31482

Honours Project

Inbound and Outbound Management with the integration of RFID system

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Abstract

As a small business expands into a franchise from a single outlet, developing a warehouse as a central distributor for storage and stock management to each outlet in the franchise becomes essential. To run the warehouse with efficiency in all aspects from handling inbound and outbound goods to storing them, an inventory management system is required, combined with RFID technology to improve the logistics inbound and outbound processing time. This developed system by this research will likely enhance all aspects of the logistics process, not only improving the handling of products received from suppliers and distributed to outlets, but also reducing human errors and labour.

1 Introduction

When building a first warehouse, owners tend to ignore the importance of inventory management system and technology come with the system. It is important to acknowledge the essential responsibility of a technology to take over the processes of a warehouse. Some of the works in a warehouse may require human interaction such as carrying and managing, however, there are works that can be replaced with a warehouse system to allow seamless warehouse management activities. One significant activity that is time-consuming, error-prone and cost-ineffective for warehouse managers is to manually manage inventory on daily basis.

From the established problem, this research puts it into consideration and constructs a suitable system solution to solve the inventory issues. Most of the inventory management system in the logistics market is expensive and requires many understanding of its functionalities to make the system to work, it may put a new owner in a challenging situation in a fast-paced market. Accordingly, the system from this research delivers the inventory management functionalities in a simple but scalable manner. It means that as the warehouse is building with a larger number of products, the system keeps its functionalities running smoothly, while the system developers can extend the system with more advanced functionalities without causing issues to the system.

The built warehouse system mentioned in this research focuses on the inbound and outbound process of the warehouse, where goods are continuously transporting in and out of the warehouse. Inbound process is where the goods are received from different suppliers, processing the goods and transferred into the warehouse storage. Outbound process is where goods, or different products are picked up from warehouse shelves, packed and delivered outside the warehouse. Within the warehouse process of receiving, managing the goods, the warehouse system integrates a RFID (Radio Frequency Identification) technology to boost the efficiency of inbound and outbound process. There are two essential components in RFID technology, RFID tag and RFID reader. RFID tag is a small electronic device which consist of a microchip and antenna. By its passive functionality, RFID tag does not require any source of power and can be scanned by any RFID reader, which emits radio waves for communication. RFID tags are applied in each product as a replacement of the traditional barcode number, or also called Universal Product Code (UPC). RFID tags can be scanned by an RFID reader in a large number at the same time, therefore, it provides quick update of the status of multiple goods. With the instantaneous update in each scan from RFID reader, warehouse manager is able to view real-time tracking inventory levels and movements.

Problem Statement:
The described warehouse system is enabled to solve common issues in warehouse management, especially owners new to warehouse operations. In the modern era of logistics and supply chain management, efficient inventory management is essential to ensure timely delivery, reduce operational costs, and maintain optimal stock levels. Traditional inventory management systems, reliant on manual data entry or barcode scanning, often face challenges in real-time tracking, data accuracy, and processing speed. These challenges, in the case of develop a franchise, can lead to significant operational inefficiencies, such as misplaced items, delivery delays, and stock discrepancies. The integration of Radio Frequency Identification (RFID) technology to the warehouse system promises to address these issues by offering real-time tracking and automated data capture. However, there is a need to comprehensively study and evaluate the potential of RFID in enhancing the inbound and outbound processes of inventory management. This research aims to bridge this knowledge gap by assessing the operational benefits, challenges, and overall impact of integrating RFID technology into inventory management system.

2 Background

2.1. RFID Technology

Having a comprehension in RFID technology is essential in the usage of technology implementation in the research. RFID, is an abbreviation of Radio-Frequency Identification, which has grown into one of the most promising technological solutions for identification and tracking. It applies the electromagnetic fields to transfer data between a reader and an electronic tag attached on an object. The RFID reader is a key part that starts and receives signals from the RFID tag. These readers are usually connected to a network and can be either portable or permanently placed. Using radio waves, the reader sends a signal to turn on the RFID tag. Once turned on, the tag sends a signal back to the reader's antenna. This signal is then turned into digital data that can be used for many purposes such as keeping track of inventory, storing data, or controlling access to secure areas. This step of turning the signal into usable data is crucial for making the RFID system work well in automatically identifying items and capturing data.

RFID Tags
There are two type of tags, passive and active tags. Passive tags are powered by the RFID reader using radio waves, whereas active tags are equipped with a battery, which can transmit data over greater distances, up to hundreds of meters. When considering type of RFID tags, it is important to consider the type of tag, type of reader, RFID frequency, and environmental interferences. These are the major factors that influence the reading distance between readers and tags. Active RFID tags, owing to their internal power source, typically possess a longer read range compared to passive tags, making them ideal for large-scale tracking operations. On the other hands, passive tags offer power efficiency and longevity, enabling continuous tracking for smaller items.

RFID system

To build a RFID system, there are different configurations to establish the interaction between RFID readers and RFID tags. There are 3 predominant types of system configurations Passive Reader Active Tag system, Active Reader Passive Tag system and Active Reader Active Tag system

In Passive Reader Active Tag (PRAT) systems, the reader remain passive, functioning as a receiver for signals from active, battery-powered tags. A key feature here is the adjustable reception range, which can be as short as 1 foot or extend up to 2,000 feet (0–600 meters). This adaptability is useful in many situations, such as tracking valuable assets over different distances.

In contrast, Active Reader Passive Tag (ARPT) systems have an active reader that both sends out signals and receives responses from passive tags, which don't have their own power source. This two-way communication is especially important in scenarios that require tag authentication, making these systems more interactive.

Furthermore, Active Reader Active Tag (ARAT) systems use both active readers and active tags. In this setup, active tags are activated upon receiving an interrogator signal from the active reader. A variation includes Battery-Assisted Passive (BAP) tags, which act like passive tags but have a small battery to power the return signal, enhancing data reporting capabilities.

Finally, there's a distinction between fixed and mobile readers. Fixed readers are designed to cover a very specific area, allowing for tight control over the reading zone. This is great for monitoring when tags move in and out of a designated area. Mobile readers offer more flexibility; they can be handheld or even attached to moving objects like carts or vehicles.

RFID Type	**Frequency Range**	**Typical Frequency**	**Read Range**	**Common Use Cases**	**Tag cost in volume**
Low-frequency (LF)	30 KHz – 500 KHz	125 KHz	10 cm	Animal tagging, Access Control	US $1
High-frequency	3 MHz – 30 MHz	13.56 MHz	0.1–1 m	Smart Cards, NFC	US$0.05
Ultra-high frequency (UHF)	300 MHz – 960 MHz	433 MHz	1 – 100m	Inventory Tracking, Supply Chain	US $5
Microwave	3.1–10 GHz	3.1 GHz	Up to 200m	High-speed data transmission	US $5

Table: RFID Frequency

This table summarizes the primary frequency bands used in RFID technology, offering insights into the typical read range and common applications for each type. It serves as a reference for consideration of the application of RFID technology for current Warehouse System research.

2.2 Application of RFID to Warehouse System

One of the pivotal explorations into the integration of RFID in logistics and warehousing comes from Zhou's research at Wuhan Business University. Zhou's study, titled "Application of RFID Information Technology in Logistics Warehouse Management," delves into the role RFID plays in enhancing the quality of logistics warehousing management (Zhou, 2018) [2]. In the similar to current research of inventory management, the paper accentuates the inherent advantages of RFID technology, emphasizing its capacity for real-time tracking, automated data capture, and the consequent improvements in operational efficiency. Zhou's research is particularly noteworthy for its comprehensive examination of the application domains of RFID. While the broader spectrum of RFID applications spans industries from public transportation to electronic ticketing, its role in warehousing stands out. The paper systematically categorizes the applications into distinct warehousing processes: inbound warehouse management, in-warehouse management, out-of-warehouse (outbound) management, transfer and stock transfer, and inventory checks (Zhou, 2018) [2]. This segmented approach offers a granular understanding of how RFID interfaces with different stages of warehousing, underscoring its pervasive impact. Furthermore, the study alludes to the global attention RFID has garnered in recent years, specifically referencing the "Made in China 2025" strategy. Such strategies, as Zhou suggests, are poised to catalyse the growth of RFID-centric computer information technology, thereby reinforcing the significance of RFID in modern inventory management systems. Drawing from Zhou's insights, it becomes evident that the integration of RFID technology into warehousing and logistics isn't merely an incremental upgrade but a paradigm shift. By offering real-time data, enhancing tracking accuracy, and streamlining operations, RFID emerges as a linchpin in the evolution of efficient inventory management systems.

Ding (2013) [5] gives us another angle, painting a broader picture of a smart WMS. He touches on the integration of sensor tech, handheld devices, and shelf readers to keep tabs on parcels as they move in and out of a warehouse. But no matter the tech method in play, the end game is pretty clear: capture the current state of parcels, process and store the info, and make sure warehouse managers can pull up that data in real time. Eventually, with all this monitoring, there's a large amount of continuous data writing and processing in the background.

Yan, Chen, and Meng's seminal research, "RFID Technology Applied in Warehouse Management System" underscores the salient features of modern warehouse management, proposing a comprehensive WMS underpinned by RFID technology. Central to their research is the conceptualization of an RFID-based WMS that not only streamlines traditional warehousing processes but also addresses contemporary challenges like value-added service flows, returns management, and dynamic customer service. This WMS, as the authors elucidate, leverages RFID middleware as a foundational platform, covering myriad operations from goods entry to delivery. The system's prowess lies in its capacity to capture, relay, verify, and update voluminous data associated with frequent warehouse activities. The implications are profound: a marked reduction in manual labour, minimization of errors like fault scanning and missed scans, and a significant boost in operational efficiency and accuracy (Yan et al., [2008]) [3].

Furthermore, Yan and his colleagues develop the strategic position of warehouses within the supply chain. Serving as pivotal junctions across various processes, warehouses are integral to the seamless functioning of the supply chain. The advent of global operation strategies and the growing emphasis on supply chain management have further magnified the significance of efficient warehouse management. In this context, the integration of computerization and automation, epitomized by RFID technology, emerges as a game-changer, heralding a new era of efficiency, accuracy, and adaptability in warehouse management.

3 Methodology

This research develops an inventory management system that is integrated with an RFID technology to interact between physical interaction of goods and digital data. As each good received from the warehouse in the inbound process, it is recognized by the RFID reader and gets updated to the system. Inventory level is updated automatically once the goods are received and get transferred to a different department. This system is constructed with a continuous communication with RFID system, therefore, inventory level for all stocks can be constantly kept track of by warehouse managers, and immediately notify when stocks are lower than the required level.

Methodology section establishes the project objectives and their impacts to the projects. Project objectives are the foundation of the research methodology.

3.1. Project Objective

O1: Analyse the roles of RFID technology in improving inventory accuracy, reducing costs, and enhancing operational time and efficiency.

O2: Recommend the most effective RFID technology for warehouse management based on the evaluation and analysis conducted in this research.

O3: Construct functional and non-functional requirements for the warehouse management system.

O4: Analyse the system's responsiveness in detecting and resolving issues in real-time.

O5: Provide clear steps of implementation for development of project.

O6: Develop a framework for evaluating the effectiveness of WMS and RFID technology integration.

O7: Analyse the potential for scaling the RFID-enabled system to cater to larger inventory volumes or multiple warehouse locations.

As the project objectives are described above, they get carried throughout the project development in the research and possibly future maintenance. Objective 1 (O1) on the quantitative and qualitative benefits of integrating RFID technology into WMS. By tracking key metrics like inventory accuracy, operational time, and efficiency, this research aims to present a robust case for RFID adoption by presenting the stimulated warehouse system configured by the research configurations. With the achievement of O1, Objective 2 (O2) will introduce the effective warehouse configurations that suits small warehouse development. This includes different types of RFID tags, readers, and backend server, and recommending the most suitable based on criteria like read range, data storage, and cost-effectiveness. When developing the warehouse software system, functional and non-functional requirements are of importance to deliver the consistent development state of the warehouse software system, this is what build Objective 3 (O3).

Real-time issue detection and resolution are critical for a warehouse system. Objective 4 (O4) seeks to evaluate how quickly and efficiently the RFID-enabled warehouse system identifies and rectifies issues like stock discrepancies, misplaced items, or system errors. This research also constructs and clearly presents the building steps of the software system that can be both stimulated and performed in real warehouse operations, that is the definition of objective 5 (O5). It is crucial in the research to build a evaluating system to monitor the warehouse software system and the performance of IoT layer. The evaluating framework (described in 3.4.1), which the data collection and data analysis will be based on to evaluate the effectiveness of the system, ensuring that the WMS and RFID integration is meeting the previously established objectives. Objective 7 (O7) is described at last to present its after-operation aim, which analyses the performance of the applied warehouse system with practical workloads, even with peak-time workloads

3.2. Research Design

3.2.1. ERD (Entity Relationship Diagram)

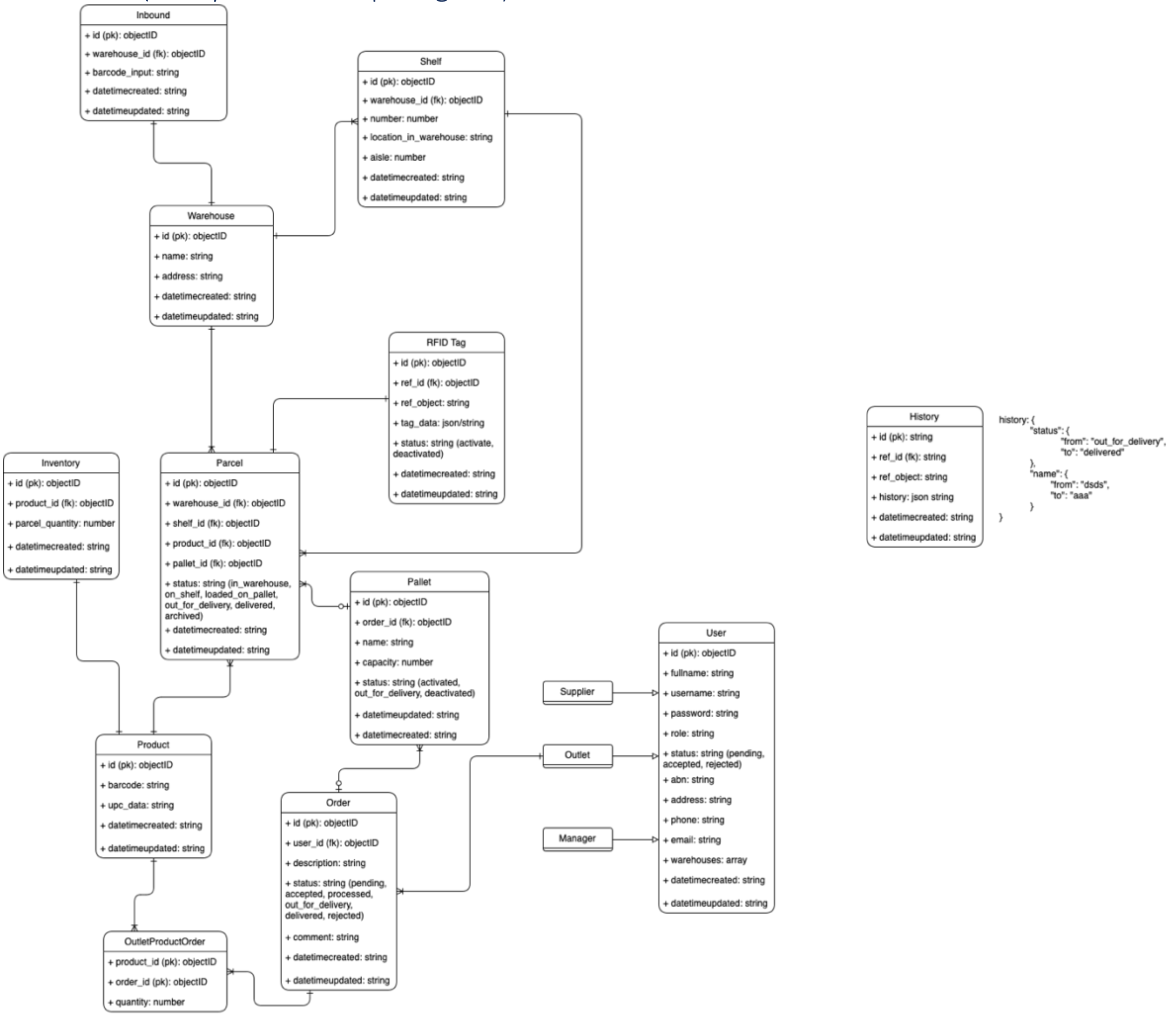

Figure: Entity Relation Diagram for Warehouse System

The above diagram establishes the entities and their relationships for the warehouse system database.

- Warehouse: Represents the primary storage and warehouse system facility, where parcels are stored, received, dispatched and updated onto the warehouse system.
- Shelf: Shelf object identification for each warehouse
- Parcel: Represents individual good, item or package of a product within the warehouse. Parcel entity is central to the warehouse system, tracking items that are either stored, in transit within the warehouse, or set for delivery.
- RFID tag: Represents an RFID tag and its data. “status” property is either in activate or deactivated state. If its status is activate, the RFID tag must have a one-to-one relationship to a parcel. The RFID tag can be deactivate for reuse purpose once the parcel has been delivered or discarded.
- Pallet: Is a flat transport structure, typically made of wood, that supports goods in a stable manner while being lifted by a forklift, pallet jack, or other jacking devices. A pallet will hold a number of parcels on top of it. Therefore, it has a one-to-many relationship to Parcel entity. A pallet can have a name on it, allowing rapid recognition of pallet in the

warehouse. The name tags of pallet can in a form of paper and attached on each side of the pallet.

- Product: Represents as a product. It holds property barcode and “upc_data” as a JSON string for its UPC data from UPC database.
- Inventory: An inventory is associated with 1 product, representing the inventory level, or number of parcels for one product in one warehouse.
- DeliveryOrder: Is the order that created by one outlet for that warehouse to make a deliver, each delivery order will contain a number of parcels from a warehouse.
- Outlet: Represent an outlet, which is a shop, or a restaurant.
- OutletOrder: Is the order requested from one outlet to the warehouse for product ordering. Once the Outlet Order is accepted, the DeliveryOrder will be created.
- SupplierOrder: Similar to OutletOrder, SupplierOrder is made by the warehouse to bulk order from one or many suppliers. Suppliers registered within the system will get a notification from the order, thus, proceed to process the ordered products.
- Supplier: Represent a supplier, includes supplier contact information
- History: This history holds history to all changes of one entity.

3.2.2. Inbound and Outbound Process

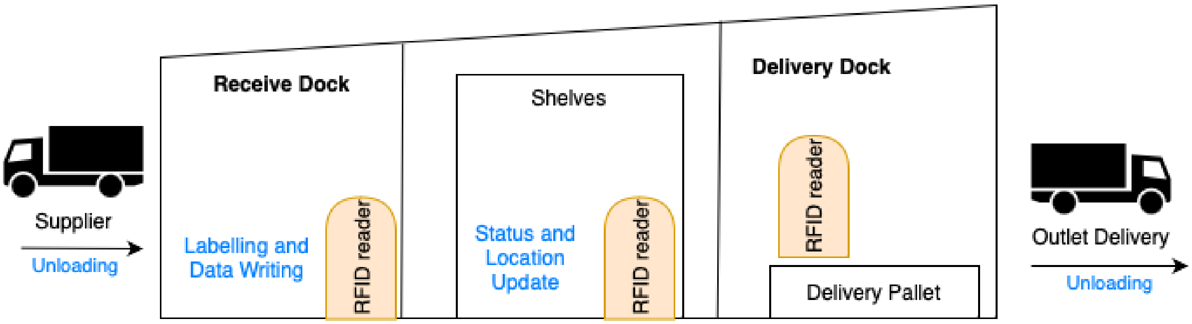

Figure: Process of Inbound and Outbound

Steps for inbound process:

1. Receiving and Quality Inspection: As the suppliers deliver the goods in a pallet form, each good/parcel will be unloaded by warehouse workers, do a quality check, and attached with an NFC tag separately, which will be placed outside of the good’s packaging. Then, each good will be put onto a conveyor belt to move through RFID inbound reader for scanning the NFC tag and update the good to the system. Inbound RFID reader will be set up in a gate at the end of the conveyor belt. In current system, warehouse workers, who are responsible for inbound management, should enter the incoming product barcode’s for incoming parcels on the Inbound Page. It is compulsory for warehouse workers to ensure the incoming parcels match with the barcode entered on the Inbound Page, as the system is only managed to have only one type of product going through the conveyor belt at one time. It is important to notice the suppliers to have one type of product in one pallet with an intention to reduce the sorting process for warehouse workers.

2. Inventory Recording: As the RFID system scan the tag attached from one good, it will send the tag data into the backend system for processing. The backend system, first, will verify the incoming barcode entered by warehouse workers from the front-end, understanding that the incoming parcels will be marked with this barcode. With the validity of incoming barcode, each tag, attached with that parcel, scanned will have the backend system added to

the database, with inventory updated for that type of product. The parcel, when is added to system, will be mark with status “in_warehouse”.

3. Storage: RFID readers are placed across shelves, there will be multiple shelves in one aisle. These RFID readers will read the status of each good, then update its status and its location. Status types are “in_warehouse”, “on_shelve”, “delivering”. If its status is “in_warehouse” and get scanned by shelve RFID reader, the backend system will update its status to “on_shelve” and attach the shelve location with the good.

Step for Outbound Process:

1. Order Processing: When an outlet wants to make an order for the warehouse, the outlet manager will make the order through the website, which is designed specifically for outlets. As soon as the outlet manager places the order, the warehouse manager will receive the order on the Manager Page, make a review and accept the pending order. Any updates in outlet order’s status will be instantaneously updated and notified to the outlet manager.

2. Processing: As the warehouse manager confirms the order, warehouse workers can start organizing the order into a pallet. There will be a portable Outbound RFID reader that can be attached to a pallet. A pallet can be created and activated on the inventory Outbound Page, the Outbound RFID reader is connected to a pallet activated on Outbound Page, hence, update any scanned parcels into the system. Only one pallet can be activated at the same time; therefore, with an RFID reader set up for outbound scanning, all incoming parcels scanned by warehouse workers will be placed into the activated pallet on the system, assuming that the parcels have been placed in the correct pallet, nowhere else. It is compulsory for warehouse workers, who are responsible for outbound management, to not move the parcels anywhere once they have been placed into the pallet. If the warehouse workers intend to move the parcels out of the current pallet, they have to set the RFID system to scan with removing purpose.

3. Delivery: Once the pallet has been fulfilled, warehouse manager can select the pallet and connect a specific outlet order for item comparison, in order to review the goods ordered by the outlet manager and goods prepared by warehouse worker on a pallet. If the order is correct, the warehouse manager can proceed to put the pallet on a truck. In current system, the warehouse manager has to manually update the status of the outlet order, hence, when the pallet of goods is moved out of the warehouse, the warehouse manager should update the status of outlet order to “Out For Delivery”. The status of a parcel, a pallet and outlet order are linked together, therefore, the status of all parcels on the pallet will be updated to “Out For Delivery” automatically, the inventory level of that product will be deducted automatically with the number of parcels moved.

4. Delivered: Once the order’s status is updated to “Delivered”, RFID tags attached on parcels should be removed on the scene of delivery, as the system will remove RFID tag from the system for reusable purposes. The status of all delivered parcels will be set to “Delivered”, while detaching the relationship with an RFID tag

3.2.3. User Stories

Warehouse Manager:

- As a warehouse manager, I want to quickly check inventory level of one product so that place order for products that are running low.
- As a warehouse manager, I want to track the movement of each parcel in the warehouse so that I can improve logistics planning and performance.
- As a warehouse manager, I want to view outlet orders that are in pending, so that I can review and confirm the order.
- As a warehouse manager, I want to view all current products in the warehouse and its inventory.
- As a warehouse manager, I want to manage users in the system, so that I can allow which user can enter the system.
- As a warehouse manager, I want to automatically update the inventory when items are moved in or out, so that the system always reflects the current stock levels.
- As a warehouse manager, I want to be able to manage RFID readers and tags within the system, so that I can ensure all devices are functioning correctly and are secure.
- As a warehouse manager, I want to easily add parcel to a pallet in the system, so that a pallet is attached to an outlet order.
- As a warehouse manager, I want to view and filter out specific parcels, so that I can validate the status of a parcel.

Warehouse Worker:

- As a warehouse worker, I want to easily process shipments into warehouse by scanning pallets through RFID reader, so that I can update the inventory with minimal manual entry.
- As a warehouse worker, I want to easily locate parcels of a product, so that I can quickly pick it up for processing.
- As a warehouse worker, I want to start scanning for a parcel to be placed into a pallet, so warehouse managers can start review for the outlet orders.

Outlet:

- As a new outlet manager, I want to register into the system by signing up with the warehouse managers, so that I can start placing orders.
- As an outlet manager, I want to place an order for the outlet, so that I can restock items that are in low stocks.
- As an outlet manager, I want to view placed orders, so that I can view ordered items in the past for review.

3.2.4. Structure of Warehouse System Layer

Warehouse System Frontend Structure: In frontend, we use React as a frontend framework to develop the webpage, in replacement of raw JavaScript. The UI library the frontend use to build on top of CSS is Ant Design and Bootstrap. There is no specific architecture in the React frontend layer, we have a layer called API service to fetch backend routes through RESTful API published by backend server.

Warehouse System Backend Structure: Backend is built with Node runtime environment, developed with Node.js backend framework. Mongo Database (Mongo) is the main database for the system due to its NoSQL flexibility and performance. In the backend server, the main architecture will be MVC architecture (Model View Controller), where model holds the entity structure designed by ERD, and database functionalities.

```
const mongoose = require("mongoose");

const parcelSchema = new mongoose.Schema(
  {
    warehouse: {
      type: mongoose.Schema.Types.ObjectId,
      ref: "Warehouse",
      required: true,
    },
    shelf: {
      type: mongoose.Schema.Types.ObjectId,
      ref: "Shelf",
    },
    product: {
      type: mongoose.Schema.Types.ObjectId,
      ref: "Product",
      required: true,
    },
    pallet: {
      type: mongoose.Schema.Types.ObjectId,
      ref: "Pallet",
    },
    status: {
      type: String,
      enum: [
        "in_warehouse",
        "on_shelf",
        "loaded_on_pallet",
        "out_for_delivery",
        "delivered",
        "archived",
      ],
      required: true,
      default: "in_warehouse",
    },
    datetimecreated: {
      type: Date,
      required: true,
    },
    datetimeupdated: {
      type: Date,
      required: true,
    },
  },
  {
    timestamps: {
      createdAt: "datetimecreated",
      updatedAt: "datetimeupdated",
    },
  }
);

const Parcel = mongoose.model.Parcel || mongoose.model("Parcel", parcelSchema);
```

Figure: Parcel Entity (Example of Model)

View layer is where the backend export the routes for the API. When accessing a URL in the frontend, the backend system will route the View layer and decide the controller to use for

URL response. With the URL response, the frontend convert the response data into its structure and display onto the browser. Express framework (Express) will handle all the URL routing and web security in the communication between web browser and backend server.

In controller layer, this is where the processing occurs to receive, validate a URL request and return a URL response. Business logic and heavy calculation are in controller layer.

IoT Backend Structure: IoT backend structure is developed similar to Warehouse System Backend Server, running and developed by Node runtime environment. IoT Backend Server is also structured with MVC architecture. Therefore, RFID system will interact through API services deployed by Warehouse Backend. IoT server will communicate with Warehouse Backend server to send data in-between.

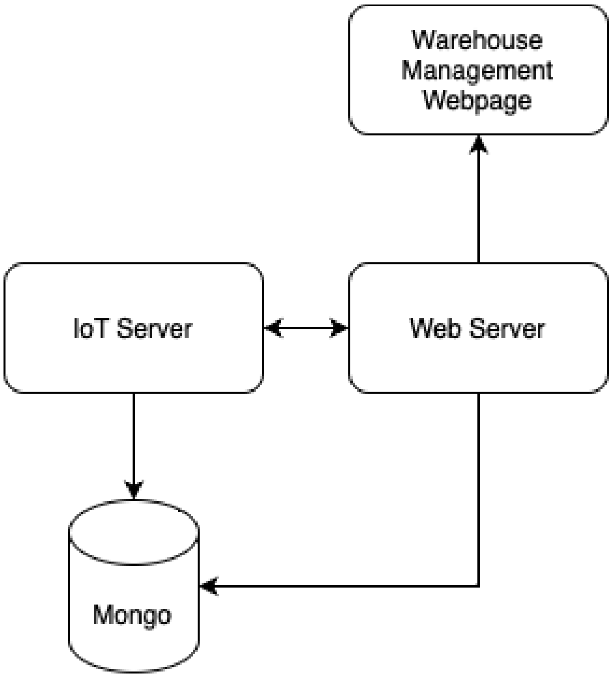

Figure: Communication Structure

3.3. Tools and Configuration

3.3.1. Small Warehouse Configurations:

IoT Layer:
(1) Smart Devices: RFID system is built with Active Reader Passive Tag (ARPT) configurations, Ultra High Frequency tag should be used for a range between 1m and 100m (applied for inbound gate and portable outbound system)
(2) IoT Central Computing: Raspberry Pi 4 Model B.
(3) Network layer: ESP32 Wi-fi modules (TCP/IP stack included), which is a network interface for RFID readers.
(4) Development Tools: C++, VS Code and Platform.io

Software Layer:
(1) Database: MongoDB (NoSQL)
(2) Backend: Node.js and Express Framework

(3) Frontend: React library, with UI frameworks, AG Grid Community Edition and Ant Design
(4) Built Tools: Vite for local development

(5) Production:
- Digital Ocean - can be used to deploy frontend and backend
- Vercel - can be used to deploy frontend and backend
- Netlify - can be used to deploy frontend
- Heroku - can be used to deploy backend

3.3.2. Research Configurations

IoT layer
(1) Smart Devices: RFID & NFC tags with 13.56 MHz will be used with an average range of 1m. RFID reader in RC522 RFID Reader Module, which contains antenna within.
(2) IoT Central Computing: ESP32 & ESP8266 module.
(3) Network layer: ESP32 Wi-fi module (TCP/IP stack included), which is a network interface for smart devices.

RFID Reader	ESP32 For Inbound RFID Reader	ESP32 For Outbound RFID Reader
3.3V	3.3V	3.3V
RST	22	21
GND	GND	GND
IRQ	Not required	Not required
MISO	19	19
MOSI	23	23
SCK	18	18
SDA	5	4

Table 1: RFID Pin Layout

Software Layer
(1) Database: MongoDB (NoSQL)
(2) Backend: Node.js and Express Framework
(3) Frontend: React library, with UI frameworks, AG Grid Community Edition and Ant Design
(4) Built Tools: Vite
(5) Production: Vercel

3.3.3. Configuration

In academic research settings, tools and configurations often diverge from real-world, practical warehouse setups, particularly concerning computational capacity and the incorporation of devices within the IoT layer. However, software layer can be implemented with IoT layer configurations built for a small warehouse (described in 3.3.1). The IoT configurations used in the research can be used abroad in different IoT use cases, which is applicable to warehouse IoT configurations. There might be variances in RFID modules, but its underlying methodology remains consistent. Research configurations for IoT layer are applied in order to maintain the budget due to expensive RFID module for a warehouse scenario, while being able to develop the required prototype and evaluate the quality of warehouse system. In the software layer, warehouse configurations can inherit from research configurations without any major changes due to its nature of scalability. This research considers software qualities applied in the system to maintain its performance throughout the inconsistent workload of inventory data. Therefore, the inventory management software is reusable for further development, and scalable for technical advancement.

3.4. Data Collection

3.4.1. Purpose

Data collection is performed in this project with intention to provide hidden data that is not visible to warehouse managers or system administration. Data collected is used to assess the accuracy and performance of the RFID system towards the operation of warehouse, comparing with the traditional barcode systems. Warehouse managers also can take advantage of the data to analyse the cost implications of implementing RFID technology against the operational benefits gained, with a focus on long-term return on investment.

3.4.2. Data Types

- Quantitative Data: This might include metrics like inventory accuracy rates, processing times for inbound and outbound logistics, or the frequency of stock discrepancies.
- Qualitative Data: Gather insights from warehouse staff or management about the practicality, challenges, and perceived benefits of RFID systems.
- Primary Sources: Data gathered directly through your system, such as RFID read rates, error rates, or system logs.

3.4.3. Data Collection Methods

- RFID System Logs: Collect data from RFID system, including tag read rates, time stamps, and error logs.
- Observational Studies: Observe how the RFID system operates in a real-world warehouse setting, or in a research configuration state.
- Surveys and Interviews: Conduct surveys or interviews with warehouse staff and managers to understand user experiences and system efficiency.

3.5. Data Analysis

3.5.1. Quantitative Analysis

In this project, there is a development of a middleware between RFID system and IoT Server to record the time between data sent from RFID system and get processed by IoT Server. Data will be saved in JSON format.

Figure: Time Record JSON format

At the time of production, multiple data has been collected from URL "/iot/inbound", which represents for the Inbound process, where parcels are scanned upon receiving and updated into the system. The average processing time is found to be 469.8 milliseconds to register one parcel into the system before moving onto next parcel.

A pallet can holds approximately 60 parcels, so processing 1 pallet with 60 parcels is calculated to take 28 seconds.
Inbound Time with RFID: *60 parcels x 0.4698 seconds/parcel = 28.188 seconds*

Otherwise, in traditional barcode scan, manual handling time is a factor that increase the processing time. Handling time can take around 2 to 4 seconds for workers to position and rotate the parcel for scanning. Workers also have to find a good view of the barcode so that the barcode scanner can read the barcode, a good scanner might take about 1 to 2 seconds per scan. Therefore, time taken for traditional barcode scanner.

Minimum Inbound Time with Barcode Scanner: *60 parcels x 3 seconds/parcel = 180 seconds (or 3 minutes)*
Maximum Inbound Time with Barcode Scanner: *60 parcels x 6 seconds/parcel = 360 seconds (or 6 minutes)*

Therefore, there is a major difference in the inbound time between 2 systems. RFID system not only reduces the processing time, but also remove any manual scanning work, which contains handling time and unavoidable human errors.

3.5.2. Qualitative Analysis

In this research, a SWOT (Strengths, Weaknesses, Opportunities, Threats) analysis is performed for qualitative analysis to understand the impact of RFID system towards warehouse operations.

Strengths

- Improved Inbound and Outbound Accuracy: RFID technology enhances inventory inbound and outbound performance, reducing discrepancies and losses.

- Real-time Tracking: Offers real-time visibility of goods, enabling more efficient warehouse operations.
- Automation and Efficiency: Streamlines processes, reducing manual labour and associated errors.
- Scalability: Easily adaptable to different sizes and types of warehouses.

Weaknesses

- Initial Costs: High upfront investment in RFID infrastructure and training.
- Technology Limitations: Issues like signal interference or tag readability can affect system reliability.
- Integration Challenges: Difficulty in integrating RFID with existing warehouse management systems and supply chain processes.
- Dependence on Technology: Over-reliance on RFID might pose risks if the system fails.

Opportunities

- Technological Advancements: Emerging improvements in RFID technology could enhance system capabilities and reduce costs.
- Market Growth: Increasing demand for efficient logistics solutions provides a market opportunity for expanded RFID use.
- Data-Driven Decision Making: RFID-generated data can be used for strategic planning and operational improvements.
- Integration with Other Technologies: Potential to integrate RFID with IoT, AI, and other technologies for enhanced warehouse automation.

Threats

- Competing Technologies: Alternative technologies like barcoding or QR codes may be preferred due to lower costs or familiarity.
- Data Security and Privacy Concerns: Potential risks in data handling and privacy need to be addressed.
- Economic Factors: Economic downturns could affect investment in new technologies.
- Regulatory Changes: Changes in regulations regarding technology use and data privacy could impact RFID adoption.

Ultimately, the SWOT analysis provides insights upon the application of RFID system into the warehouse. With its considerable strength in revolutionizing the warehouse inbound and outbound process, it also comes with significant weaknesses and threats that need to be carefully managed. Warehouse owners and managers should take this SWOT analysis to understand the state of the system in the production environment.

3.6. Ethical Consideration

Privacy and Data Security

- Inbound and Outbound Tracking: The use of RFID in tracking items and activities in inbound and outbound logistics can inadvertently lead to detailed monitoring of employee work patterns and behaviours. It's vital to ensure that such monitoring does not infringe on personal privacy and is strictly confined to operational needs.

- Sensitive Data Protection: The data collected, especially during the inbound and outbound phases, may include sensitive information about suppliers and customers. Ensuring the security and proper use of this data is an ethical imperative.

Transparency and Consent

- Disclosure to Employees and Suppliers: Clear communication about the use of RFID technology in tracking activities during inbound and outbound processes is essential. Stakeholders should be aware of what data is being collected and how it will be used.
- Consent for Data Use: Where possible, consent should be obtained, especially when data collection extends beyond basic operational requirements. This is particularly relevant when suppliers' data is involved.

Accuracy and Non-Discrimination

- Reliability in Tracking: Ethical responsibility includes ensuring the accuracy of RFID tracking to prevent errors that could unfairly impact employees, suppliers, or customers, especially in inventory management and order fulfillment.
- Objective Decision Making: Care must be taken to avoid biased interpretations of data collected from inbound and outbound processes, ensuring fair treatment of all parties involved.

Health, Safety, and Environmental Considerations

- Safe Deployment: The installation and operation of RFID systems, particularly in high-traffic areas associated with inbound and outbound processes, must not compromise employee safety.
- Environmental Responsibility: The life cycle of RFID tags, often used in large quantities in inbound and outbound operations, should be managed responsibly to minimize environmental impact.

3.7. Limitations

While RFID technology significantly enhances warehouse management, particularly in streamlining inbound and outbound processes, it comes with certain limitations. Technical challenges such as limited read ranges and interference issues can impede the accuracy of RFID in tracking goods during inbound and outbound activities, potentially leading to missing data in inventory level. Additionally, tag collision, where multiple tags interfere with each other, is a concern in high-volume settings typical of inbound and outbound operations.

Moreover, the substantial initial investment required for RFID infrastructure, coupled with ongoing maintenance costs, can be a significant barrier, particularly for smaller operations. Integrating RFID systems with existing warehouse management and resource planning systems can be complex. Environmental factors like temperature and humidity can also affect RFID performance, a concern in warehouses with varying storage conditions.

In terms of the system model, inventory level for each product is currently limited to total quantity. The inventory specific to a shelve or a moving pallet is not considered. The inventory level is increased when a parcel is scanned by the Inbound RFID reader, on the other hand, decreased when a pallet and its corresponding parcels is set to “Out for Delivery”.

The establishment of limitations provide warehouse owners the overview of system constraints, enabling the overall understanding of the system abilities. Supported with ethical consideration, warehouse owners are able to analyse and make smarter decision towards RFID system.

4 Final Prototype

4.1. RFID system

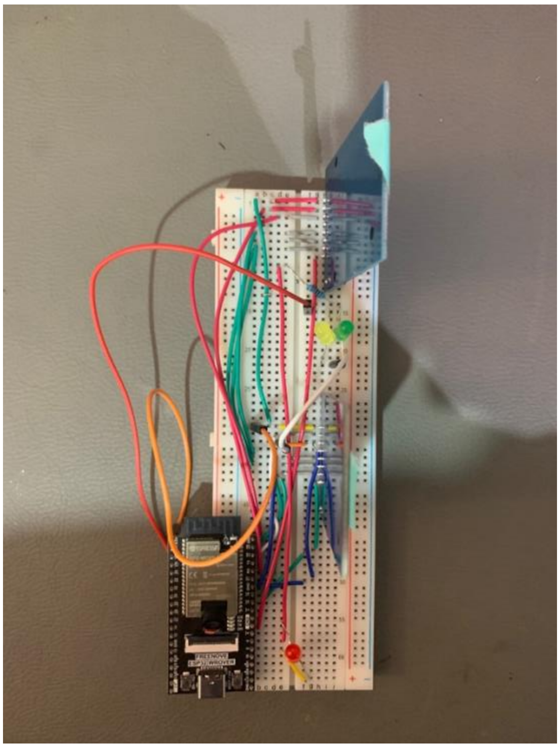

Figure: RFID system (Research Configurations)

From PIN layout established from IoT configurations, the figure gives a visual overview of RFID system. There is the main board for processing which is the ESP32, 2 RIFD reader, 3 LED lights, red, yellow and orange. Red light represents for error in the system, where yellow light lights up when the RFID system is processing after a scan. Once the scan is successful and the parcel is updated to the system, the green light will light up.

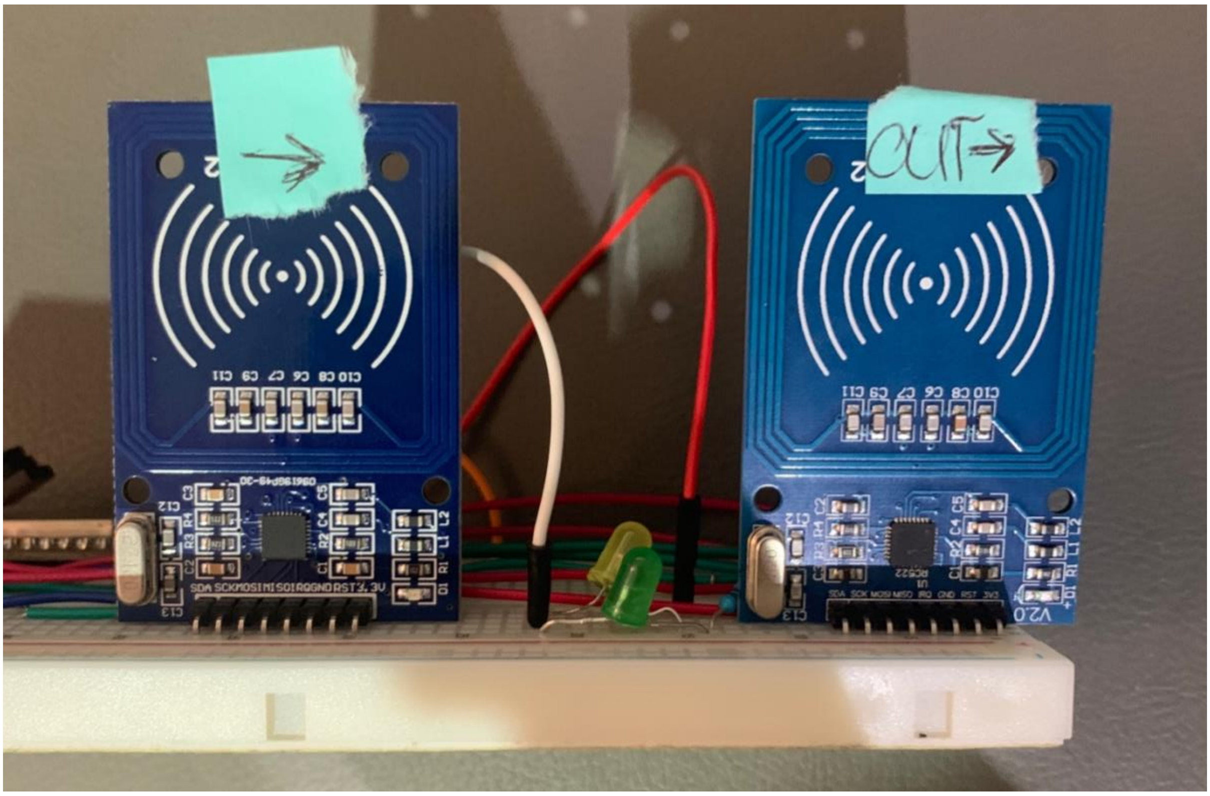

Figure: Inbound Reader (Left) and Outbound Reader (Right)

In research configuration, Outbound Reader is fixed at one place. However, in a practical warehouse, as described in outbound process in 3.2.2, the Outbound Reader should be portable and can be attached to a pallet trolley, in order to update any parcels placed onto the pallet.

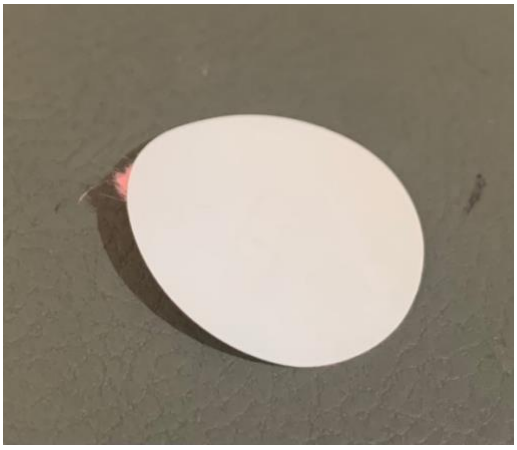

Figure: Sticky NFC Tag for Parcel

This NFC tag should be attached at the first step of inbound process, which is receiving goods from suppliers. Inbound warehouse workers should open their pallet, put each parcel onto the conveyor belt while attaching this tag onto the parcel.

4.2. IoT Backend Code/Logic

```
Receive tag_id from IoT
Get barcode input from Inbound

get Tag
if (tag is existed)
    // Do scanning existed tag
    return

if (barcode is None)
    error


if (product is not existed with the barcode)
    create Product object with barcode and upc data
    create Inventory object if not existed
else
    get Product object with barcode

create Parcel object with product_id
create Tag object with ref_id=parcel_id, ref_object=Parcel

get Inventory with product_id
increase parcel_quantity by 1 from inventory
```

Figure: Inbound logic when receiving a parcel

```
Receive tag_id from IoT
Receive status from IoT

get Tag

if (tag is not existed)
    return


get Parcel from ref_id in Tag object
update status of Parcel

get Inventory with product_id

if status is turned into out_for_delivery or archived:
    deduct parcel_quantity of inventory by 1
elif status is from "out_for_delivery":
    increase parcel_quantity of inventory by 1
    set pallet of the parcel to null
```

Figure: Inbound logic when scanning existing tag

```
Receive tag_id from IoT

get Tag
get Parcel with Tag

if (if tag is not existed and parcel is not existed)
    return

Filter out a pallet with "activated" status

Update Parcel pallet_id // Connect parcel to a pallet
update Parcel status to "loaded_on_pallet"
```

Figure: Outbound logic, adding parcels to pallet

```
# Update status to out_for_delivery for one outlet order

get OutletOrder by id
get Pallet(s) for the OutletOrder

get all Parcels from the Pallet(s)

check if status of OutletOrder is changed from
"in_warehouse"/"on_shelf"/"loaded_on_pallet" to "out_for_delivery", if
not return;

get Product of each Parcel, merge into an array of distinct Products
get Inventory of each Product, merge into an array of Inventories

# Get parcel quantity of each product
obj = {}  #In format { "6546445e38eba19c6cf7ebdc": 2,
"6547623c36ba1c6e8277b7cb": 3}
for parcel in Parcels:
    get product_id from parcel
    if obj[product_id] not existed:
        obj[product_id] = 1
    else:
        obj[product_id] += 1

# Update inventory for all products
for inventory in Inventories:
    get product_id from inventory
    delivered_parcel_quantity = obj[product_id]

    inventory.parcel_quantity -= parcel_quantity
    inventory.save()

update status of all Pallet(s) to "out_for_delivery"
update status of all Parcels to "out_for_delivery"

update status of OutletOrder to "out_for_delivery"
```

Figure: Outbound logic when a pallet is processed for delivery

4.3. Frontend Pages

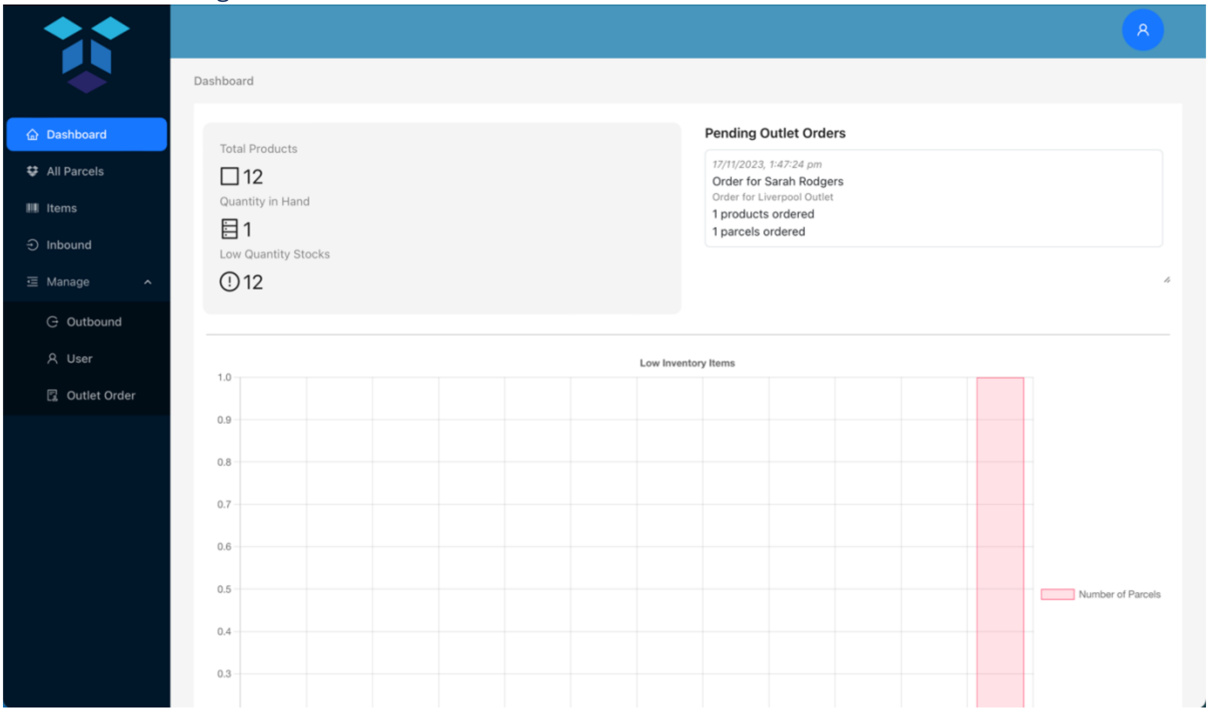

Figure: Dashboard Page

Dashboard Page offer live data updates, so that warehouse managers can quickly view inventory level instantaneously. Information such as total products, quantity in hand and low quantity stocks are updated immediately on parcels getting scanned.

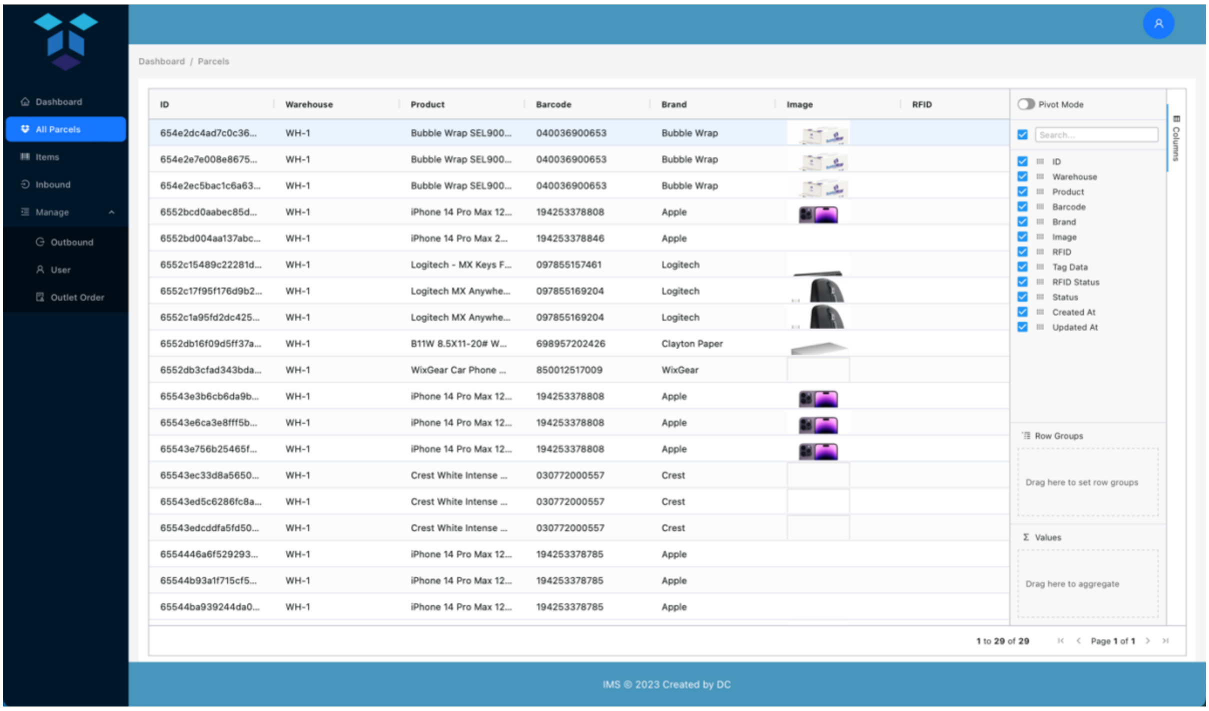

Figure: Parcels Page

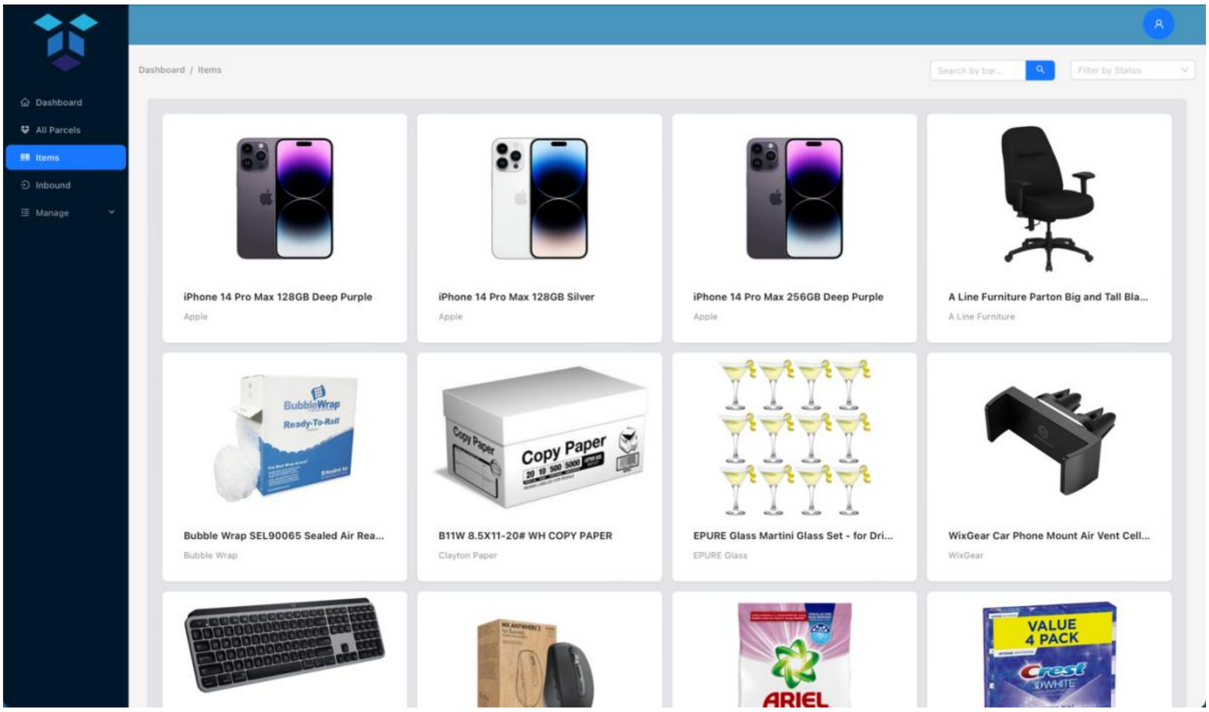

Figure: Items Page

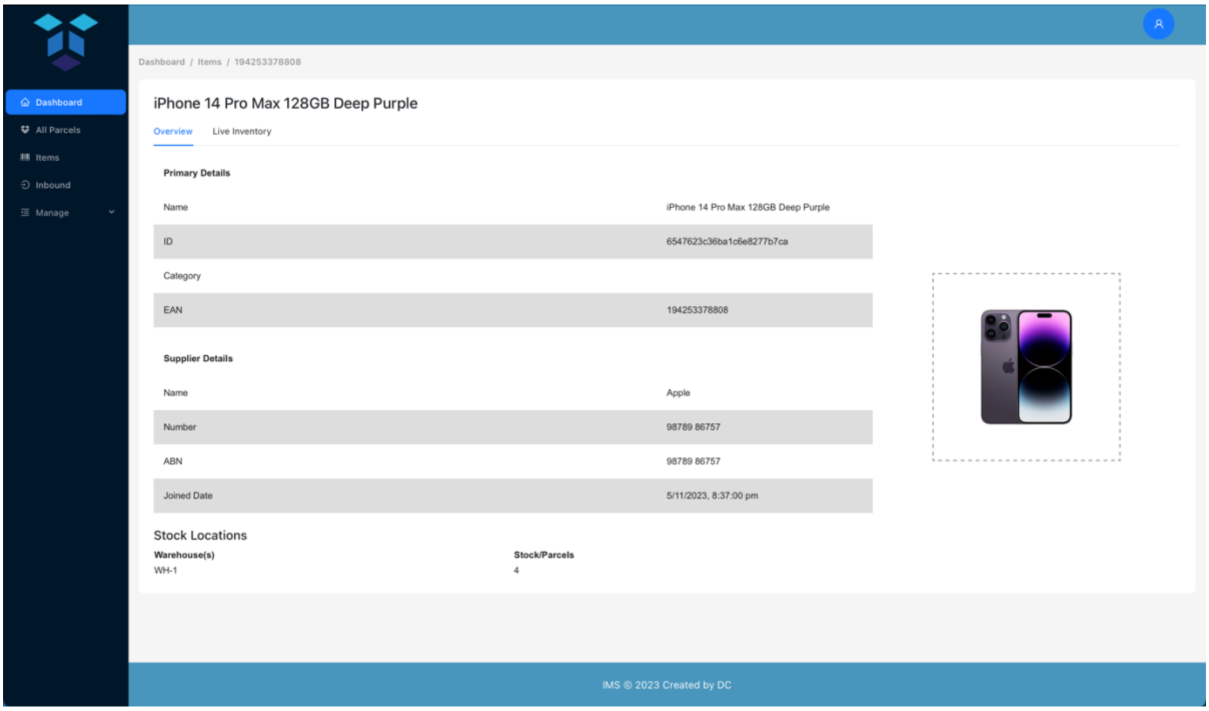

Figure: Item Details Page

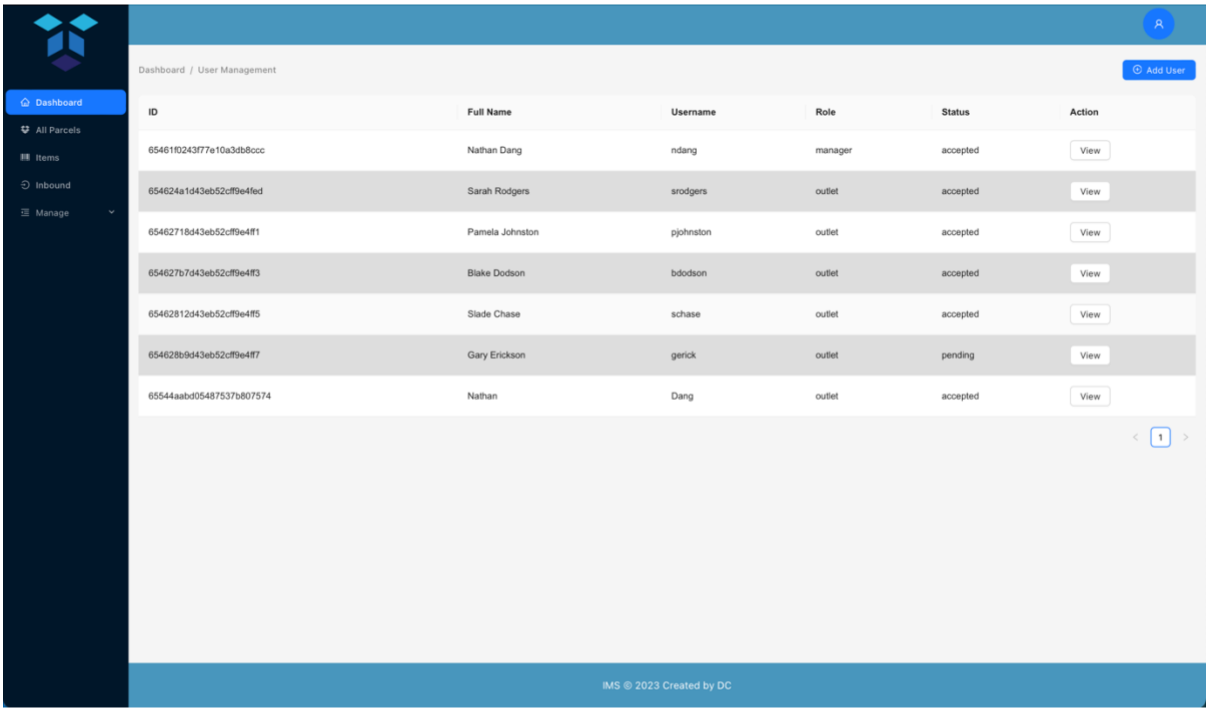

Figure: User Management Page

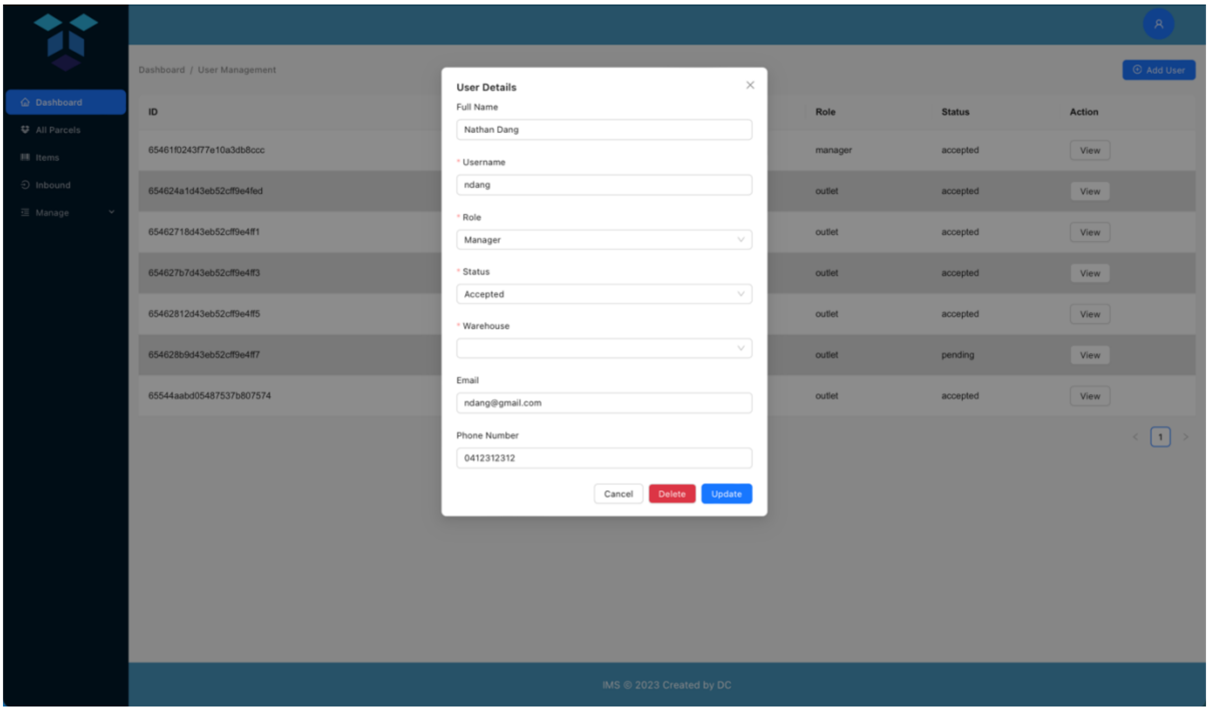

Figure: View User Details Page

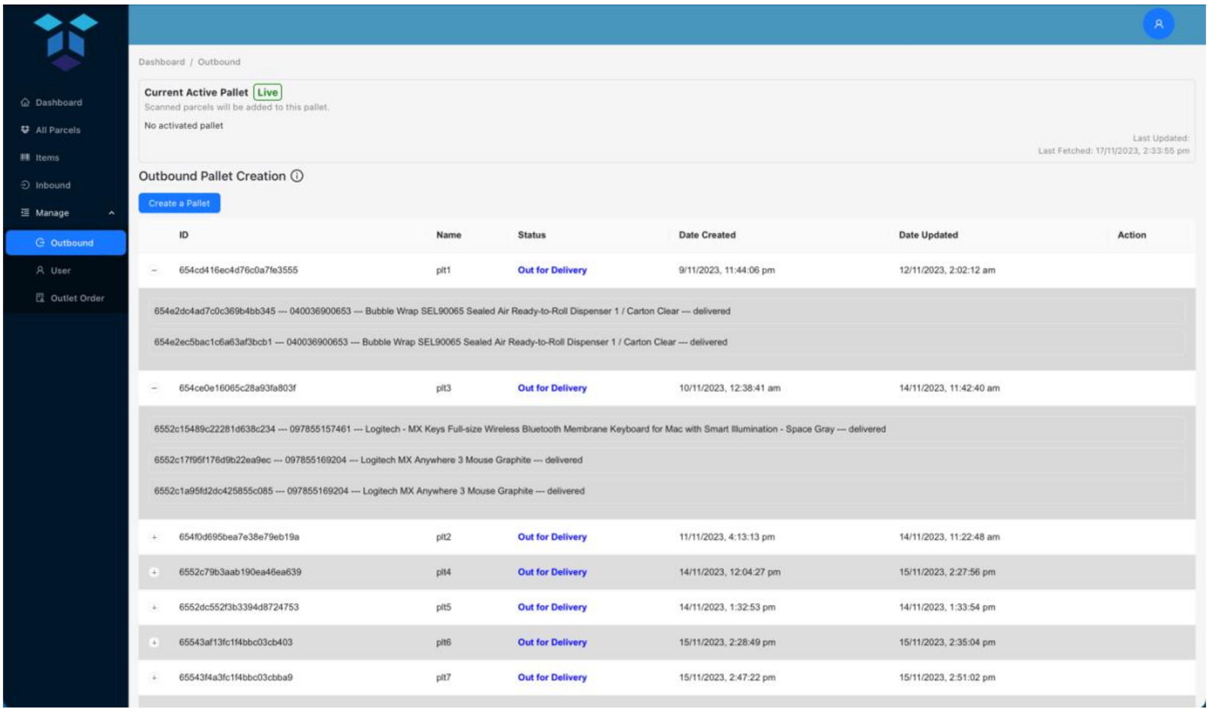

Figure: Outbound Management Page

When attaching Outbound RFID reader to pallet, outbound warehouse workers have to ensure to activate the pallet on *Outbound Management* page. So that scanned parcels will be connected to a pallet on the warehouse system, allowing warehouse managers to review and accept the order for delivery

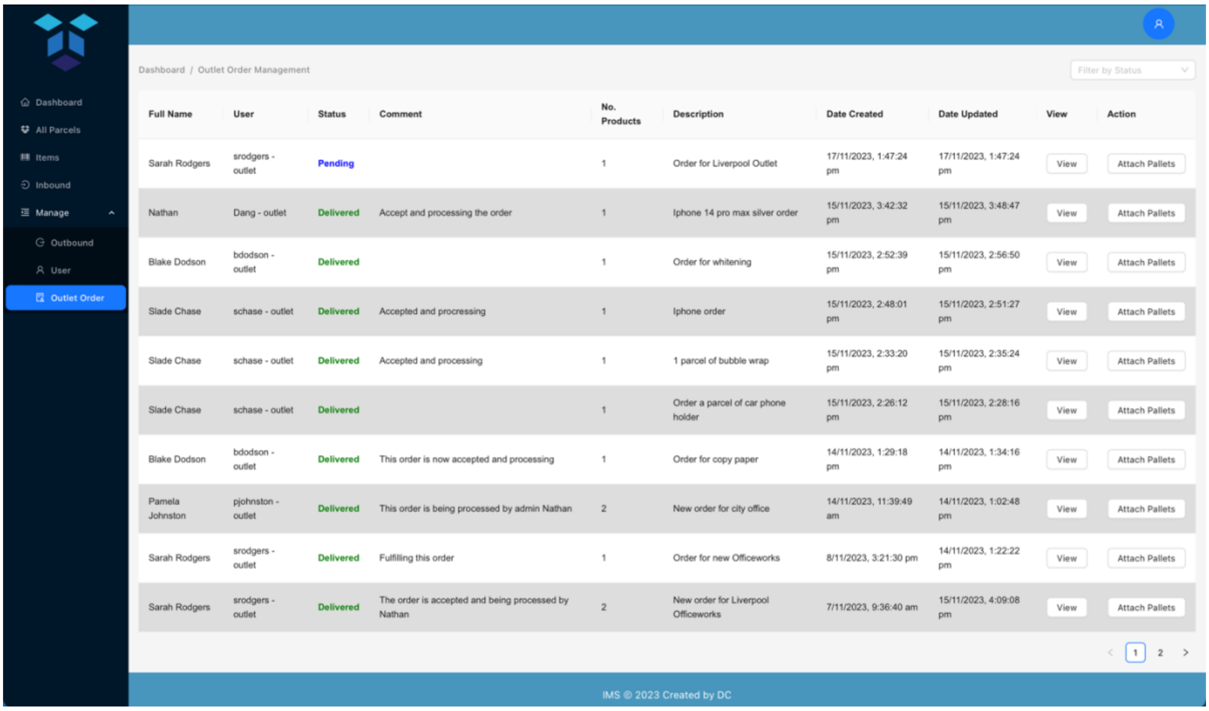

Figure: Outlet Orders Page

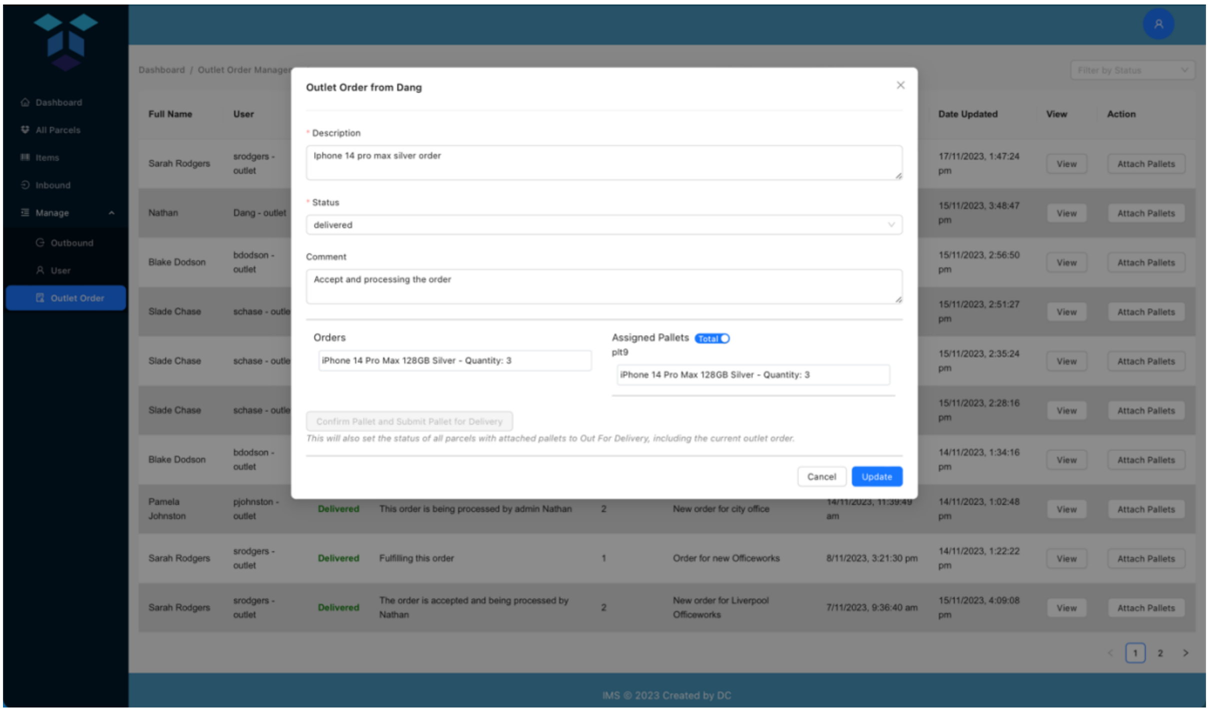

Figure: Outlet Order Details Page

Warehouse Managers can use *Outlet Order Details Page* to review the outlet order, update the status of order, and confirm the order for delivery.

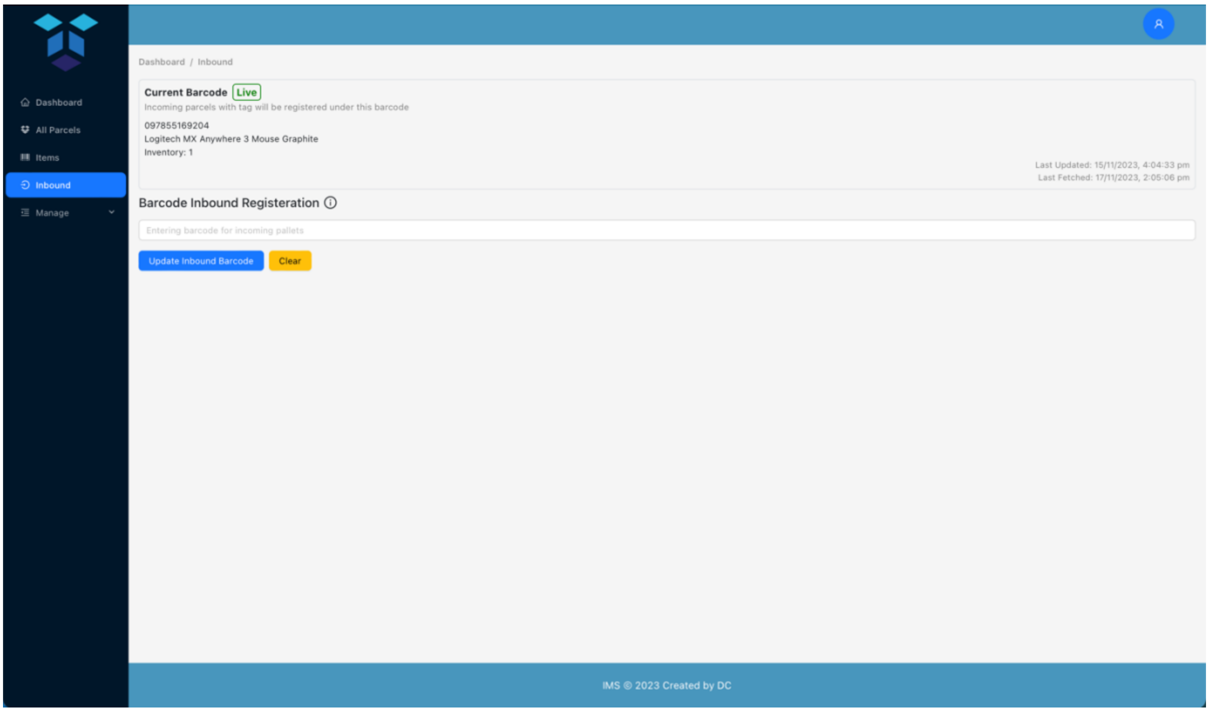

Figure: Inbound Page

Inbound warehouse workers, after attaching the tag to each parcel, and before putting onto the conveyor belt for scanning, have to put the barcode input onto this *Inbound Page* (Inbound inventory recording step), so that the Inbound RFID system can understand the type of product that all incoming parcels are.

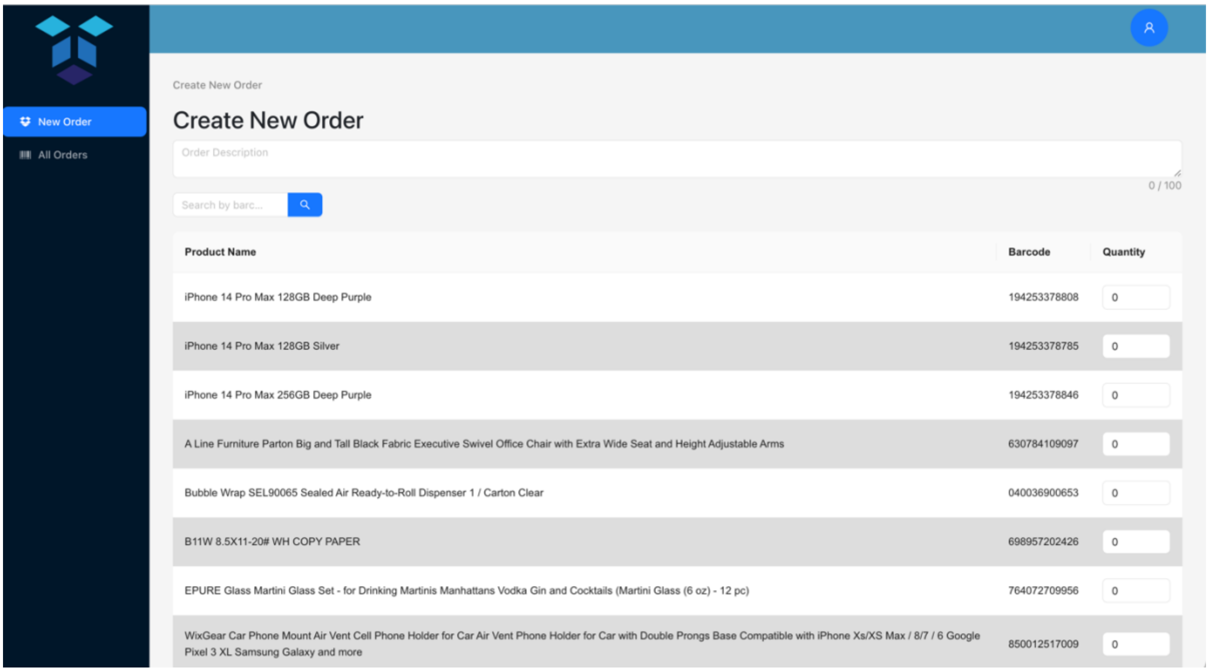

Figure: Outlet Page to make a new order

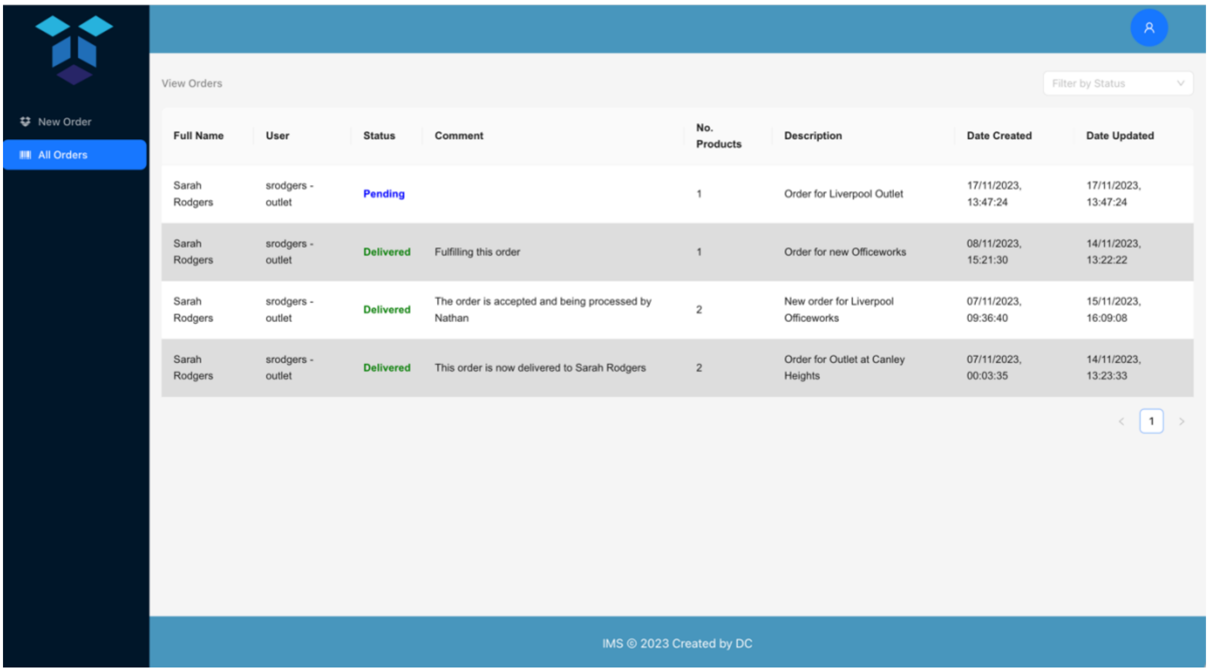

Figure: Outlet Orders Page for current outlet

6 Conclusion

In conclusion, the system developed by this research has delivered with minimum requirements for warehouse owners to understand the RFID system implementation to the warehouse system, specifically on inbound and outbound process. The application of RFID system in warehouse systems has been demonstrated with improvements in inventory management, reducing processing times, and enhancing visibility of goods. The research finds that the processing time with the RFID system is significantly better than the traditional barcode system, which is 3 minutes less for each pallet with one type of product. In contrast to its efficiency and performance, this research also considers ethical element of technological field and its limitations towards warehouse operations. Ultimately, the continuous advancement of RFID technology mitigates many of its limitations, further solidifying its role in the future of warehouse operations.

7 Recommendations

Looking at long terms, it is recommended for business owners to invest in scalable RFID solutions that can adapt to the business's expansion. Firstly, business owner should develop a comprehensive training programs for warehouse staff, ensuring they are proficient in using and managing the RFID system for inbound and outbound section, thereby enhancing operational efficiency and reducing system errors. Regular maintenance and updating of the RFID system are also recommended to align with technological advancements and evolving business needs. Additionally, integrating advanced analytics tools is crucial for extracting valuable insights from RFID data, supporting strategic decision-making. Finally, ensuring seamless integration of the RFID system with suppliers and outlets is also a feature for effective and efficient management of inbound and outbound logistics. These recommendations, when implemented, will optimise warehouse management processes, supporting the business's growth and transition into a franchise model.

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