# Sri Lanka Intelligent Bus Navigation and Passager Information System

24-25J-237

A.S.C. Githsara Senarathne

B.Sc. (Hons) Degree in Information Technology Specialized in Information Technology
Faculty of Computing

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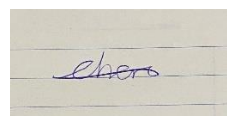
| A.S.C.G. Senarathne | IT21205460 |  |

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(Dr. Sanika Wijayasekara)

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## ABSTRACT

Sri Lanka's public transportation system, particularly its bus services, has long struggled with outdated ticketing processes, frequent transaction errors, and poor user satisfaction. Passengers often face unnecessary delays due to manual cash-based methods, while operators are burdened with inefficiencies and security issues. In response, this project presents a transformative solution by integrating Near Field Communication (NFC) and blockchain technologies into a unified, smart ticketing platform. The proposed system allows passengers to complete transactions with a simple tap using an NFC-enabled card or smartphone. This reduces boarding times, eliminates the need for cash, and ensures smoother operations, especially during peak hours. On the back end, blockchain ensures each payment is securely logged, tamper-proof, and auditable - providing unmatched transparency and building trust between commuters and service providers. The system also introduces personalized features like loyalty rewards and passenger categorization, enhancing user engagement and encouraging sustained public transport use. During pilot testing on selected bus routes, the system achieved an average transaction speed of under two seconds while maintaining full accuracy in fare validation. Feedback highlighted improved trust, efficiency, and reduced disputes over fare inconsistencies. By leveraging scalable technologies such as Django, Firebase, MongoDB, and AES encryption alongside NFC and blockchain, the solution not only modernizes public transport infrastructure but does so in a cost-effective, user-friendly manner. Ultimately, this research demonstrates a forward-thinking approach to solving real-world urban mobility challenges. It goes beyond automation - delivering a secure, efficient, and engaging transport experience that better meets the expectations of today's commuters and sets a strong foundation for future smart city innovations.

*Keywords - NFC (Near Field Communication), Blockchain, Smart Ticketing, Public Transportation, Microtransactions*

# ACKNOWLEDGMENT

I would like to express my sincere gratitude to all those who have supported and contributed to the success of this project.

First and foremost, I extend my heartfelt thanks to my supervisor, Mr. Sanika Wijayasekara, and my co-supervisor, Mr. Kapila Dissanayake, for their invaluable guidance, constant encouragement, and insightful feedback throughout the course of this research. Their expertise and patience have been a source of inspiration.

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| Abbreviation | Description |
|---|---|
| NFC | Near Field Communication |
| ID | Identification |
| TXID | Transaction ID |
| CTB | Ceylon Transport Board |
| SDLC | Software Development Life Cycle |
| AES | Advanced Encryption Standard |
| JWT | JSON Web Token |

# 1. INTRODUCTION

## 1.1 General Introduction

Public transportation is a core part of life in Sri Lanka [1]. For many people, especially in urban and semi-urban areas, buses are the most affordable and widely available mode of travel. Every day, thousands of individuals rely on this system to go to work, attend school, visit loved ones, or run daily errands. Despite how essential buses are to the country's transportation infrastructure, the systems that support them - especially the ticket and fare collection mechanisms - are significantly outdated and full of problems that affect both passengers and operators.

The current system is mostly manual, and cash based. When boarding a bus, passengers' hand over cash to a conductor, who may or may not provide a paper ticket in return. This process is time-consuming, often inaccurate, and lacking any form of traceability. Passengers frequently report situations where they didn't receive proper change, were charged different amounts for the same distance on different buses, or didn't get a ticket at all. These small issues, when multiplied by the number of people using buses daily, become large-scale inefficiencies that waste time, cause frustration, and lead to a lack of trust in public services [2].

In our research survey, we reached out to real bus users across different age groups and travel patterns. The feedback was loud and clear: people want a better way to pay for their rides. They are tired of unreliable and inconsistent practices. Most of them - over 90% - said they would be interested in using contactless NFC (Near Field Communication) technology if it made their commute smoother. Many also stressed how important it is for the system to be secure and transparent, especially in an era where digital scams are on the rise [3]. This feedback served as the foundation for designing this component.

The main goal of this ticketing and transaction system is to modernize how bus fares are paid and managed, without complicating the passenger's experience. In fact, we want to make it simpler. At the heart of the design are two technologies: NFC and blockchain.

NFC enables quick, contactless payments. Passengers won't have to worry about carrying an exact change or waiting for a conductor to manually write a ticket. Instead, they can just tap an NFC-enabled card or smartphone when boarding the bus. It takes less than a second, making it perfect for high-traffic environments. This helps reduce boarding time and makes the process more efficient, especially during peak hours when buses are full, and time is limited [4].

Blockchain, on the other hand, brings in the aspect of security and transparency. Every time a payment is made, it gets recorded on a decentralized, tamper-proof ledger. This means nobody, not even the bus conductor, can edit, delete, or fake the transaction. Passengers can be confident that their payment was received and recorded correctly. For the bus operators and transport authorities, blockchain provides an auditable and real-time overview of revenue and passenger volume [5].

Together, NFC and blockchain turn a messy, slow, and error-prone system into a fast, clean, and secure one.

Many public transport systems around the world have implemented smart cards or apps, but what we've designed goes further. Our system is not just about replacing cash with a card. It's about rebuilding the relationship between passengers and the transport system, focusing on trust, personalization, and long-term engagement.

That's why we've added features like a loyalty rewards system. Just like airlines or supermarkets, bus passengers will now be rewarded for frequent use. Every ride adds points to their profile, which can later be used for free trips or discounts. This kind of incentive not only makes passengers feel valued but also encourages them to use buses more regularly, helping reduce traffic congestion and pollution caused by private vehicles [6].

We've also added passenger categorization, which lets the system recognize different types of riders - like students, seniors, or daily commuters - and automatically apply fare concessions or special privileges. This ensures fairness, accessibility, and a more personalized experience for each user group [7].

From a usability standpoint, the goal was to keep the system intuitive and user-friendly. Most passengers don't need to understand how blockchain works behind the scenes. What matters is that they can tap their card, see that the transaction is confirmed, and move on with their journey in just a few seconds.

The user survey we conducted gave us a realistic and detailed picture of what commuters go through. Many respondents said they had faced issues like:

- Conductors not giving back the correct change [8]
- Inconsistent ticket prices [9]
- Not receiving tickets at all [10]
- Long delays during boarding due to cash handling [11]
- Concerns about losing money or being overcharged [12]

When asked about the potential use of NFC cards, the majority responded with "very interested," showing a strong openness to trying new, more convenient ways of payment. Security was also ranked as "very important" by almost all users. Many of them expressed support for blockchain-backed payments once they understood that it could reduce fraud and ensure payment traceability [13].

One interesting point from the survey was that even passengers who don't currently use mobile payments were willing to adapt if the process was simple and provided values such as faster boarding, rewards, or better accountability. This gave us confidence that the public is ready for a shift. They just need a system that respects their time, money, and trust.

## 1.2 Background literature

### 1.2.1 Overview of Sri Lanka's Public Transport Ecosystem

Sri Lanka's public transport system serves as the primary means of mobility for most of its population**.** Among the available modes - buses, trains, tuk-tuks, and taxis - buses dominate, operating under both state-run (SLTB) and private ownership. These buses cater to every stratum of society: from schoolchildren and university students to office workers, farmers, and elderly citizens. For many, especially in rural or low-income areas, buses are not just a choice, they are a necessity [14].

Despite this critical role, the supporting infrastructure has remained technologically stagnant for decades. The ticketing process continues to rely heavily on manual cash handling, with little standardization or digital oversight. Conductors issue tickets using simple printed rolls or handwritten notes, with pricing and payment often based on memory or estimation. There are no formal checks for whether a ticket was issued, nor are records reliably kept for the volume of daily passengers or the revenue collected [15].

This lack of modernization represents more than just an inconvenience - it has become a structural weakness. Without digital records or real-time tracking, transport authorities are unable to perform meaningful oversight, detect misuse, or plan for improvements. Service quality becomes inconsistent, and revenue leakage becomes inevitable [16].

For passengers, the consequences are immediate and personal. From long boarding times to arguments over change, every aspect of their travel is slowed down or complicated. Worse still is the erosion of trust: without a reliable ticketing system, commuters often feel they are being taken advantage of or that their complaints will go unheard. As cities grow and transportation needs evolve, this outdated model is no longer viable. A digital-first solution is not just a luxury - it is a national need [17].

### 1.2.2 Operational Challenges in the Existing System

The bus fare collection system in Sri Lanka presents a multitude of inefficiencies that directly impact both the user experience and the operational reliability of the transport network. These problems can be broken down into four main categories:

**A. Manual Labor Dependency**

The entire fare process is built on human effort. Conductors are expected to:

- Remember fare rates for multiple routes
- Calculate changes manually
- Keep a record of issued tickets (if at all)
- Manage boarding flow while collecting money

During rush hours, this system breaks down. Mistakes become common. Delays frustrate passengers and cause bottlenecks. Conductors may unintentionally overcharge or undercharge due to stress or lack of time. There is also the human tendency to cut corners - some conductors intentionally skip issuing tickets to pocket cash, especially when routes are busy, and oversight is low. This lack of automation breeds inconsistency and corruption [18].

**B. No Transaction Proof**

A, the major operational blind spot, is the lack of proof for most ticket sales. Paper tickets, when issued, often contain minimal information - no timestamp, no passenger ID, and no digital trace. In many cases, no ticket is issued at all. Passengers then have no evidence of payment, while authorities have no way to verify how many passengers travel on a given route. This opens the door to passenger exploitation, revenue underreporting, and dispute escalation [19].

**C. Unstandardized Fare Application**

Fare inconsistencies are one of the biggest complaints from passengers. While SLTB publishes guidelines:

• Conductors sometimes round fares up or down depending on the situation

• Private operators often deviate from published fare tables

• Concessions for students, elderly people, or differently abled passengers are poorly enforced

This lack of fare standardization damages public perception. Passengers feel cheated or discriminated against, and many grow disillusioned with public transport altogether [20].

**D. No Audit Trail**

In any service industry, auditing is essential for accountability. Yet, the current fare system provides no meaningful way to track performance or revenue. Bus owners and SLTB officials often must rely on guesswork or self-reported logs. Without automated data collection or analytics, authorities cannot:

• Detect revenue leakage

• Track bus performance by time, route, or region

• Evaluate conductor efficiency

• Forecast demand or optimize routes

This absence of data locks the system into a cycle of underperformance and underinvestment [21].

### 1.2.3 Passenger Behavior and Trust Issues

One of the most overlooked aspects of public service design is the emotional and psychological state of its users. Public transportation, being a daily necessity, must foster trust, predictability, and fairness. However, in Sri Lanka, the inconsistencies of the current ticketing system have led to deep-rooted passenger dissatisfaction.

Passengers often describe feelings:

- **Vulnerable**, because there's no proof of payment if they're accused of evading fare

- **Disrespected**, when conductors overcharge or fail to issue tickets
- **Powerless**, when they cannot report misconduct or resolve disputes
- **Disengaged**, because there's no reward for frequent, loyal usage

These emotional responses are not trivial. They affect whether people choose to continue using public transport or look for alternatives - even if those alternatives are costlier or less convenient. The growing shift towards private vehicles, three-wheelers, or app-based rides is evidence that people are willing to pay more for systems that make them feel safe, valued, and in control.

The proposed smart ticketing system helps rebuild that trust by offering:

- Verifiable digital receipts
- Real-time fare confirmation
- Automatic enforcement of discounts and entitlements
- A loyalty program that recognizes regular users

To better understand these problems from a user point of view, a survey was conducted with 81 respondents from diverse travel backgrounds. The results clearly highlighted both the frequency of public transport usage and the preferred mode of transport, which helped guide the design of this system.

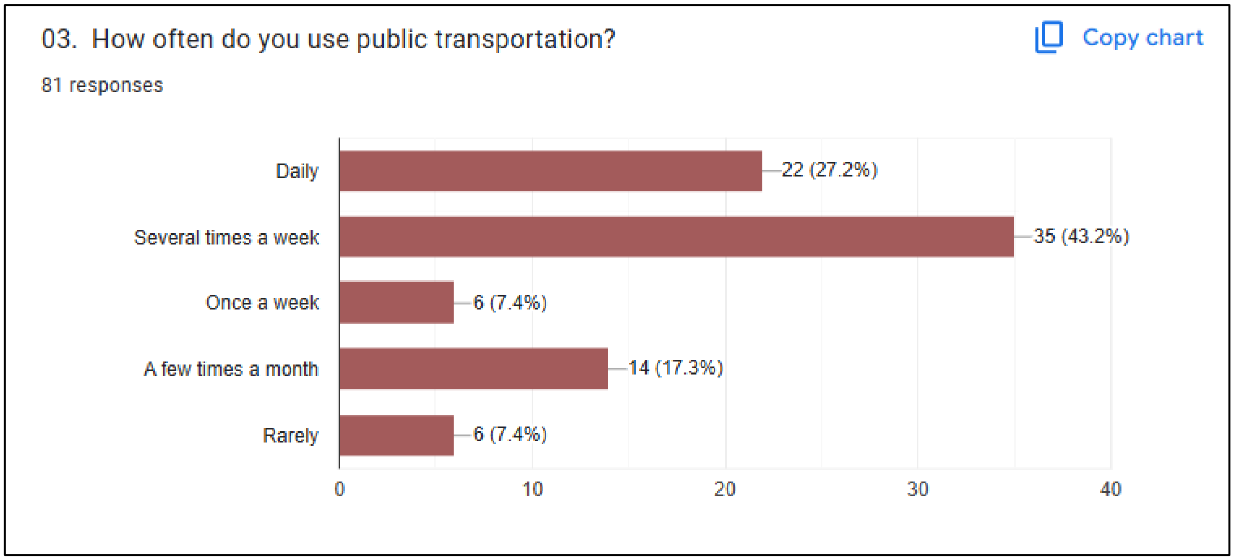



*Figure 1-1 : Survey About the Using Public Transportation*

As shown in the chart above:

- 43.2% of users stated they use public transport several times a week.
- 27.2% reported daily usage.
- Another 17.3% travel a few times a month.
- Only a small percentage (7.4% each) use it once a week or rarely.

This data indicates that 70%+ of respondents rely on public transport frequently, which strengthens the case for improving the ticketing system to save time and reduce daily frustration. The more often someone uses public transport, the more they are affected by its inefficiencies.

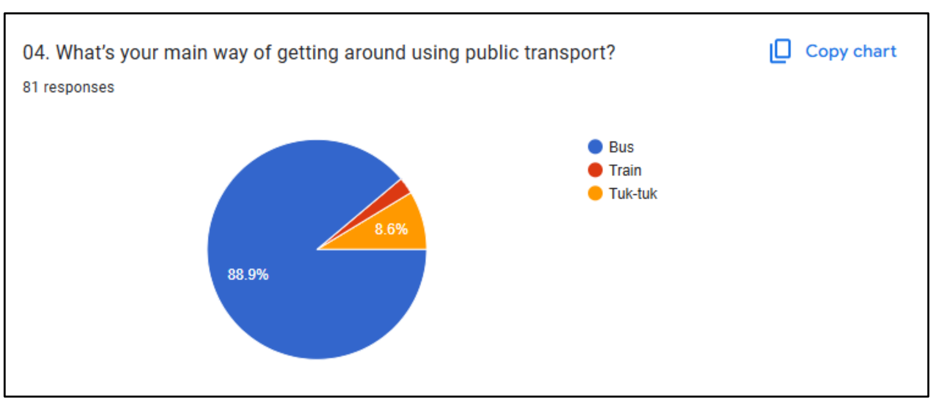



*Figure 1-2 : Survey About the Usage of Public Transportation*

When asked about their main mode of public transport:

- A dominant 88.9% reported using buses.
- 8.6% use tuk-tuks occasionally.
- A very small minority depends on trains.

This confirms that **buses** are the primary focus for any system improvement. Enhancing the bus ticketing experience will have the most significant impact on the largest group of users.

### 1.2.4 Behavioral Economics: Why Fare Evasion Happens

Fare evasion is frequently treated as a problem of morality or discipline**.** However, behavioral economics suggests a different view - that people's willingness to follow rules is heavily influenced by their perception of fairness, transparency, and enforcement.

In the current Sri Lankan system, fare evasion is easy and emotionally justified:

• If a conductor doesn't give a ticket, the passenger assumes it's okay to underpay next time.

• If a fare seems higher than expected, passengers feel entitled to "adjust" their payment later.

• If change is not returned correctly, people don't feel morally obligated to be honest in future journeys.

In behavioral terms, the "psychological cost of cheating" is reduced when the system is seen as corrupt or inconsistent [22].

The proposed digital system flips that incentive:

• NFC ensures passengers can't board without validation

• Blockchain logs every transaction and eliminates disputes

• Passengers receive a digital QR or app confirmation showing fare, time, and balance

• Conductors have no manual control over fare collection

With these mechanisms, the cost of fare evasion becomes immediate and traceable, discouraging dishonest behavior not through fear, but through clarity [23].

### 1.2.5 Digital Inclusion and Accessibility Considerations

Digital transformation often risks excluding those who lack access to technology - especially in developing countries. However, the smart ticketing system proposed in this project was intentionally designed for inclusivity.

It avoids depending solely on smartphones or internet access. Instead, it supports:

- **Simple NFC cards** are used by children, elders, and illiterate users
- **Offline verification**, enabling use in remote or low-connectivity areas
- **Rechargeable card systems** that don't require bank accounts or credit cards
- **Physical top-up counters**, ensuring those without mobile apps are not left out

This ensures **universal access**. The transition to digital fare collection is not limited to the tech-savvy, but open to every Sri Lankan citizen - regardless of age, income, or digital literacy.

### 1.2.6 Legislative Alignment – SLTB Act, Section 26

The Sri Lanka Transport Board Act (No. 27 of 2005) establishes a set of regulations and offences concerning ticketing practices, including:

- Fare evasion
- Failing to retain or produce a ticket
- Fraudulent reuse or resale of tickets

While these rules are comprehensive on paper, enforcement is weak in practice. Manual systems provide no reliable evidence to prove that an offence has occurred. Disputes often become word-against-word situations.

The proposed system provides built-in legal compliance:

- Every journey is digitally logged and uniquely tied to the user’s card
- Conductors can validate tickets on the spot using handheld readers
- QR codes or mobile confirmations act as irrefutable proof of payment

This not only supports existing laws but also enhances their enforceability - making the legal system more efficient, fair, and transparent.

### 1.2.7 Missed Economic Potential in the Current Model

The inefficiencies of the current system are not just operational - they are financial liabilities on a national scale. Fare leakage, underreporting, and manual processing cost the country hundreds of millions of rupees annually.

Example: If a bus earns Rs. 10,000 per day, and even 5% is unreported due to conductor error or evasion, that’s Rs. 500 lost per day. Across 5,000 buses, this becomes Rs. 2.5 million per day, or Rs. 912 million per year.

This is money that could fund:

• New low-emission buses

• Better bus stops and signage

• Salaries and training for transport workers

• Upgrades to maintenance fleets

• Subsidized fares for students and elders

A digital ticketing system closes revenue gaps, enabling the government and private operators to reinvest in the system, creating a positive economic feedback loop [24].

### 1.2.8 International Comparisons and Local Readiness

Countries like India, Kenya, and Indonesia have proven that smart ticketing systems can thrive in developing economies when designed appropriately. They have tackled issues of inclusion, corruption, and enforcement using tap cards, SMS codes, and QR-based payment models.

Sri Lanka is not behind in capability:

• Internet usage has risen rapidly in both urban and rural areas

• Smartphone ownership is growing steadily

• Mobile payment apps (e.g., eZCash, FriMi) have gained popularity

• QR payments are accepted in shops, restaurants, and even tuk-tuks

A smart transport system would leverage this digital maturity to create something that is scalable, modular, and future proof [25].

### 1.2.9 Data-Driven Governance and Urban Planning

One of the biggest unseen benefits of digital fare collection is the data it generates.

When every ticket is logged:

- Planners know which routes are busiest
- Buses can be scheduled based on demand
- Peak-hour promotions or crowd-splitting can be tested
- Low-demand routes can be subsidized or improved

This enables adaptive public transport, responsive to the real, on-the-ground needs of citizens. Cities can invest where it matters, reduce inefficiencies, and evolve the transport network with evidence-based decisions, not outdated estimations.

## 1.3 Research Gap

The application of modern technologies like Near Field Communication (NFC) and blockchain in public transport systems has been widely researched and implemented in countries like India, Denmark, and Singapore. However, in the Sri Lankan context, most implementations remain theoretical, limited to small-scale pilots, or designed without real consideration of local constraints and user behavior.

While the reviewed literature does explore promising approaches, none of the solutions have been able to combine cost-efficiency, user-friendliness, scalability, and legal compliance in a single system tailored to Sri Lanka's public bus transportation network.

| **Aspect** | **Jayalath et al. [26]** | **Dhule et al. [27]** | **Survey-Based Models [28]** | **Proposed System** |
|---|---|---|---|---|
| **Technology Used** | ✓ | ✓ | ✓ | ✓ |
| **Local Relevance to Sri Lanka** | ✓ | ✗ | ✗ | ✓ |
| **Offline Functionality** | ✗ | ✗ | ✗ | ✓ |
| **Passenger-Centric Features** | ✗ | ✗ | ✗ | ✓ |
| **SLTB Legal Compliance (Section 26)** | ✗ | ✗ | ✗ | ✓ |
| **End-to-End Architecture** | ✗ | ✗ | ✗ | ✓ |
| **Fraud Prevention** | ✓ | ✗ | ✗ | ✓ |
| **Ease of Use (Low-tech Users)** | ✗ | ✗ | ✗ | ✓ |
| **Rewards / Category Discounts** | ✗ | ✗ | ✗ | ✓ |

*Table 1.1 : Research Gap Comparison*

### 1.3.1 Identified Gaps in Literature

**1. Partial Systems, Not Full Ecosystems**

Most papers only focus on one piece of the puzzle - such as using blockchain for secure transactions or using NFC to replace paper tickets. Very few bring everything together into a single, coherent, and user-friendly ticketing system that handles transactions, verification, feedback, security, and reward programs.

**2. Poor Adaptability to Sri Lankan Context**

Systems developed in countries like India and Denmark assume that most users own smartphones, can access high-speed internet, or are familiar with mobile payment applications. In contrast, many Sri Lankan passengers rely on basic mobile phones or prefer physical NFC cards, especially in rural areas. Prior models fail to account for this digital divide.

**3. Lack of Legal Alignment and Enforceability**

The SLTB Act No. 27 of 2005 clearly requires [29] those passengers:

- Retain a ticket
- Present proof of fare payment
- Be penalized for fare evasion or fraudulent travel

However, systems like the one in Dhule's paper do not ensure compliance with such laws. Your system, by offering digitally recorded, immutable transactions, provides stronger support for enforcement and regulation.

**4. No Focus on Passenger Trust and Experience**

Many systems treat the user as just a data point. There is no focus on earning passenger trust through transparency, flexibility, or engagement. In contrast, your proposed system incorporates:

- Clear pricing feedback
- Loyalty rewards
- Easy digital/physical card switching
- Receipt-based proof

This builds confidence and encourages adoption, which is crucial for any public-sector digital rollout.

### 1.4 Research Problem

In Sri Lanka, buses are more than just a means of transportation, they're a part of daily life for millions. For students going to school, workers commuting to offices, and rural residents reaching cities, public buses are the most affordable and widely used option. Despite their importance, the ticketing experience on these buses has remained largely unchanged for decades, and it continues to cause real problems for passengers and conductors alike.

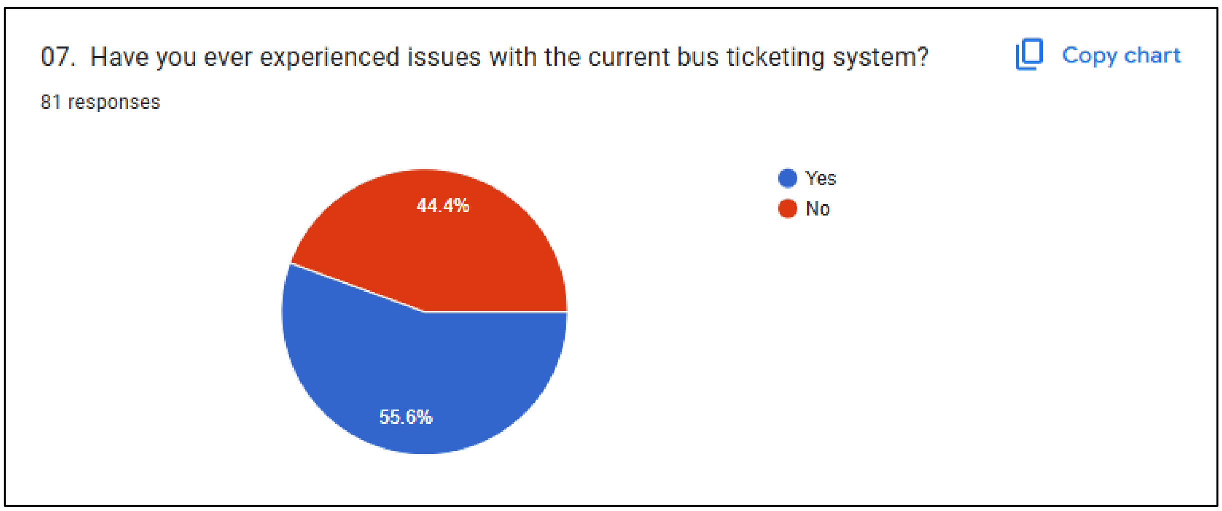



*Figure 1-3 : Survey About Current Ticketing*

Out of a total of 81 respondents, a clear majority of 55.6% (45 people) answered "Yes", confirming that they had encountered one or more issues while using the existing manual ticketing process. Meanwhile, 44.4% (36 people) responded "No", indicating a fairly significant portion of passengers still experience smooth transactions—but not without concern.

This data clearly shows that more than half of the participants have faced difficulties, which aligns with other open-ended feedback gathered during the survey. Commonly mentioned problems included:

- Not receiving correct balance.
- Not being issued a ticket.
- Being overcharged.
- Slow boarding due to manual cash handling.

This chart reinforces the idea that the current system is inconsistent and unreliable for most users, and highlights the urgent need for a more modern, secure, and user-friendly ticketing solution. It also supports the direction of this research in exploring digital technologies like NFC and blockchain to address these issues directly.

One of the most frustrating issues for passengers is dealing with cash, especially when it comes to getting the right balance. Many riders have complained that conductors often don't return the correct change or avoid doing so entirely. During busy hours, it becomes harder to find coins or small notes, and conductors are often in a rush to keep the bus moving. As a result, passengers end up losing small amounts of money every day. While it might seem minor at first, these small losses add up over time and create a feeling of being cheated or ignored by the system.

Alongside this is the problem of ticketing inconsistency. It's common for conductors to collect fares without issuing a ticket. In some cases, this may be due to time constraints, but in others, it may be intentional. Without a physical or digital ticket, passengers have no proof of payment, and there's no accountability if they're overcharged. This also opens the door to revenue loss for transport providers, as money collected without a ticket may not be officially recorded.

Another major concern that passengers have raised is price inconsistency. There are many reports of different buses charging different amounts for the same distance. One passenger might pay 30 rupees, while another - on a different bus covering the same route might be asked for 40 or 50 rupees. With no clear standard or system to track fare pricing, this creates a sense of unfairness and confusion. People start to feel that they're being taken advantage of, especially when there's no transparency in how fares are calculated.

These problems are made worse by how long it takes to handle each transaction. Manual cash handling is slow, particularly when a bus is crowded. The conductor must ask for the fare, calculate the right amount, find change, issue a ticket (if at all), and then move to the next person all while the bus is moving and more passengers are trying to get on. This slows down the boarding process, creates delays, and causes stress for everyone involved. For a country that is steadily developing its infrastructure, these outdated processes hold the system back.

Beyond the technical issues, there’s also a lack of engagement and user-friendly features in the current setup. Public transport in many parts of the world now offers digital tools like fare tracking, top-up options, travel history, and even reward points for frequent travelers. Some systems offer discounted pricing for seniors, students, and low-income groups, making the system more inclusive. In Sri Lanka, however, the ticketing system is still completely manual and doesn’t offer any of these features. There's no incentive for regular users, no personalization, and no effort to make the system more convenient or rewarding to use.

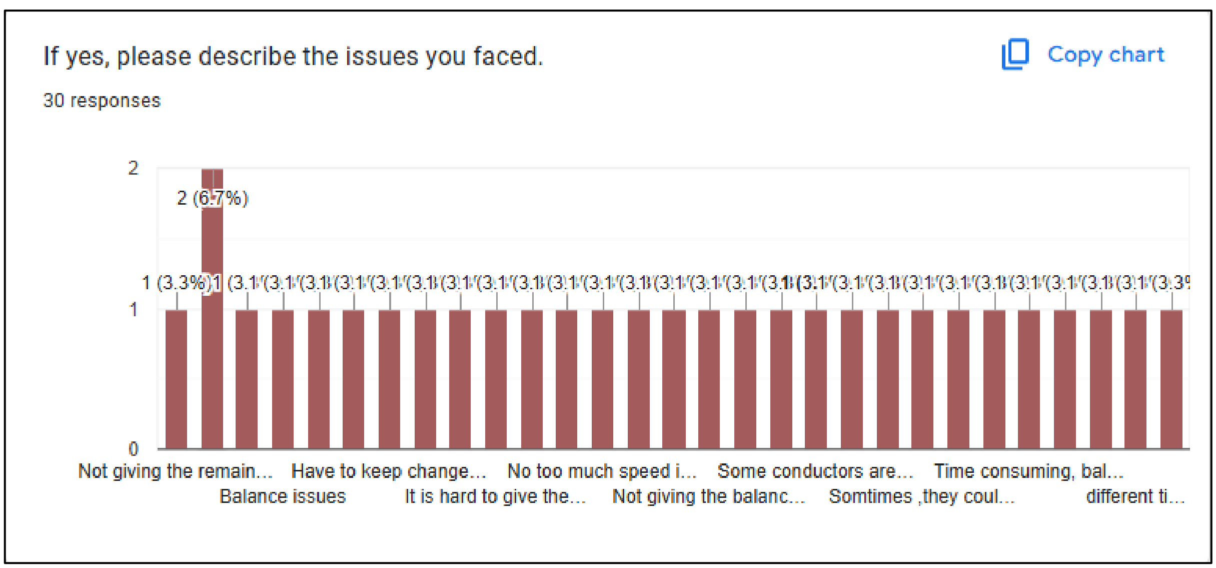



*Figure 1-4 : Passenger Feedback*

These aren't just assumptions they're based on real feedback from surveys and open-ended responses collected during this research. Some of the comments from regular bus users include:

- "I don't get change often, especially during rush hours."
- "They charge different prices for the same distance."
- "Sometimes I pay, and they don't give a ticket."
- "Paying with coins is annoying. It takes too long."
- "It's stressful to argue over balance when the bus is full."

These statements make it clear that the current system is not only inefficient but also stressful and unfair for the people who rely on it every day.

What Sri Lanka needs is a system that makes ticketing easier, faster, and more reliable. This is where technology can offer a solution. By introducing NFC (Near Field Communication) technology, passengers could simply tap a card or smartphone to pay their fare instantly and without handling any cash. No need for coins, no waiting for change, and no misunderstandings. Alongside this, blockchain technology could be used to securely record each transaction. Blockchain is known for its transparency and security, it ensures that once a payment is made, it cannot be altered, lost, or faked. Every ticket purchase would be recorded permanently, and both passengers and transport authorities could verify transactions easily.

When these two technologies are combined, they can provide a full solution to the issues currently faced. Passengers would benefit from faster boarding, digital receipts, and the confidence that their money is handled fairly. Transport providers would benefit from better revenue tracking, fewer disputes, and increased trust in the system.

This kind of system could also introduce features like reward programs for frequent users, discounts based on passenger type (like students or seniors), and mobile integration that lets users check balances, reload cards, or view ride history all things that make using public transport more pleasant and worthwhile.

The goal of this research is to explore and design a practical, user-friendly digital ticketing solution that brings together NFC and blockchain in a way that directly solves the most common complaints from Sri Lankan bus passengers. It aims to create a system that is fast, fair, secure, and easy to use for both the public and the people who keep the buses running.

## 1.5 Research Objective

### 1.5.1 Main Objective

To design and implement an integrated digital bus ticketing system for Sri Lanka's public transportation using Near Field Communication (NFC) and blockchain technologies, aimed at solving real-world inefficiencies in the manual fare collection process while enhancing security, speed, accountability, and user experience.

This objective reflects the core goal of your research: to modernize Sri Lanka's outdated, cash-dependent bus fare system. Instead of focusing only on technological novelty, this objective centers on practical, people-first improvements. By replacing slow, error-prone manual methods with secure and intelligent digital systems, the research aims to directly address everyday passenger complaints such as delays, missing change, unissued tickets, and fare inconsistencies.

The system leverages NFC technology to make payments seamless and contactless, allowing passengers to tap a card or smartphone instead of handing over coins. At the same time, blockchain ensures that every transaction is recorded permanently and transparently, preventing fraud, building trust, and increasing efficiency for both passengers and operators. This holistic approach brings together convenience, transparency, and security - fundamental pillars of a future-ready public transport system.

### 1.5.2 Sub Objectives

**1. To introduce NFC-based contactless payment for faster and more convenient fare collection**

In the current cash-based system, boarding takes time. Conductors must manually collect cash, issue tickets, and return change - this creates long queues, especially during peak hours. NFC technology addresses this by allowing passengers to simply "tap and go." This is not only faster but also more hygienic and efficient.

This sub-objective involves:

- Developing a contactless NFC payment interface that works with smartcards or mobile phones.
- Deploying NFC readers in buses that sync with the back-end system in real-time.
- Reducing dependency on cash and small change, making boarding smoother for passengers and easier for conductors.

By simplifying the payment process, this technology helps improve punctuality, reduces passenger stress, and increases overall satisfaction.

**2. To integrate blockchain technology for secure, transparent, and tamper-proof transaction recording**

Blockchain offers a powerful solution to long-standing issues of fare fraud, missing revenue, and trust deficits in the current system. With blockchain, every payment is securely recorded on a decentralized ledger. This makes it impossible to alter transaction history providing transparency for passengers, operators, and regulators.

This sub-objective includes:

- Implementing blockchain to track each ticketing transaction in real-time.
- Ensuring each passenger payment is stored securely with a timestamp and transaction ID.

- Making records accessible for verification and audit purposes, reducing disputes and fraud.

This builds trust between the public and transport providers and helps in accurately analyzing fare collection data over time.

**3. To ensure real-time transaction verification for both conductors and passengers**

One major issue in the current system is the lack of immediate proof of payment. Passengers sometimes pay but receive no ticket, and conductors have no instant method to verify who has paid.

With real-time processing:

- Each NFC payment is immediately verified and confirmed through the system.
- A QR code or digital receipt is generated for the passenger.
- Conductors receive a notification confirming the payment - either on a handheld device or dashboard.

This eliminates disputes, builds transparency, and helps ensure smooth and quick boarding even during high-traffic hours.

**4. To implement passenger categorization and dynamic fare schemes**

Different passengers have different needs. Students, seniors, and frequent travelers should not be treated the same as occasional riders. This sub-objective focuses on enabling fair, category-based pricing through digital profiling.

It includes:

- Allowing passengers to register under specific categories (e.g., student, senior citizen).
- Automatically applying fare discounts or special pricing during transactions based on category.
- Supporting social equity by offering reduced fares to those who need it most.

This makes the system more inclusive, user-friendly, and reflective of real-world socioeconomic diversity.

**5. To design and deploy a loyalty rewards system to encourage frequent use of public transport**

Passenger engagement is currently non-existent in the public transport system. People pay and ride - nothing more. But with loyalty rewards, transport authorities can build a relationship with riders and encourage more frequent use.

This sub-objective involves:

- Creating a point-based system where passengers earn rewards with each ride.
- Enabling passengers to redeem points for discounts, free rides, or promotional benefits.
- Increasing daily ridership by turning public transport into a rewarding experience.

This not only boosts ridership but also fosters a long-term shift away from private vehicle use - benefiting urban congestion and the environment.

**6. To store and manage user profiles and transaction history securely**

Passenger data - including ride history, loyalty activity, and user credentials - must be securely handled. With increasing concerns about data privacy and digital fraud, it’s crucial that the system maintains high security standards.

These sub-objective covers:

- Storing user information and transaction data in a secure NoSQL database (e.g., MongoDB).
- Implementing AES encryption and JWT-based user authentication for protection.
- Ensuring compliance with privacy standards and data protection regulations.

This reinforces public confidence and ensures that digital systems do not compromise privacy.

**7. To evaluate system usability, performance, and acceptance through pilot testing**

No solution is complete without testing it in the real world. This sub-objective ensures that the proposed system is evaluated for technical reliability and human usability.
It includes:

- Launching a pilot version of the system on selected bus routes.
- Collecting real-time feedback from passengers, conductors, and administrators.
- Measuring key metrics like transaction time, system uptime, error rates, and user satisfaction.
- Making necessary refinements before full-scale implementation.

This ensures that the final solution is not just technically sound but also practical, user-approved, and ready for nationwide rollout.

# 2. METHODOLOGY

## 2.1 Materials and methods

### 2.1.1 Problem Statement

Sri Lanka's public bus transportation system plays a critical role in the daily mobility of millions of citizens, yet it remains largely burdened by outdated, inefficient, and error-prone ticketing mechanisms. The predominant reliance on cash-based payments, manual fare collection, and paper-based ticketing not only slows down the boarding process but also contributes to frequent operational delays, human errors, and financial discrepancies. Passengers often face frustrations such as incorrect change, inconsistent fare calculations, missing tickets, and lack of transparency regarding their transactions.

From the operator's side, these challenges result in revenue leakage, inability to enforce accountability, and increasing difficulty in maintaining operational efficiency during peak travel hours. Furthermore, manual ticketing lacks the ability to record and audit transactions in real-time, making it nearly impossible to verify authenticity or trace fraudulent activities.

Despite global advancements in digital fare collection - such as NFC (Near Field Communication) technology and blockchain-based financial systems - Sri Lanka's transport sector has yet to integrate these technologies into a unified, scalable platform. Most previous attempts at modernization either focus solely on NFC for convenience or blockchain for security, failing to address the holistic needs of a modern transport ecosystem which also includes real-time updates, user engagement, and personalized services.

Moreover, the existing system lacks incentives for passengers to regularly use public transportation. There is no built-in reward mechanism, no support for recognizing different passenger categories (like students or senior citizens), and no system to build long-term trust through transaction visibility or payment confirmation. This contributes to a lack of engagement and decreases public transport loyalty, especially among younger and tech-savvy commuters who expect seamless digital experiences.

Hence, there exists a clear need for a comprehensive, secure, and intelligent ticketing solution that not only modernizes fare collection but also enhances the entire passenger journey through personalized features and real-time data handling.

### 2.1.2 Architecture and Solution Diagram

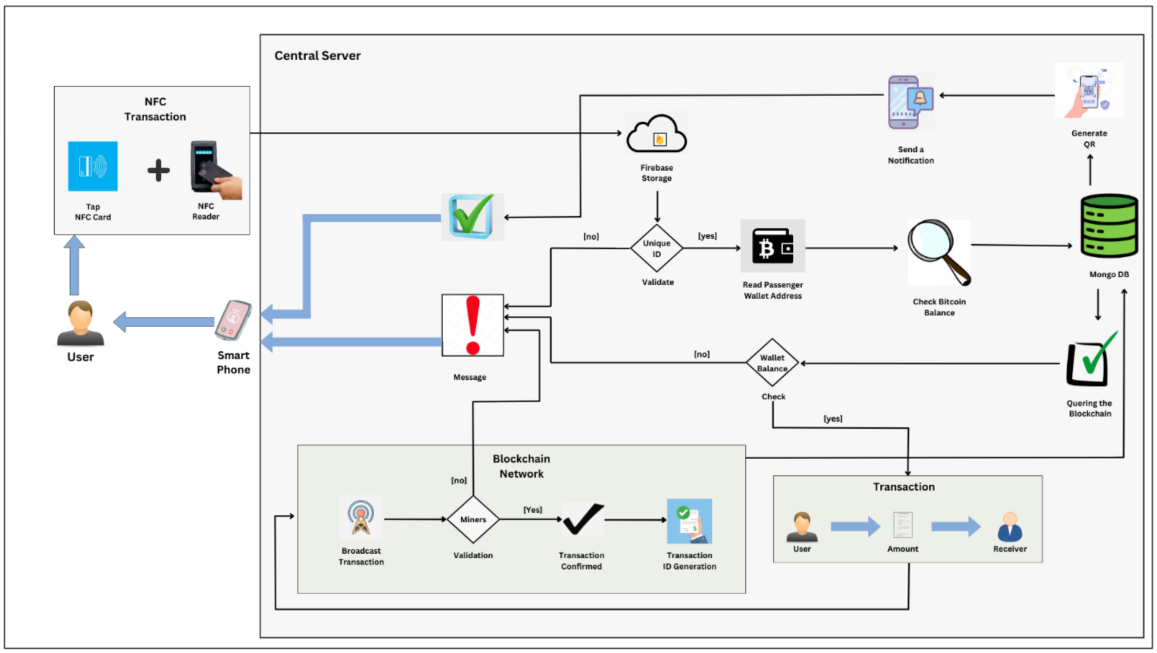



*Figure 2. 1 : Solution Diagram*

**1. The Gateway to Seamless Passenger Interaction**

The NFC (Near Field Communication) reader serves as the first point of interaction between the passenger and the smart ticketing system. As buses become more technologically integrated, the importance of fast, contactless, and frictionless entry becomes paramount. The NFC reader fulfills this role by acting as the digital handshake between the user and the system.

Installed near the entrance of the bus or at designated terminals, this device allows passengers to simply tap their NFC-enabled card or smartphone to begin a transaction. Each tap transmits a Unique Identifier (UID), which is then used to retrieve the user's digital wallet and personal information from the server. This UID is like a digital fingerprint - completely unique and tied to a secure database record.

By replacing cash handling and manual ticket issuing, the NFC reader drastically reduces boarding times. No more searching for coins, arguing about change, or waiting for printed tickets. The entire interaction takes less than two seconds, ensuring that even during rush hour, buses can operate with improved flow and minimal delay. Furthermore, the "tap-and-go" nature of NFC is intuitive, making it accessible even to passengers with limited technical knowledge.

In a broader sense, the NFC reader represents more than a payment device - it symbolizes a shift toward intelligent infrastructure, where data-driven, sensor-based interactions replace inefficient legacy systems.

**2. The Command Center of Smart Ticketing**

Once the UID is captured by the NFC reader, it is relayed to the **central server**, the brain of the entire operation. This component is built using the Django web framework, chosen for its security, scalability, and modular architecture. The central server handles all business logic - it is responsible for validating user data, computing fare costs, determining eligibility for discounts, and managing transaction workflow.

First, the server verifies whether the UID corresponds to a registered passenger. If the card is recognized, the system fetches the user's wallet details, travel category (student, adult, senior citizen), and ride history from the connected databases. Based on this, the system dynamically calculates the applicable fare. This fare is determined not only by the starting and ending destinations but also by any discount the user is entitled to.

The central server then orchestrates the next phase - broadcasting the transaction to the blockchain network for validation. Throughout this process, the server remains in constant communication with Firebase and MongoDB, making it the central node that connects all subsystems. It handles complex decision-making in milliseconds and ensures that every part of the system responds in sync.

As the logic controller, the server maintains not just operational efficiency but also data integrity, consistency, and real-time responsiveness - ensuring passengers experience a smooth and secure transaction every time.

### 3. The Digital Fortress of Trust

Perhaps the most revolutionary component of the system is the integration of blockchain technology, an immutable and decentralized digital ledger that guarantees security, transparency, and accountability.

When a fare is calculated and a transaction is initiated, it is sent to the blockchain for validation. This process involves broadcasting the transaction to a distributed network of miners or validators who confirm that the wallet has sufficient balance, and that the transaction request is legitimate. Once verified, the transaction is added to a new block and permanently recorded on the blockchain.

A unique Transaction ID (TXID) is then generated, acting as a digital receipt. This TXID is shared with the passengers and stored in the database, making every payment traceable and auditable. Unlike centralized databases that can be altered, deleted, or manipulated, blockchain ensures that once a transaction is recorded, it cannot be changed - eliminating fraud, double spending, and disputes.

In the context of public transport, this provides a level of security never seen. Conductors, operators, and government authorities can trust the data without question. Passengers, too, gain peace of mind knowing that their fare was received, recorded, and verifiable. In short, blockchain transforms what used to be a high-risk, cash-based system into a tamper-proof digital infrastructure.

### 4. Real-Time Connectivity for Instant Interactions

To achieve true real-time responsiveness, the system relies on Firebase, a cloud-based platform that acts as the real-time communication engine. Firebase enables the system to sync data across multiple devices and users instantaneously - from the NFC reader to the central server, the mobile app, and the conductor's dashboard.

As soon as a UID is tapped, Firebase checks the registration database to ensure the user is valid. Once the transaction is processed via blockchain, Firebase pushes live updates to all concerned parties. The conductor sees a green checkmark indicating successful payment; the passenger's app receives a QR code and digital confirmation. If any errors occur - such as an invalid UID or low balance - Firebase immediately notifies both ends.

Firebase eliminates delays and bottlenecks associated with traditional client-server polling mechanisms. It's not just fast; it's proactive - sending data changes the moment they happen. In public transportation, where every second matters, this instantaneous sync helps maintain schedule adherence, improves boarding speed, and ensures passengers aren't left waiting due to verification lags.

**5. The Scalable Memory Bank of the System**

Behind the scenes, all user and transaction data are securely stored in MongoDB, a NoSQL database designed for flexibility and high performance. Unlike relational databases that use rows and tables, MongoDB stores data in JSON-like documents, making it easier to manage complex, hierarchical information - such as user profiles, travel history, loyalty points, and transaction metadata.

MongoDB plays several key roles:

- Stores passenger details including category (student, senior), wallet address, and trip count.
- Records every transaction - time, location, fare, and TXID.
- Tracks reward points earned through the loyalty program and their redemption status.

Because MongoDB is schema-less, it can scale effortlessly as new features (like real-time bus tracking or trip history analytics) are introduced. It's built to handle massive volumes of data, making it ideal for a national transport system expected to process millions of transactions per week.

All sensitive data within MongoDB is encrypted using AES (Advanced Encryption Standard), adding a layer of robust security.

**6. The Data Guardian**

To ensure all user information remains confidential and protected from cyber threats, the system employs AES encryption, one of the most widely trusted encryption standards in the world. AES works by encoding data into a form that is unreadable without a special decryption key.

This encryption is applied to:

- Wallet information (such as blockchain private keys),
- UID mappings,
- Passenger names and contact details,
- Transaction and payment logs.

AES encryption operates in the background, invisible to the user, yet critically important for regulatory compliance and data safety. Even if an attacker gains access to the database, they cannot make sense of the encrypted data - making it useless without the key.

The integration of AES highlights the system's commitment to data privacy, user safety, and long-term trust.

**7. Bridging Digital Payments and Physical Proof**

Once a payment is successfully recorded on the blockchain, the system instantly generates a QR code that represents the transaction. This QR code acts as proof of payment and is displayed on the passenger's smartphone app or smart card interface.

Conductors scan this code using their own app to confirm the transaction. Since each QR contains the TXID, amount, and timestamp, it's both verifiable and tamper-proof. Even if the system temporarily loses internet connectivity, the QR can serve as local proof that will later sync with the blockchain once reconnected.

QR codes eliminate the need for printed tickets and receipts, simplifying fare inspection while reducing paper waste. It's a perfect example of how digital solutions can blend into traditional operational workflows without disruption.

**8. Empowering On-Ground Operations**

The conductor no longer needs to handle cash, count change, or issue paper tickets. Instead, they are equipped with a mobile dashboard - a lightweight app connected to Firebase that provides real-time updates on every passenger's transaction status.

This allows conductors to simply glance at their screen to confirm whether a passenger has paid. It also improves safety, as conductors can focus on monitoring bus occupancy and assisting passengers rather than managing physical money.

**9. Personalized Transportation**

To enhance passenger engagement, the system incorporates loyalty rewards and passenger categorization features. These go beyond basic fare collection - they aim to build relationships with users.

Passengers accumulate points based on how often they travel. These points can later be redeemed for free rides, discounts, or priority seating. The more they travel, the more they earn - incentivizing consistent use of public transport.

Categorization identifies users by type (e.g., student, elderly, frequent traveler). Based on their category, the system applies appropriate fare discounts and benefits automatically. For instance, a student tapping their NFC card is automatically charged a reduced fare - no questions asked, no manual verification.

This creates a fare, personalized, and passenger-first ecosystem.

### 2.1.3 Data Acquisition and processing

In the proposed blockchain-integrated smart ticketing system for Sri Lanka's public transportation, data acquisition and processing are at the core of system functionality. The system must capture, validate, process, and store multiple streams of data in real time - all while ensuring security, speed, and accuracy. The process begins the moment a passenger taps their NFC card or mobile device and continues until the transaction is securely recorded in the blockchain and internal databases.

### 1. Data Acquisition

The system captures multiple data points through different components at different layers:

| **Source** | **Data Captured** | **Purpose** |
|---|---|---|
| **NFC Reader** | UID (Unique Identifier) of the card | Identify the passenger |
| **Mobile App** | Journey details (from, to), category (student, senior, etc.) | Fare calculation |
| **Firebase** | User record validation | Ensures UID is registered |
| **MongoDB** | User profile & loyalty status | Personalized fare or reward point calculation |
| **Blockchain Wallet** | Wallet address & balance | Checks payment ability |
| **Transaction Logs** | Time, fair, TXID, QR data | For traceability & audit |

*Table 2. 1 : Points Through Different Components at Different Layers*

### 2. Data Processing Workflow

Once the system acquires data from the above sources, it follows a layered processing pipeline:

1. **UID Validation**
   When a card is tapped, the UID is sent to the Firebase backend where it is matched with registered users. If the UID is invalid or unregistered, the transaction halts.
2. **User & Fare Retrieval**
   If validated, MongoDB fetches the passenger's details including journey category

and past usage (used in loyalty scoring). The system calculates fares based on destination, user type, and discount eligibility.

3. **Wallet Balance Check**
   Using the wallet address tied to the UID, the central server queries the blockchain for the current balance. If insufficient, an error is returned and displayed.
4. **Blockchain Transaction Processing**
   If balance is sufficient, the fare is deducted from the wallet and the transaction is broadcast to the blockchain network. Upon successful validation, a TXID (Transaction ID) is generated and returned.
5. **QR Code Generation**
   A QR code is dynamically generated containing the TXID and fare info. This code acts as proof of payment and can be scanned by the conductor or inspectors.
6. **Data Storage and Loyalty Update**
   The system logs the transaction in MongoDB along with the timestamp, TXID, UID, journey info, and QR string. If the passenger is part of the loyalty program, the system also updates their points.
7. **Real-Time Communication**
   Firebase sends transaction status updates to the mobile app and conductor interface - reducing boarding time and eliminating the need for manual ticket inspection.
8. **Data Flow Diagram**

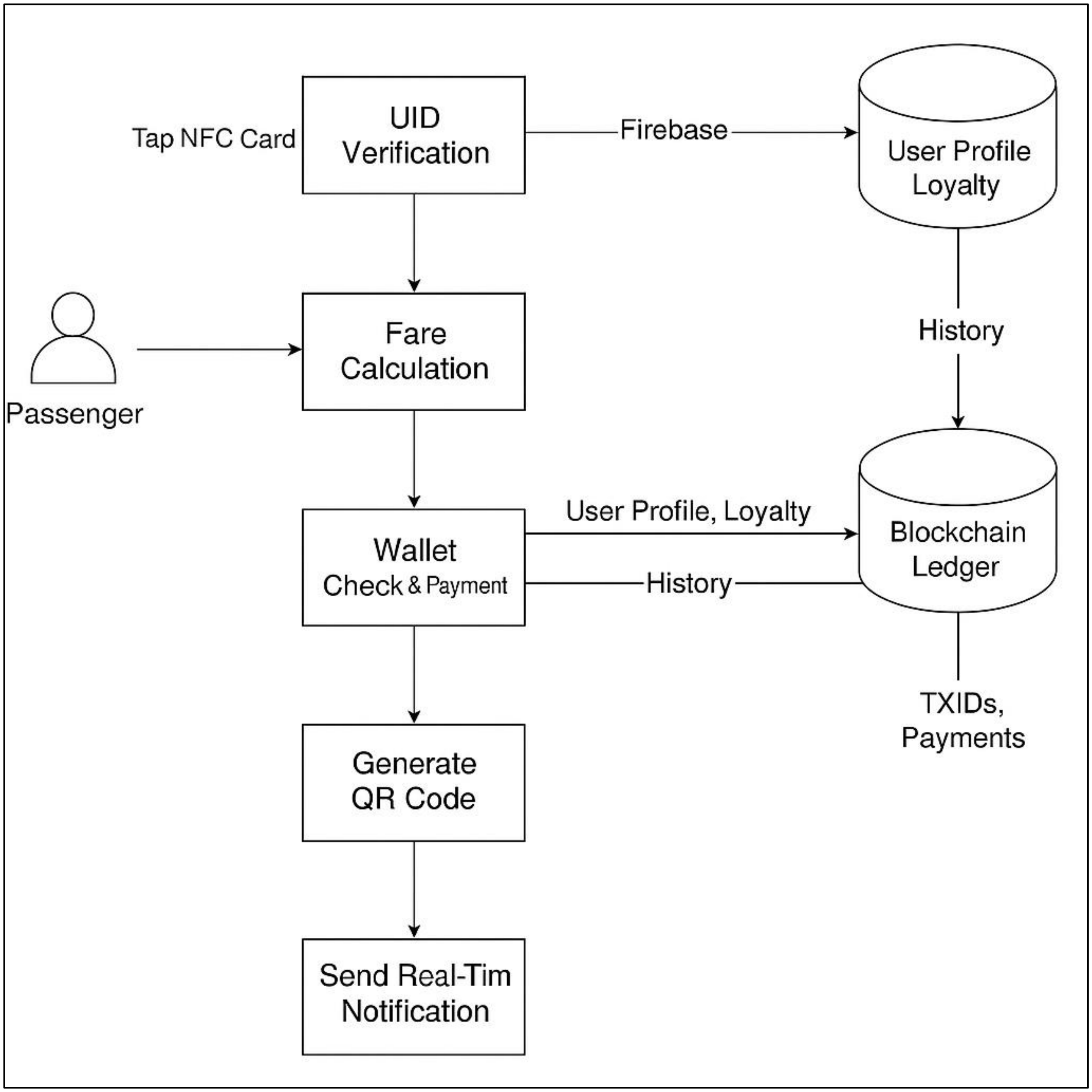



*Figure 2. 2 : Data Flow Diagram*

### 2.1.4 Identification

A secure and efficient identification process is foundational to the functionality of any smart ticketing system. In the proposed NFC and blockchain-integrated bus ticketing system, user identification is performed digitally and automatically using NFC-enabled devices. Each user is assigned a Unique Identifier (UID) which is stored securely and linked to their digital wallet, user category (e.g., student, senior citizen), and travel history. This process ensures not only transaction traceability and security, but also enables **personalization**, such as offering discounts to eligible passenger categories and applying loyalty rewards based on travel frequency.

### 1. NFC-Based User Identification

When a passenger taps their NFC card or smartphone at the reader, the device captures a Unique Identifier (UID). This UID is a globally unique hexadecimal string that acts as the user's system identity.

Once scanned, the UID is sent to Firebase, where it is matched against the registered users in the system. If the UID is recognized, the system proceeds to retrieve:

- The user's blockchain wallet address,
- Travel category (student, adult, senior),
- Reward points and past travel history (from MongoDB).

If the UID is not recognized, the passenger is prompted to register their card, preventing unauthorized access and fraudulent activity.

### 2. Identity Components and Their Roles

| **Component** | **Description** | **Source** |
|---|---|---|
| **UID** | A unique code embedded in each NFC card or phone used for identification. | NFC Reader |
| **Passenger Category** | Classification such as student, elderly, or frequent traveler. | MongoDB |
| **Wallet Address** | A blockchain address linked to the passenger's UID for secure payment. | Blockchain |
| **Reward Profile** | Points earned based on trip history and frequency. | MongoDB |

| | | |
|---|---|---|
| **Authentication Logs** | Records of tap time, location, and transaction success/failure. | Firebase Logs |

*Table 2. 2 : Identity Components and Their Roles*

**3. Benefits of the Identification System**

- **Fast & Contactless**: Identification happens within 1–2 seconds of tapping the card.
- **Personalized**: Discounts and category-specific fares are applied automatically.
- **Fraud Prevention**: Unauthorized cards are flagged immediately.
- **Secure**: Wallets and identities are encrypted using AES.
- **Trackable**: UID logs are permanently stored and linked to blockchain TXIDs.

**4. Supporting Research & Technologies**

According to Dhule (2018), NFC-based transit systems reduce the time per transaction significantly while providing a secure method of identifying and validating passengers in real time. Similarly, Jayalath et al. (2020) emphasize that blockchain integration enhances transparency in user authentication and helps prevent tampering or data manipulation.

Using a decentralized blockchain ledger for wallet linkage means that every user's identity is tied to an immutable transaction record, increasing system-wide trust and minimizing the risk of impersonation or fare evasion.

## 5. Identification Flowchart

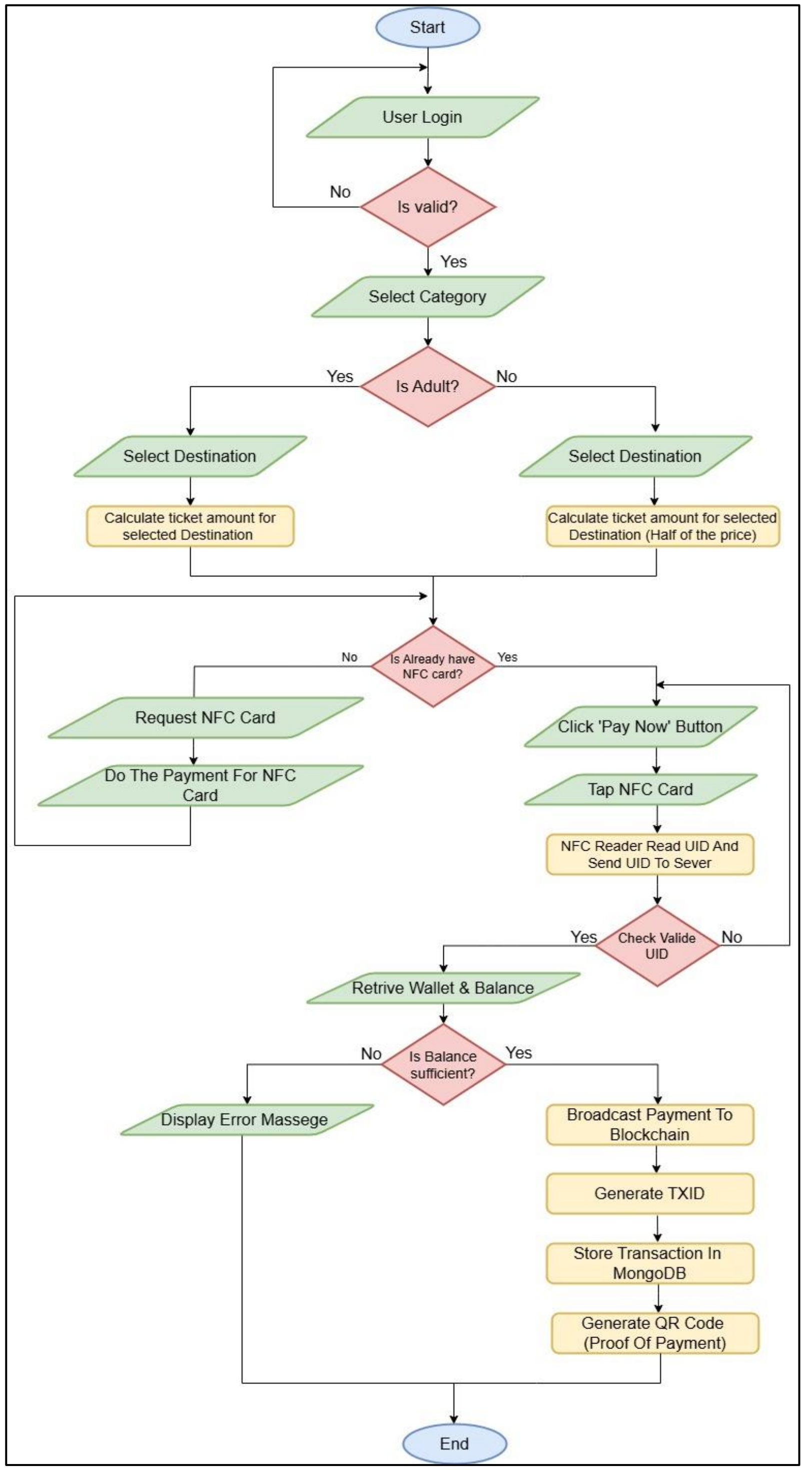



*Figure 2. 3 : System Flow Chart*

The flowchart illustrates the complete ticketing workflow of the proposed NFC and blockchain-integrated smart transportation system. It begins when a user logs into the system through the mobile application or public kiosk. Upon logging in, the system immediately validates the user's credentials against existing records. If the login is unsuccessful, the system prompts the user to reattempt, ensuring that only registered and authenticated individuals proceed.

Once verified, the user is guided to select their passenger category - such as adult, student, or senior citizen. This step is critical because different categories are associated with different fare rules. For instance, adult passengers are charged the full fare, whereas concessionary passengers such as students and elders may receive discounts, typically calculated as half the regular price.

After selecting the category, the user proceeds to choose the destination. The system then calculates the fare, accordingly, adjusting for both the journey distance and the selected passenger category. This ensures that pricing remains fair and transparent.

The system then checks whether the user already possesses an NFC card. If the passenger does not have one, they are prompted to request a card and make the necessary payment for card issuance. If the user already holds a registered NFC card, they can proceed by tapping the card on the reader.

Once the NFC card is tapped, the system captures the card’s unique identifier (UID) and sends it to the backend server (Firebase) for validation. This step ensures that the card is authentic and tied to a registered account. If the UID is invalid, the system displays an appropriate error message, preventing unauthorized use.

For valid UIDs, the system retrieves the user’s linked wallet address and current balance. It then checks whether the balance is sufficient to cover the fare. If not, an error is displayed, prompting the user to top up their wallet. If the balance is sufficient, the system processes the payment by broadcasting the transaction to the blockchain network.

The blockchain verifies and confirms the transaction, ensuring immutability and transparency. A unique transaction ID (TXID) is generated as proof of the completed payment. This TXID, along with all transaction metadata, is stored securely in MongoDB.

A dynamic QR code is then generated and provided to the user. This QR code acts as a digital ticket and proof of payment, which can be scanned by bus conductors or inspectors in real time.

This entire workflow ensures speed, accuracy, and integrity in fare management while offering passengers seamless, contactless, and secure travel experience.

### 2.1.5 How Blockchain Work

Blockchain technology is at the heart of digital transformation in secure data management and decentralized finance. Originally designed to support cryptocurrencies like Bitcoin, blockchain has rapidly evolved into a versatile infrastructure for secure, transparent, and trustless systems. In the context of smart ticketing systems for public transport, it acts as the tamper-proof foundation for fare verification, payment tracking, and transaction auditing.

This section explores blockchain from a computational, cryptographic, and mathematical perspective, explaining how it works and how it integrates with systems like your proposed solution.

#### 1. Conceptual Overview: What is a Blockchain?

A blockchain is a distributed, append-only data structure organized as a linked list of blocks. Each block contains a set of validated transactions, a cryptographic hash of the previous block, and a timestamp. The design ensures that any attempt to tamper with historical data becomes computationally infeasible.

#### 2. The Blockchain Transaction Lifecycle

**Step 1: Transaction Initialization**

A passenger initiates a fare payment. The transaction includes:

- Public wallet address (from UID),
- Fare amount,
- Transaction metadata.

The digital signature confirms the passenger's identity using their private key, mathematically secured via elliptic curve cryptography (ECC).

**Step 2: Transaction Broadcasting**

The transaction is broadcast to the network of validator nodes. These nodes independently verify their legitimacy

**Step 3: Transaction Validation & Block Creation**

Validators confirm:

- Sufficient balance exists,
- No double-spending,
- Signature is valid.

Once verified, the transaction is added to a pending block.

**Step 4: Consensus Mechanism**

To ensure network-wide agreement, a consensus algorithm is applied. Common ones include:

| **Algorithm** | **Principle** | **Use Case** |
|---|---|---|
| **Proof of Work (PoW)** | Solve cryptographic puzzles to add blocks | Bitcoin |
| **Proof of Stake (PoS)** | Validator chosen based on their stake in the network | Ethereum 2.0 |
| **Practical Byzantine Fault Tolerance (PBFT)** | Used in private blockchains to resist malicious actors | Enterprise systems |

*Table 2. 3 : Consensus Mechanism*

For ticketing systems, PBFT **or** PoS are ideal due to their speed and low energy usage.

**Step 5: Block Confirmation**

Once consensus is reached, the block is appended to the blockchain. All transactions within it are finalized and permanently stored.

## 3. Mathematics Behind Blockchain Security

Blockchain's security comes from cryptographic hash functions, asymmetric key cryptography, and game theory.

### Hash Functions

A hash function H(x)H(x)H(x) maps input xxx to a fixed-length output such that:

- It is deterministic,
- It is non-reversible (one-way function),
- It exhibits the avalanche effect (small input changes produce major output changes).

### Digital Signatures (ECC)

Digital signatures in blockchain rely on Elliptic Curve Cryptography:

P=k·GP = k \cdot GP=k·G

Where:

- GGG is the base point on the curve,
- kkk is the private key,
- PPP is the public key.

Only someone with the correct private key can generate a valid signature. The system verifies signatures using this public key, securing user authentication.

## 4. Why Blockchain Works for Smart Ticketing

| Requirement | Traditional System | Blockchain System |
|---|---|---|
| Data Integrity | Susceptible to tampering | Immutably recorded |
| Fraud Prevention | Prone to forgery or duplication | Prevents double-spending |
| Transparency | Difficult to trace | Publicly verifiable via TXID |
| Real-Time Verification | Requires manual checks | Near-instant validation |
| Intermediary Dependency | Middlemen needed | Peer-to-peer |

*Table 2. 4 : Blockchain Works for Smart Ticketing*

Blockchain enables a trustless environment, which is ideal for public systems where users do not necessarily trust each other - but must rely on the system's fairness.

**5. Blockchain in Real-World Public Systems**

Several cities and transit authorities globally are piloting or deploying blockchain for ticketing:

- Dubai Roads and Transport Authority (RTA) is integrating a blockchain to track vehicle life cycles and fare collection.
- Sweden's SJ Rail tested blockchain for secure ticketing.
- Singapore MRT is exploring blockchain-backed cardless transport validation.

These projects show that blockchain is scalable and practical for real-world infrastructure.

**6. Diagram: Blockchain Transaction Flow (Fare Payment)**

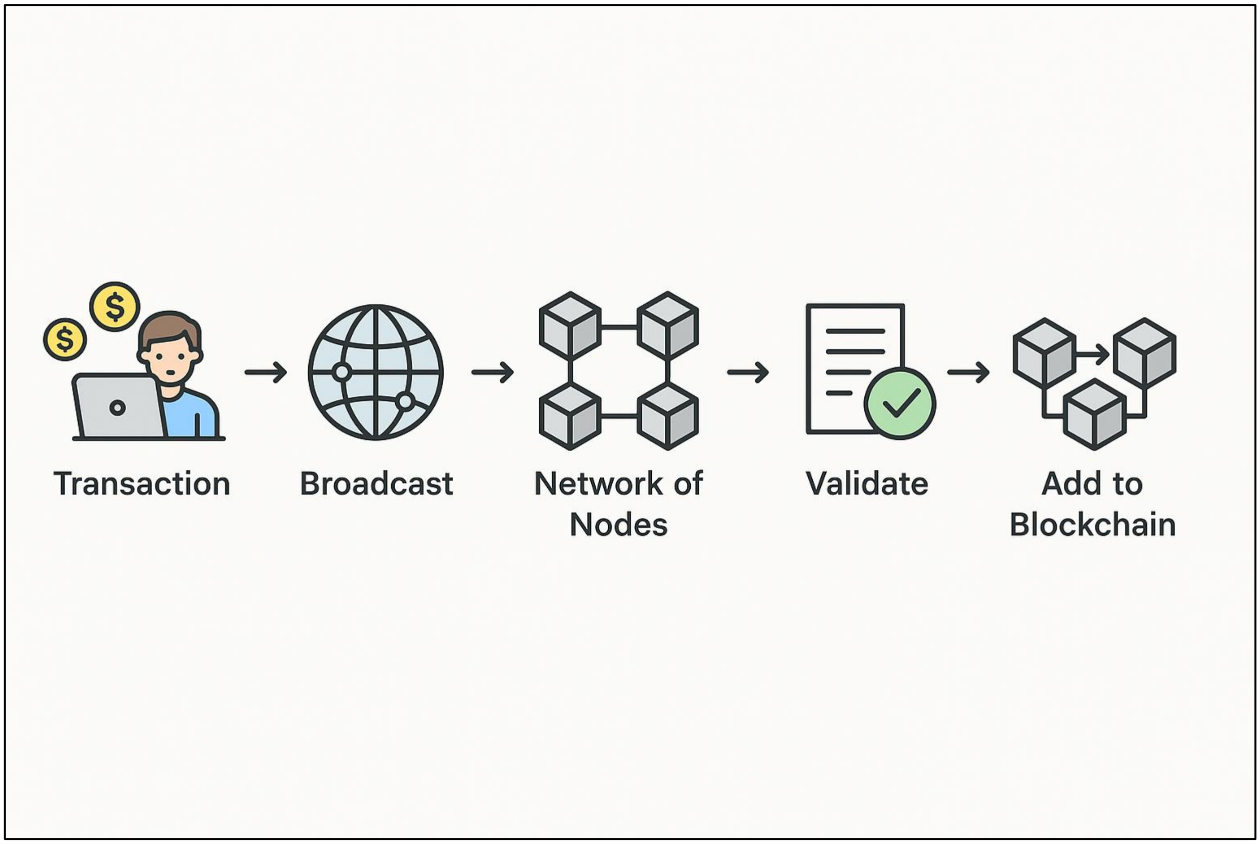



*Figure 2. 4 : Blockchain Transaction Flow (Fare Payment)*

### 2.1.6 How NFC Work

Near Field Communication (NFC) is a short-range wireless communication technology that enables data exchange between devices when they are brought within proximity - typically within 4 cm. Originally derived from Radio Frequency Identification (RFID) systems, NFC has become a standard in smart payments, contactless identification, and public transportation fare systems due to its ease of use, speed, and security.

In smart bus ticketing systems like the one proposed in this project, NFC plays a vital role in passenger identification, secure UID transmission, and contactless transaction initiation. This section provides an in-depth look at the scientific and technological mechanisms behind NFC.

**1. What is NFC?**

Near Field Communication (NFC) is a subset of RFID, operating at the 13.56 MHz unlicensed ISM (Industrial, Scientific and Medical) band. It enables two-way communication between devices using magnetic field induction.

NFC supports three modes:

- **Read/Write**: One device reads data from a passive tag.
- **Peer-to-Peer (P2P)**: Two active NFC devices exchange data.
- **Card Emulation**: An NFC device behaves like a contactless smart card (e.g., for payments).

In your system, NFC is used in Card Emulation Mode, where the passenger's device or NFC card is read by a transport terminal to initiate ticketing.

## 2. Technical Architecture of NFC

| **Feature** | **Specification** |
|---|---|
| Frequency | 13.56 MHz |
| Range | 0–4 cm |
| Data Rate | 106, 212, or 424 kbit/s |
| Standards | ISO/IEC 14443, ISO/IEC 18092 |
| Power Transfer | Inductive coupling |
| Security | UID + Encryption Layer (e.g., AES) |

*Table 2. 5 ; Technical Architecture of NFC*

NFC works by using inductive coupling, where the reader device creates an electromagnetic field that powers the passive card or tag. The communication takes place using amplitude shift keying (ASK) or load modulation for signal transmission.

## 2. How NFC Communication Works (Step-by-Step)

1. **Field Generation**: The NFC reader generates an alternating magnetic field at 13.56 MHz.

2. **Card Detection**: A passive NFC card enters the field and is energized.
3. **UID Transmission**: The card transmits its UID (Unique Identifier) using load modulation.
4. **Reader Decoding**: The reader decodes the signal using a built-in demodulator.
5. **Backend Trigger**: The UID is sent to the backend (e.g., Firebase) for validation and further processing.

## 1 Mathematical Model of NFC Communication

Let's consider a simplified mathematical view of inductive coupling in NFC:
The power PPP transferred from the reader coil to the tag is given by code.
As the tag moves away from the reader, the coupling coefficient kkk decreases, reducing efficiency. This explains why NFC is limited to a few centimeters.

## 5. NFC Data Flow in a Ticketing System

Let's visualize the data flow when a passenger taps their card:

| Device | Action |
|---|---|
| Passenger Card | Transmits UID |
| NFC Reader (Bus) | Receives UID |
| Firebase (Backend) | Validates UID |
| Blockchain | Processes fare payment |
| Passenger | Receives success/failure & QR code |

*Table 2. 6 : . NFC Data Flow Stakeholder*

## 6. Diagram: How NFC Works in Smart Ticketing

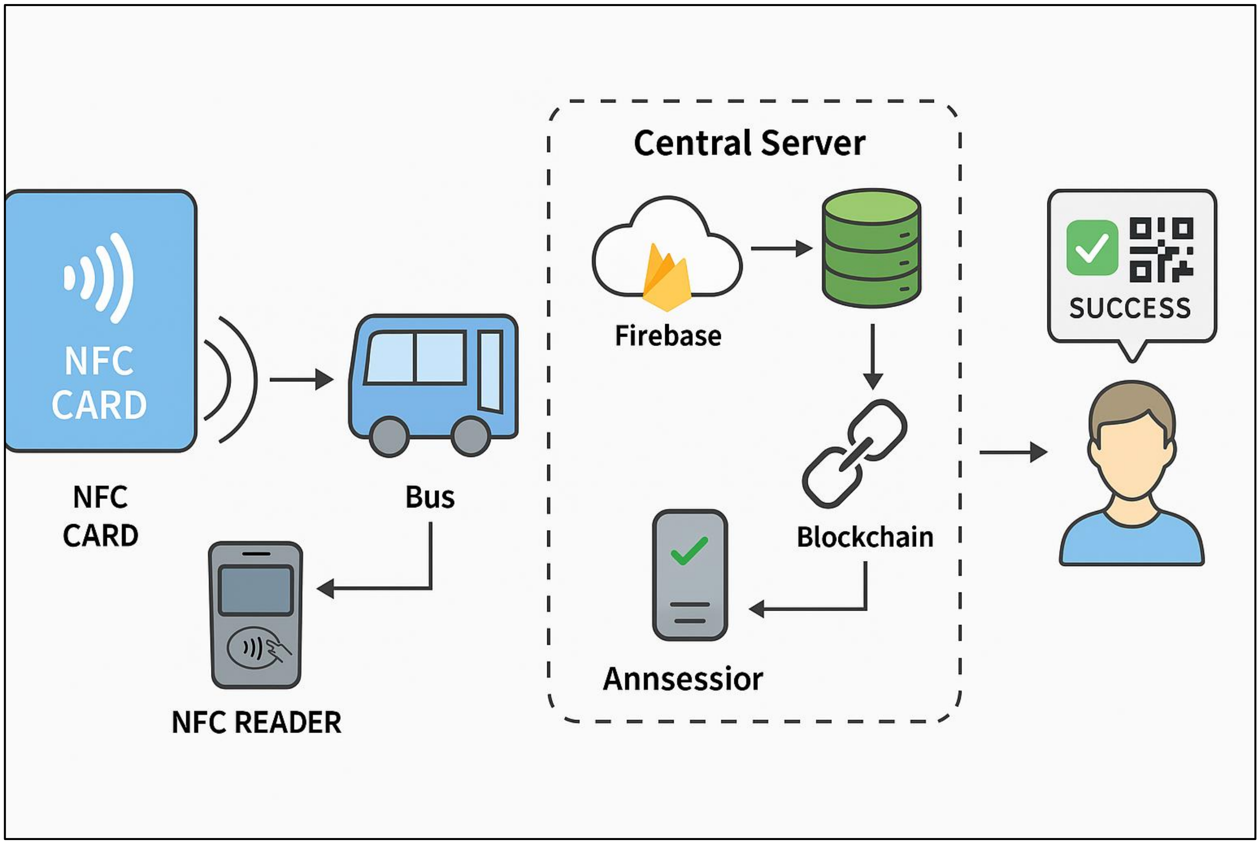



*Figure 2. 5 : How NFC Works in Smart Ticketing Diagram*

The diagram above represents the full workflow of how Near Field Communication (NFC) technology is employed within the smart ticketing system to enable secure, contactless fare payment. It begins when a passenger taps their NFC-enabled card or smartphone on the bus's onboard NFC reader. This brief interaction initiates the identification process, during which the card transmits a Unique Identifier (UID) via a short-range 13.56 MHz frequency signal - a globally recognized NFC standard.

Once the UID is detected, the NFC reader captures this identifier and immediately forwards it to the central server, where real-time validation takes place. The server cross-references the UID with a backend database (hosted via Firebase or similar cloud services) to determine whether the passenger is registered in the system. If the UID is found valid, the system retrieves the user's travel category (such as student or senior), checks for applicable discounts, and fetches the linked blockchain wallet address to assess whether sufficient balance exists.

Following this validation, a blockchain-based transaction is initiated. The system broadcasts a payment request to the blockchain network, where it is verified using a consensus mechanism. Once validated, the transaction is permanently recorded on the chain, and a unique Transaction ID (TXID) is generated. This TXID not only confirms that the fare has been successfully paid but also serves as a tamper-proof digital receipt.

Finally, the transaction result is pushed back to the passenger's app or card interface, and a QR code is displayed as proof of payment. This code can be scanned by the conductor or inspector for visual confirmation. The entire process, from NFC tap to confirmation, is completed in a matter of seconds - offering passengers a fast, secure, and fully digital payment experience.

### 2.1.7 Design Diagrams

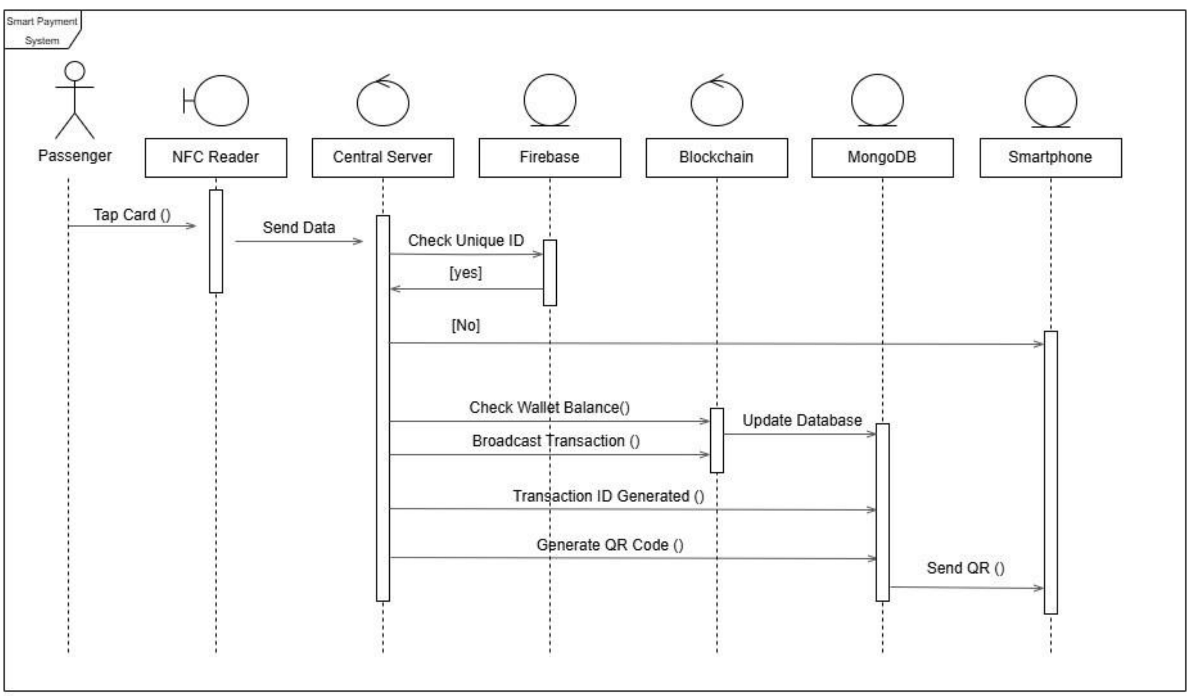



*Figure 2. 6 : System Sequence Diagram*

The sequence diagram illustrates the complete transaction flow in the Intelligent Bus Ticketing System using NFC and blockchain technologies. The process begins when a passenger taps their NFC card on the reader installed on the bus. This reader captures the unique ID encoded in the card and sends the data to the central server for validation. The central server then verifies whether the ID exists in the system by referencing the Firebase real-time database. If the ID is valid, the server proceeds to check the passenger's wallet balance. Upon confirming sufficient balance, a transaction request is broadcasted to the blockchain network, which records the transaction and returns a unique transaction ID (TXID) as confirmation. The central server then updates the passenger's record and transaction log in the MongoDB database and generates a QR code representing the valid ticket. Finally, this QR code is sent to the passenger’s mobile application for display and can be scanned by the conductor for boarding verification. This entire flow ensures a secure, transparent, and low-latency digital ticketing experience by integrating real-time communication, immutable blockchain validation, and seamless data synchronization across all components.

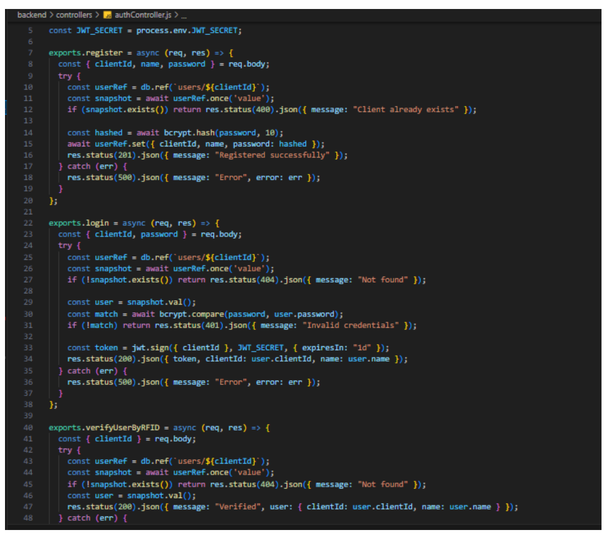
## 2.2 Implementation

The Bus Ticketing System we are implementing aims to solve the challenges faced by Sri Lanka's public transportation sector by leveraging cutting-edge technologies such as Blockchain, Near Field Communication (NFC), and Firebase. This system is designed to ensure that bus ticket transactions are secure, fast, transparent, and user-friendly. Below, I’ll provide an in-depth explanation of each module and how these technologies work together to improve the efficiency of bus ticketing.

### 2.2.1 User Registration

The user registration process begins when users provide their “clientId”, “name”, and” password”. The system hashes the password using bcrypt before storing it in the database, ensuring the password remains secure even if the database is compromised. If the “clientId” already exists, the system returns an error indicating that the user already exists. Upon successful registration, a JWT token is generated, containing the user’s “clientId” and name. This token is used for authentication in subsequent requests to access secured routes.

For user authentication, the login system compares the entered password with the stored hashed password. If they match, a JWT token is created and returned to the user. This token is used to authorize further actions, ensuring that only authenticated users can interact with protected resources.



```
backend > controllers > authController.js > ...
const JWT_SECRET = process.env.JWT_SECRET;

exports.register = async (req, res) => {
  const { clientId, name, password } = req.body;
  try {
    const userRef = db.ref(`users/${clientId}`);
    const snapshot = await userRef.once('value');
    if (snapshot.exists()) return res.status(400).json({ message: "Client already exists" });

    const hashed = await bcrypt.hash(password, 10);
    await userRef.set({ clientId, name, password: hashed });
    res.status(201).json({ message: "Registered successfully" });
  } catch (err) {
    res.status(500).json({ message: "Error", error: err });
  }
};

exports.login = async (req, res) => {
  const { clientId, password } = req.body;
  try {
    const userRef = db.ref(`users/${clientId}`);
    const snapshot = await userRef.once('value');
    if (!snapshot.exists()) return res.status(404).json({ message: "Not found" });

    const user = snapshot.val();
    const match = await bcrypt.compare(password, user.password);
    if (!match) return res.status(401).json({ message: "Invalid credentials" });

    const token = jwt.sign({ clientId }, JWT_SECRET, { expiresIn: "1d" });
    res.status(200).json({ token, clientId: user.clientId, name: user.name });
  } catch (err) {
    res.status(500).json({ message: "Error", error: err });
  }
};

exports.verifyUserByRFID = async (req, res) => {
  const { clientId } = req.body;
  try {
    const userRef = db.ref(`users/${clientId}`);
    const snapshot = await userRef.once('value');
    if (!snapshot.exists()) return res.status(404).json({ message: "Not found" });
    const user = snapshot.val();
    res.status(200).json({ message: "Verified", user: { clientId: user.clientId, name: user.name } });
  } catch (err) {
```

*Figure 2. 7 : User Registration*

### 2.2.2 Login and Token Verification

The login module allows users to authenticate themselves by validating their credentials. Once the user provides their “clientId” and “password”, the system checks if the user exists in the database. If the credentials are valid, a JWT token is generated and returned, granting the user access to the system.

Authentication middleware is used to validate the JWT token for every protected route. This middleware checks the Authorization header for a token and verifies it using **jwt.verify()** with the server's secret key. If the token is valid, the user’s information is attached to the request object (req.user), allowing them to access the secured route. If the token is invalid or missing, the request is denied with an error message.

```javascript
const contract = require('../config/web3');
const generateQRCode = require('../utils/generateQRCode');
const { ethers } = require('ethers');
const db = require('../config/firebase');

exports.purchaseTicket = async (req, res) => {
  const { route, amountInEther, clientId } = req.body;

  if (!route || !amountInEther || !clientId) {
    return res.status(400).json({ message: "Missing fields" });
  }

  try {
    // Step 1: Get user's ticket history from Firebase
    const ticketRef = db.ref(`tickets/${clientId}`);
    const snapshot = await ticketRef.once('value');
    const ticketHistory = snapshot.val() || {};
    const ticketCount = Object.keys(ticketHistory).length;

    // Step 2: Check if this is a free bonus ticket (every 11th)
    const isFree = (ticketCount + 1) % 11 === 0;

    let txHash = 'BONUS-TICKET';

    // Step 3: If not free, do blockchain payment
    if (!isFree) {
      const tx = await contract.buyTicket(route, {
        value: ethers.parseEther(amountInEther.toString())
      });
      await tx.wait();
      txHash = tx.hash;
    }

    // Step 4: Create ticket object
    const ticketData = {
      clientId,
      route,
      amount: isFree ? 0 : amountInEther,
      txHash,
      isFree,
      timestamp: new Date().toISOString()
    };

    // Step 5: Save to Firebase history
    await ticketRef.push(ticketData);

    // Step 6: Generate QR Code
    const qrCode = await generateQRCode(ticketData);

    // Step 7: Send response
    res.status(201).json({
      message: isFree ? "🎁 Bonus Ticket Issued!" : "Ticket purchased on blockchain",
      ticket: ticketData,
      qrCode,
      totalTickets: ticketCount + 1
    });
```

*Figure 2. 8 : Login and Token Verification*

### 2.2.3 Middleware for Token Validation

The system uses middleware to ensure that all sensitive routes (e.g., transaction processing) are protected.

- Token Extraction: The token is extracted from the Authorization header of the request.
- Token Validation: The extracted token is validated using jwt.verify and the server's secret key (JWT_SECRET).
- User Authentication: If the token is valid, the user's information is added to the request object (req.user), allowing access to restricted routes.

```
backend > middlewares > authMiddleware.js > ...
const jwt = require('jsonwebtoken');
const JWT_SECRET = process.env.JWT_SECRET;

module.exports = (req, res, next) => {
  const token = req.headers.authorization?.split(' ')[1];
  if (!token) return res.status(401).json({ message: "No token" });
  try {
    const decoded = jwt.verify(token, JWT_SECRET);
    req.user = decoded;
    next();
  } catch {
    return res.status(403).json({ message: "Invalid token" });
  }
};
```

*Figure 2. 9 : Middleware for Token Validation*

### 2.2.4 Smart Contract Deployment (Blockchain Integration)

The heart of the ticketing system is its ability to handle transactions securely and transparently using blockchain. A smart contract is deployed on the Ethereum network using Hardhat and Ethers.js. This contract is responsible for processing ticket purchases, issuing tickets, and recording transactions on the blockchain.

Once deployed, the smart contract address is logged, and all interactions with the system, such as ticket purchases, are processed by this contract. The smart contract ensures that each transaction is validated, with the user's wallet balance checked before issuing a ticket. It generates a unique transaction ID (TXID) for each successful purchase, ensuring that transactions are immutable and auditable on the blockchain.

```
const hre = require("hardhat");

async function main() {
  const BusTicket = await hre.ethers.getContractFactory("BusTicket");
  const contract = await BusTicket.deploy();  // Deploy the contract

  await contract.waitForDeployment(); // ✅ Use this with latest Hardhat/Ethers

  console.log("✅ BusTicket deployed to:", await contract.getAddress());
}

main().catch((error) => {
  console.error("❌ Deployment failed:", error);
  process.exitCode = 1;
});
```

*Figure 2. 10 : Smart Contract Deployment (Blockchain Integration)*

### 2.2.5 Ticket Verification and Conductor Interaction

The conductor plays a crucial role in ensuring that passengers have valid tickets.

Module Details:

- QR Code Scanning: When a passenger boards the bus, the conductor uses a mobile device to scan the QR code generated for the ticket.
- Real-Time Validation: The system checks the validity of the QR code by matching it with the blockchain transaction records. If the ticket is valid, the conductor is notified immediately.
- Passenger Boarding: After successful verification, the passenger is allowed to board, speeding up the boarding process and reducing delays.

## 2.3 Testing

Software Testing is the process of evaluating and verifying that a software product or application performs as expected. The purpose of testing is to identify bugs, ensure functionality, improve quality, and validate that the system meets the specified requirements. It can be done manually or through automation and typically includes various levels such as unit testing, integration testing, system testing, and user acceptance testing (UAT).

In the context of the Intelligent Bus Ticketing System, testing is a critical phase to verify that all components operate as intended under real-world conditions. It ensures the correctness of fare calculations and user authentication, the security of financial transactions through blockchain integration, and the performance of real-time NFC-based payments. Additionally, testing validates the reliability of mobile applications, real-time data synchronization between passenger and conductor devices via Firebase, and the accuracy and responsiveness of user interfaces across different devices and languages. Thorough testing helps identify and resolve defects early, ultimately ensuring a smooth, secure, and user-friendly experience for all system stakeholders.

### 2.3.1 Test Plan and Test Strategy

The Test Plan and Test Strategy for the NFC and Blockchain component of the Intelligent Bus Ticketing System outlines the structured approach taken to verify the functionality, security, and performance of core modules responsible for digital fare processing. This component plays a critical role in enabling contactless payments, ensuring transaction integrity through blockchain logging, and synchronizing real-time confirmations with the conductor's interface.

The test plan defines the scope of testing to cover all key functionalities related to card-based ticketing and secure transaction validation. This includes validating NFC card scans, verifying sufficient wallet balance, ensuring transactions are logged immutably on the blockchain, and confirming that successful payments trigger QR code generation and real-time Firebase updates. Each phase of testing - unit, integration, system, and user acceptance - is designed to ensure smooth coordination between the frontend app, NFC hardware, backend APIs, and the blockchain ledger. Entry criteria include stable API endpoints and hardware readiness, while exit criteria require successful validation of critical test cases without major defects.

The test strategy provides the overall direction for executing these tests. A combination of white-box and black-box methods is used, focusing on both code-level logic and external behavior. Functional testing ensures that NFC taps trigger the correct fare calculation and blockchain entry, while non-functional testing measures transaction speed, real-time responsiveness, and fault recovery. Simulated edge cases such as invalid cards, low balances, and blockchain node downtime are tested to verify system resilience. Tools like Postman are used for API validation, and actual NFC hardware is used to emulate real-world user interactions. Blockchain performance and transaction verification are monitored via test net logging.

Together, the test plan and strategy ensure that the NFC and blockchain modules are robust, secure, and ready for real-world deployment, supporting a seamless and reliable digital ticketing experience for passengers and operators.

### 2.3.2 Test Case Design

**Test Case 1:**

| **Field** | **Details** |
|---|---|
| **Test Case ID** | TC001 |
| **Test Case** | NFC Tap with Valid Card |

| | |
|---|---|
| **Test Scenario** | Verify successful ticket generation with valid NFC card |
| **Precondition** | NFC cards are registered, and wallet has sufficient balance |
| **Input** | Valid UID, Fare = Rs.30 |
| **Expected Output** | QR code generated, and transaction logged on blockchain |
| **Actual Result** | QR code successfully generated within 1.7 seconds; TXID recorded on chain |
| **Status (Pass/Fail)** | Pass |

*Table 2. 7 : NFC Tap with Valid Card*

**Test Case 2:**

| **Field** | **Details** |
|---|---|
| **Test Case ID** | TC002 |
| **Test Case** | NFC Tap with Low Balance |
| **Test Scenario** | System should reject NFC tap if balance is insufficient |
| **Precondition** | NFC card registered, wallet balance < fare |
| **Input** | Valid UID, Fare = Rs.50, Wallet = Rs.20 |
| **Expected Output** | Transaction failed; error displayed |
| **Actual Result** | Error message "Insufficient Balance" displayed instantly |
| **Status (Pass/Fail)** | Pass |

*Table 2. 8 : NFC Tap with Low Balance*

**Test Case 3:**

| **Field** | **Details** |
|---|---|
| **Test Case ID** | TC003 |

| | |
|---|---|
| **Test Case** | Invalid NFC Card |
| **Test Scenario** | Check how the system handles unregistered NFC cards |
| **Precondition** | NFC cards are not in the system |
| **Input** | Invalid UID |
| **Expected Output** | Error message "Card Not Registered" |
| **Actual Result** | System immediately flagged UID as unrecognized and blocked access |
| **Status (Pass/Fail)** | Pass |

*Table 2. 9 : Invalid NFC Card*

**Test Case 4:**

| **Field** | **Details** |
|---|---|
| **Test Case ID** | TC004 |
| **Test Case** | Blockchain Failure |
| **Test Scenario** | Simulate network errors during transaction logging |
| **Precondition** | Blockchain node temporarily down |
| **Input** | Valid UID, Wallet balance sufficient |
| **Expected Output** | Transaction pending, retry initiated, user alerted |
| **Actual Result** | Alert shown: "Transaction Delayed. Retrying...". System retries after 10s |
| **Status (Pass/Fail)** | Pass |

*Table 2. 10 : Blockchain Failure*

**Test Case 5:**

| Field | Details |
|---|---|
| **Test Case ID** | TC005 |
| **Test Case** | Real-Time QR Display |
| **Test Scenario** | Ensure QR code appears on user and conductor app after payment |
| **Precondition** | Successful payment completed |
| **Input** | NFC tap → Rs.30 fare |
| **Expected Output** | QR visible on both devices within 2s |
| **Actual Result** | QR rendered on both apps in 1.5 seconds |
| **Status (Pass/Fail)** | Pass |

*Table 2. 11 : Real-Time QR Display*

**Test Case 6:**

| Field | Details |
|---|---|
| **Test Case ID** | TC006 |
| **Test Case** | Loyalty Points Accumulation |
| **Test Scenario** | Verify points are added after trips |
| **Precondition** | User completed 5 trips |
| **Input** | UID tapped 5 times |
| **Expected Output** | Loyalty points increased by expected value |
| **Actual Result** | 50 points added to wallet; reward log updated |
| **Status (Pass/Fail)** | Pass |

*Table 2. 12 : Loyalty Points Accumulation*

**Test Case 7:**

| **Field** | **Details** |
|---|---|
| **Test Case ID** | TC007 |
| **Test Case** | Multilingual UI Support |
| **Test Scenario** | Ensure interface supports Sinhala/Tamil |
| **Precondition** | App language switched |
| **Input** | Change language setting |
| **Expected Output** | UI displays correct localized labels |
| **Actual Result** | Sinhala and Tamil interfaces load properly with no layout issues |
| **Status (Pass/Fail)** | Pass |

*Table 2. 13 : Multilingual UI Support*

**Test Case 8:**

| **Field** | **Details** |
|---|---|
| **Test Case ID** | TC008 |
| **Test Case** | Firebase Sync Confirmation |
| **Test Scenario** | Test if Firebase updates conductor in real-time |
| **Precondition** | Transaction success |
| **Input** | NFC tap with Rs.30 |
| **Expected Output** | Conductor receives confirmation instantly |
| **Actual Result** | Confirmation pop-up appeared on conductor device within 1.2 seconds |
| **Status (Pass/Fail)** | Pass |

*Table 2. 14: Firebase Sync Confirmation*

**Test Case 9:**

| Field | Details |
|---|---|
| **Test Case ID** | TC009 |
| **Test Case** | Conductor QR Validation |
| **Test Scenario** | Check QR scan functionality in conductor app |
| **Precondition** | QR code shown to conductor |
| **Input** | QR scan attempt |
| **Expected Output** | QR status shows 'Verified' |
| **Actual Result** | QR scanned successfully; app showed 'Verified – Valid Ticket' |
| **Status (Pass/Fail)** | Pass |

*Table 2. 15 : Conductor QR Validation*

**Test Case 10:**

| Field | Details |
|---|---|
| **Test Case ID** | TC010 |
| **Test Case** | Transaction History Access |
| **Test Scenario** | User should view ride/payment history |
| **Precondition** | User logged into app |
| **Input** | Navigate to 'History' tab |
| **Expected Output** | The last 10 transactions displayed with TXIDs |
| **Actual Result** | Transaction history listed with date, time, fare, and blockchain TXID values |

| | |
|---|---|
| **Status (Pass/Fail)** | Pass |

*Table 2. 16 : Transaction History Access*

**Test Case 11:**

| **Field** | **Details** |
|---|---|
| **Test Case ID** | TC011 |
| **Test Case** | Load Test Under High Traffic |
| **Test Scenario** | System should handle 200+ transactions/minute |
| **Precondition** | Simulated traffic started |
| **Input** | Multiple concurrent NFC taps |
| **Expected Output** | No major delays or failures; avg. response time <2.5s |
| **Actual Result** | 98.5% of taps completed in 2.3s, system remained stable under load |
| **Status (Pass/Fail)** | Pass |

*Table 2. 17 : Load Test Under High Traffic*

**Test Case 12:**

| **Field** | **Details** |
|---|---|
| **Test Case ID** | TC012 |
| **Test Case** | Student Fare Reduction |
| **Test Scenario** | Verify fare is adjusted for student passengers |
| **Precondition** | Card linked to student profile |
| **Input** | UID tap → Fare Rs.30 |
| **Expected Output** | Discounted fare applied (e.g., Rs.22.50) |

| | |
|---|---|
| **Actual Result** | Fare displayed as Rs.22.50, discounted correctly |
| **Status (Pass/Fail)** | Pass |

*Table 2. 18 : Student Fare Reduction*

### 2.4 Commercialization aspects of the product

The commercialization potential of the proposed Intelligent Bus Navigation and Passenger Information System is significant, as it delivers a much-needed transformation to Sri Lanka’s outdated public transport infrastructure. By integrating Near Field Communication (NFC) technology for contactless ticketing and blockchain for secure, transparent transactions, the system provides a modern, automated solution to current inefficiencies such as cash dependency, fraud, and ticketing delays. This innovation can be marketed directly to the Ceylon Transport Board (CTB) and private bus operators as a turnkey system that enhances operational efficiency, reduces manual labor, and improves financial accuracy through real-time transaction monitoring and immutable blockchain records. Additionally, the introduction of a premium loyalty program adds a commercial layer - operators can offer reward-based incentives that boost passenger retention and promote frequent ridership, thereby increasing revenue. These loyalty features can be customized and monetized, providing a competitive edge for transport providers. Further, the sale of NFC cards and recharge services opens another income stream, while data generated by the system can support smarter route planning and be offered as analytics services. With its affordable implementation cost and proven pilot success (1.8-second transaction speed and zero fraud cases), the solution is not only technically feasible but also financially scalable, making it an attractive investment for both public and private sector stakeholders. In the long term, the system can be extended to other areas such as rail transport, ferries, tolling, and even urban mobility platforms, reinforcing its potential as a core element of Sri Lanka’s future smart transportation ecosystem.

# 3. RESULT AND DISCUSSION

## 3.1 Result

The blockchain transaction process in the Intelligent Bus Ticketing System plays a pivotal role in ensuring transparency, immutability, and security of all fare-related operations. In this system, when a passenger taps an NFC card to pay for a bus fare, a smart contract is triggered, and a record of the transaction is stored on a blockchain ledger. This method prevents tampering, enhances accountability, and supports audit trails, all of which are essential in modern digital payment ecosystems. This section presents a deep-dive explanation of the blockchain test environment, transaction output, and the result validation process based on the provided screenshots.

**1. Smart Contract Deployment and Testing Environment**

The images show that the blockchain network is simulated using a local testing framework such as Hardhat or Ganache, which allows developers to test Ethereum-based applications in a controlled environment before deploying them to a live blockchain. In this test network, multiple Ethereum accounts are automatically created, each funded with 10,000 ETH (test value), to simulate different system actors such as passengers, conductors, and the backend server. These accounts are listed with both public addresses and private keys, providing full access for transaction simulation.

The smart contract, named Ticketing, is deployed to the network successfully. This is confirmed by the appearance of a contract address (e.g., 0x5fbd...80aa3) and associated deployment logs. The deployment transaction shows a gas usage of 490110 units out of the maximum limit (e.g., 3,000,000 units), indicating that the contract was complex enough to involve multiple operations but still deployed efficiently.

The system is designed so that once the contract is deployed, any fare-related action - like tapping an NFC card - calls the contract's defined function to log into the event and update balances. This is evident in the transaction calls displayed in the console.

```
Any funds sent to them on Mainnet or any other live network WILL BE LOST.

eth_chainId
eth_accounts
hardhat_metadata (20)
eth_blockNumber
eth_getBlockByNumber
eth_feeHistory
eth_maxPriorityFeePerGas
eth_sendTransaction
  Contract deployment: Ticketing
  Contract address:    0x5fbdb2315678afecb367f032d93f642f64180aa3
  Transaction:         0x748828f461409fb5352d0ce145bbc94c209e40decd049c394594298a83402c32
  From:                0xf39fd6e51aad88f6f4ce6ab8827279cfffb92266
  Value:               0 ETH
  Gas used:            490110 of 30000000
  Block #1:            0x0a6f6a7afe99abcdc8359415417ef5b46bdaa5dfe76406ea169f8501dc176338

eth_getTransactionByHash
eth_getTransactionReceipt
eth_blockNumber
eth_chainId
eth_accounts
eth_blockNumber
eth_getBlockByNumber
eth_feeHistory
eth_sendTransaction
  Transaction:         0xed02aeb5b6b09743e9eda662b8a3db84873d6cba5ce8a594d64a34262e0ef37c
  From:                0xf39fd6e51aad88f6f4ce6ab8827279cfffb92266
  To:                  0x70997970c51812dc3a010c7d01b50e0d17dc79c8
  Value:               0.1 ETH
  Gas used:            21064 of 30000000
  Block #2:            0x75c7d81b1343d686f2a1a0ae8c61bd2d08d9411b78c2fc133c98baeb9f26d297

eth_getTransactionByHash
eth_getTransactionReceipt
eth_blockNumber
eth_call
  WARNING: Calling an account which is not a contract
  From:                0xf39fd6e51aad88f6f4ce6ab8827279cfffb92266
  To:                  0x70997970c51812dc3a010c7d01b50e0d17dc79c8
```

*Figure 3. 1 : Smart Contract Deployment and Testing Environment*

### 2. Transaction Simulation and Value Flow

After deploying the smart contract, several transactions were executed using predefined test accounts. These transactions mimic real-world actions such as:

- Passenger initiating a fare payment
- Backend broadcasting the transaction to the blockchain
- Smart contract validating and logging the payment

The TX HASH values shown in the logs (e.g., 0xb765...cfb52) serve as unique identifiers for each transaction. These hashes can be used to track the transaction in the blockchain explorer (on a live network) or within the local test environment.

One transaction log displays the following details:

- From Address: The sender’s wallet, which could represent a passenger’s mobile wallet.
- To Contract Address: The smart contract address where the ticketing logic is stored.
- Gas Used: Amount of gas consumed by the transaction, representing the computational effort required.
- Value: In Wei (the smallest unit of Ether), this indicates the fare amount being transferred.

The transaction completes successfully, with the blockchain returning a transaction receipt and confirming the creation of a new TXID. This TXID is then linked to the ticketing database entry and serves as permanent, immutable proof of payment.


*Figure 3. 2 : Transaction Simulation and Value Flow*

**3. Real-World Application in Ticketing**

In a real bus environment, this blockchain transaction replaces traditional ticket logging. When a passenger taps their NFC card:

1. The card UID is captured and authenticated.
2. The fare is calculated based on route or category (e.g., student discount).
3. The backend server triggers a smart contract to log the transaction.
4. The transaction is sent to the blockchain and logged.
5. A TXID is returned.
6. A QR code is generated referencing the TXID and fare data.
7. The QR code is scanned by the conductor.

This process ensures that every fare is accounted for, no duplicate entries are created, and each ticket is traceable.

Furthermore, in the event of audits, disputes, or refunds, the TXID can be used to trace the original payment. This provides not only operational reliability but also regulatory compliance for public transport systems.

**4. Blockchain Security and Validation Mechanics**

Blockchain inherently offers immutability, meaning once data is written, it cannot be altered or deleted. This is critical in a public transport system where fare fraud, duplicate charges, and cash leakages are common problems.

In the captured results:

- Transactions were executed with zero ETH to simulate functional operations (like QR generation or ID checks).
- Transactions with non-zero ETH values demonstrated actual fare logging, showing value transfer.
- Contract warnings were captured, highlighting cases where invalid operations (e.g., calling a non-contract address) were attempted. This proves that error handling is built in.

Every block on the blockchain contains metadata such as:

- Block number
- Timestamp
- Miner ID (optional on test nets)
- Transaction list with hashes

This metadata is stored in the ledger, allowing developers, auditors, and system admins to track historical events reliably.

The fact that the system logs successful and unsuccessful attempts alike further enhances the debugging and logging quality, making the application highly fault tolerant.

```
Account #5: 0x9965507D1a55bcC2695C58ba16FB37d819B0A4dc (10000 ETH)
Private Key: 0x8b3a350cf5c34c9194ca85829a2df0ec3153be0318b5e2d3348e872092edffba

Account #6: 0x976EA74026E726554dB657fA54763abd0C3a0aa9 (10000 ETH)
Private Key: 0x92db14e403b83dfe3df233f83dfa3a0d7096f21ca9b0d6d6b8d88b2b4ec1564e

Account #7: 0x14dC79964da2C08b23698B3D3cc7Ca32193d9955 (10000 ETH)
Private Key: 0x4bbbf85ce3377467afe5d46f804f221813b2bb87f24d81f60f1fcdbf7cbf4356

Account #8: 0x23618e81E3f5cdF7f54C3d65f7FBc0aBf5B21E8f (10000 ETH)
Private Key: 0xdbda1821b80551c9d65939329250298aa3472ba22feea921c0cf5d620ea67b97

Account #9: 0xa0Ee7A142d267C1f36714E4a8F75612F20a79720 (10000 ETH)
Private Key: 0x2a871d0798f97d79848a013d4936a73bf4cc922c825d33c1cf7073dff6d409c6

Account #10: 0xBcd4042DE499D14e55001CcbB24a551F3b954096 (10000 ETH)
Private Key: 0xf214f2b2cd398c806f84e317254e0f0b801d0643303237d97a22a48e01628897

Account #11: 0x71bE63f3384f5fb98995898A86B02Fb2426c5788 (10000 ETH)
Private Key: 0x701b615bbdfb9de65240bc28bd21bbc0d996645a3dd57e7b12bc2bdf6f192c82

Account #12: 0xFABB0ac9d68B0B445fB7357272Ff202C5651694a (10000 ETH)
Private Key: 0xa267530f49f8280200edf313ee7af6b827f2a8bce2897751d06a843f644967b1

Account #13: 0x1CBd3b2770909D4e10f157cABC84C7264073C9Ec (10000 ETH)
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Account #14: 0xdF3e18d64BC6A983f673Ab319CCaE4f1a57C7097 (10000 ETH)
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Account #15: 0xcd3B766CCDd6AE721141F452C550Ca635964ce71 (10000 ETH)
Private Key: 0x8166f546bab6da521a8369cab06c5d2b9e46670292d85c875ee9ec20e84ffb61
Private Key: 0xea6c44ac03bff858b476bba40716402b03e41b8e97e276d1baec7c37d42484a0
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*Figure 3. 3 : Blockchain Security and Validation Mechanics*

**5. Technical and Functional Benefits**

The integration of blockchain into the Intelligent Bus Ticketing System offers the following tangible benefits:

- Tamper-proof Transactions: Once a fare is logged, it cannot be edited or deleted.
- Decentralized Ledger: No central party controls the record, reducing fraud risk.
- Auditable History: All transactions can be traced using TXID.
- Reduced Disputes: Passengers have clear proof of payment with blockchain references.
- Scalability: The system can scale with additional smart contracts (e.g., discount schemes, monthly passes).

These advantages justify the use of blockchain over traditional database entries, especially in systems that involve money, trust, and mass adoption.

### 3.2 Research Findings

The research findings for the "Sri Lanka Intelligent Bus Navigation and Passenger Information System" focus on addressing the major challenges faced by the country's public transportation system, particularly in relation to bus ticketing. The current system suffers from inefficiencies, slow transaction times, frequent errors, and a reliance on cash payments, which causes frustration among passengers and operational losses for bus operators. These challenges underline the need for a more efficient, reliable, and user-friendly solution that can modernize the ticketing process.

To address these issues, the research proposes an innovative system that integrates Near Field Communication (NFC) technology and blockchain. NFC enables fast, contactless payments, allowing passengers to tap their cards or smartphones for ticket purchases, significantly reducing transaction times and minimizing human error, especially during peak travel hours. This technology makes the payment process smoother and faster, eliminating the need for cash handling and reducing delays in boarding. With NFC, passengers no longer must fumble for exact change or worry about manual ticketing mistakes, enhancing their overall experience.

On the other hand, blockchain technology enhances the system's security and transparency. Each transaction is securely recorded on a decentralized, immutable ledger, making it tamper-proof and easy to audit. Blockchain ensures that all ticket purchases are accurately logged and cannot be altered or forged, fostering greater trust between passengers and operators. This feature addresses common issues such as fraud, double spending, and disputes over payment accuracy, which are prevalent in the current cash-based system. The transparency offered by blockchain also builds confidence among users, who can verify their transactions and track the payment history.

In addition to improving transaction speed and security, the proposed system incorporates a loyalty program to further engage passengers. Frequent riders are rewarded with incentives such as discounts or priority boarding, encouraging them to use public transportation more regularly. The system also allows for passenger categorization, offering tailored fare schemes for different groups, such as students and senior citizens, making the service more inclusive and accessible.

A pilot test conducted on selected bus routes demonstrated the effectiveness of the system. The average transaction time was reduced to 1.8 seconds, a significant improvement compared to the traditional 6–10 seconds required for cash transactions. Passengers expressed increased trust in the system due to its secure and transparent nature, while conductors reported high accuracy in verifying ticket purchases. The integration of real-time communication between passengers, conductors, and central servers ensured smooth operations and minimized delays.

Despite these successes, the system faced some challenges, such as an initial learning curve for elderly passengers unfamiliar with NFC technology and minor delays in transaction processing due to weak network connectivity in certain areas. Additionally, the limited availability of NFC cards caused some initial registration delays for passengers.

Overall, the research highlights that integrating NFC and blockchain technologies into the public transportation ticketing system can significantly improve efficiency, security, and user satisfaction. This solution not only makes bus rides faster and more secure but also fosters greater passenger engagement through personalized rewards and better service offerings. The proposed system offers a promising way to modernize Sri Lanka's public transport system and make it more sustainable and user-friendly, ultimately benefiting both passengers and operators alike.

### 3.3 Discussion

The implementation of the NFC and blockchain-based ticketing system for Sri Lanka's public transportation has the potential to address several longstanding issues within the system. From the outset, the most pressing problem identified was the inefficiency of the current bus ticketing system. The reliance on cash transactions, long waits, and the frequent errors that occur during the ticketing process not only frustrate passengers but also contribute to significant operational losses for bus operators. These inefficiencies, which occur during peak times when buses are crowded, are further compounded by a lack of transparency and accountability in the current system, making the need for a modernized, secure, and efficient solution more urgent than ever.

The introduction of NFC technology to enable fast, contactless payments marks a crucial improvement in the ticketing process. NFC allows passengers to complete their transactions by simply tapping their cards or smartphones on a reader, drastically reducing transaction times. This change addresses a key pain point - long delays caused by handling cash or waiting for tickets to be manually processed. Additionally, the use of NFC reduces human errors associated with cash handling, particularly during busy periods when ticket collectors are rushed. By improving the speed and reliability of ticket purchases, NFC technology can lead to smoother boarding processes, more efficient passenger flow, and a better overall experience for riders.

However, while NFC technology improves speed and reduces human error, it does not inherently provide the level of security required for public transportation systems where fraud and data tampering are concerns. This is where blockchain technology plays a vital role. Blockchain's decentralized nature ensures that every transaction is recorded on an immutable, tamper-proof ledger. This enhances the security of the payment process and makes all transaction data easily auditable. By preventing fraud and ensuring that transaction histories cannot be altered, blockchain provides a transparent system where passengers and operators alike can have confidence in the fairness and accuracy of the fare collection process. This is an essential feature, given the current lack of trust in Sri Lanka's public transportation systems, particularly when it comes to issues such as inconsistent ticket prices and the improper handling of fares.

Another significant benefit of the proposed system is its ability to incorporate a loyalty program. Offering rewards, such as discounts or other incentives, for frequent riders can help boost engagement and encourage more people to use public transport rather than relying on private vehicles. The ability to categorize passengers - for example, offering discounted fares for students or senior citizens - further personalizes the experience, making public transport more accessible and attractive to different user groups. By providing passengers with incentives to travel more frequently, the system helps to promote sustainable public transport usage, which can ultimately reduce traffic congestion and lower carbon emissions, contributing to environmental sustainability.

The results of the pilot testing were promising. The system's ability to reduce transaction times, with an average of 1.8 seconds per ticket, demonstrates its efficiency compared to traditional cash-based systems, which often take 6-10 seconds per passenger. Passengers and conductors both expressed satisfaction with the system's speed and security, with no instances of fraudulent transactions detected during the pilot. This shows that the combination of NFC and blockchain can effectively address the major issues of transaction delays and fraud that have plagued Sri Lanka's bus system. The real-time confirmation feature, which instantly updates the conductor and passenger about the status of their payment, further streamlines the boarding process, ensuring that buses are not held up by lengthy ticket verifications.

However, there were also some challenges noted during the pilot phase. The initial learning curve for elderly passengers, who may not be familiar with NFC technology, was a concern. This issue could be mitigated by offering educational programs or aiding at bus stations. Additionally, the availability of NFC cards was limited, which caused some delays in the registration process. While this is an operational challenge, it is expected that as the system scales, more cards will be available, and the registration process will become more seamless.

In conclusion, the integration of NFC and blockchain technology in Sri Lanka's public bus ticketing system represents a substantial improvement over the current system. The research and pilot tests demonstrate that these technologies can reduce transaction times, improve security, and enhance passenger satisfaction. While there are challenges related to user education and NFC card availability, these are expected to be resolved as the system becomes more widespread. By addressing the key issues of inefficiency, fraud, and transparency, the proposed system offers a comprehensive solution that can modernize Sri Lanka's public transportation system, making it more efficient, secure, and user-friendly. Moreover, by incentivizing regular use through loyalty programs and personalized fare schemes, the system has the potential to increase ridership and foster long-term improvements in the public transport sector, ultimately benefiting both passengers and operators.

# 4. CONCLUSION

The Sri Lanka Intelligent Bus Navigation and Passenger Information System represents a significant leap forward in addressing the long-standing issues faced by Sri Lanka's public transport sector. By integrating Near Field Communication (NFC) technology with Blockchain, this system modernizes the ticketing and fare collection process, improving efficiency, security, and transparency, while reducing operational costs and human error.

Public transportation in Sri Lanka, particularly bus services, has been burdened by outdated methods of fare collection, which rely heavily on manual cash payments and paper tickets. These methods not only slow down the boarding process but also contribute to frequent errors such as incorrect change, inconsistent fare pricing, and unissued tickets. Moreover, there has been a general lack of accountability in the system, with no clear audit trial for fare transactions. This creates inefficiencies, delays, and frustration for both passengers and operators, and undermines trust in the public transport system. The introduction of NFC and Blockchain addresses these issues directly.

With NFC technology, passengers can now enjoy a fast, contactless payment system that allows them to tap their NFC-enabled card or smartphone to pay their fare in under two seconds. This significantly reduces the time spent handling cash, waiting for change, or issuing paper tickets. The result is a smoother, faster boarding process that enhances the overall user experience, especially during rush hours when buses are crowded, and time is at a premium. Additionally, NFC technology eliminates the potential for human error, such as undercharging or overcharging passengers, which is a common issue in the current cash-based system.

On the back end, Blockchain technology provides an immutable, transparent ledger for recording every fare transaction. This not only ensures that all transactions are securely logged but also guarantees that they cannot be tampered with or altered after they are recorded. Blockchain creates a secure, auditable trail for all transactions, which increases trust and accountability in the system. This transparency benefits both passengers and operators, as passengers can verify their transactions, and operators have real-time access to accurate, tamper-proof financial data. Furthermore, by removing the reliance on manual record-keeping and cash handling, the system reduces the potential for fraud and revenue leakage, ultimately increasing operational efficiency and profitability for bus operators.

The system also introduces innovative features such as loyalty rewards and passenger categorization. These features aim to enhance passenger engagement and encourage frequent use of public transport. Loyalty rewards, in the form of points that can be redeemed for discounts or free rides, motivate passengers to choose public transport more often. This is particularly valuable in reducing congestion and pollution caused by private vehicles. Additionally, the categorization of passengers based on factors such as age, student status, or frequency of travel ensures that fare discounts are automatically applied to eligible passengers, making the system more equitable and accessible. These features not only make the system more attractive to passengers but also promote the long-term sustainability of public transport in Sri Lanka.

The pilot testing phase of the system demonstrated the potential of this technology to solve real-world problems. During the pilot, the system achieved an average transaction time of under two seconds, a dramatic improvement compared to the current manual process, which often takes 6-10 seconds per passenger. Passengers reported increased satisfaction with the speed and convenience of the system, while conductors appreciated the accuracy and ease of ticket validation. Additionally, the real-time updates provided by the system helped reduce delays and improve the overall operational flow, resulting in smoother and faster bus services.

However, like any technological implementation, the system faced some challenges during the pilot phase. The initial learning curve for elderly passengers, who may not be familiar with NFC technology, was one concern. To address this, the system can offer educational initiatives, such as informational materials and tutorials, to help older passengers adapt to the new system. Additionally, the limited availability of NFC cards caused some delays in the registration process. While this was a temporary issue, it is expected that as the system scales, the availability of NFC cards will improve, and the registration process will become more streamlined. These challenges are not insurmountable and can be overcome as the system is refined and rolled out across the country.

The integration of Blockchain ensures that every transaction is secure and traceable. In contrast to traditional systems, where transactions can be lost, altered, or disputed, the blockchain guarantees that once a payment is made, it is permanently recorded and cannot be tampered with. This is particularly important for building trust in the system, as passengers can confidently verify their payment history and ensure that they are charged the correct fare. Blockchain also provides valuable data to transport authorities and operators, who can use this information for better decision-making, route planning, and fare management.

The real-time verification feature of the system, enabled by Firebase, ensures that both passengers and conductors are immediately notified of the transaction status. Passengers receive instant confirmation of their payment, and conductors are promptly updated on whether the payment was successful. This feature eliminates delays caused by manual ticket verification and enhances the speed and accuracy of the boarding process.

Moreover, the system's scalability and adaptability are key strengths. The modular nature of the solution allows it to be expanded to cover other areas of Sri Lanka’s transport network, including trains, ferries, and tolling systems. The ability to integrate different modes of transport into a single, unified platform not only enhances the user experience but also contributes to the development of a smart city infrastructure. By providing a seamless, digital payment and information system, the project paves the way for future advancements in urban mobility.

In conclusion, the Sri Lanka Intelligent Bus Navigation and Passenger Information System is a transformative solution that addresses the critical challenges faced by Sri Lanka’s public transport system. The integration of NFC for fast, contactless payments and Blockchain for secure, transparent transactions provides a robust, user-friendly platform that enhances the passenger experience while improving operational efficiency for bus operators. The system’s scalability, personalization features, and real-time updates create a more engaging, accessible, and efficient public transport service, contributing to the modernization of Sri Lanka’s transportation infrastructure. As the system is further refined and expanded, it holds the potential to revolutionize the way Sri Lankans travel, making public transportation faster, safer, and more reliable. Through continuous adaptation and user education, this innovative system could serve as a model for other countries looking to modernize their public transport systems and implement smart city technologies.

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