcharging, while also logging the anomaly for administrative review.

A. Block Diagram

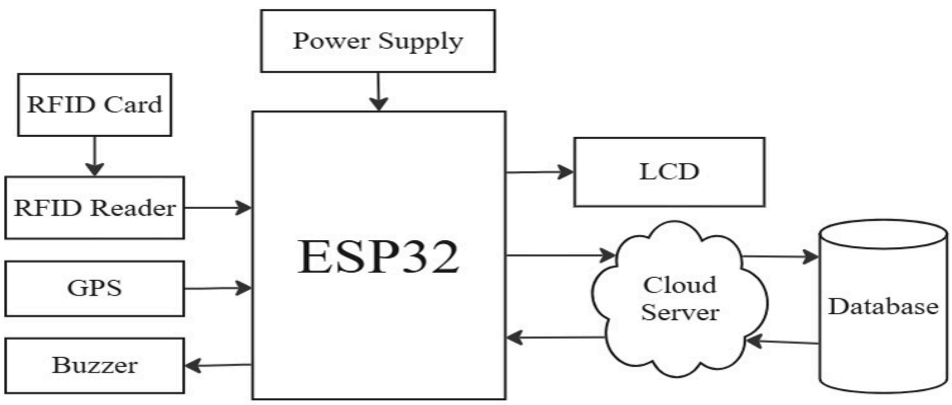

Figure 1: Block Diagram of Automatic Bus Fare Collection System

Journal of Advanced College of Engineering and Management

B. Flowchart

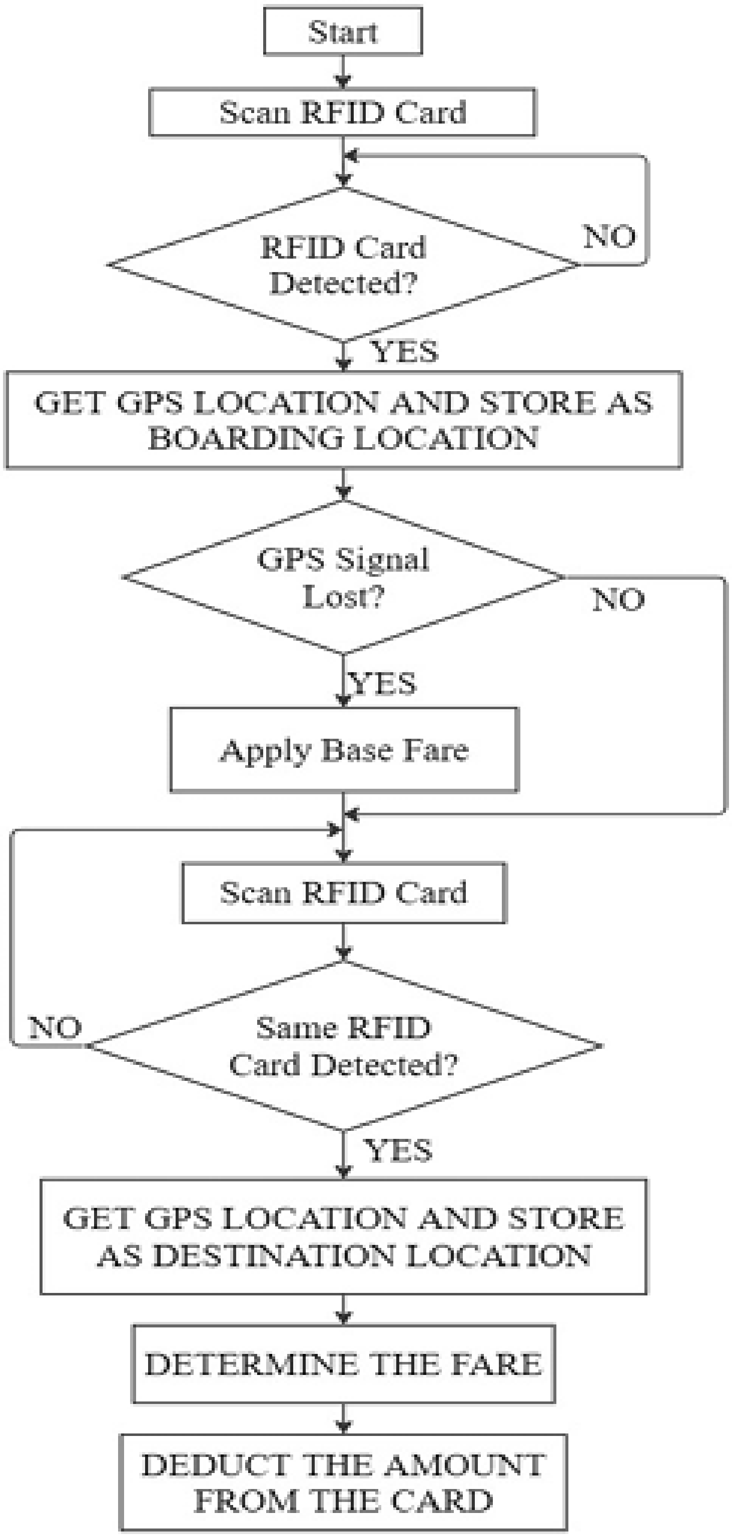

Figure 2: Flowchart of Automatic Bus Fare Collection System

C. Schematic Diagram

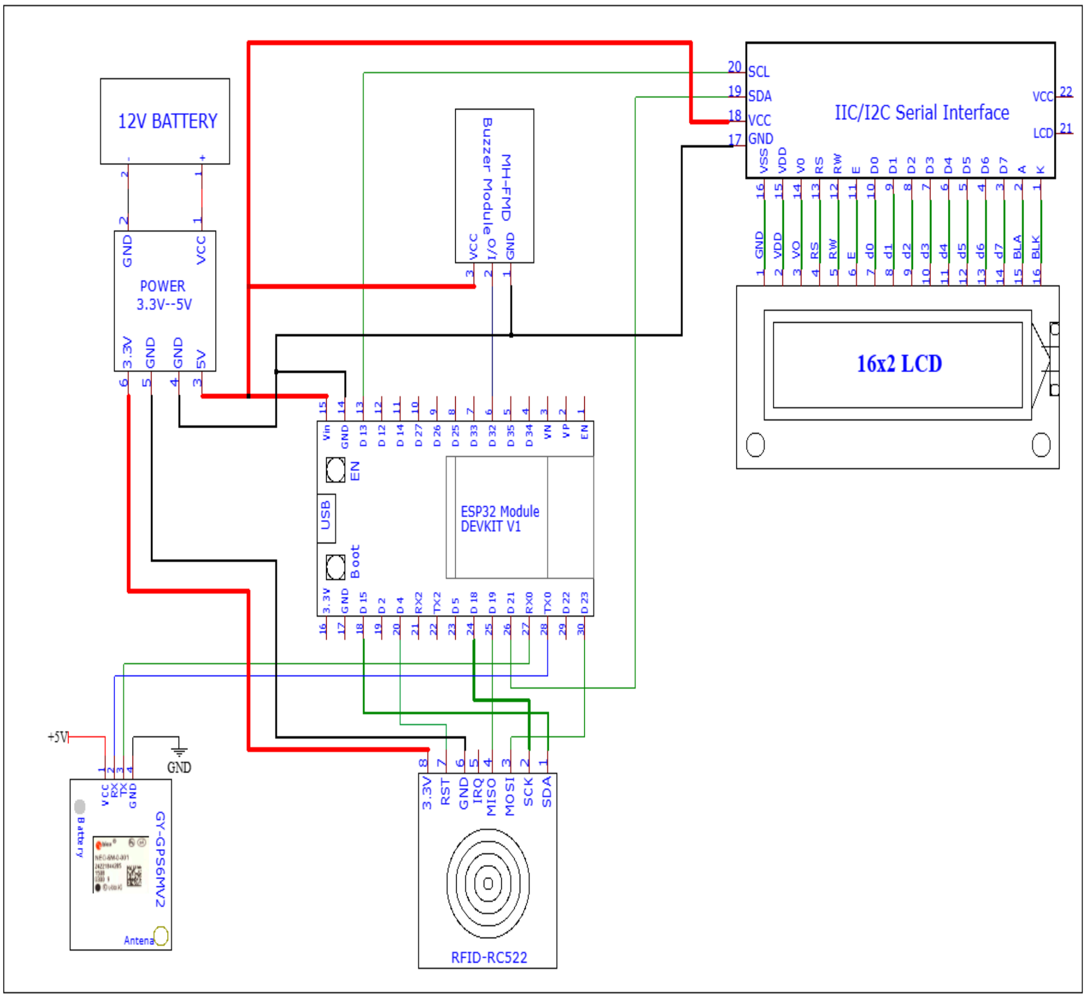

Figure 3: Schematic Diagram of Automatic Bus Fare Collection System

C. Security Considerations

Security was a key design priority to protect passenger data, prevent fraud, and ensure system integrity. All the communications between the ESP32 microcontroller and the backend server were encrypted using symmetric encryption. The web interface and payment transactions were conducted over HTTPS with TLS which ensures confidentiality and integrity during data transfer. To reduce the risk of RFID card cloning, each card was linked to a unique identification number which is stored in the backend database. The system performs real-time verification of card IDs, transaction time and travel distances. Any suspicious or duplicate scan events are logged and notified for administrative review. Future improvements could include two-factor authentication for user accounts, blockchain-based transaction auditing and biometric verification at boarding points. These improvements help to build user trust and support long-term scalability of the system in urban transport areas.

4. RESULTS AND DISCUSSION

The results of this system tests demonstrated the feasibility and effectiveness of this solution. RFID+GPS based fare collection significantly reduced the time consumed in boarding and fare processing from an average of 9.95 s to 3.15 s during rush hours. Also reducing delays during rush hours by nearly 70% per passenger on average. The system consistently took about two seconds to meet real-time requirements. Real-time GPS tracking enabled accurate fare calculations based on the distance traveled by the passenger with the accuracy above 98%, and the backend database provided consistent records of all passenger activities. Financially, manual bus fare collection in Kathmandu busses suffers from 15 to 25% revenue leakage due to fare evasion and under-reporting. This system is set to reduce leakage by at least 20% which helps in the recovery of significant amount for bus operators. Also, integration of the eSewa payment gateway enabled online top-up and secure digital payments.

A. System View

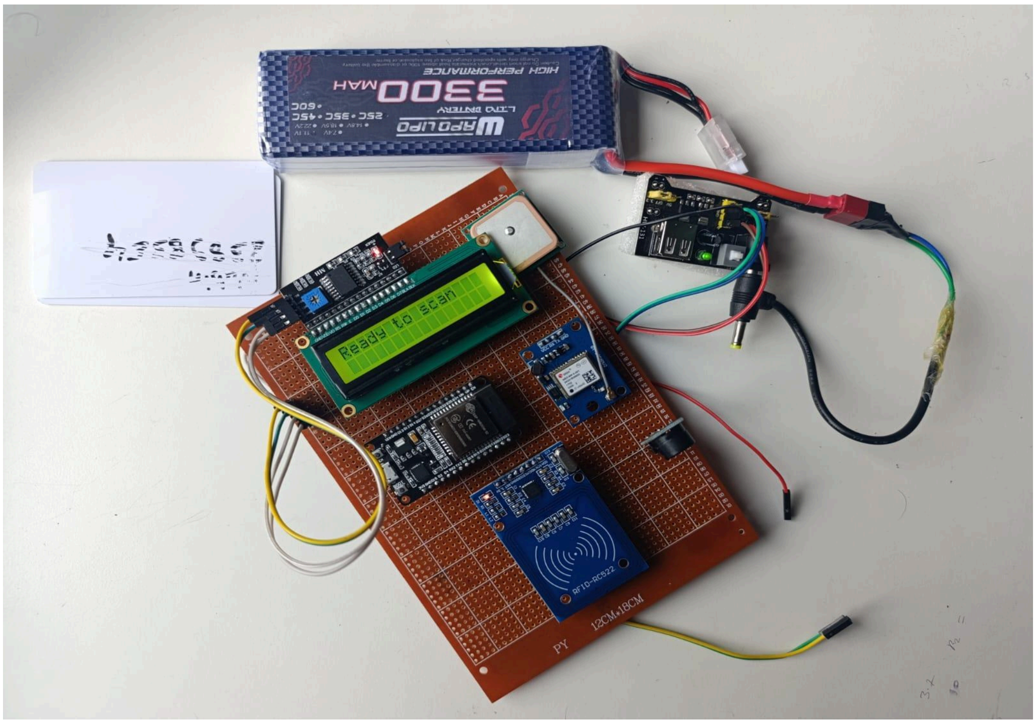

Figure 4.1: Hardware Setup

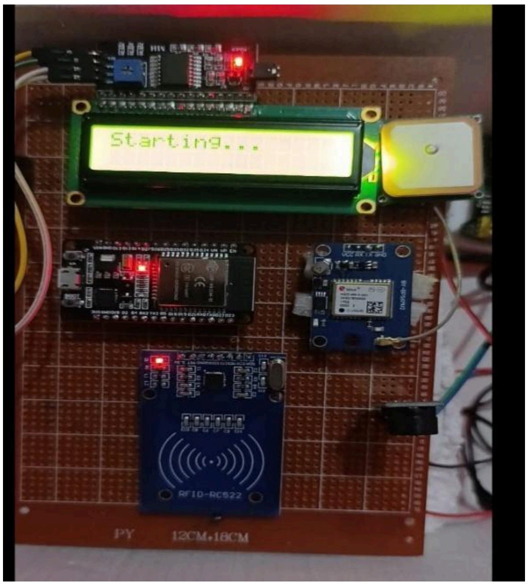

Figure 4.2: Starting System

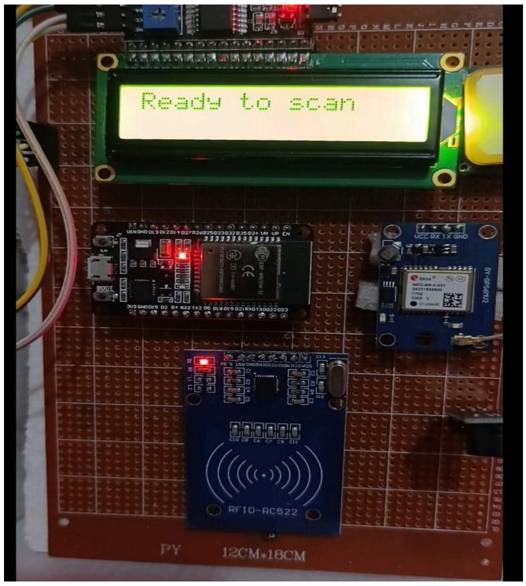

Figure 4.3: Ready to Scan Card

Figure 4.4: Scan Successful at Entry Point

Figure 4.5: Scan Successful at Exit Point

B. Website View

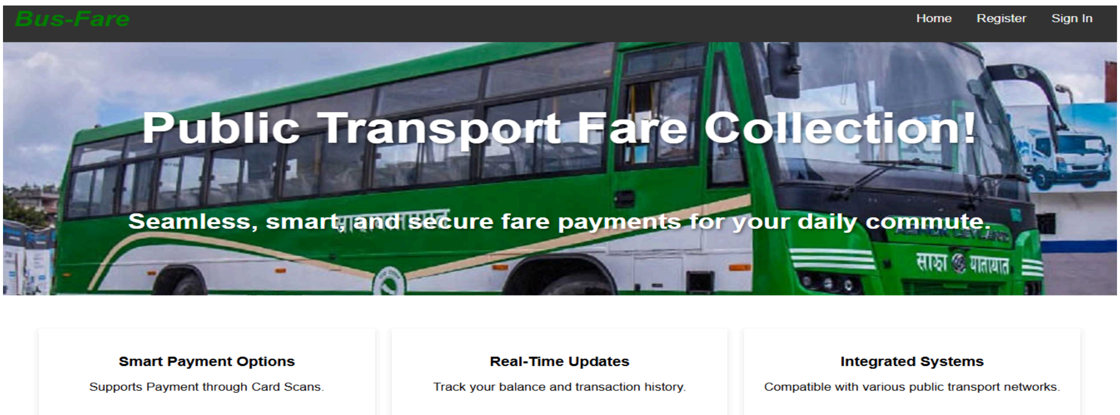

Figure 4.6: Home Page

Figure 4.7: User Registration Page

C. Test Data

No. of Trips	Actual Distance (km)	System Distance (km)	GPS Error Margin (m)	Manual Boarding Time (s)	System Boarding Time (s)	Time Saved (%)
1	9.7	9.85	150	9.7	2.8	71.1
2	13	13.5	500	9.9	3.3	66.7
3	7	7.1	100	9.7	3.4	64.9
4	3.4	3.455	55	11.9	3.3	72.3
5	5.1	5.22	120	10.2	3.2	68.6

Table 1: Per-Trip Data

No. of Trips	Avg. Actual Distance (km)	Avg. GPS Error Margin (m)	Avg. Manual Boarding (s)	Avg. System Boarding (s)	Avg. Time Saved (%)
5	7.64	185	9.95	3.15	68.72

Table 2: Average of per-trip data

D. Limitations

Still there are several limitations observed in this system. RFID cards can be lost or damaged which may result in a difficulty for the passengers. The use of GPS may cause irregular inaccuracies due to poor signal reception in urban areas. The limited availability of the recharge stations also affected its usability. The system may experience connection issues, power failures or software malfunctions which may affect operation of the system. Also, all passengers may not be familiar with RFID technology, so it requires awareness campaigns and user training for them.

E. Cost-Benefit Analysis

The system implementation cost for a single bus was approximately NPR 15,000, which included the ESP32 microcontroller, RFID readers, GPS module and integration with the eSewa gateway. Scaling this system setup to a fleet of 100 buses will require around NPR 1.5 million in initial investment. Based on different field studies, manual fare collection in Kathmandu Valley buses results in an estimated revenue leakage of 15 to 25%. It is caused due to fare evasion, under-reporting and human error. With an average annual revenue of NPR 50,000 per bus, 100 bus generates about NPR 50 lakhs per year, in which NPR 10 lakhs is typically lost. By automating fare collection and implementing accurate distance-based fare calculation, this system is projected to reduce this leakage by at least 20%, which is equivalent to a recovery of NPR 10 lakhs annually across 100 buses. In addition to the revenue protection, the system offers significant efficiency gains. Boarding time was reduced by 68.72%, which can improve schedule management and allow operators to increase the number of daily trips without additional fuel or staffing costs. The combination of direct revenue recovery and operational efficiency improvements shows the payback period of less than six months for operators adopting this system at large scale. After this period, the system contributes directly to the cost savings and increased profitability for the operators.

5. CONCLUSIONS

This research successfully demonstrated that an Automatic Bus Fare Collection System based on RFID and GPS can significantly enhance the efficiency of public transportation systems in Nepal. The system results show that boarding time was reduced by an average of 68.72%, which allowed faster passenger flow and improved schedule management. GPS-enabled distance-based fare calculation achieved over 98% accuracy, ensuring fair and transparent transactions. Furthermore, the system is projected to reduce annual revenue leakage by approximately 20% which is equivalent to recovering around NPR 10 lakhs per year across 100 buses. Beyond financial and operational gains, the system enhances passenger convenience, minimizes fare disputes, and provides operators with valuable data for route optimization and financial monitoring. With the modernization, the demand for smart and transparent transportation solutions is increasing. This system lays a practical foundation for modernizing Nepal's public transport sector into a more reliable, scalable and sustainable model.

6. SUGGESTIONS AND RECOMMENDATIONS

Future improvements should look at scaling the system and the make the use of the system easy and reliable for all. A mobile app can be dedicated to allow users to check balances, recharge accounts and receive notifications about fare deductions and card activity. The introduction of biometric authentication, i.e. fingerprint or facial recognition, will provide an extra layer for card security and help to reduce its misuse. The addition of more recharge counters and integration with more digital payment gateways will enhance accessibility for more users. Finally, the addition of artificial intelligence and data analytics will help in the prediction of real-time requirements, route optimization and dynamic fare adjustments based on traffic condition and passenger density.

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