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The Application of Near Field Communication (NFC) in Public Transportation: Current Practices, Challenges, and Future Prospects

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Abstract:

In the field of public transportation, the introduction of NFC technology can realize contactless payment and automatic ticket checking functions, significantly improving system efficiency and passenger experience. The article first reviews the development history of the public transportation system and the basic principles of NFC technology, and then analyzes the technical architecture and working principle of the NFC payment system. Through the cases of public transportation systems in many cities around the world, the practical application and effect of NFC technology are demonstrated. This article also verifies the transaction speed, stability and user satisfaction of NFC technology in the public transportation system through a series of experimental evaluations. The results show that NFC technology has excellent performance in terms of processing speed, system stability and user satisfaction, especially during peak hours, its advantages are more obvious. At the same time, the research also pointed out the limitations of current NFC technology applications and the challenges faced in practical applications. In the future, NFC technology will become more complete and is expected to provide passengers with a more personalized and intelligent service experience.

Keywords: Near Field Communication; Public Transportation; Ticketing; RFID.

1. Introduction

The World Health Organization projects that by 2022, 56.9% of people on Earth would reside in cities, up from 54% in 2014 [1]. Public transportation systems play a vital role in urban transportation. As this trend continues, the demand for public transportation resources is also increasing, especially in large cities with dense populations and frequent economic activities. It is not only the artery of urban operation, but also a key link connecting all corners of the city and promoting social exchanges and economic development.

In addition, the demand for business and leisure travel across cities, across borders, and using multiple modes of transportation is also increasing, covering a variety of modes of transportation from trains, subways and buses to trams, taxis, river boats and ferries. All of these trends are prompting governments, municipal authorities and transportation management departments to find ways to provide smarter and more passenger-centric travel experiences.

In the field of public transportation, advances in applied technology have significantly improved the overall performance, efficiency and user experience of the system. Automated fare systems or e-ticketing systems, as well as innovative transport ticketing solutions were created precisely to respond to the growing demand and create a better travel experience. The introduction of electronic payment systems allows passengers to quickly pay fares through smartphones or smart cards, reducing the cumbersome and time-consuming cash transactions. The implementation of the automatic ticket checking system not only speeds up the entry and exit of passengers, but also improves the accuracy and safety of ticket management. The application of these technologies optimizes passengers' travel experience and provides public transportation operators with more efficient operation and management tools. It also helps reduce traffic congestion and environmental pollution, thus contributing to the sustainable development of cities.

The adoption of NFC technology is a component of the public transportation industry's current digital transition. With the help of Near Field Communication (NFC), two devices can exchange data wirelessly across short distances (about 4 cm). NFC is based on Radio Frequency Identification (RFID) technology. The core principle of NFC technology is to establish a wireless connection between two compatible devices through electromagnetic induction for fast, short-distance data transmission.

In application scenarios, NFC is generally used for payment and identity authentication, especially in public transportation systems, where NFC technology is widely used in contactless payment systems and automatic ticket checking systems.

After the public transportation system bid farewell to the early paper tickets, magnetic stripe cards were usually used for payment and ticket inspection. However, magnetic stripe cards were gradually replaced by more advanced technologies due to their defects such as easy wear, abnormal magnetization, short service life and slow reading and writing speed. Smart cards (such as RFID-based contactless cards) then became mainstream. They store and transmit data through built-in chips, with higher reliability and efficiency. However, smart cards still need to be carried physically, which makes passengers face inconvenience in the event of losing or forgetting to bring cards. The rise of NFC technology solves these problems. It supports both card types and integration into mobile devices such as mobile phones. Passengers can complete payment and ticket inspection by simply using smartphones or other mobile devices with NFC functions. The application of this technology makes public transportation payment systems more environmentally friendly, efficient and convenient. Especially in modern cities, passengers can not only reduce ticket purchase and queuing time through mobile payment and contactless ticket inspection, but also enjoy a more seamless travel experience. The evolution of public transportation payment and ticket inspection systems from early magnetic stripe cards to smart cards and now NFC technology reflects the continuous advancement of payment technology in public transportation systems and promotes the entire industry to develop in a more intelligent and digital direction [2, 3].

The research objective of this paper is to explore the application status, technical implementation, advantages and disadvantages, and future development direction of NFC technology in public transportation systems. Specifically, this paper will analyze the application mode of NFC technology in public transportation, including the architecture and technical principles of the NFC payment system and its impact on the efficiency of the transportation system and passenger experience. At the same time, this paper will also discuss the challenges of NFC technology in practical applications, such as device compatibility, security, and infrastructure construction.

The structure of this paper will be developed from the following parts. First, the background introduction section will outline the development history of public transportation systems and the basic principles of NFC technology and its application background in public transportation. Next, the literature review section will review related studies and explore the application experience and current status of NFC technology in public transportation. The technical model section will introduce the technical architecture and working principle of the NFC payment system in detail. The application scenario section will explore the actual application cases of NFC in public transportation systems in major cities around the world. After that, the experiment and evaluation section will analyze the advantages and limitations of NFC technology based on actual data and provide quantitative evaluation results. Finally, this paper will summarize the research results in the summary section, propose the development direction and prospects of NFC technology in future public transportation systems, and suggest how to overcome the current technical bottlenecks to further promote the intelligent development of public transportation systems.

2. Literature Review

In recent years, with the advancement of science and technology, the application of technology in public transportation systems has achieved significant development. Electronic payment technology and automatic fare collection systems are one of the core technologies of modern public transportation. The application of electronic payment technology provides passengers with a more convenient ticket purchasing and riding experience, and the automatic ticket checking system effectively improves the operational efficiency of public transportation. Hong Kong, Seoul, Paris, Chicago, and London were the first cities to use passive contactless smart card integrated circuits (ICs) for automated fare collecting beginning in the 1990s. By 2016, contactless payment and transportation technologies were being implemented in over 1,000 cities [2]. Contactless ticketing offers customers and transport operators clear advantages over previous fare collection methods - such as cash, paper and magnetic stripe tickets. As a result, the user experience is improved and passengers are able to access the transportation system faster.

For operators, contactless technology also brings stronger anti-fraud revenue protection, lower maintenance costs (compared to the mechanical moving parts of magnetic stripe reading equipment), and improved operational efficiency by speeding up boarding. The technological development of NFC not only promotes the popularization of contactless payment, but also provides a more intelligent and efficient solution for automatic ticket checking and passenger management system.

NFC chips are integrated into smartphones, allowing customers to make contactless payments using their phones. In 2006, the first version of the NFC tag specification was released, and Nokia launched the first NFC-enabled mobile phone in the same year. The public transport industry quickly recognized the potential of this contactless data transmission technology in ticketing. Approximately 100 smartphones and mobile phones could exchange data via NFC as of 2013. Apple also declared at the end of 2014 that the iPhone 6 would be the first device to support the NFC standard. It is worth noting that technical standards and specifications related to near field communication (NFC) have played a vital role in the public transport sector, especially those developed by the International Organization for Standardization (ISO). Early implementations were not standardized, and the industry soon realized the need for a standardized contactless air interface. As a result, ISO/IEC 14443 and ISO/IEC 18092 were created, and these days, many applications use them as international standards for contactless communication. Specifically designed for contactless smart cards, ISO 14443 is an international standard that specifies the communication protocol between the card and the reader. It is extensively utilized in public transportation electronic ticketing systems [4, 5].

Currently, there are a variety of wireless communication technologies that can support contactless technology. Based on the characteristics of public transportation applications, NFC technology is compared with other common wireless communication technologies as shown in Table 1[6].

Table 1 Summary of Different Wireless Technology Comparative Details

Items	Bluetooth	WIFI	GPRS/3G	NFC	NFC observation for public transport
Transaction distance	10-100m	300m-40km	1km-35km	0.1m	Intended for a voluntary action
Transmission speed	2Mbit/s	54Mbit/s	14Mbit/s	848kbit/s	Acceptable speed
Connection set up time	6s	2s	1s	20 ms	Extremely fast
Connection reliability	Low	Medium	Medium	Extremely high	Extremely reliable
Robustness against interferences	Normal	Normal	Normal	Extremely high	Extremely robust
Compatibility with transport infrastructures	Zero	Zero	Zero	Almost total	Compatibility with infrastructure
Compliance with transaction times	No	No	No	Total	Acceptable transaction times

Compared with wireless communication technologies such as Wi-Fi and Bluetooth, NFC has a suitable data transmission rate and has significant advantages in connection establishment time, connection reliability, anti-interference ability, and compatibility with public transportation facilities. The short communication distance can effectively guarantee Only expected transactions occur. Based on the above reasons, NFC technology is very popular in public transportation system applications and has become one of the most widespread technologies.

By streamlining and expediting fare purchases, enabling one-touch ticket entry, supporting additional applications (like real-time travel updates and loyalty programs), and utilizing a single payment and access method for multiple public transportation modes (such as rail, bus, and subway), NFC technology improves the convenience and enjoyment of using public transportation for passengers [2].

At the same time, NFC technology also faces some challenges in its application, including user privacy and security issues, technical implementation difficulties and cost-effectiveness considerations, and how to effectively deal with device compatibility issues in actual deployment. These are the main issues currently facing the application of NFC technology in the public transportation field.

Public transportation departments must come to an agreement with smartphone manufacturers on a common NFC standard for mobile devices in order to avoid having to do separate compatibility testing for every smartphone that is introduced to the market. As a result, the Smart Ticketing Alliance (STA), East Japan Railway Company (JR East), and American Public Transportation Association (APTA) have partnered. Within the open NFC ecosystem, this partnership has created multiple use cases for NFC smartphone applications in public transit, covering over 80% of the world's electronic ticketing systems. The application of open standards like ISO 18092 and 21481 is necessary in these situations. Concurrently, criteria covering application scenarios like mobile ticketing and public transportation services have been created and specified by the Global System for Mobile Communications Association (GSMA) for mobile NFC terminals [7].

In order to standardize smartphone technology and enable certification and widespread usage, the GSMA has released "test manuals," which provide a set of technical specifications for the devices. Regarding NFC, the GSMA abides with the NFC Forum's recommendations. To guarantee global smartphone NFC technology and RFID infrastructure interoperability, the Global Certification Forum (GCF) and the NFC Forum have also started working together. This would provide consistent testing and certification of upcoming NFC smartphone generations, enabling a progressive global unification and harmonization of NFC technological standards.

In addition to the public transportation sector, NFC technology has also been widely used in other fields, especially in payment systems and identity recognition. In the payment field, NFC technology is widely used in mobile payment systems such as Apple Pay and Google Pay, and these experiences are of great reference significance for the electronic ticketing system in public transportation. In addition, in terms of identity recognition, NFC technology has been used for smart card identity documents, which provides security for the ticketing system in public transportation. Compared with other technologies, such as QR code and Bluetooth, NFC has obvious advantages in speed, security and user convenience. Although QR code technology has the advantage of low cost, it is not as good as NFC in reading speed and security; while Bluetooth technology has the problems of high-power consumption and long connection time. Therefore, in the public transportation system, NFC technology has irreplaceable advantages in terms of speed, convenience and security, but the characteristics of other technologies can also be used to supplement and optimize specific application scenarios.

3. Methodology and Technical Model Basis

With the use of inductive coupling, NFC (Near Field Communication) technology enables short-range wireless communication between two suitable devices that are near together—typically within a few millimeters. NFC technology is based on Radio Frequency Identification (RFID). It permits automated data transfer in both directions between two NFC-capable devices. NFC operates at the globally unlicensed frequency of 13.56 MHz, offering three different data transmission rates—106 kbit/s, 212 kbit/s, and 424 kbit/s.

NFC technology features both active and passive communication mode, which can be further classified into three operational modes. The communication method in each mode of operation of NFC is different. These differences affect the field of operation and how it is used:

1. Peer-to-Peer Mode (Active Mode): This mode complies with the ISO/IEC 18092 standard. It facilitates communication and data exchange between two NFC-compatible devices. At any given time, either device can act as the initiator or the target.
2. Reader/Writer Mode: This mode is compatible with the ISO/IEC 14443 standard. It allows devices to read NFC tags, such as those integrated into smart posters or other objects.
3. Card Emulation Mode: In this mode, data stored on cards, such as smart cards, is read by an NFC reader. The device capable of NFC communication functions similarly to a smart card when connecting to the NFC reader. Users can retrieve information, such as ticketing data, using their smartphones in this mode.

In public transportation systems, NFC technology enables data transmission and reading through inductive coupling. When a passenger brings an NFC card (such as a transit card or smartphone) near a reader, the coil in the card detects the electromagnetic field emitted by the reader, generating an electric current that activates the chip. Communication between the NFC card and the reader then begins, and using contactless communication protocols like ISO 14443, data is exchanged bidirectionally via modulated radio frequency signals. This process includes data reading, verification, and payment confirmation, typically completed within a few hundred milliseconds, ensuring the convenience and efficiency of card tapping in public transportation.

As shown in Figure 1, one of the technological models in public transportation, specifically the roaming journey. This model is based on a media-supported smart ticketing system. A passenger using an Integrated Fare Management System (IFMS) obtains a medium (such as a contactless card or a smartphone APP) from the fare system in Public Transit Network A, allowing them to travel within Public Transit Network B. This medium can store travel credentials, which may come from pre-purchased fare products (prepaid policy) or be associated with registered customer credentials to settle the fare after the journey (postpaid policy).

The roaming journey business process addresses the scenario where a passenger, already possessing a travel medium provided by their local network (Network A), uses that same medium to travel within another public transportation network (Network B) [8].

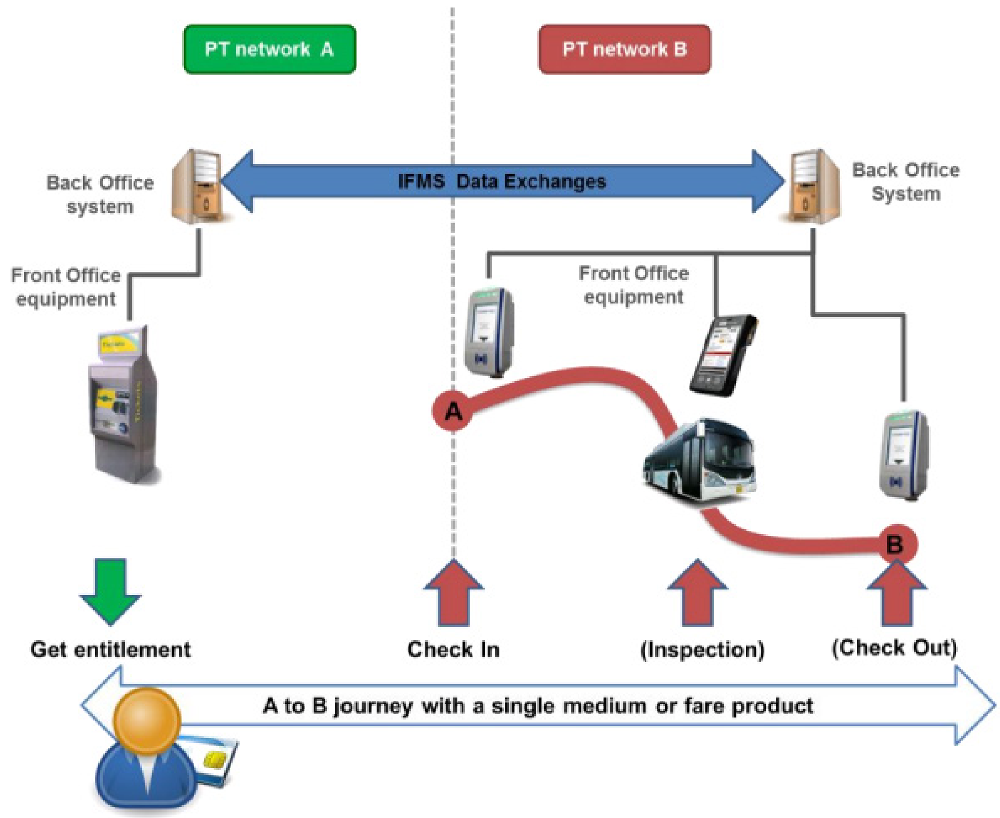

Fig. 1 Description of a Roaming journey

In public transportation systems, the technical model of NFC cards usually includes data storage, authentication, and encryption security mechanisms. Common NFC cards such as Mifare cards are widely used in bus and subway systems. The technical architecture of Mifare cards is based on a partitioned storage mode. The card is divided into multiple independent data blocks, each of which can be used to store different types of data (such as balance information, pass records). These data blocks can be controlled by specific access rights to protect the security of sensitive information. The data in the card is protected by encryption algorithms. Common encryption mechanisms include AES or DES encryption to prevent unauthorized reading and data tampering. The life cycle management of NFC cards includes card issuance, recharge, use, and recycling, and each stage has corresponding technical guarantees. For example, when the card is issued, the card will be given a unique identification code and initial key; during the recharge process, encrypted communication with the backend server is carried out through a secure channel; during use, the card needs to be verified by the key of the card reader; and finally, when recycled, the card data can be reset for reuse.

Although NFC technology is widely used in public transportation, it also faces some security and privacy challenges. For example, Data leakage, Copying attack, Wormhole attack [9], etc. are all security risks that NFC technology may encounter in an open environment. To address these challenges, security experts have proposed a variety of technical measures to enhance the security of NFC systems. Rolling Code Encryption is a commonly used protection mechanism that ensures the uniqueness of each transaction through dynamically generated encryption codes, thereby effectively preventing replay attacks. In addition, encryption technology during NFC data transmission is also very important. By enhancing the protocol's performance, security, and confidentiality through the use of asymmetric and symmetric encryption algorithms, hash functions, timestamps, and survival periods. While the shared key is encrypted by the asymmetric encryption method, the transmitted content is encrypted using the symmetric encryption algorithm. Both the key distribution and the authentication procedure are secure [10]. Combined with technologies such as dual authentication and device fingerprint recognition, NFC systems can further enhance user privacy protection and security in public transportation.

4. Applications

As shown in Figure 2 that NFC technology has been widely used in public transportation systems in many cities and countries around the world [2], bringing significant convenience and efficiency improvements. For example, London's Oyster card is a classic case of NFC technology application. Passengers can quickly complete subway and bus payments through this contactless card, which greatly improves the operational efficiency of the transportation system. Singapore's EZ-Link card also uses NFC technology and is widely used in city buses, subways and small consumption payments. Through these applications, NFC technology has significantly improved users' travel experience. Users do not need to carry cash or buy paper tickets, reducing queuing time and simplifying the payment process. In addition, these systems demonstrate extremely high reliability and are able to withstand daily use by a large number of users with low operating costs. User acceptance is also generally high, especially after integration with smartphone payment, the usage rate has further increased.

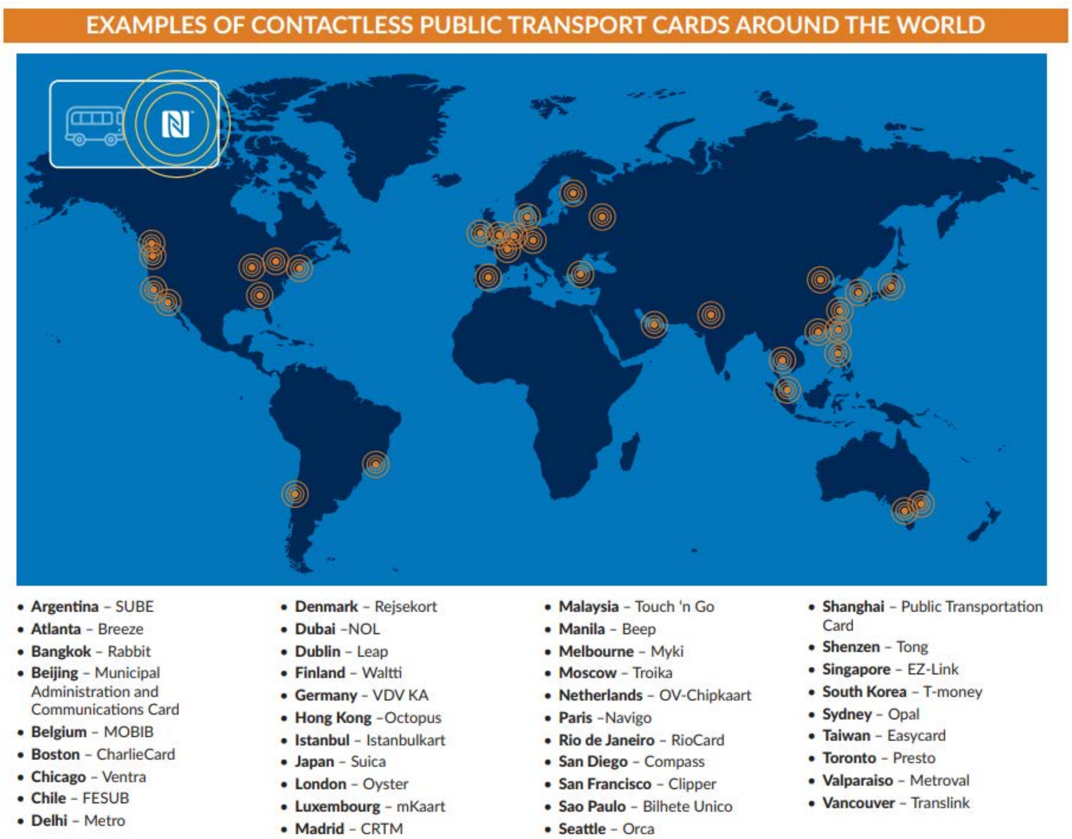

Fig. 2 Examples of Contactless Public Transport Cards Around the World

In China, NFC technology is also widely used in public transportation systems in large cities. Most bus cards and subway systems in Beijing, Shanghai and Guangzhou use NFC technology. For example, Beijing's "One Card" system and Shanghai's "Transportation Card" system both support NFC functions, and passengers can complete contactless payments through physical cards or smartphones. In particular, with the popularity of smartphones, more and more users choose to complete transportation payments through the built-in NFC function of their mobile phones, instead of relying on traditional physical cards.

However, NFC applications in the Chinese market also face some practical problems. First, although NFC bus cards have been popularized in various places, the technical standards have not yet been fully unified, and there are still compatibility issues in cross-city use. Secondly, there are also differences in compatibility between different devices, and some older mobile phones do not support NFC functions. In addition, although young users have a high acceptance of NFC technology, some older users are still accustomed to using traditional paper tickets or cash payments, which limits the full popularization of NFC technology.

In the future, the application of NFC technology in public transportation is expected to expand further, especially driven by the popularization of smartphones and technological integration. With the continuous development of mobile payment technology, NFC technology will be more widely integrated with smartphones and become a core tool for users' daily travel and payment. In addition, NFC technology can also be combined with other cutting-edge technologies, such as blockchain and artificial intelligence, to further enhance security, data management and operational efficiency. For example, blockchain technology can be used to manage and verify ticketing data in public transportation systems to ensure the transparency and security of transactions; artificial intelligence can optimize the operation of public transportation systems and passenger flow management by analyzing NFC data. In addition, within the framework of smart cities and the Internet of Things (IoT), NFC technology can interact with other smart devices and sensors to achieve seamless urban traffic management. For example, future NFC cards may not only be limited to payment, but can also be used for identity authentication, parking payment or shared transportation services, thereby achieving wider applications throughout the city system.

5. Experiment and Model Evaluation

In this study, we designed a series of experiments to evaluate the application effect of NFC technology in public transportation system. The main goal of the experiment is to verify the transaction speed, stability and user satisfaction of NFC technology in public transportation system. To this end, we built a simulated bus card system, including NFC card reader, laptop and simulated bus fare billing system software. In the experiment, we used a variety of NFC devices, including Android and Apple smartphones and NFC cards of different models, to ensure the wide applicability of the test results. The experimental design also includes observation of user behavior and simulation during peak and off-peak hours to compare the experimental results.

The process of collecting experimental data involves multiple aspects. First, we collected users' transaction data, including transaction time, transaction success rate and user interaction fluency, by simulating the NFC card reader in the bus card system. In addition, we also tested the reading and writing speed of the card to evaluate the response speed of NFC technology in actual applications. The stability of data transmission was tested by simulating different network conditions and user usage scenarios to ensure stable data transmission in various environments.

When analyzing the experimental results, we used quantitative and qualitative methods. Quantitative analysis focuses on transaction speed and error rate, while qualitative analysis focuses on the evaluation of user satisfaction. Through user surveys and feedback, we collected subjective evaluations on the experience of using NFC technology. The results show that NFC technology performs well in the public transportation system, with fast transaction speed, low error rate and high user satisfaction. Especially during peak hours, NFC technology can provide fast and stable services, significantly improving the operational efficiency of the public transportation system and the travel experience of passengers.

6. Conclusions

This article deeply explores the application of NFC technology in public transportation systems, revealing its significant role in improving transportation efficiency and improving passenger experience. The study found that NFC technology significantly improves the convenience and efficiency of public transportation by enabling fast contactless payment and automatic ticket checking. The application of NFC technology is not limited to payment systems, but also extends to many aspects such as passenger identity verification, ticket management and data collection. Experimental results show that NFC technology has excellent performance in terms of processing speed, system stability and user satisfaction. Especially during peak hours of urban traffic, its advantages are more obvious.

Although NFC technology has broad application prospects in the field of public transportation, this study also has some limitations. First, the experimental scale is relatively limited and mainly conducted in a simulation environment, which may not fully reflect all challenges in real applications. Secondly, the data sample mainly represents the public transportation system in a specific region, and there may be geographical bias, which limits the general applicability of the research results. Future research can expand the scale of the experiment to include more regions and types of public transportation systems to enhance the breadth and depth of the study. In addition, future research can also explore the combination of NFC technology with other emerging technologies (such as blockchain, artificial intelligence), and its application effects in different cultural and technological backgrounds.

Looking to the future, NFC technology has huge potential for application in public transportation systems, especially in smart cities and IoT environments. With the continuous advancement of technology and advancement of standardization work, NFC technology is expected to be more widely used around the world. The development of NFC technology can not only improve the operational efficiency of public transportation, but also provide passengers with a more personalized and intelligent service experience. For the public transportation industry, continuing to promote the popularization and application of

NFC technology and strengthening its integration with other technologies will be the key to achieving sustainable development. At the same time, technology research and development should focus on user experience, system compatibility, data security and privacy protection to ensure the healthy development of technology. In short, NFC technology has broad application prospects in the field of public transportation and deserves continued attention and investment from the industry and researchers.

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