

The Role and Effectiveness of RFID Technology in Intelligent Transportation Systems

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ABSTRACT

The paper investigates how RFID technology supports the functioning of Intelligent Transportation Systems (ITS) and evaluates its effectiveness in real world settings. RFID enables wireless communication between objects and readers, allowing transportation managers to access data automatically and make quicker, more accurate decisions. Examples of effective applications include vehicle identification, toll collection, public transit coordination, parking control, and fleet monitoring. Drawing on a range of studies and pilot implementations, the research points out that RFID improves efficiency and sustainability but is still constrained by high installation costs, compatibility issues, and weak institutional coordination. The findings suggest that integrating RFID with emerging tools such as IoT, AI, and Blockchain could make future transportation systems more secure, adaptive, and connected.

Keywords: *RFID, Intelligent Transportation Systems, Vehicle Tracking, Toll Collection, Smart Mobility, Fleet Management*

1. INTRODUCTION

Rapid urbanization and the growing demand for mobility have made it increasingly important to design transportation systems that are both efficient and sustainable (Öz & Fidan, 2023). Conventional transport networks, which depend heavily on manual control and limited data sharing, often struggle to meet these rising expectations. In recent years, Intelligent Transportation Systems (ITS) have gained attention as an integrated approach that uses digital communication and real time information to improve how people and goods move through cities.

Among the tools supporting ITS, Radio Frequency Identification (RFID) stands out as a practical and widely adaptable technology. It allows vehicles, cargo, and even passengers to be identified and tracked automatically through wireless signals exchanged between tags and readers. By enabling fast and reliable data collection, RFID has proven valuable in areas such as traffic regulation, vehicle tracking, and logistics management.

Governments and private organizations alike have implemented RFID in toll collection, ticketing, parking control, and fleet management systems. These efforts show how RFID can make transportation more automated, transparent, and efficient. Nevertheless, challenges such as high setup costs, interference problems, and the lack of cross system compatibility still limit its widespread use.

The purpose of this paper is to evaluate RFID's contribution to Intelligent Transportation Systems by discussing its technical components, real world applications, and current barriers to adoption. The study also considers how integrating RFID with newer technologies—like the Internet of Things (IoT), Artificial Intelligence (AI), and Blockchain can lead to more connected and adaptive mobility solutions in the future.

2. OVERVIEW OF RFID TECHNOLOGY

RFID is a technology that enables the tracking of the movements of an object carrying a tag equipped with a microprocessor and an antenna, through the information stored on

the tag and the use of wireless communication technology (RF signals). (Yüksel & Zaim, 2009)

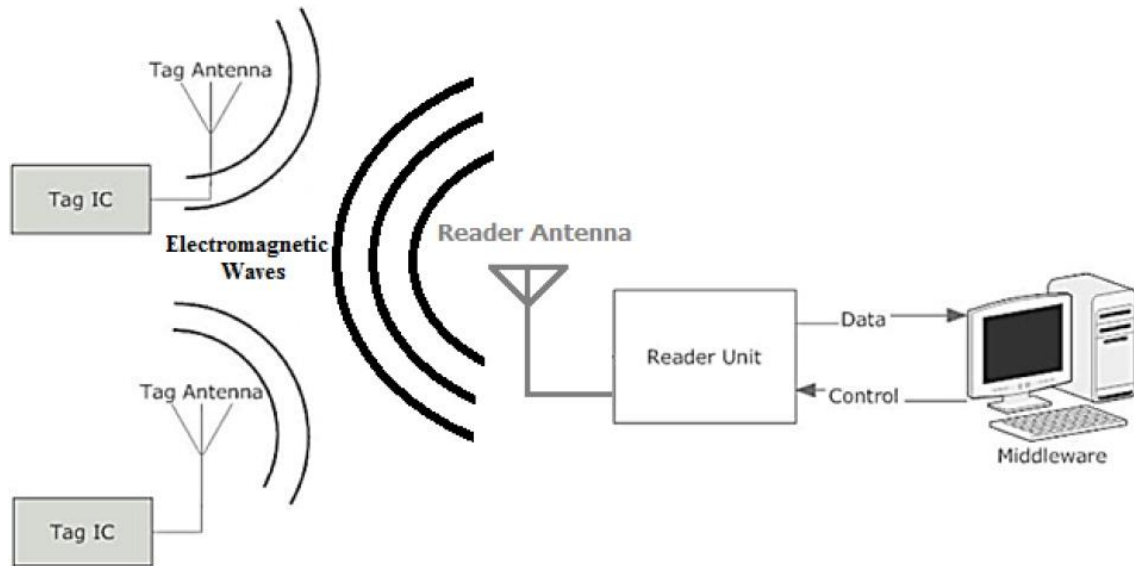


Figure 1. A typical RFID system will comprise RFID tags, RFID reader and middleware, see (Repanovici, 2013)

It communicates with the tag via the reader antenna, which receives radio signals from the tag within the reading area. After receiving the signals from the tag, the reader decodes them and transmits the information to the software. The software enables this data to be processed and used in decision making. (Repanovici, 2013)

In the past two decades, Radio Frequency Identification (RFID) technology has evolved into an indispensable element across numerous industries such as logistics, healthcare, retail, and security. Within the transportation sector, RFID has demonstrated its effectiveness in vehicle identification, passenger management, and the enhancement of real time information exchange. These applications highlight RFID as a crucial enabler of Intelligent Transportation Systems (ITS), where uninterrupted communication and dependable data acquisition play a vital role in ensuring efficiency and safety. (Hannan et al., 2014)

3. INTELLIGENT TRANSPORTATION SYSTEMS (ITS)

Intelligent Transportation Systems (ITS) are integrated frameworks that combine information and communication technologies with transportation infrastructure to enhance mobility, safety, and environmental sustainability. They operate through real time data acquisition, automated control, and communication networks that allow authorities to manage traffic more efficiently and respond to dynamic road conditions. (Papageorgiou et al., 2003)

Intelligent Transportation Systems (ITS) integrate information and communication technologies with transportation infrastructure to improve mobility, safety, and environmental performance. Through real time data collection, automated control, and interconnected communication networks, ITS enable authorities to manage traffic more effectively and respond quickly to changing road conditions. A variety of technologies support these systems, including Global Positioning Systems (GPS), wireless sensor networks, cameras, and Internet of Things (IoT) devices. Together, these tools make it possible to monitor traffic flow, adjust signal timing, and optimize routes. As cities continue to grow and transportation demands rise, the importance of accurate and contactless data collection has become more evident. In this regard, Radio Frequency Identification (RFID) technology offers a valuable solution, providing fast and reliable identification even under diverse environmental conditions. (Want, 2006)

Vehicle tracking is considered one of the core areas of ITS. Traditional vehicle tracking systems often rely on GPS, GSM, or GPRS technology to track vehicle movement and transmit location data. (Chen & Liu, 2010; Almomani et al., 2011) Although effective, these systems often suffered from high costs, limited coverage, and data latency. Modern developments have expanded the scope of tracking systems by integrating RFID and IoT based solutions, enabling real time, scalable, and secure vehicle monitoring (Hannan et al., 2014)

According to Deng (2015), RFID based tracking systems utilize strategically placed readers along roadways and tags attached to vehicles. Communication between these

components enables precise location detection and the continuous transmission of data to central databases, where the information is processed through Geographic Information Systems (GIS). This integration forms a more resilient and automated tracking framework that enhances the overall efficiency of Intelligent Transportation Systems (ITS).

Within the broader ecosystem of Intelligent Transportation Systems (ITS), RFID plays a transformative and increasingly vital role. Its integration strengthens data reliability, enables seamless communication between vehicles and control centers, and reduces the need for direct human intervention. These improvements not only make traffic management more efficient but also support the ongoing development of smart cities by promoting real time decision making and predictive analytics in urban mobility planning. (Luo, 2008)

4. APPLICATIONS OF RFID IN ITS

4.1. Vehicle Tracking

Among the many uses of RFID in Intelligent Transportation Systems (ITS), one of the most common is vehicle tracking. In earlier years, tracking mostly depended on GPS and GSM networks to locate vehicles. While these methods worked to some extent, they often came with drawbacks such as high costs, unstable signals, and noticeable delays in data transmission. (Almomani et al., 2011) RFID overcomes many of these challenges by providing fast, contactless, and accurate identification of moving vehicles.

According to Deng (2013), In most RFID based tracking systems, vehicles carry small tags while readers are placed at specific points such as roadside units or control gates. When a vehicle enters a reader's range, its tag is detected automatically, and the collected data is sent to a central system through a network connection. The information can then be displayed or analyzed using Geographic Information Systems (GIS), which helps plan routes more efficiently and keep track of vehicle movement.

Recent developments by Pan et al. (2023), introduced a multi feature RFID tracking method that uses roadside checkpoints equipped with antennas and readers to capture vehicle tag signals in motion. Through this setup, vehicles can be monitored across different environments such as city streets, storage facilities, or underground parking areas. The collected data is then used to build a single, real time tracking framework that simplifies trajectory analysis and overall traffic management.

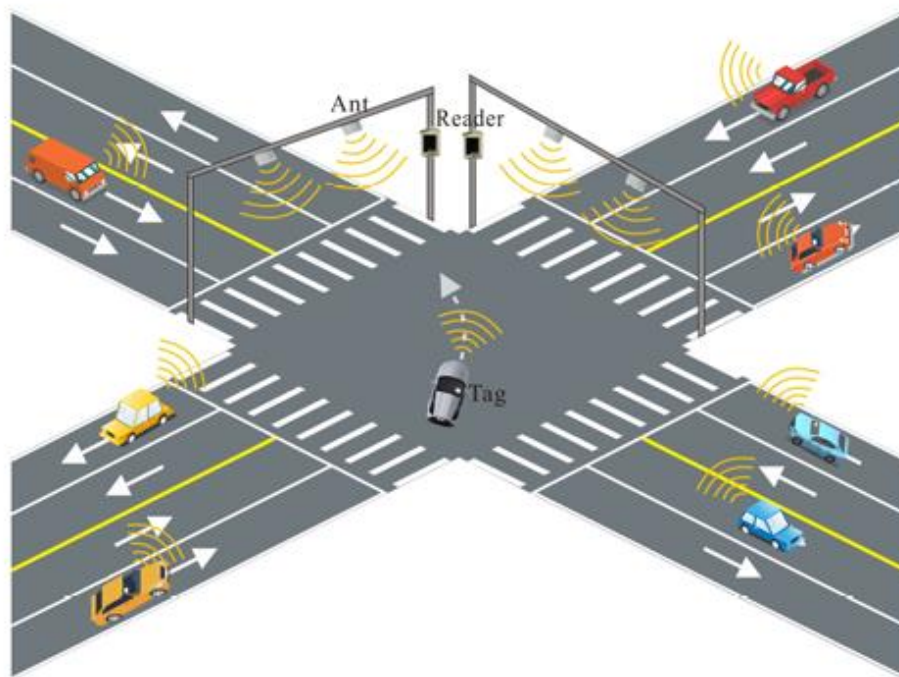


Figure 2. UHF RFID vehicle trajectory tracking model (Pan et al., 2023).

4.2. Electronic Toll Collection

In recent years, many countries have introduced RFID based electronic toll collection (ETC) systems. Examples include E ZPass in the United States, FASTag in India, and HGS/OGS in Türkiye, all of which operate on the same basic principle. Each vehicle is fitted with an RFID tag that is connected to a payment account and automatically charged when the vehicle passes through a toll gate equipped with a reader (Hannan et al., 2014).

These systems mark an important move toward smarter transportation infrastructure and play a key role in improving traffic flow and reducing congestion.

Even with these benefits, RFID based toll systems still face some practical challenges. Problems such as signal interference, data protection, and the absence of universal standards continue to limit their broader adoption (Sharma et al., 2020). In the coming years, ETC platforms are likely to combine RFID with newer technologies such as the Internet of Things (IoT) or blockchain to strengthen security, improve scalability, and ensure better compatibility across systems (Want, 2006).

4.3. Public Transportation Systems

Public transportation has been one of the first areas to benefit from the use of RFID within Intelligent Transportation Systems (ITS). With this technology, transit agencies can manage passenger flow, fare collection, and vehicle operations more efficiently. When RFID cards or tags are embedded in travel passes, passengers can simply tap or hold their cards near a reader to board buses, metros, or trains without physical contact. This approach saves time during boarding and reduces the need for paper tickets or cash transactions, resulting in smoother and faster service (Hannan et al., 2014; Sharma et al., 2020).

In addition, RFID based bus monitoring systems such as the model proposed by Hannan et al. (2014) allow operators to see where their buses are and when they are expected to arrive. When RFID is used together with GPS and wireless networks, it not only improves the accuracy of location tracking but also helps ensure greater safety for passengers and more transparent fleet operations (Tanyaş, 2023).

4.4. Parking And Fleet Management

RFID technology now plays an essential role in how modern transportation systems manage parking and vehicle fleets. With its ability to identify vehicles automatically and collect data in real time, it helps improve efficiency, safety, and overall system

transparency in both public and private operations. In a typical RFID based parking setup, antennas and readers placed at entry and exit points detect the tags attached to cars. When a vehicle is recognized, the system logs the time of entry or exit, calculates the parking fee, and updates the records automatically—removing the need for manual processing. (Sharma et al., 2020; Want, 2006)

This kind of automation helps shorten waiting lines and removes the need for printed tickets, making the overall parking process faster and easier for users. It also allows managers to monitor how parking spaces are being used and adjust capacity through centralized software tools. In some modern systems, RFID works alongside sensors that can identify empty spaces and direct drivers to available spots. Beyond improving convenience, these technologies also help ease traffic congestion and lower carbon emissions in crowded urban areas (Hannan et al., 2014).

5. CHALLENGES AND LIMITATIONS OF RFID IN INTELLIGENT TRANSPORTATION SYSTEMS (ITS)

Although RFID technology provides major benefits within Intelligent Transportation Systems (ITS), its adoption still comes with a number of technical, financial, and organizational hurdles. Issues such as installation costs, data management, and system compatibility continue to challenge large scale deployment. The following section discusses these limitations in detail and highlights possible strategies for overcoming them.

5.1. Technical Challenges

RFID systems depend on wireless communication, which makes them vulnerable to environmental interference. Factors like nearby metal surfaces, electromagnetic noise, or harsh weather can weaken radio signals and lower the accuracy or range of readings (Want, 2006). In busy or densely populated areas, signals from multiple readers sometimes overlap, causing collisions or repeated data entries. Another challenge lies in

connecting RFID readers with existing ITS components such as GPS units, sensors, and databases. Doing so often requires careful network planning and common standards to ensure smooth system integration (Pan et al., 2023).

5.2. Economic and Infrastructural Barriers

Although RFID technologies have shown great promise in improving the efficiency of Intelligent Transportation Systems (ITS), their large scale adoption remains limited by economic and infrastructural constraints. Setting up a complete RFID system often demands substantial investment—not only for hardware such as readers, antennas, and servers but also for compatible software and integration into existing transport frameworks. For smaller operators or municipalities, particularly in developing countries, such expenses can represent a serious financial burden that delays or even prevents implementation (Hannan et al., 2014).

Apart from the initial investment in hardware, the continuous upkeep of RFID systems poses a notable financial challenge. Ensuring uninterrupted operation requires trained personnel, a dependable energy supply, and regular calibration of equipment to maintain accurate tracking. In many cases, the absence of clearly defined maintenance protocols leads to fluctuating performance levels and higher long term costs (Want, 2006). Additionally, the upkeep of extensive RFID reader networks in outdoor settings brings several logistical difficulties. Exposure to adverse weather conditions, voltage instability, and physical wear can shorten device lifespan, thereby raising both maintenance and replacement expenses (Deng, 2015).

5.3. Data Privacy and Security Concerns

As RFID systems depend on wireless data transmission, they are naturally exposed to certain security risks, including interception, cloning, and unauthorized access. When encryption and authentication measures are weak or inconsistent, sensitive data such as a vehicle's identity, its movement history, or financial transactions—may be leaked or

misused. These risks raise ongoing ethical and legal debates, particularly in public transit and toll collection environments (Hannan et al., 2014). Furthermore, questions of data ownership remain largely unsettled across many ITS projects. It is often unclear which party government agencies, private operators, or third party service providers should hold responsibility for safeguarding collected information and defining its permissible use (Atilgan et al., 2025)

5.4. Organizational and Policy Limitations

The adoption of RFID technology within Intelligent Transportation Systems (ITS) faces not only technical and financial constraints but also a range of organizational and policy related difficulties. A key problem stems from the fragmented nature of transport governance, where different agencies function separately under varying legal frameworks. Such institutional disconnection often results in conflicting standards and slower administrative decisions (Hannan et al., 2010). One additional barrier lies in the lack of a clear, nationwide policy framework for RFID adoption. Many initiatives are launched at the municipal or regional level without coordination, resulting in fragmented systems that cannot easily communicate with one another (Want, 2006). At the same time, inadequate oversight of data governance and privacy increases the potential for misuse and gradually weakens public trust.

CONCLUSION AND FUTURE WORK

The integration of RFID technology within Intelligent Transportation Systems (ITS) has greatly improved automation and operational intelligence in today's transport networks. By enabling reliable, contactless data exchange, RFID contributes to smoother traffic flow, greater safety, and better overall service quality. Its successful use in vehicle identification, toll payment, and public transport management shows its importance as a core driver of smart mobility solutions.

Despite these achievements, widespread adoption still faces notable economic, technical, and organizational constraints. High installation and maintenance costs, fragmented policy environments, and limited data protection practices remain key barriers. Overcoming these challenges will require stronger coordination among policymakers, researchers, and industry actors to develop shared standards and sustainable investment models.

Future research should prioritize linking RFID with emerging digital infrastructures such as the Internet of Things (IoT), Artificial Intelligence (AI), and Blockchain. These integrations could strengthen data security, improve interoperability, and support predictive decision-making in ITS applications. Expanding RFID's role in autonomous vehicle communication, smart logistics, and urban traffic optimization may also open new directions for sustainable transport innovation.

In summary, RFID is not merely a supporting tool but a central element driving the transition toward intelligent, connected, and environmentally conscious mobility systems.

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