



## Rail Freight Container Management System Utilizing Radio Frequency Identification and Cargo Tracking Technology

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### Abstract

Real-time monitoring of cargo in transit is essential for improving safety and operational efficiency in public railway transportation systems. Although technologies such as Radio Frequency Identification (RFID) and Global Positioning System (GPS) have been widely applied in logistics, their systematic implementation within the Railway of Thailand remains limited. This paper proposes a real-time railway freight container management system designed to reduce operational errors and prevent cargo loss. The proposed system integrates UHF RFID technology with GPS-based tracking, enabling continuous identification and localization of cargo containers. Tracking data is transmitted to a centralized web-based platform via wireless communication networks for real-time monitoring and management. Experimental evaluation conducted under real operational conditions demonstrates that the system achieves an average end-to-end latency of 185 ms, with a maximum observed delay of approximately 310 ms, confirming its suitability for real-time railway logistics operations. GPS-based container localization yields a mean absolute positioning error of 4.8 meters, with a 95% confidence interval of 4.2–5.4 meters, based on 200 ground-truth samples. Comparative analysis shows that the parcel misplacement rate is reduced from 2.3% under manual handling procedures to 0.4% after system deployment, representing an 82.6% reduction in operational errors. The software platform adopts standard design patterns to enhance reliability and maintainability, while secure authentication is ensured using a bcrypt-based hashing mechanism. The results confirm the practicality and effectiveness of the proposed system for large-scale railway freight logistics.

**Keywords:** Logistic, Radio Frequency Identification, Global Positioning System, Web Browser, and Railway



## 1. Introduction

In recent years, Thailand has made continuous efforts to develop national rail system standards, with a focus on advancing both technological innovations and regulatory frameworks. Among these efforts, the development of freight rail transport technology presents a significant challenge that requires further attention. This challenge arises primarily from the diverse nature of the country's freight transport system, which integrates maritime, air, and land transport, each characterized by distinct operational processes and resource demands. Currently, both public and private sectors are actively involved in the logistics industry, leading to intense competition in critical areas such as delivery times, cost efficiency, and customer service [1]. In response to these pressures, many logistics providers have undertaken substantial initiatives to enhance their operations. Rail-based freight transport continues to be a widely utilized mode of transportation in Thailand, and due to the increasing market competition, rail freight operators are now under pressure to expedite the development of infrastructure and logistics management systems in order to improve operational efficiency and secure a competitive edge.

The logistics system has been defined in [2] as the management of product flow from the point of origin to the point of consumption in order to meet customer requirements. In [3], logistics is further characterized as a component of the supply chain responsible for managing transportation, warehousing, and the efficient flow of products. These definitions underscore the importance of aligning logistics development efforts with established theoretical frameworks. Consequently, many organizations have enhanced their freight logistics operations through the adoption of technologies such as web applications and Radio Frequency Identification (RFID). A web application is a software system that allows users to send and retrieve data from a database via an internet-connected web browser [4]. RFID, by contrast, is a contactless automatic identification technology that utilizes radio waves to identify and

track objects, thereby enabling faster data exchange [5].

Numerous systems can be integrated into freight management [6], which typically includes four main components: (1) order fulfillment and data management, (2) planning and control systems with functional capabilities, (3) accurate and timely response systems, and (4) statistical analysis and decision-making functionalities [7]. Previous research has demonstrated the integration of web services and web application technologies into logistics systems [8]. However, web applications alone may not fully address the complex operational needs of real-world logistics. Therefore, it is crucial to incorporate Radio Frequency Identification (RFID) technology to enhance logistics management effectiveness. For example, S. J. Barro-Torres *et al.* developed a maritime freight container management system using RFID, which facilitated traceability, efficient container reservations, and accurate vehicle dispatching to final destinations [9]-[10]. In 2012, RFID technology was further applied to communication between autonomous vehicles and cargo, enabling automation in transportation and handling systems, thereby improving precision and reducing processing times [11].

While web and RFID technologies have significantly advanced logistics systems, they have yet to be specifically designed or validated for rail-based freight logistics in Thailand. Therefore, this study proposes the design of a rail freight container management system that integrates RFID and cargo tracking technologies. The structure of this paper is as follows: Section 2 provides theoretical background, Section 3 outlines the system design, Section 4 discusses the implementation and evaluation, and Section 5 draws the conclusion.

## 2. Materials, Equipment, and Research Methodology

### 2.1 Radio Frequency Identification System

RFID technology shares architectural similarities with smart card systems, as it stores data within a memory unit embedded in an RFID tag or transponder. These tags may vary in form and are not limited to plastic cards. Communication between the RFID reader and the

tag occurs through the transmission of radio frequency (RF) signals, with air serving as the transmission medium. Consequently, technical standards are necessary to regulate data transmission and power exchange between the reader and the tag [12-13].

A critical factor in selecting RFID equipment is the operating frequency, which refers to the frequency at which the reader transmits signals. The tag may respond using the same or a different frequency band, typically distinguished by load modulation techniques. RFID systems are generally classified into four frequency bands, as outlined in Table 1.

Table 1 Frequency bands used in RFID Systems.

Frequency Band	Range	Wavelength	Operating Distance
Low Frequency (LF)	30 kHz - 300 kHz	10 km - 1 km	<50 cm
High Frequency (HF)	3 MHz - 30 MHz	100 m - 10 m	<3 cm
Ultra High Frequency (UHF)	300 MHz - 3 GHz	1 m - 10 cm	<9 m
Microwave	3 GHz - 300 GHz	30 cm - 1 mm	>10 m

As shown in the table, the effective operating distance increases with frequency. However, practical deployment is influenced by several factors, including reader power output, antenna gain, positioning of the reader and tag, data transmission techniques, and the type of tag. In practice, Low Frequency (LF) and High Frequency (HF) systems generally use standardized frequencies across countries (e.g., 135 kHz for LF and 13.56 MHz for HF), whereas Ultra High Frequency (UHF) and Microwave frequencies vary by region. This research focuses on the UHF band between 920-925 MHz, in accordance with Thailand’s national telecommunications equipment standard for RFID systems [14].

### 2.1.1 Safety Regulations

When the human body is exposed to radio frequency (RF) environments, it may absorb RF energy, which can be harmful if it exceeds

specified limits. Potential effects of excessive RF energy exposure include cell expansion, disruption of the blood-brain barrier, and alterations in brainwave activity. The absorption of RF energy by the body is quantified by the Specific Absorption Rate (SAR), which is calculated using the following formula:

$$SAR = \frac{CE^2}{d} \tag{1}$$

where C represents tissue conductivity (S/m), E is the electric field strength (V/m), and d is the mass density of the tissue (kg/m<sup>3</sup>). Safety limits for RF exposure vary by region, as detailed in Table 2.

Table 2 SAR limits for RFID equipment.

Standard	SAR Limit
IEEE (Institute of Electrical and Electronics Engineers)	0.2 W/kg (whole-body exposure)
FCC (Federal Communications Commission)	1.6 W/kg (measured over 1 gram of tissue)
Europe (European Committee for Electrotechnical Standardization)	2.0 W/kg (measured over 10 grams of tissue)

### 2.1.2 Electromagnetic Wave Reflection

When a transmitting antenna emits electromagnetic waves toward a target, the waves propagating through the air may encounter obstacles or various objects. This interaction can cause part of the wave energy to be absorbed by these objects, converting it into heat. The remaining energy may scatter in multiple directions with varying intensities depending on the angle of incidence. Some of this scattered energy may also be reflected back toward the transmitting antenna. Radar technology leverages this principle of wave reflection to measure the distance and position of target objects. Similarly, RFID systems using backscatter techniques rely on the reflection of electromagnetic waves to transmit data from RFID tags to readers.

The reflective properties of objects generally improve with higher operating frequencies. As a result, RFID systems often operate in high-frequency bands, such as 900 MHz, 2.45 GHz, or

even higher. In RFID systems, the reader antenna emits electromagnetic waves omnidirectionally with an effective isotropic radiated power ( $P_{EIRP}$ ). The power flux density  $W$  that reaches the RFID tag can be calculated using Equation (2). The tag antenna then reflects a portion of the received power, denoted as  $P_S$ , back to the reader.

$$P_S = \sigma W \tag{2}$$

where  $\sigma$  denotes the Radar Cross Section (RCS) [15–16]. Generally, the electromagnetic wave reflected from the RFID tag radiates omnidirectionally into free space, forming a spherical pattern originating from the point of reflection, as illustrated in Figure 4. The power of the reflected wave decreases proportionally to the square of the distance ( $r_2^2$ ) from the reflection point. Therefore, the power density incident on the reader antenna can be determined using Equation (3).

$$W_B = \frac{P_S}{4\pi r_2^2} = W \left( \frac{\sigma}{4\pi r_2^2} \right) = \frac{P_{EIRP}}{4\pi r_1^2} \left( \frac{\sigma}{4\pi r_2^2} \right) \\ = \frac{P_{EIRP}\sigma}{(4\pi r_1 r_2)^2} = \frac{P_{EIRP}\sigma}{(4\pi)^2 r^4} \tag{3}$$

As illustrated in Figure 1, within the RFID system

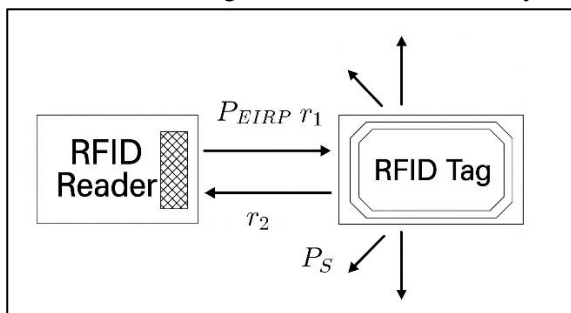


Figure 1 Signal reflection from a RFID Tag.

As shown in Figure 1, within the RFID system, the radar cross-section (RCS) is a key parameter used to quantify an object’s ability to reflect electromagnetic waves. The RCS value depends on several factors, including the object’s size, material composition (e.g., metal reflects signals more effectively than plastic), surface texture characteristics that influence signal reflection, the wavelength of the operating frequency, and the polarization of the incident waves.

## 2.2 Global Positioning System

The Global Positioning System (GPS) is a satellite-based navigation system that has been operational since the mid-1990s. It consists of 24 satellites orbiting the Earth twice daily, ensuring that at least four satellites are visible from any location on Earth at any given time. This system enables continuous, all-weather global position and altitude determination with accuracies ranging from centimeters to 20 meters, depending on the quality of the receiver and the measurement method used. Positioning is achieved by calculating the distance between satellites and receivers using the formula: Distance = Speed × Time. A minimum of three satellite signals is required for accurate location determination. GPS comprises three main segments [17]:

1. Space Segment: Managed by the U.S. Department of Defense, the NAVSTAR GPS constellation includes 24 satellites (21 active and 3 backups) that orbit at approximately 20,162.81 km above the Earth’s surface. These satellites are arranged in six orbital planes inclined at 55 degrees relative to the equator. Although initially developed for military purposes, civilian access is now allowed, albeit with reduced precision (approximately 5–15 meters). Each satellite is equipped with atomic clocks, which maintain an accuracy of 3 nanoseconds.

2. Control Segment: Ground stations communicate with the satellites via radar to monitor and ensure accurate satellite orbits, altitude, and speed, transmitting corrections as necessary. This segment includes five monitoring stations, such as those located in Diego Garcia and Hawaii, along with a master control station in Colorado Springs, USA.

3. User Segment: The user segment includes both civilian and military entities. Civilian users have developed modern GPS receivers capable of providing high-precision positioning on a global scale.

GPS has achieved widespread adoption globally, with significant public familiarity facilitated by the integration of digital traffic systems and organized urban planning. GPS devices are commonly used in taxis, and travelers often replace paper maps with PDAs or



smartphones equipped with GPS. Current GPS systems can provide navigation down to street-level addresses or telephone numbers. In this study, GPS technology is applied to track railway freight containers.

### 2.3 Hardware

The RFID system operates within the Ultra High Frequency (UHF) range (920-925 MHz), which is commonly utilized in warehouse applications. The hardware components include computers, both desktop and handheld RFID readers, and RFID tags. The software includes a web application and an Android-based mobile application designed for data management and visualization.

When a customer initiates a shipment, a service counter staff member records the shipment details (sender, receiver, destination station, phone number) and attaches an RFID tag to the cargo. This tag enables the RFID reader to capture shipment data, which is then transmitted through a web application and API to a centralized database. The item is subsequently loaded into a freight container and shipped. The final stage involves the receipt of the item at its destination.

Cargo and container tracking is facilitated through the use of an NB-IoT Shield, an Arduino Uno board, and a GPS module. These components are assembled and programmed to transmit the latitude and longitude of the cargo to a server database. Users can access tracking information via a mobile application by entering a tracking key issued on the shipping receipt. The application displays shipment details, including the sender and receiver names, origin and destination stations, and the delivery status.

## 3. Design and Implementation

### 3.1 System Architecture

This research proposes a railway freight container management system that integrates Radio Frequency Identification (RFID) technology with cargo tracking through a mobile application utilizing global positioning data. The system aims to automate key operations within the railway logistics network of the State Railway of Thailand.

To implement this system, RFID readers are deployed with network connectivity and adapted to interface seamlessly with existing rail transport workflows. These workflows include parcel intake and dispatch, item verification before container loading, in-transit tracking, and final destination confirmation. The destination of each parcel is incorporated into a process designed to be fully compatible with the operational framework of the State Railway of Thailand. By adopting this method, the system enables the tracking of cargo within freight containers, whether it is loaded, unloaded, or mistakenly left behind in a specific container. Data collection is conducted via a wireless Local Area Network (LAN), as most RFID readers are installed at operational points to support real-time inspection and future scalability.

Each container is equipped with a dedicated RFID tag, and each train is fitted with a GPS module for precise location tracking. The system supports real-time monitoring of train locations. For instance, when a train is at Hua Lamphong Station, the system reflects the status of parcel intake, loading operations, and tracks the goods in transit between stations. As shown in Figure 2, the system overview diagram illustrates the interconnected functions, including container management, train localization, cargo transportation, parcel status verification, and shipment operations. Shipping workflows follow the regulations of the State Railway of Thailand, with each container identified by its origin and destination data.

The system receives input from both users and devices, which is then processed by specialized software. This software communicates with APIs to transmit and receive data. Upon data transmission, access authorization is verified through a security framework before the data is stored in the database. Communication occurs over a UDP/IP network, enabling long-distance interaction between various system states and clients.

The software platform features a graphical user interface (GUI) developed using .NET technology, which interacts with the database and RFID readers. The software architecture

incorporates multiple design patterns, including Façade, Abstract Factory, Data Access Object (DAO), and Value Object (VO) [18], optimizing

system modularity and maintainability, as shown in Figure 3.

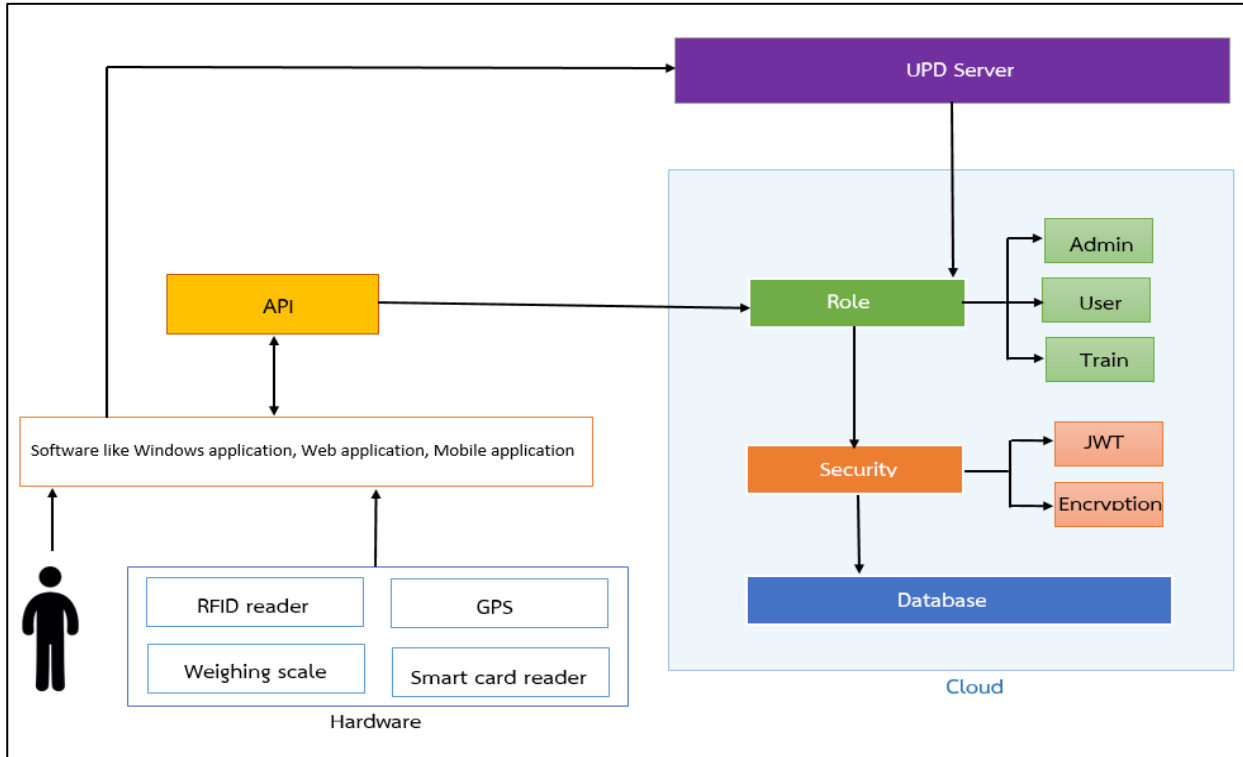


Figure 2 System architecture diagram.

The RFID-based railway freight container management system supports three levels of user access permissions: 1. User – General station staff with limited access to specific features via the web application, such as parcel intake and dispatch, cargo tracking, and individual reporting. 2. Train – Onboard personnel with access to portable RFID reader functions, enabling them to add, remove, modify, and verify cargo using RFID tags assigned to containers and trains. 3. Super Admin – High-level users, such as station masters and managers, with full access to all web application features, including shipment auditing, tracking oversight, station-wide reporting, and user activity monitoring.

### 3.2 System Operation

During system operation, when data is received from devices such as weighing scales, national identification card readers, or RFID tags, the collected information is forwarded to

the software platform. This data is transmitted via an API for processing and is then returned to the software for display and user interaction.

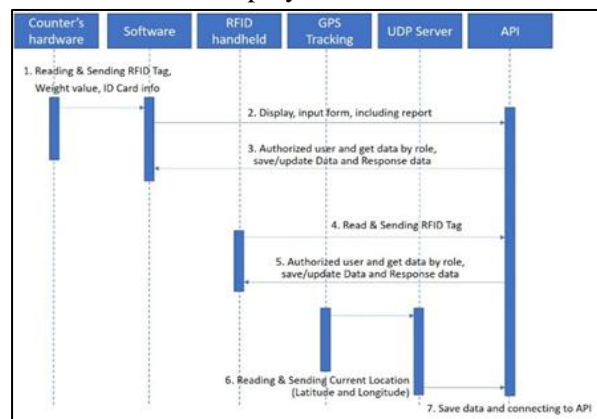


Figure 3 System operation workflow.

Similarly, for handheld RFID readers, once the data is captured, it is transmitted to the API for processing and subsequently returned to the device for display. In the case of GPS data, once the

location information is obtained, it is first sent to a UDP server, which then forwards the data to the API for further processing.

The system was deployed under real operational conditions and evaluated across multiple freight-handling processes. Performance data were collected during 200 live operational events, covering parcel intake, container loading, in-transit tracking, and delivery confirmation.

### 3.3 Data Security

To ensure data security during user registration and system login, users are required to authenticate using a username and password. Passwords are encrypted according to the bcrypt standard, which provides high security and is non-reversible. Bcrypt utilizes the Eksblowfish algorithm, a one-way hashing method that makes decryption infeasible. Each encryption result is unique, as the algorithm employs multiple rounds of processing.

All user login sessions are secured using a token-based authentication mechanism implemented through the JSON Web Token (JWT) standard, with authentication tokens generated from JSON-formatted data and encoded using Base64Url encoding for secure session management. RFID communication follows the EPC Gen2 protocol operating in the 920–925 MHz frequency band, while GPS tracking data are transmitted to the central system using UDP/IP to support low-latency data delivery. Together, these communication and security protocols ensure secure authentication, controlled access, and reliable data exchange across the proposed system.

Furthermore, external access to the database is strictly restricted. It is not accessible via public IP addresses and can only be accessed through a Secure Shell (SSH) connection, providing an additional layer of system-level security.

## 4. Experimental Results

### 4.1 Demonstration and Operational Workflow

The operational workflow of the railway freight container management system, which utilizes RFID technology, is designed to

optimize processes by integrating both hardware and software components. In this system, hardware is employed to capture data, which is then transmitted to the software for storage in a database, where it can be managed and processed subsequently.

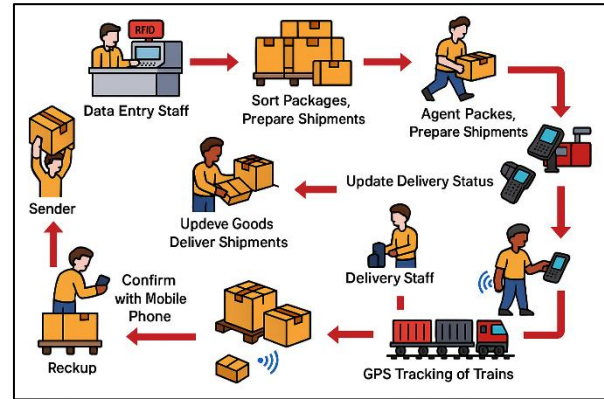


Figure 4 Railway freight container management system using RFID.

As illustrated in Figure 4, when a sender arrives at the station to ship a parcel, the station staff registers the shipment into the system and attaches an RFID tag to the item. Upon the train's arrival, the staff loads the tagged parcel onto the designated freight container. The RFID system then scans the train, container, and parcel to capture all relevant data. Throughout the journey, as the train passes through various stations, both the sender and recipient can track the parcel in real-time via a mobile application. Upon arrival at the destination station, the onboard freight staff scans the parcel again and hands it over to the station officer for collection by the recipient.

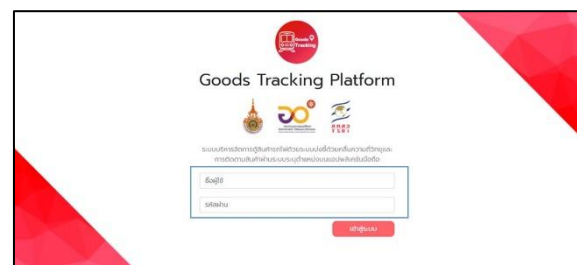


Figure 5 Web application interface for staff operations.

Shipment data, including sender and receiver names, as well as the destination station, is managed through a web application interface at the sending station, as shown in Figure 5. The system

allows staff to input shipment details, generate and print the RFID tag, and scan it using a desktop RFID reader. After validating all data, the staff confirms the entry to store the information in the database, as illustrated in Figure 6. A printed receipt is then issued to the sender, as shown in Figure 7.

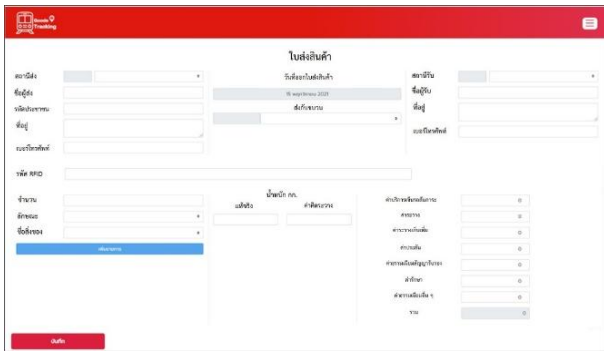


Figure 6 Web application interface for generating shipping orders.

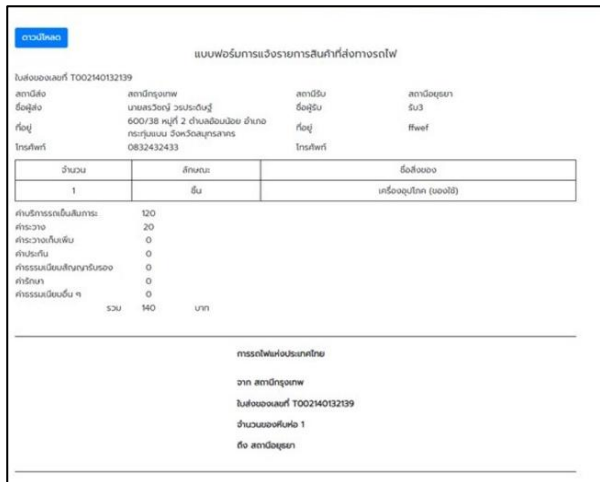


Figure 7 Receipt detailing shipment information.

When it is time to load the parcel into the freight container, the staff opens the RFID handheld reader application, as shown in Figure 8, and scans the RFID tags on the parcel, the container, and the train. Alternatively, the relevant data can be selected from a menu within the application for ease of use. Once the train departs, staff can verify the items that need to be unloaded at each station and summarize the delivery information through the web application. Upon reaching the final destination, the staff uses the RFID handheld reader to scan the

parcel tag and update its delivery status to "Delivered at Destination Station."

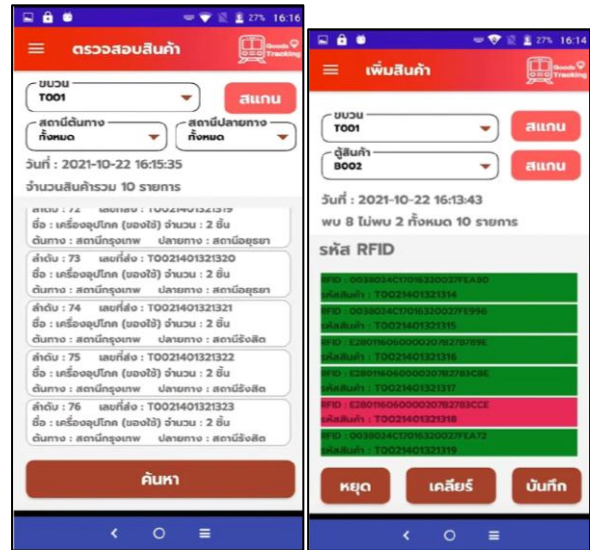


Figure 8 RFID-Based parcel verification application for staff.

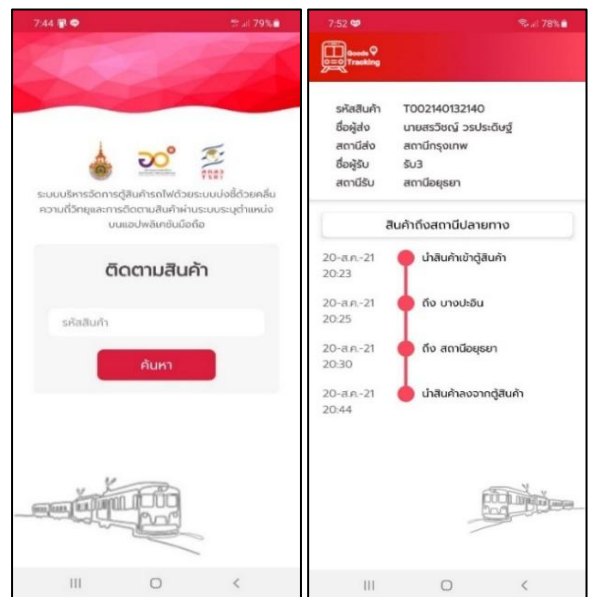


Figure 9 Application for parcel tracking.

Finally, when the customer arrives to collect the parcel, the service counter staff scans the RFID label on the item using a desktop RFID reader. This action updates the parcel status to "Delivered." Both the sender and recipient can verify the parcel's location through the mobile application's GPS-based tracking system, as shown in Figure 9, by entering the tracking number provided on the receipt.

#### 4.2 Performance Evaluation and Operational Impact Analysis

RFID readers were installed at parcel intake and loading points within railway stations, while handheld RFID readers were used by onboard staff during loading and unloading operations. Each freight container was equipped with a UHF RFID tag, and GPS tracking modules were installed on trains to enable continuous location monitoring during transit. The installation setup and device interactions are illustrated in the accompanying diagrams, reflecting real operational conditions as presented in figure 10.

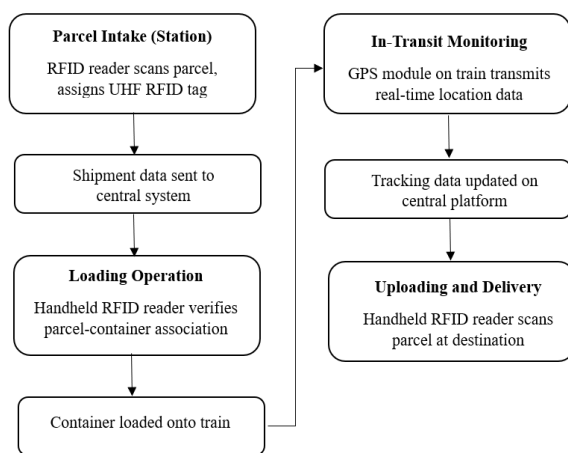


Figure 10 Installation setup and operational workflow of the RFID–GPS-based railway freight container management system.

The proposed system architecture integrates UHF RFID readers, GPS tracking modules, and a centralized web-based platform to support real-time railway freight monitoring. System performance was evaluated under real operational conditions by measuring the end-to-end processing time from RFID tag detection to database update. The results indicate an average latency of 185 ms, with a standard deviation of 42 ms, based on 200 recorded transactions, while the maximum observed latency was approximately 310 ms. These results confirm that the system satisfies real-time operational requirements for railway logistics. In addition to latency performance, the accuracy of GPS-based container localization was assessed using ground-truth reference data. The system achieved a mean absolute positioning error of 4.8 meters, with a 95% confidence interval of 4.2–5.4

meters, calculated from 200 reference measurements, which is adequate for container-level tracking in railway environments.

To evaluate the operational impact of the proposed system, a comparative analysis was conducted between conventional manual handling procedures and the RFID–GPS-based workflow. The results demonstrate a substantial improvement in handling accuracy after system deployment. Specifically, the parcel misplacement rate was reduced from 2.3% under manual operations to 0.4% after implementation, corresponding to an 82.6% reduction in operational errors. This reduction highlights the system’s effectiveness in minimizing human error and improving the reliability of railway freight operations. Overall, the findings indicate that the proposed system not only meets technical performance requirements but also delivers measurable operational benefits in real-world railway logistics environments.

The total system implementation cost was 420,000 THB. Annual operational savings, primarily due to reduced labor requirements and improved loss prevention, were estimated at approximately 310,000 THB per year, resulting in a return-on-investment period of 16.3 months.

#### 4.3 Contextual and Organizational Implications

As depicted in Figures 11 and 12 [19-20], the findings align with the State Railway of Thailand’s Enterprise Development Plan (2015–2024), specifically under Strategic Goal 2: Increasing Revenue and Reducing Costs, and Strategy 2.1: Enhancing Efficiency in Core Business Operations. Within this framework, Program 2.1.2: Increasing Revenue from Passenger and Parcel Transport outlines two key initiatives: 1. The Parcel Delivery Service Enhancement Project in collaboration with Thailand Post, and 2. The “SRT EXPRESS” Fast Cargo Delivery Project — both of which closely correspond to the objectives of this research. As shown in Figure 10, the personnel structure within the Passenger Service Division is categorized into two groups: an approved workforce of 1,330 positions and the actual workforce numbers of 676, 684, 715, 739, and 723 personnel in 2020, 2021, 2022, 2023, and 2024, respectively. This results in an average staffing level of approximately 50% of the approved capacity. Consequently, the scope of

service delivery remains constrained due to limitations in workforce availability.

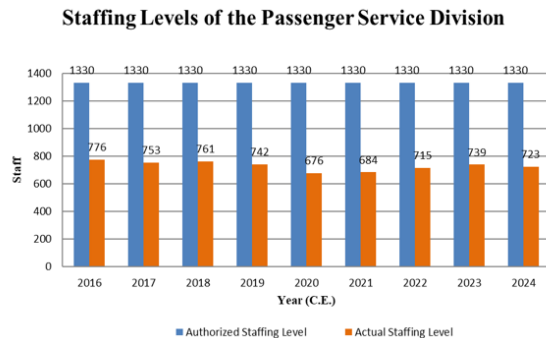


Figure 11 Graph showing personnel allocation in the passenger service division responsible for parcel handling.

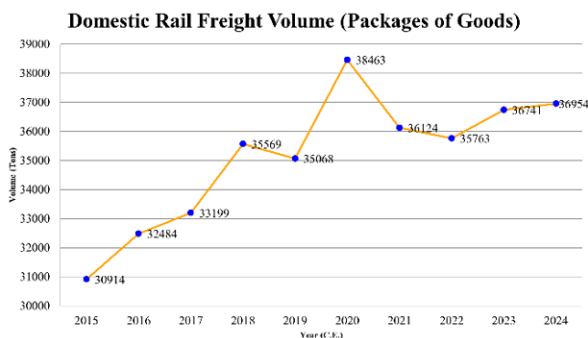


Figure 12 Graph showing domestic rail freight volume.

In contrast, Figure 12 illustrates the domestic rail freight volume (parcel shipments), showing an upward trend. In 2019, the total volume was 35,068 tons, which increased to 38,463 tons in 2020. Although there was a slight decline to 36,124 tons in 2021, the volume still exceeded the 2019 levels. This comparison highlights a significant discrepancy: while freight volume has consistently grown year-over-year, actual staffing levels have steadily decreased. This disparity underscores a critical capacity gap and reinforces the necessity for the proposed management system, which has been designed to support the anticipated growth in the railway parcel logistics sector in the coming years.

## 5. Conclusion

This research presents a railway freight container management system that integrates UHF RFID technology with GPS-based real-time cargo tracking to improve operational efficiency and

reliability in railway logistics. The proposed system combines RFID hardware, GPS modules, and a web-based software platform supported by a centralized database and API-based communication framework, with secure user authentication implemented using a bcrypt-based hashing mechanism.

Experimental evaluation under real operational conditions demonstrates that the system achieves an average end-to-end latency of 185 ms, with a maximum observed delay of approximately 310 ms, confirming its suitability for real-time railway freight monitoring. GPS-based container localization attains a mean absolute positioning error of 4.8 meters, with a 95% confidence interval of 4.2–5.4 meters, while operational errors are significantly reduced, as evidenced by a decrease in parcel misplacement rate from 2.3% under manual handling procedures to 0.4% after system deployment, representing an 82.6% reduction in errors. In addition, the system demonstrates economic feasibility, with a total implementation cost of 420,000 THB and an estimated payback period of 16.3 months. Future work will focus on extending the system to support larger-scale deployment across additional railway lines and integrating advanced data analytics techniques to further enhance predictive monitoring and operational decision-making.

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## 8. References

- [1] Logistics Cost Working Group. Thailand logistics report 2023. Bangkok: Office of the National Economic and Social Development Council; 2024.
- [2] Li X. Operations management of logistics and supply chain: issues and directions. *Discrete Dyn Nat Soc.* 2014;2014:1-7.
- [3] Adiweno L, Zagloel T, Ardi R. Designing economic and environmental system dynamic model of halal supply chain on third-party logistic industry in Indonesia. In: Proceedings of the 4th International Conference on Industrial and Business Engineering; 2018; Macau, China. p.34-40.
- [4] Hussain T. An approach to evaluate the performance of web application systems. In: Proceedings of the International Conference on Information Integration and Web-based Applications and Services; 2013; Vienna, Austria.
- [5] Wang Z, Wang H, Pang Y. Integration of logistics information system and RFID technology. In: Proceedings of the International Conference on Information Technology and Computer Science; 2009. p.138-141.
- [6] Charoenporn P. Smart logistic system by IoT technology. In: Proceedings of the International Conference on Information and Education Technology; 2018. p.149-153.
- [7] Tang Z. The applied research of information system project management in logistics enterprises. In: Proceedings of the 2nd International Conference on Business Computing and Global Informatization; 2012. p.477-480.
- [8] Jiang H, Fang H, Li Y. Design and implementation of logistics information management system based on web service. In: Proceedings of the International Symposium on Distributed Computing and Applications for Business Engineering and Science (DCABES); 2015. p.130-133.
- [9] Barro-Torres SJ, Fernandez-Carames TM, Gonzalez-Lopez M, Escudero-Cascon CJ. Maritime freight container management system using RFID. In: Proceedings of the 3rd International EURASIP Workshop on RFID Technology; 2010. p.93-96.
- [10] Kato T, Higuchi M. A handling management system for freight with the ambient calculus and UHF RFID tags. In: Proceedings of the International Conference on Network-Based Information Systems; 2012. p.364-371.
- [11] Bouabdellah K, Haffaf H. Communication architecture based on intelligent autonomous vehicles for container terminals. In: Proceedings of the 12th International Conference on ITS Telecommunications; 2012.
- [12] ECTI Association. RFID technology and its applications [Internet]. Available from: <http://www.ectithailand.org/emagazine/views/60> [accessed 21 Apr 2022].
- [13] Finkenzeller K. RFID handbook: fundamentals and applications in contactless smart cards and identification. 2nd ed. New York: John Wiley & Sons; 2003.
- [14] National Broadcasting and Telecommunications Commission. Technical standards for telecommunications equipment and devices: radio frequency identification (RFID) [Internet]. Available from: <http://www.ratchakitcha.soc.go.th/DATA/PDF/2560/E/289/51.PDF> [accessed 21 Apr 2022].
- [15] Pouzin A, Vuong TP, Tedjini S, Pouyet M, Perdereau J, Dreux L. Determination of measurement uncertainties applied to the RCS and the differential RCS of UHF passive RFID tags. In: Proceedings of the IEEE Antennas and Propagation Society International Symposium; 2009. p.1-5.
- [16] Skali S, Chantepy C, Tedjini S. On the measurement of the delta radar cross section ( $\Delta$ RCS) for UHF tags. In: Proceedings of the IEEE International Conference on RFID; 2009. p.346-351.
- [17] Kaplan ED, Hegarty CJ. Understanding GPS/GNSS: principles and applications. 3rd ed. Norwood (MA): Artech House; 2017.



- [18] Gamma E, Helm R, Johnson R, Vlissides J. Design patterns: elements of reusable object-oriented software. Boston: Addison-Wesley; 1995.
- [19] State Railway of Thailand. Annual report 2015–2024. Bangkok: State Railway of Thailand; 2024.
- [20] State Railway of Thailand. Enterprise plan 2015–2024, fiscal year 2023 edition. Bangkok: State Railway of Thailand; 2023.