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RFID based warehouse management system. a case study of rok industries

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RFID BASED WAREHOUSE MANAGEMENT SYSTEM. A CASE STUDY OF ROK INDUSTRIES

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A Dissertation Submitted in Partial Fulfillment of the Requirements for the Award of the Degree of Master of Science in Embedded and Mobile Systems of the Nelson Mandela African Institutions of Science and Technology

Arusha, Tanzania

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ABSTRACT

In the supply chain and logistics industry, the precision of the data assets inventory plays a crucial role in warehouse activities. The operations like storage locations arrangement, inventory management, and maintaining the flow of incoming and outcoming goods lead to the success of the warehouse. Nowadays, most people prefer online shopping all over the world because it is faster than local trade. Thus, there's massive information in the supply chain and logistics sector to explore in order to improve operations of the warehouse such as receiving, ordering, shipping, storage assignment to facilitate the automation in the warehouse. As result, this research is proposed to improve warehouse activities. The RFID-based warehouse management system automates storage and inventory management without any human intervention. In order to accomplish the objectives of the study, a software program was developed with sets of rules, and an algorithm to optimize the inventory operations with the help of RFID technology. The predefined rules help in giving priorities to some of the selected products to store and retrieve in the indicated location. The long-range RFID reader is used in this project. The reader is attached to the entrance of the gate of the warehouse to facilitate the reading of incoming goods. Once the goods arrive in the warehouse, the storage location function will assign to each one the storage location and update status in the database. A handheld reader attached to the forklift facilitates inventory management and communicates with the application via a wireless network and finally store data in the database for future use. After developing this system, a test was conducted for testing the feasibility and applicability of the system. The output showed that the inventory management operation was made strides, and the correctness of inventory location increased from 72.8% to 99%. The cycle time moreover decreases from 60 minutes to 20 minutes which is down to 28.79%.

DECLARATION

I, **Fabien Ngaboyimbere**, declare to the Senate of Nelson Mandela African Institution of Science and Technology that this report is my unique work that has neither been submitted nor presented for a similar award in any institution.

	20th October 2021
Fabien Ngaboyimbere (Candidate)	Date
	20th October 2021
Dr. Michael Kisangiri (Supervisor 1)	Date
	20th October 2021
Dr. Judith Leo (Supervisor 2)	Date

CERTIFICATION

The undersigned certify that they have read and recommended for acceptance by the Nelson Mandela African Institution of Science and Technology the project report entitled: RFID based warehouse management system, in fulfillment of the requirements of the degree of Master of Science in Embedded and Mobile Systems with Embedded systems specialization of the Nelson Mandela African Institution of Science and Technology.

20th October 2021

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Dr. Michael Kisangiri (Supervisor 1) Date

20th October 2021

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Dr. Judith Leo (Supervisor 2) Date

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DEDICATION

I dedicate this work to my family (My wife and daughter) for their dedicated time and encouragement during my entire course of study.

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LIST OF ABBREVIATIONS

AIDC	Auto ID Data capture
ASDM	Agile Software Development Model
CENIT@EA	Centre of Excellence for ICT in East Africa
CEP	Complex Event Processing
CMOS	Complementary Metal Oxide Semiconductor
COCSE	School of Computational and Communication Sciences and Engineering.
CRC	Cyclic Redundancy Checks
ECA	Event-Condition-Action
EMOS	Embedded and Mobile System
EPC	Electronic Product Code
EPM	Event Processor Manager
FIFO	First-In-First-Out
HLE	High-Level Even
HRIS	Handheld Reader Integrated System
IDE	Integrated Development Environment
LCD	Liquid Crystal Display
LIFO	Last-In-First-Out
MIPS	Million Instructions per Second
NM-AIST	Nelson Mandela African Institution of Science and Technology
PDA	Personal Digital assistants
RCP	Rich Client Platform
RFID	Radio Frequency Identification
S/R	Storage/Retrieval
SDLC	Software Development Life Cycle
SID	Shelf ID
SKU	Stock Keeping Unit
SQL	Structured Query Language
TCP/IP	Transmission Control Protocol/Internet Protocol
TID	Tag ID
UHF	Ultra-High Frequency
LJYZN-10x	RFID reader model 10x
WMS	Warehouse Management System

CHAPTER ONE

INTRODUCTION

1.1 Background of the Problem

1.1.1 Radio Frequency Identification Technology

Radio-Frequency Identification is a smart card that stores data on the transponder (tag). However, even if Radio Frequency Identification Technology is a smart card but has a specialty of getting powered and exchange data using magnetic or electromagnetic fields through its tag compared to other cards of similar functions (Finkenzeller, 2010). This technology uses small electronic devices that consist of a small integrated circuit (chip) and an antenna sometimes build in the chip. The chip has the capability of carrying more than 2000 bytes of data. This technology uses radiofrequency waves to transfer data between a reader and tags. See the basic functionalities of RFID technology as shown in Fig. 1.

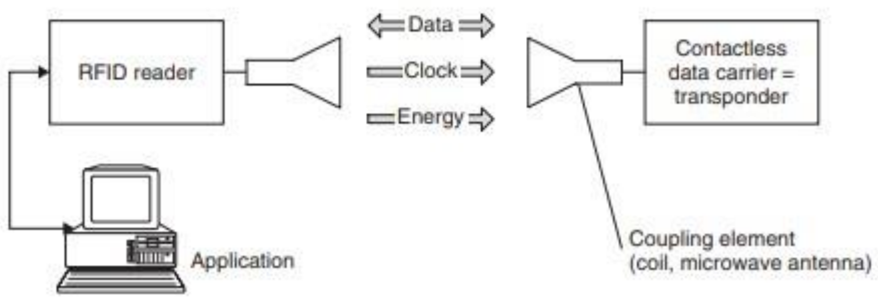

Figure 1: Radio Frequency Identification Functionality

Often, RFID technology has two main parts which are RFID readers and tags. Radio Frequency Identification tags are a special kind of transceiver that is attached to the targeted object. They have the capability of storing all information of the monitored object. Currently, RFID technology has been used in different areas such as healthcare, supply chain, inventory and material management, stock management, shipping, smart groceries, access control, attendance management systems (Ming *et al*., 2010). It is a fabulous real-time commerce apparatus that makes a difference in superior management supply chains, covers the inbound of products, products outbound, and internal inventory operation stream and increment benefit, and diminishes the cost by improving the usability of the distribution center management system. The WMS constructed with the assistance of RFID innovation makes strides to the productivity of warehouse and auto announcing era and self-recording of receiving and picking process.

1.1.2 Supply Chain Management

A supply chain is a series of sequence processes where various organizations such as manufacturers, suppliers, distributors, and retailers sit together and collaborate with each other to study the processes of their products from raw materials to finished goods and provides a good way of finished goods should reach to the end-users (customers) as shown in Fig. 2.

Supply chain management is a joining work with the most errand of connecting major trade capacities and commerce description inside and over companies into a cohesive and high-performing commerce show. It incorporates all of coordination management activities such as the stream of merchandise, capacity or storage assignment, materials, data, and stores from providers or suppliers to manufactures to last constructing agents, and lastly to the dissemination centers (warehouses and retailers), and eventually to the ultimate customer, and manufacturing operation as well, and it drives coordination of shape (warehouse layout) and activities with and over- promoting marketing, deals, products design, finance, and information technology (Stock & Boyer, 2009).

The circulation of goods in the supply chain incorporates the movement of goods between all people involved (i.e., from manufacturer to end-user). The data flow includes completing orders and shipping and upgrading status as shown in Fig. 2.

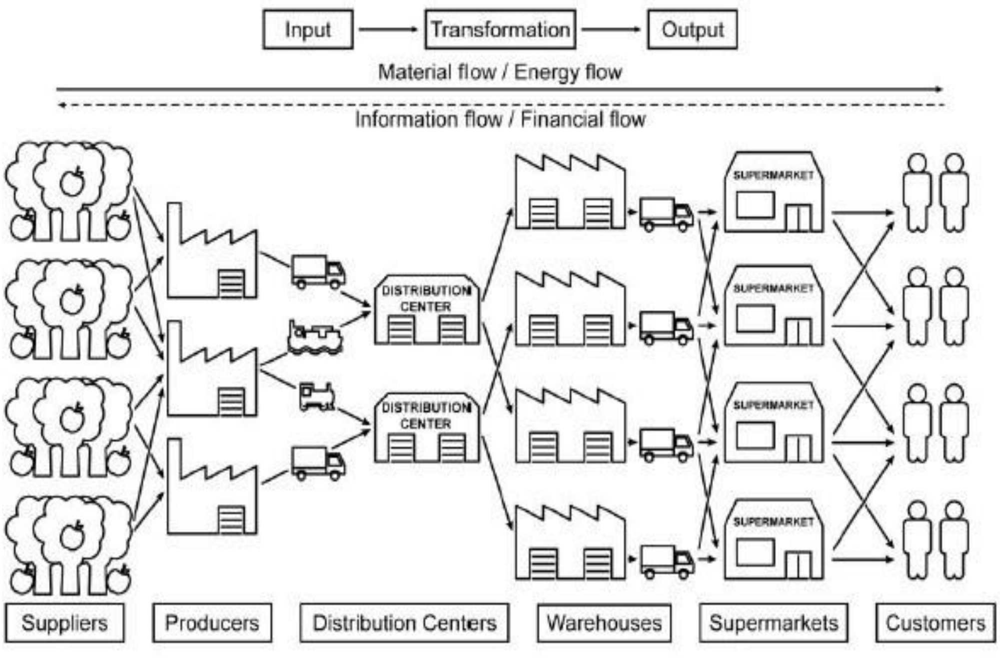

Figure 2: Supply Chain

1.1.3 Warehouse Management

According to Boenzi *et al*. (2015), warehouse activities contribute about 20% of the companies' logistics costs valued activities for this task are value-added services, administration management, inventory costs operation, transportation costs, and packaging. Warehouses play a great role in a firm's logistics system (Solev *et al*., 2011).

By utilizing warehouses, firms can make products accessible "when" and "where" customers demand them. It could be a basic hub in a Business. Within the process of the supply chain, it is continuously joint of the processes, like between acquiring and manufacturing, between manufacturing and selling, between whole and retailing, and among the switch of transportation. Warehouse operation like planning and control of warehouse facilities and systems has become more complex within the supply chain. Warehousing is frequently required to perform schedule coordination operations such as stock capacity, order status, sorting, cycle checks, loading/offloading, and clients benefit. Destitute utilization of costly warehouse space, manual mistakes, off-base distinguishing proof of the item amid receipt and dispatch, finding things within the distribution center will affect the efficiency and benefit which comes about within the organization's notoriety and losses (Kerridge, 1987).

The key side of the supply chain is warehouse management. It mainly aims to monitor the movement and storage locations of goods within the warehouse and manipulate all transaction processes such as receiving, picking, shipping, and putaway (A *et al*., 2012). The WMS also helps in optimizing the stock by updating the status of goods in the database base on real-time information. Often the Auto-ID Data capture (AIDC) such as barcodes scanners, Personal Digital assistants (PDA), wireless networks, and RFID are used in warehouse management systems to efficiently maintain the flow of goods in the warehouse. According to Sabbaghi and Vaidyanathan (2008), once data is collected with one of the above AIDC, there is batch synchronization with the help of a real-time unguided transmission network to a central database. The database can then help to manipulate data based on the requirements of the operators of the warehouse.

The common reason of warehouse is offer assistance in giving a computerized handle to print out the receipt of stock and encourage warehouse exercises, oversee the physical and consistent representations of products within the warehouse. It also helps in order processing management and logistics management in picking, packing, and shipping items.

Inventory management is one of the basic components of productive supply chain management that results in success in commerce. The inventory management decisions are dependent on the data assembled from computerized or manual control systems (Uçkun *et al*., 2008). In this manner, the programmed warehouses helped a lot in inventory management operations since they coordinated numerous functions and have focal points such as a speedier turnover speed, a low rate of item frailty, and the capacity to store more items in a smaller area.

However, few organizations can modernize their warehouses, basically since they require an additional investment sometimes expansive and a high level of technical skills and management capabilities. In addition, a long-term plan of automated systems becomes a barrier for some companies. Subsequently, most of the institutions still embrace the plane warehouse, which is characterized as a typical distribution center without high racks or automatic hardware (e.g., robotic arms, mechanized guided vehicles).

Traditionally, in such a plane stockroom, the items are haphazardly put on the floor without arrangement or pallets, and the operation performances for the most part depend on the operator's memory and experiences, which comes about in more transaction time and a lot of errors (Hausman *et al.*, 1976). With the more production of different types of products and increasingly complex client orders, the distribution center managers have been facing a big challenge in using the traditional model of manual operation. In a plane warehouse, the critical restrictions faced by the supervisors may be concluded as follows:

(i) How to distinguish a storage/retrieval task methodology for quick-moving products?

(ii) How to distinguish a storage/retrieval task methodology for quick-moving products?

(iii) How to assist the operators to choose the items more quickly and precisely once the task decisions have been made?

(iv) How to make strides in the operational effectiveness of the distribution center as client orders become more complex?

(v) How to improve inventory visibility within the supply chain, to way better synchronize material and information streams and decrease inventory discrepancies?

In order to address the mentioned questions, the analyst contributes to developing and inventive remote technology, specifically, radio frequency identification. In this ponder, the researcher presents an RFID-based warehouse management system (RFID-WMS) to progress the warehouse operations. This framework benefits from the advantages of RFID in data collection, such as remote object identification, multi-object identification, and more storage space.

Particularly, RFID permits object to communicate information around themselves automatically without human mediation.

1.2 Problem Statement

The primary key element in the management of any businesses' activities are having new added value. The activities done within a warehouse are considered as a system that transforms inputs such as material, information, and machines into outputs like products or services (Ivanov *et al*., 2019).

The proper management of the warehouse facilitates organizations to maintain proper track of inventory and its levels as per requirement, it increases accuracy and reduces labor works without forgetting to ensure proper maintenance of warehouse as well as storage locations of stocks. This will come up with ease and satisfaction to the supplier and distributors to retain the inventory management and its maintenance as well. Therefore, the warehouse management system is advantageous in both the storage and maintenance of the inventory. Undoubtedly, several studies demonstrated that proficient warehouse management is vital to an organization's operation execution (Quintero-Angel & Peña-Montoya, 2020).

However, numerous organizations nowadays have not considered the issue of warehousing into consideration, the capacity of merchandise and dissemination from the same warehouses are done barely that's without any arrangements, burglary cases have been on the rise giving the compromise on the common morals of specialists, due to the disorganization and insufficient consolidation of present-day data innovation which comes with great warehouse management systems, it has brought about to mistake arrange administration strategies which have managed a major blow to the organization as an entirety (Lambert *et al*., 1998).

The RFID usage on WMS has been distinguished as one of the greatest influencers of the trading world nowadays (Bartezzaghi & Ronchi, 2003). The researcher will streamline the present working process and expand efficiency within the distribution center using RFID technology (Pane *et al*., 2018). Even though numerous organizations accept that RFID benefits expansive operations that have significant budgetary muscle, there's proof that even a little warehouse can advantage from RFID innovation advancements. This will be accomplished through automation of their operation by emerging internet-based services (Jain *et al*., 2018).

1.3 Rational of the Study

Indeed, suitable innovative industrial solutions can be derived from traditional manufacturing knowledge and methods of supply chain operations. But, if the ability to keep and pass such knowledge is lost, then it stands the danger of extinction (Kamali, 2019). Traditional manufacturing l knowledge needs to be sustainably accessed and passed over to generations and such sustainability can be well achieved with the use of digital tools such as RFID with long-range capability.

1.4 Objectives

1.4.1 General Objectives

This project aims to develop a Warehouse Management System with an integrated RFID-based technology to improve the entire inventory operations by providing automated and accurate warehouse management.

1.4.2 Specific Objectives

(i) To establish the requirements for developing the RFID-based warehouse management system.

(ii) To design and develop the proposed system.

(iii) To evaluate the performance of the developed system based on storage/retrieval assignment, operational efficiency of the warehouse, and inventory visibility.

1.5 Research Questions

(i) What are the best programming language for warehouse management system?

(ii) How should warehouse management system be designed and developed to meet the proposed descriptions?

(iii) How do we know whether the developed system responds as it was expected?

1.6 Significance of the Study

The warehouse could be a critical hub in business. Within the supply chain, it is continuously at the joint of the firms, like between purchasing and manufacturing, between manufacturing and selling, between wholesale, and retailing and among the switch of transportations. This Warehouse Management System coordinates with radio frequency technology that can communicate with specialized labels that are inserted in pallets, shelves, and different areas (i.e. entrance and departure points) inside the warehouse to automate warehouse activities such as receiving, ordering, and shipping. Moreover, the built-in antenna handheld RFID reader will be connected to the forklifts to assist in filtering information consequently and checking capacity area for faster inventory operations. With settled RFID readers at the entrance and the exit point of the warehouse, handheld UHF RFID readers on the warehouse hardware, and RFID resource and area labels on waypoints and resources, the RFID based warehouse management system will give more prominent levels of automation, mistake diminishments, and decision support.

1.7 Delineation of the Study

In this study, only ROK Industries staff and other employees especially warehouse operators were surveyed during data collection. The study also emphasized the department of Loading and offloading as a case study. The consent of all members who participated in the study was observed by involving only people who were willing to participate. Security issues such as authentications were not tested and evaluated during a system evaluation.

CHAPTER TWO

LITERATURE REVIEW

2.1 Warehouse Management

Most warehousing activities comprise stock capacity, arrange item blending, cross-docking, and client's benefits. Goksoy *et al*. (2013) agreed to the reality by saying that an efficacy use of warehouse capacity and assets management will increase the accuracy of warehouse and the benefits of customers will be increased. In this way, a tremendous sum of writing centers on the use of the warehouse, particularly on the programmed warehouse has increased. Boenzi *et al*. (2015) said that warehouse management can be categorized into two categories: theoretical picking orders and modeling as a workshop planning issue. Most of these ponder depend on the presumption that cannot maintain the traditional methods of object recognitions by making a difference on the variation of inventory management which is extremely verified manually. In the past years ago, RFID as advanced technology has finished up well known within the field of industry trading in the coordination of supply chain (Asif & Mandviwalla, 2005). In this way, increasingly supervisors take under consideration the appropriation of RFID to adjust the working taken a toll against the prerequisites on building digitalized store-houses.

The main warehousing operations consist of inventory storage, order product mixing, cross-docking, and customer service (Suryanto *et al*., 2018). The most important of them is inventory management, including storage/retrieval management and inventory control addressed that efficient utilization of space and resources in a warehouse will result in higher accuracy and better customer service (Ballard, 1996). Thus, a vast amount of literature focuses on the use of the warehouse management system, especially on automatic warehouse management, which can be organized into the following two categories: optimal order-picking and modeling as a job shop scheduling problem (Oliveira, 2007). Most of these studies depend on the assumption that the inventory record is accurate. However, this assumption does not hold. The traditional way of identifying and remedying the inventory deviations is doing costly audits by manual checking (Min & Eom, 1994).

In the past decade, a new technology, radio frequency identification, has become popular in the fields of business and industry, particularly in the logistics and supply chain management (SCM) domain. Thus, more and more managers take into account the adoption of RFID to balance the operating cost against the requirements on building an automatic warehouse and manual checking.

2.2 Radio Frequency Identification Technology

According to the prototype of RFID and sensors network for the elder healthcare progress report Moh *et al*. (2005), RFID application has been adopted by many organizations in the middle east last few years ago. The inventors categorized the RIFD application area into four angles of applications which are innovative services, security issues, healthcare treating, and agricultural applications (A *et al*., 2012).

Nowadays, most companies are trying to improve their material flow by adopting RFID technology into their business operations. Atali *et al.* (2011) examined the regard of RFID under imperfect stock data. Delen *et al.* (2007) used RFID technology to collect data from the retailer of products of one of its major suppliers. In this study, the researcher explains the reason why business owners should integrate RFID technology in daily working operations. He said that this technology offers assistance to eliminate the data loss and delay of data flow without forgetting data sharing speed. Additionally, Attaran (2007) also talks about how RFID-based object trucking technologies can be utilized to progress the permeability of information. McFarlane and Sheffi (2003) emphasized the impact of RFID on the utilization of space in the warehouse (e.g., warehouse capacity) and planning in a complex manufacturing process. Wang *et al.* (2010) demonstrated that when RFID is well developed, tested, and implemented in any company, the accuracy should be 100%. For more progressed inquire about data innovation, we prompt the readers who are interested to survey the information of Spina *et al*. (2015).

2.3 Overview on the Similarities and Differences of RFID and Barcodes Technologies

Most companies utilize a manual system in their warehouse center whereas others are utilizing barcodes. As technology is developing day by day, it has been observed that barcode these days isn't consistent (Chen *et al*., 2007). It has numerous impediments such as short read range, cannot track more than one thing at once, is slower, and requires human intervention. It is expected that barcodes should be scanned every time while all labeled RFID products are trucked within few seconds at once (Choy *et al*., 2009).

To scan a barcoded product, the operator needs to press the product near the scanner while the RFID tag needs to be in the range of the antenna magnetic field (Delen *et al*., 2007). Choy *et* *al.* (2009) drew the comparison between manual, barcodes, and RFID systems concerning the time execution management as shown in Fig. 3.

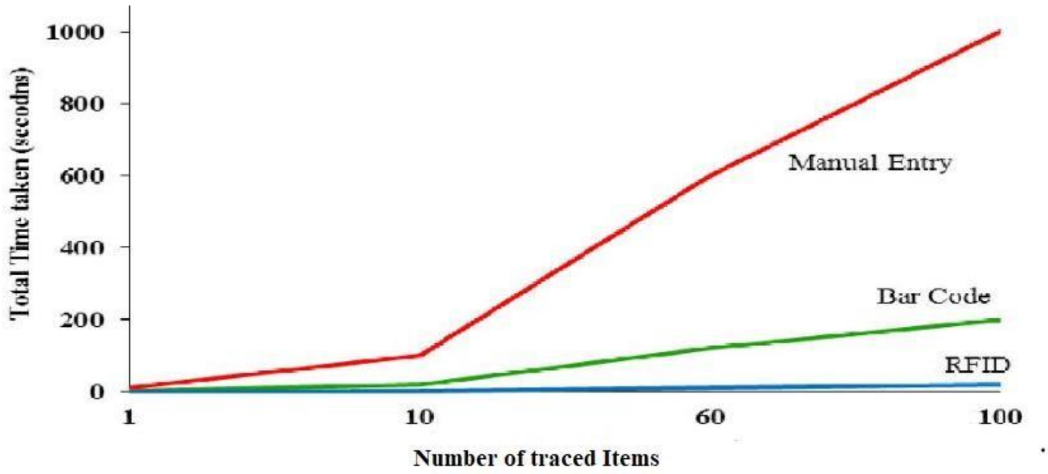

Figure 3: Radio Frequency Identification vs Barcodes with Respect to Time

There is no best system for actual tracking of items in the industry, operations inside warehouses are done based on the selected method that fits the requirements of the manufacturing processes but the RFID tracking is more productive than others imply.

2.4 Related Works

Up to 80% of the existing writings on RFID technology analyses the power of RFID by conducting a survey and using a sample of some successful projects that adopted RFID technology. During the conduction of research on this advanced technology, researchers focused on the area of application of RFID like objects trucking (Wang *et al.*, 2010). The Research analysts designed an RFID system to digitalize and improve the quality services of the restaurant called sushi in terms of quality of service (Gunasekaran *et al*., 2006). Atali *et al.* (2011) also designed a service sector-based customer-facing diffusion model to computerize an organization using RFID. Anand and Wamba (2013) point out the exchange esteem of RFID to engage or energize more organizations to execute it.

There's endless literature on the use of RFID to highly control inventory and boost the operation of a supply chain. Wang *et al.* (2010) apply the labeling techniques using RFID barcodes techniques to increase the productivity of supply chain operations. Gaukler and Seifert (2007) raised their interests, rollout strategies, and cost-sharing agreements for the execution of RFID based on item tracking in the supply chain of goods. Doerr *et al.* (2006) researched by analyzing the advantages of RFID innovation for inventory management in an organization. Goksoy *et al.* (2013) utilized the factorial structure for the non-cost related benefits of the utilization and the routine ROI (return on investment) examination to overview the regard of executing RFID. Gaukler *et al.* (2007) illustrated how the cost of item-level RFID ought to be assigned among supply chain collaborators such that supply chain benefit is upgraded.

Wang *et al.* (2010) conducted the research using RFID technology in the warehouse of the Tobacco industry. In this system, the authors divided the system into three main modules following the requirement of the Tobacco industry. With the implementation of this system in this industry, warehouse directors attain better inventory control. In this framework, a set of events and storage/retrieval rules are defined to improve the functionalities of the Tobacco industry's warehouse. The variation of inventory operation by automating some of its tasks is essential since both big and small businesses have costs (Blinder *et al*., 1981). Delen *et al.* (2007) emphasized the use of the computerized system to make accurate inventory management.

The supply chain technique where the procurement department interferes with the early stages of item improvement makes a difference in having superior performance. Uniting the marketing and procurement with the rest of the process especially within the early and arrange stages to pick up customization and avoid the covered upmarket instability.

The work of Chow *et al.* (2006) is the one closest in spirit to our research. They present a design of an RFID-based resource management system (RFID-RMS) for use in a warehouse operations environment. The goal of the system is to formulate a resource usage package to enhance the effectiveness of resource operations by integrating RFID, case-based reasoning (CBR) technologies, and the programming model for forklift route optimization. The results of applying RFID-RMS to the GENCO Distribution System illustrate that the utilization of warehouse resources is maximized while work efficiency is greatly enhanced. The authors extend their work in Poon *et al.* (2009).

However, with an emphasis on building a digital warehouse with multiple functions as an automatic warehouse, this study is quite different from Chow's work. First, in order to enhance the warehouse capacity, the consideration of the situation of adopting the drive-in racks (also called passage racks) to store the products was adopted. The character of drive-in racks, Last-Last-In-First-Out (LIFO) goods rotation, is incompatible with research objectives, First-In-First-Out (FIFO) rule. Hence, a methodology was proposed to apply the FIFO rule in the drive-in racks situation in the case study. Second, instead of order-picking operations, palletization of cartons of the same products onto a pallet embedded with an RFID tag was used. Thus, the products are transported in the form of pallet units. In addition, how to improve the visibility of inventory information in the whole supply chain by the introduced RFID technology is also the concern of this research.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Introduction

Chapter three explains the methodologies that were employed to accomplish this study. The study area, data collection methods, analysis techniques, and system development are described in this chapter.

3.2 Research Design

In order to facilitate the good operation of the research study and getting an expected output that is intended to answer the research question, the research design is inevitable *(*Heppner *et al.*, 2016). Radio frequency identification technology was used by the researcher to enhance the operation of the warehouse at ROK industries in Kenya. To accomplish this study, several tasks with regard to research objectives were undertaken that included assessment of existing warehouse operations, requirement specification that involved elicitation and analysis for developing WMS to be used in the implementation of the system, define a set of basic events and storage/retrieval rules using an event-condition-action (ECA) mechanism to improve the feasibility and flexibility of RFID-WMS, use C# programming language to develop WMS.

3.3 Research Case Study

The RFID-WMS was conducted at ROK industries in Kenya. ROK industries is an industry established in the year 2010 and starts its operations in 2011. In the beginning, the company started its operations by manufacturing candles with mere 20 Employees. Currently, ROK Industries LTD is one of Kenyan industries which manufactures Petroleum Jellies, Milking Jellies, Candles, Tapes, Glucose products and other many products. ROK industries takes pride in manufacturing and supplying high-quality products that meet international safety standards for the Kenyan Market and the entire Eastern Africa Region. This industry has up to five small warehouses which occupy a space of approximately 500 square meters. These storehouses receive goods from production workshops on a daily basis both raw material and finished goods. The RFID-WMS is proposed to be implemented in this warehouse to enhance the accuracy of inventory operations.

3.4 Data Collection Techniques

The data collection of this project was collected based on the output of discussion made with ROK target people to study methods of existing warehouse operations and looking at how RFID technology will be integrated with warehousing activities in order to increase its performance. In addition, the approaches were performed to analyze the existing warehouse performance. The interview and discussion discussed with these people in the warehouse helped us to analyze the feasibility of this system.

3.5 Data Analysis and Presentation

Data pre-processing was conducted before the analysis to make it consistent where OpenRefine and Google sheet tools were used. OpenRefine is a powerful and easy tool that allows intelligent processing, cleaning, reshaping, and batch editing of both unstructured and messy data (Ratra & Gulia, 2019). Tableau and R software were employed to analyze the quantitative data. Both visualization and descriptive statistics methods for R was used to visualize the data. In which R is known for its effectiveness in data handling and it has a collection of intermediate tools used for data analysis (Hanafi & Fadilah, 2017). The use of tableau was also considered and used due to its influence by its interactive features and ability to provide dynamic results (Murphy, 2013).

3.6 System Development Approaches

All projects involving system development, follow the same phased approach to the system analysis and design called software development life cycle (SDLC) aiming at producing a high-quality system within the time limit and estimated costs (Tuteja & Dubey, 2012). Software development life cycle involves different approaches called models. In this project, the Agile Software Development Model (ASDM) will be used to implement this study. The ASDM is chosen among various system development methods because it is appropriate for senior developers which have not have immense experience in software development because of its easy features. It welcomes changes in requirements and provides frequent small incremental releases which are improved one after another. It concentrates on delivering good well-working computer programs frequently and consistently while reducing project overhead and increasing business esteem.

3.7 Data Collection Methods

The qualitative approach was employed to collect data from ROK industries employees particularly those from the loading and offloading department to identify and assess the current methods for warehouse management and their attitude and perception towards using RFID. In addition, the approaches were performed to investigate the existing systems and the drawbacks in Kenya. A face-to-face interview with the interview guide was conducted among 8 participants involving 5 warehouse operators and 3 warehouse managers. The observation was also employed to get to know existing works and the gaps.

3.8 Implementation of RFID Based Warehouse Management System

3.8.1 Tools Used in the Development of RFID-WMS

The RFID-based warehouse management is a system that will combine both hardware and software for its functionality.

(i) Main Hardware Requirements

- **Built in Antenna UHF RFID Reader**

A built-in antenna UHF RFID reader is a long-range integrated with an antenna reader that facilitates tag reading. It uses radiofrequency waves to transmit and get information between itself and RFID labels to recognize, categorize, and track things. Radio Frequency Identification readers are typically divided into two distinct classes, a mobile and fixed reader. Both have within them a microchip, an antenna, and sometimes an external antenna and storage memory. They have different ports for association and support distinctive types of communication protocols and are compatible with Low frequency, Tall Recurrence, Ultra Tall Frequency. The Ultra High-Frequency reader is preferred to be utilized in this project due to its advantage compared to others. It incorporates a huge read run, speed. Figure 4 is the UHF RFID reader used in this project.

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Figure 4: **Long Range Distance RFID Reader**

- **Handheld Reader**

The RFID handheld reader is a well-programmed device that helps in inventory management activities. Once a given Item is shipped from the warehouse, the handheld reader will scan it and update both storage location and the inventory. It is an integrated UHF RFID reader which has an antenna and an electronic circuit. The information can be written and rewritten on a tag. The RFID has an electronic circuit that facilitates data processing, storing, modulating, and demodulating radio waves received or sent by the antenna. The role of the antenna is to transmit and receive radio frequency waves. The project uses the UHF passive tag usually called RFID labels. Figure 5 illustrates the UHF RFID handheld reader.

Figure 5: **UHF RFID Handheld Reader**

- **Radio Frequency Identification Tag**

The RFID tag is a transponder that is made up of an integrated antenna and an electronic circuit. The information can be written and rewritten on a tag. The ID written on the tag is known as the EPC (Electronic Product Code). The electronic circuit is used for data processing and storing as well as modulating and demodulating radio waves received/sent by the antenna. The antenna is used to transmit and receive radio frequency waves. Radio Frequency Identification tags are categorized into two types such as passive and active. The UHF passive tag will be used in this project. The Fig. 6 is UHF RFID tag.

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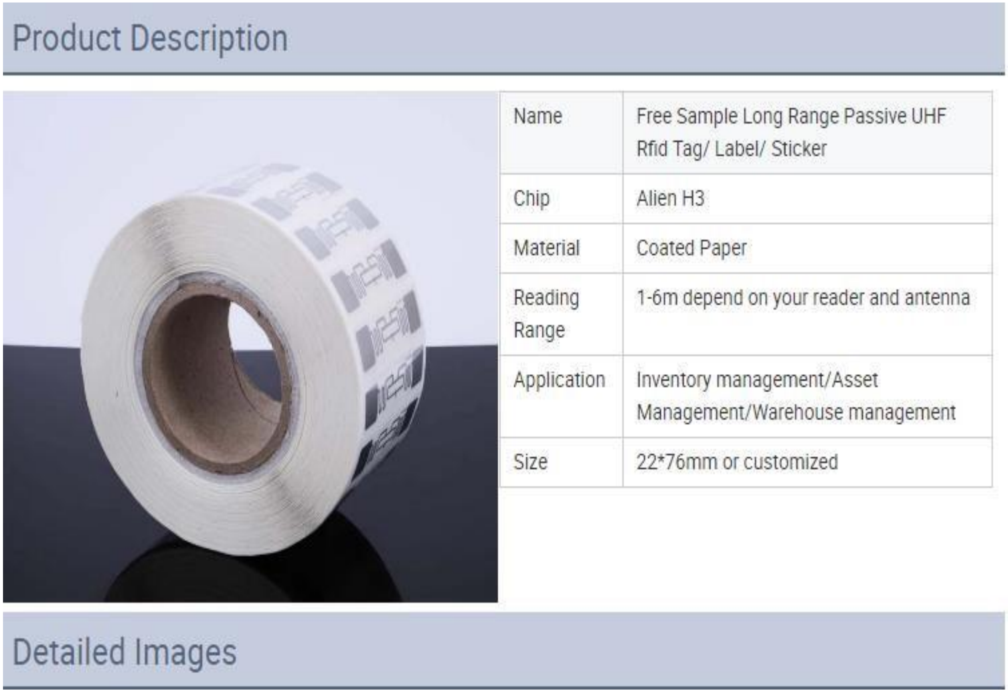

Figure 6: Radio Frequency Identification Tag

- **Microcontroller**

The ATmega328 microcontroller embedded in the Arduino Uno board is preferred in the implementation of this system. This microcontroller is chosen because of its high performance, and low power consumption. The ATmega328 has the capability of executing one million instructions per second (MIPS) per megahertz. For that reason, the power consumption and processing speed of the system will be optimized. See the Arduino Uno board and ATmega328 Microcontroller in Fig. 7.

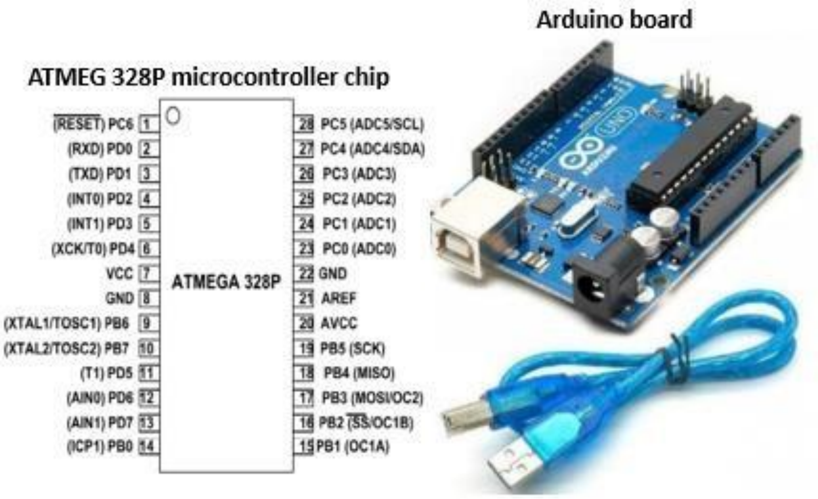

Figure 7: ATMEG 328P Microcontroller Chip Embedded in Arduino Uno Board

- **Liquid Crystal Display**

The Liquid Crystal Display (LCD) is an electronic display device that is utilized in several applications. This project used LCD 20x4 in prototyping and monitor/laptop screen during its implementation. It will display all steps and operations required by the distribution center manager and operators. Figure 8 is the LCD used in this project.

Figure 8: The LCD 20x4 Display

(ii) Software Requirements

- **Warehouse Management System**

The fundamental warehouse processes are receiving, putaway, storage, picking, packing, shipping, labor management, and reporting. Optimizing these six processes will allow you to streamline the warehouse operation, decrease cost and mistakes, and accomplish a better perfect order rate (Gong & de Koster, 2011). The computer application provides a user-friendly interface between the microcontroller and the computer to achieve the desired objective. The created application makes a difference in information processing and reports generation. See the home page of the developed application in Fig. 9.

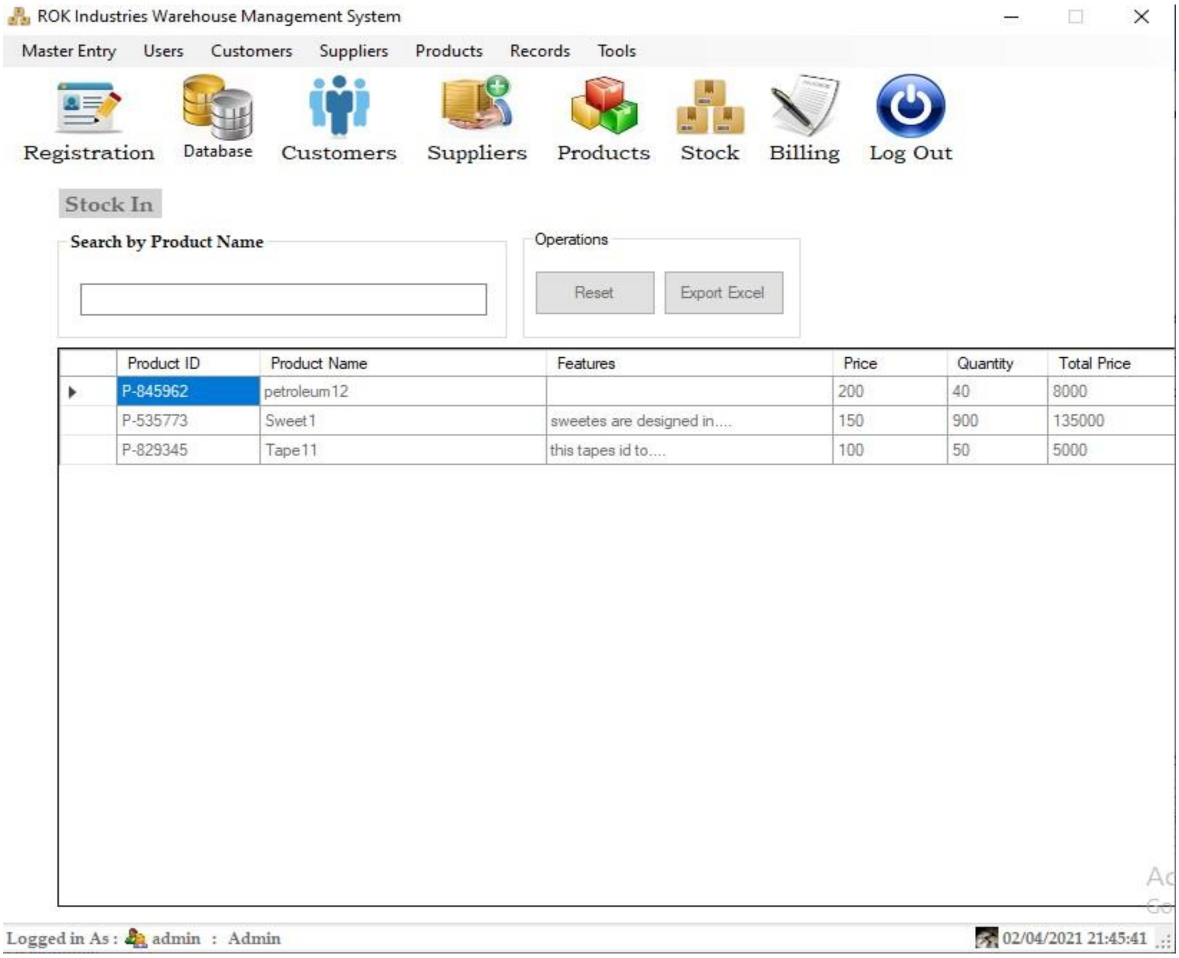

Figure 9: **Warehouse Management System Home Page**

- **Database**

A database is a set of related, organized data, large stored, and accessed electronically from a computer system. The Structured Query Language (SQL) database embedded in the visual studio is used for processing, recovering, and putting away for record-keeping for future use. Figure 10 database structure of the system created in the visual studio.

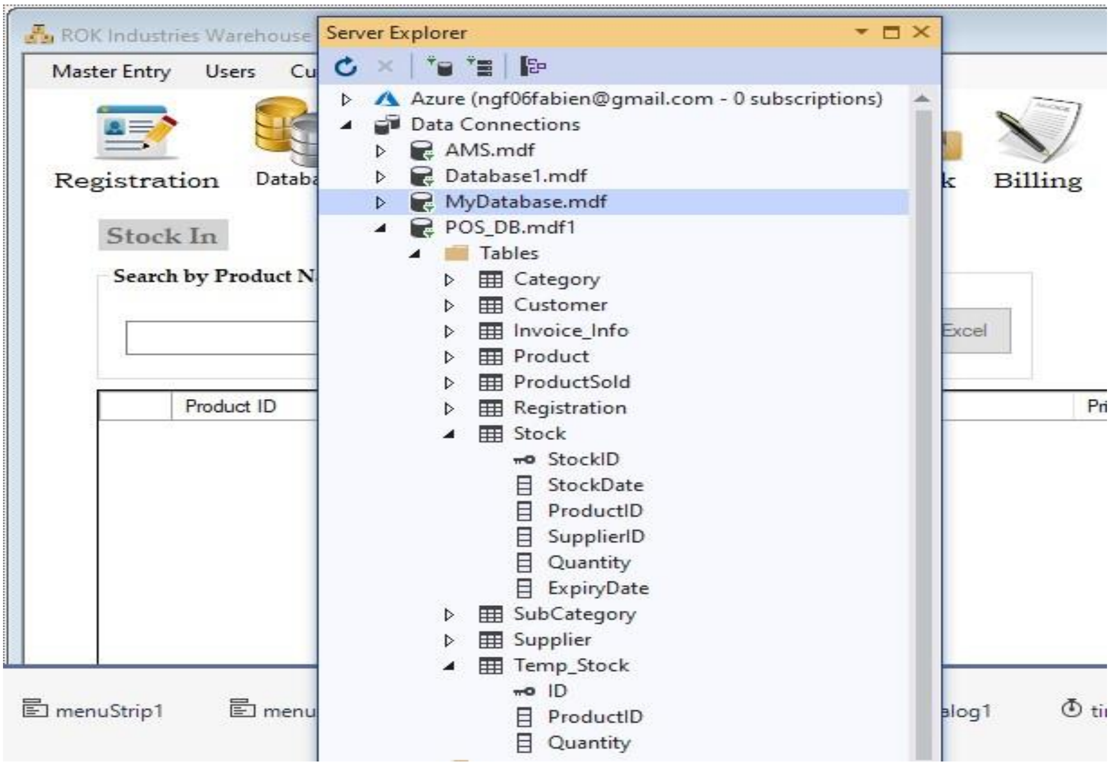

Figure 10: Illustration of WMS Database

➢ **Microsoft Visual Studio**

Microsoft Visual Studio is an integrated development environment (IDE) from Microsoft utilized to create diverse sorts of computer programs, websites, web apps, web services, and portable apps. Visual Studio uses Microsoft computer program development stages such as Windows API, Windows Forms, Windows Presentation Foundation, Windows Store, and Microsoft Silverlight. It can create both local code and manage code. In this project, Windows Form as a software development platform helped to plan the different Client interfaces of WMS. See the Screenshot of Visual Studio 2019 editing the source code of a C# during the design of the main menu of WMS as shown in Fig. 11.

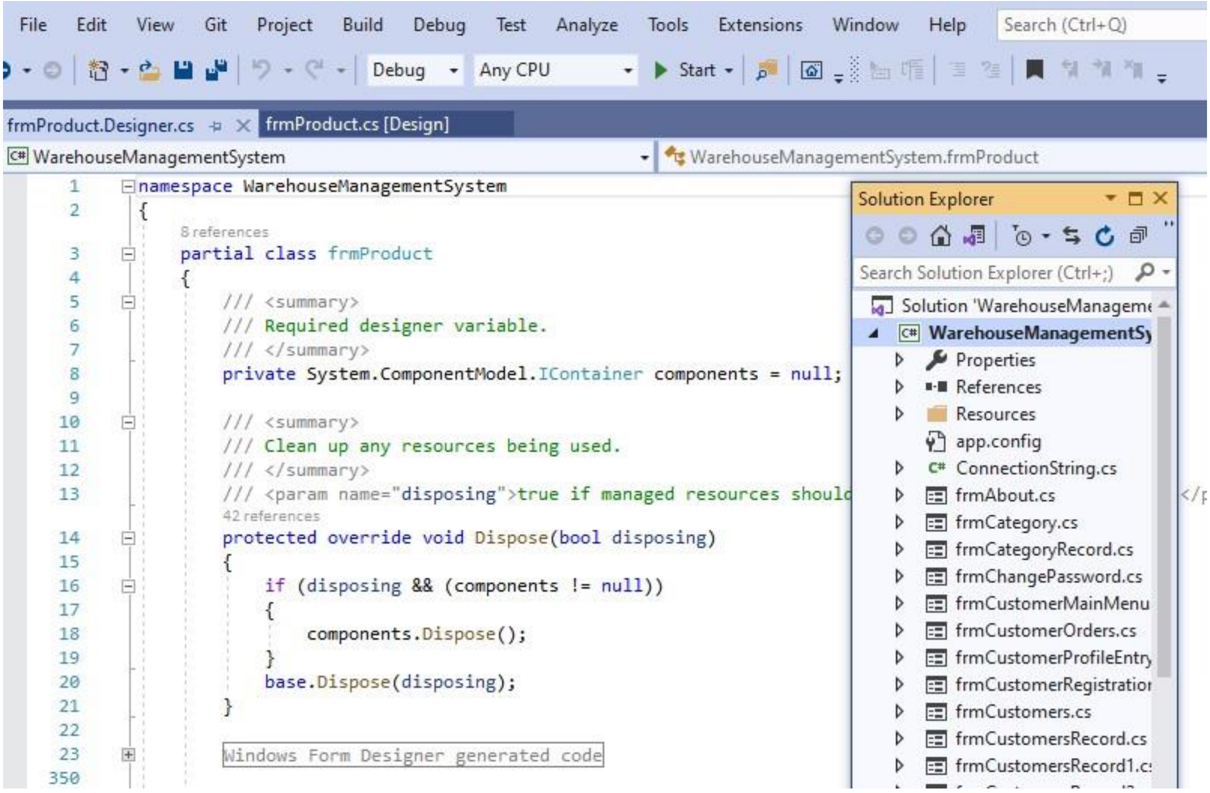

Figure 11: Screenshot Showing Visual Studio 19 while Programming Main Menu of WMS

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Introduction

Chapter four expresses the results obtained from collected data through discussions and interviews with target people in ROK, systems requirements elicitation and specification, systems development, and a detailed discussion of the results. This investigation aimed at confirmation of the current approaches used by ROK's warehouse activities in performing an inventory of goods. The examination looked to decide the challenges confronted by the available applied strategies and the stakeholders' viewpoint on the selection of the utilize of RFID innovation as the cutting edge approach in warehousing operations.

4.2 System Architecture

The system architecture of this project is divided into three distinct components. The warehouse management system plays a significant role among these components. It is the central pillar of the entire system. This part is an application designed to monitor and control warehouse operations and materials right from the point they are received in the warehouse and stored in their appropriate storage until they reach consumers (customers).

The second component is the Handheld Reader Integrated System (HRIS). It arranges and controls the use of forklift drivers for internal inventory operations. It communicates with WMS via wireless communication. The Back-End Module is the third component of this system. It consists of a database and events commands actions (ECA) created to store permanent information for future processing. It is in these components where events and rules are identified. Figure 12 summarizes the system architecture of RFID-WMS.

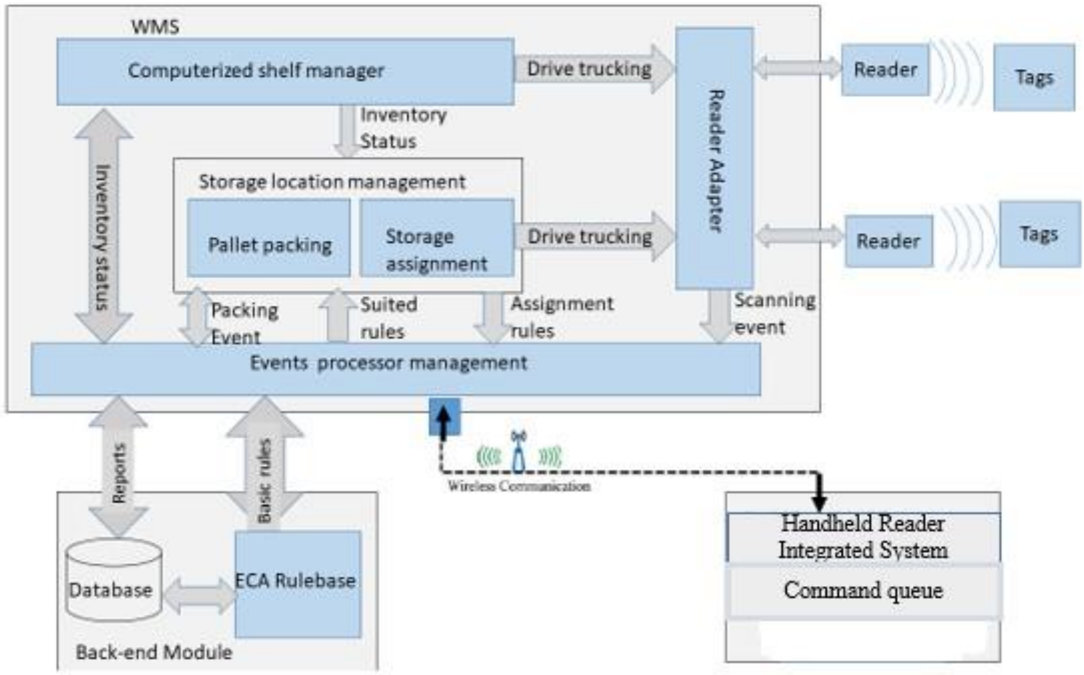

Figure 12: System Architecture of RFID-WMS

4.2.1 Warehouse Management System (WMS)

The WMS is a computer application designed based on software specifications provided by ROK authorities. It is composed of Computerized Shelf Management, storage location management, RFID reader intermediary application (reader adapter), and event processor management. The design of the system allows users to login into the system with credential information.

(i) Computerized Shelf Management

One of the reasons for this study is to improve the warehouse capacity by implanting some automation in its operations. To achieve this goal; it is necessary to make good utilization of warehouse space. This part of the system controls all inventory activities within the warehouse and helps operators to keep inventory operations smooth.

A pallet is a flat structure usually made of wood. It is used to manage the transportation of goods and arrange a good storage policy of goods. Once the pallet is attached to the RFID tag, it is called a Digital pallet. It contains the necessary product information like the price, specification, expiration date, and/or production date. Figure 13 illustrates the status of the digital pallet.

A Shelf is a square or rectangular form of wood or other rigid materials placed on any object like a wall or looking like a piece of the object made in wood that has a physical space for the storage or display of any items. A shelf is called digital if an ID number and name are attached to it and also have a tag ID of a pallet to differentiate it from others. It should have either full, half, or empty status.

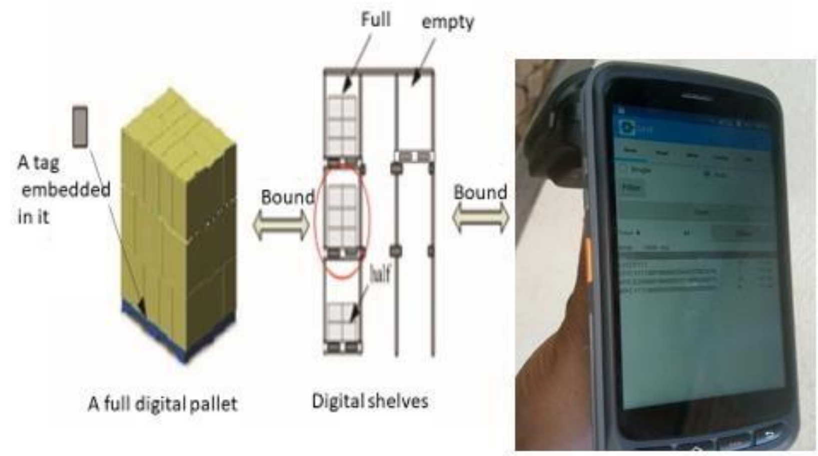

Figure 13: Demonstration of Relationship Between HRIS, Digital pallet, and Digital Shelf

Since a digital pallet has its own unique TID, it is easy to identify it from other pallets in the warehouse. Thus, all pallets in the supply chain will be easily monitored and maintained whenever they are while other pallets can't be accessed automatically in the supply chain since no unique ID is attached to them. Furthermore, the WMS helps to provide several interfaces to operators to facilitate inventory management with respect to the customers' needs. The HRIS provides notifications and updates the database for every executed query. As output, this module provides a visible layout of the warehouse management with only one person monitoring the entire system.

(ii) Radio Frequency Identification Intermediary Application (Reader Adapter)

As the title of this project indicates, RFID Based warehouse management uses RFID technology to track products within the warehouse. In this project, an intermediary application is developed between WMS and physical readers. This application provides user interfaces to reader functionalities. It accepts any type of RFID reader after installation of its drivers and connecting with the WMS.

(iii) Storage/Retrieval Component

In this project, the storage location plays a significant role in the functionalities of RFID-WMS. The automatic retrieval assignment feature helps to improve the previous warehouse operations to facilitate internal inventory management. The RFID reader helps operators to gather the tag IDs and barcode data of products during the packaging stage before sending them into the warehouse. In addition, if the placed order is not enough to complete the entire pallet, a part of it is delivered, and the remaining data is recorded and updated by the storage and retrieval component.

At receiving stage, goods are scanned by the reader before entering the warehouse for the storage location stage. In the warehouse, a storage and retrieval algorithm is used to assign the location to the incoming products. A set of rules is predefined in the database in such a way that each shelf has a status of either occupied or free. After choosing the storage (assign an item to a rack), this component will retrieve and lock that shelve to avoid another assignment and upgrade its status in the database.

- **Storage/Retrieval Rules**

To maintain a competitive advantage and meet customer demands in today's challenging environment, more and more organizations focus on the storage/retrieval assignment for the benefits of reduced picking travel time, less congestion, and enhanced space utilization (Mansuri, 1997). However, most of the research in the literature focused on solving the specific problems with an invariable environment (e.g., specific racks or specific goods). When the environment has been changed, their algorithms and methods will not adapt.

Considering the limitation of existing systems, a set of basic rules was defined for storage/retrieval assignment, in order to improve the flexibility and adaptability of WMS. In this system, the practice of storage/retrieval assignment is based on a set of basic ECA rules, which are triggered to evaluate conditions and perform relevant actions automatically. For different requirements in practice, the storage/retrieval assignment rules must be accordingly various. In order to achieve that, the researcher concludes 10 of the most common rules used in practice and illustrates that, with combinations of different ones, this system can flexibly adapt to different requirements.

Rule 1: Random. This means that any available digital shelf is equally likely to be an assignment. This rule is mostly used in the traditional warehouse by manual operation, for the reason of easy-to-perform.

Rule 2: Closest. It is widely used in various warehouses, especially in an automatic warehouse with high racks. The assignment strategy follows the principle that an available digital shelf, which is closer to an I/O point, has the higher priority to be assigned, regardless of its velocity of turnover.

Rule 3: Velocity. It is quite similar to the 'closest' rule except that it takes into account the velocity of turnover. The shelf closer to an I/O point will be available for the higher velocity of turnover.

Rule 4: Weight. For safety reasons related to the fixedness of racks, the heavier goods should be placed on the lower digital shelf on the racks. It is an important rule of the assignment for high racks.

Rule 5: Comparability. It means that similar products should be placed separately to avoid mistakes.

Rule 6: Identity. This rule denotes that the same products should be placed together for convenience to manage inventory.

Rule 7: Balance. Distribute velocity across zones as evenly as possible for reduction of congestion.

Rule 8: Shape. An item with a special shape should be placed in a special space to enhance space utilization.

Rule 9: First-In-First-Out (FIFO). The rule means that when there are more than two units, the first unit making its way into inventory will be assigned first for delivery. It is a significant rule for the management of items with short lift cycle time.

Rule 10: Last-In-First-Out (LIFO). Contrary to FIFO, it means that the first unit into inventory will be delivered last.

In the above set of rules, the last two rules (i.e., Rule 9 and Rule 10) are usually used when a delivery assignment event is triggered, while the former eight rules are usually used when a storage assignment event is triggered. Using these basic rules or a combination of some rules, the WMS can provide an extensible set of storage/retrieval strategies to help managers to achieve a specific assignment goal. An example of using the ECA mechanism for storage assignment with the above rules is shown in Fig. 14. Assume that there is an item required to be placed on the rack, which contains four digital shelves, denoted as A1, A2, A3, and A4. Assume that shelves A2 and A3 are closer to an I/O point than A1 and A4. When a Storage_

Confirm event has been generated, it will trigger the database to retrieve the relevant rules from the rule base. Based on the Random rule, the database verifies the condition that 'Shelf_State¼ ''empty'' for the four shelves, then generates three new events (Event 6, Event 7, and Event 8) as shown in Fig. 14. Combining the Random rule with the closest rule, the database generates new events subsequently by verifying the corresponding condition. In this way, the results of the storage assignment using the rules, composed by Random, Closest, Identity, and Balance, are reported by the database as follows: the item will be placed on shelf A2 if shelf A1 placed the same item, or else, placed on shelf A3.

From the analysis of the above example, it is clear that the combination of different rules enables the system to provide the different assignment results, so as to satisfy the different users' preferences. In other words, the result depends on the rule's priority specified by the users before assignment. If the Balance rule takes priority over the Identity rule according to the specification, the above example results in shelf A3. Otherwise, it results in shelf A2 or A3, according to the products placed on shelf A1. It is clear that the above set of rules can be flexible to different requirements of different products and users. However, one may argue that if the layout of shelves has been changed, the above rules may not adapt to the new racks anymore. This problem can be solved by a few modifications of the corresponding rules. As discussed in previous sections, with the help of ECA implementation, the modifications can be easily accomplished by modifying the condition part of the ECA rules dynamically. Therefore, a flexible and adaptable storage/retrieval assignment is achieved.

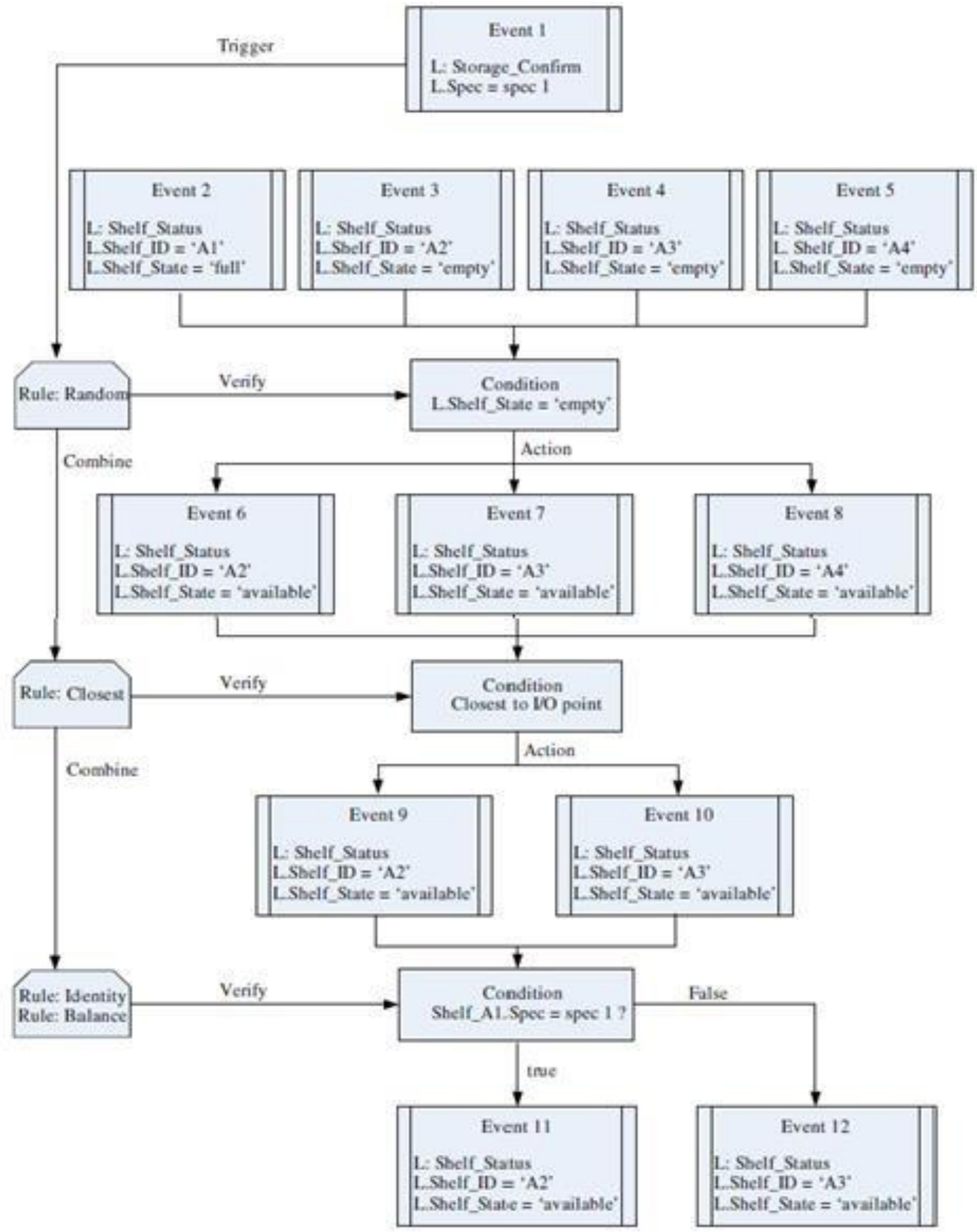

Figure 13: An Example of Events Procession Using ECA Rules

(iv) Event Processor Manager

This component helps the WMS to identify the generated events and evaluates them on time. The EPM has two types of events: the basic events and high-level events (HLE). The basic events are those produced by physical devices such as RFID readers while HLEs are events produced by system applications (e.g., WMS).

The grouping, filtering, and complex event processing (CEP) constructor functions are processed when the input event are accepted by the event buffer with the help of Event program manager, as shown in Fig. 15.

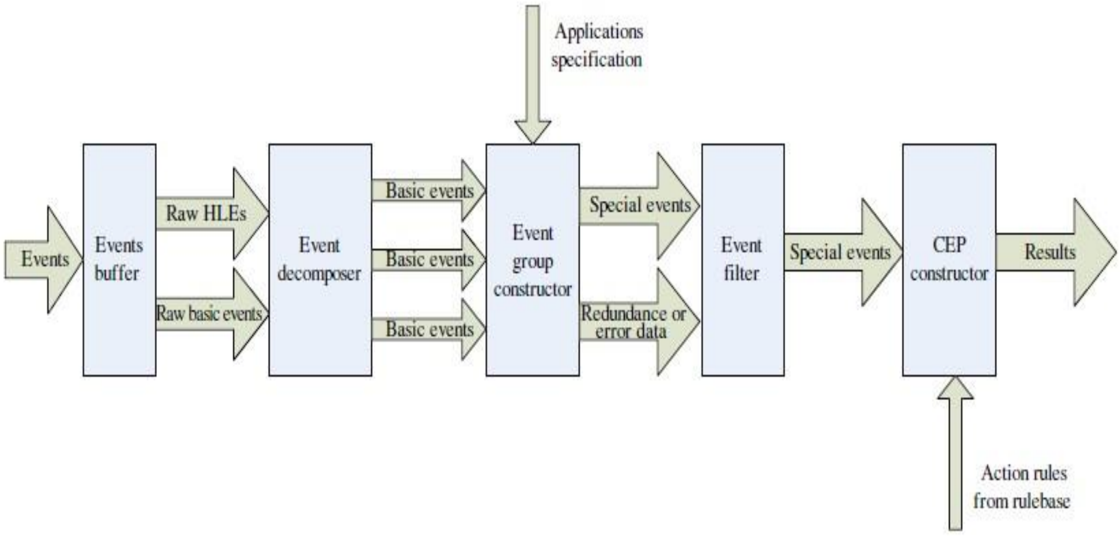

Figure 14: Event Processor Manager Structure

Since all events got to be decayed into the basic events before being stacked into the event program, they are gathered into extraordinary events for instance capacity tasks or overhauling information after going to the event constructor. In case two or more same events, the filter is called to remove them and rectify any other mistakes which will happen within the system with the assistance of the constructor, and at long last, the results are sent to WMS. For instance, if a packaging event is loaded, the decomposer breaks down it into an RFID check with Tag IDs and a barcode scan with barcode data. Both the RFID scan and barcode events are converted into basic events at the packaging stage and after they are grouped into the special event after reaching the event group constructor i.e. being called by the application.

4.2.2 Handheld Reader Integrated System (HRIS)

This subsystem is developed separately from other subsystems. It is embedded in a UHF handheld RFID reader which will be fixed on the forklift. It consists of a command queue that is in charge of different commands used in the system. Since the HRIS is attached to a forklift truck moving around in the warehouse, it helps to collect data automatically when passes around the reader and communicate with WMS to update inventory data in the database. Forklift drivers are not allowed to transport more than one pallet at the same time. They transport them one by one to avoid some mistakes that may happen. This implies that a trucker vehicle (forklift) should run some commands if the previous one has been completed. Besides, HRIS communicates with WMS that a given command has been executed to avoid double execution of a given command. See the sequence diagram shown in Fig. 16 for more details on the functionalities of the transaction series mentioned above.

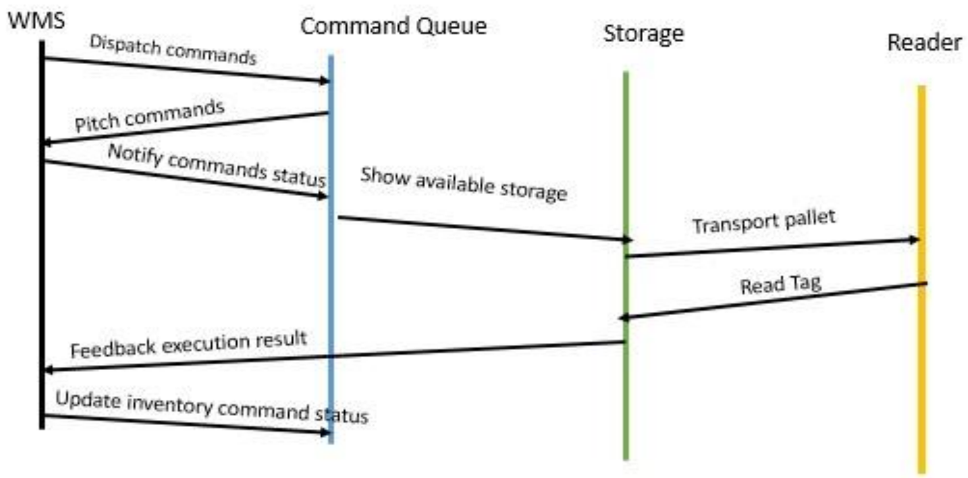

Figure 15: The Diagram Showing process of HRIS Transactions

4.2.3 Back-End Components

This component has two primary parts which are a dynamic database and a house of rules. This dynamic database can distinguish all exercises and any circumstance happening in a transaction of the framework and respond to them without any user interaction or indeed application demand. As result, it can offer assistance to the system to prepare and react to an event interior or exterior of it (Qiao *et al*., 2007). The second portion of the back-end module is the Event Commands Action. It summarizes the essential rules required within the framework to facilitate the execution of diverse transactions in real-time. The application of the rule-based will offer assistance to perform the following activities within the rule base: add a rule, modify a rule, or delete a rule.

4.3 Analysis of Current Warehouse Process

The digitalized warehouse management is a continuous concept that manufacturers, the facilities of production, and supply chain elements are proposing to increase efficiency and lower the high cost of warehouse activities. In this manner, a modern warehouse management framework is under development for ROK industries asset tracking utilizing RFID technology. In this warehouse, all incoming items are within the shape of cartons with a glued barcode to recognize them uniquely. Before the goods are shipped, operators must check each item's barcode one after another to gather necessary information of future when they are needed. All activities in this warehouse are done manually, and goods are stored on the ground in the warehouse without any defined rule.

In a commonplace stream of warehouse activities, after packaging, products are brought into the warehouse which is known as receiving process. Once the products come into the warehouse, the operator makes an arrangement based on his/her memory and own experience to locate them with storage space. When an order is placed, the operator has the task of remembering the location of the ordered items. At that point, some operators should be around to carry these items to the delivery area. Once the products pass through the exit gate, operators scan them one by one using barcodes scanners. During scanning barcodes data, some mistakes may happen. For that reason, one operator should use a computer application to check whether something wrong happened and make a manual inventory report at the end of the day.

After a clear explanation of existing warehouse activities, some proposals have been raised for the improvement of the warehouse operations. Specifically, the following angles have been tackled and described in the analysis of the requirements stage: the storage process, delivering, barcodes scanning process, digitalizing pallets (by assigning RFID tags), and inventory management process.

4.4 Requirements Analysis

By analyzing the discussions with warehouse managers and warehouse operators, we outlined the necessities of the system. See Table 1 for more details on these discussions. After an examination of their necessities, the researcher proposes the RFID-WMS framework. In order to keep a proper use of warehouse capacity, the drive-in rack was proposed during products shaping. In order to avoid some mistakes and complications of the operations, operators transport goods as a pallet, and the RFID labels are attached to the pallet instead of the product, for the reason that it is the foremost advantageous mode of RFID adoption within the industry (Bottani & Rizzi, 2008).

Table 1: Requirements for RFID-WMS

People involved	Necessities
	Applying drive in racks to increase warehouse space
	Improve warehouse operation procedures through the use RFID tags
Manager	Record keeping
	Having a visualized warehouse inventory information
	Recording the stock in and Stock out data
	Providing a quick inventory reports
	Provide an automatic decision for storage/retrieval assignment
Operators	Providing an alert system in case of errors

4.5 Warehouse Layout Design

The previous warehouse design has no well-structured layout. Based on the analysis requirements of the RFID-WMS, the drive-in racks were proposed in designing the layout of the warehouse before implantation RFID. The layout of the entire warehouse designed using the drive-in rack shown in Fig. 17 has six layers. The warehouse length is eight racks in depending on the capacity of trucks.

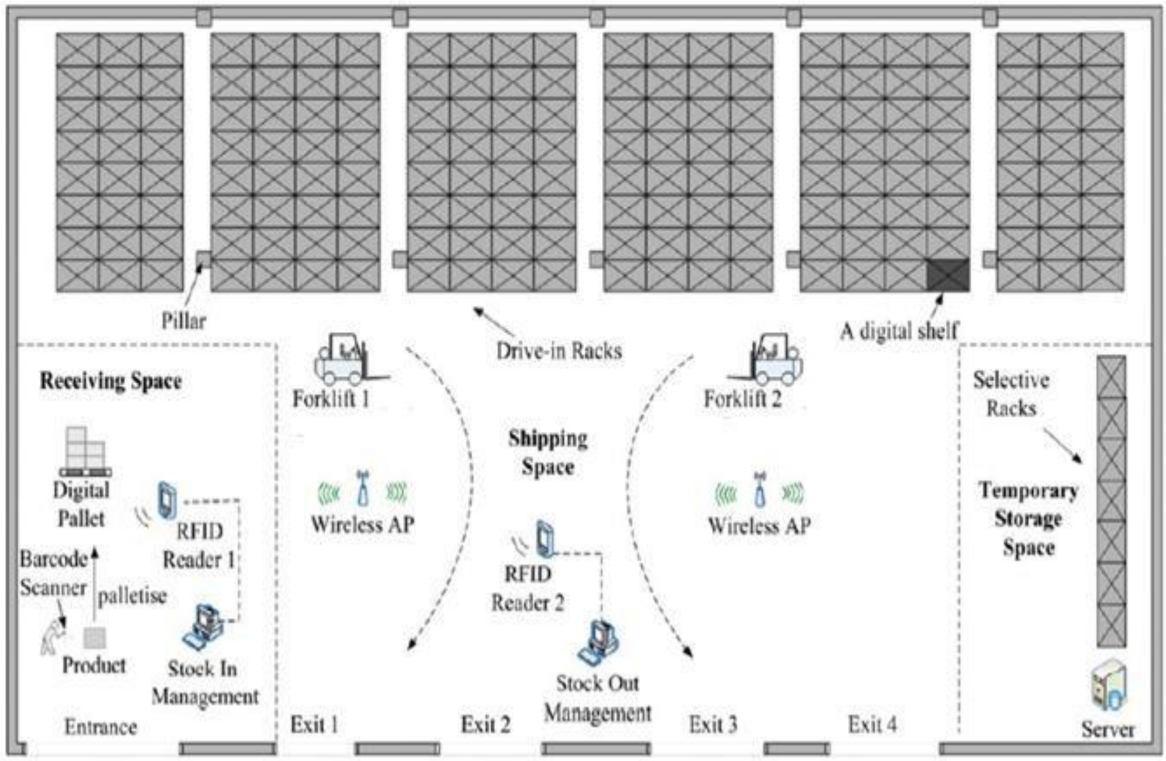

Figure 16: The Warehouse Layout

According to Choy *et al.* (2009), in order to have good readings of the RFID reader, it's better to place the reader in the eyesight position to facilitate forklift reading and scan effectively. The first reader is fixed at the entry of the warehouse to scanning of the incoming products, and the second reader is on the exit gate to read out coming items.

The receiving products are palletized and stored in their corresponding locations, and operations of collection data are done by barcode scanners and RFID readers at the same time. Once the order is completely ready to ship, the forklift drivers transport it to the vehicle for shipping, and once it passes through the reader on the gate, the reader2 scans all data and update the information in the database. The long-range RFID reader has been used to facilitate the readings of pallets at a certain distance.

4.6 Radio Frequency Identification Based Warehouse Management System Design

After analyzing the requirements of the RFID-WMS, the researcher classified its functionalities into the following five parts: human resources subsystem, receiving subsystem, ordering subsystem, shelf management subsystem, and handheld reader integrated subsystem as described below:

(i) Human Resources Management Subsystem

The human resource tool in this study helps warehouse managers to manipulate the operator's performance and the daily evaluation by analyzing the recorded information for a given date.

(ii) Stock in Subsystem

The receiving part of this study has numerous functions. First, it helps to know the storage location of incoming items on a real-time basis concerning storage rules in rulebase. Secondly, the warehouse user may use this subsystem to create a storage space with the help of storage commands from rulebase and send them to the HRIS for the forklift reader to implement them. Lastly, once this subsystem receives a confirmation from HRIS, it automatically upgrades data in the database.

(iii) Stock Out Subsystem

This subsystem is for doing inventory management within the warehouse to solve the problem of ordering and shipping activities. It provides the capability of retrieval assignment after ordering a given pallet from its storage and communicates with WMS to update data in the database. In case of incorrect pallet detection, this subsystem can know it by comparing and matching its tag Id with the tag assigned to the shelf and provide an alert to the forklift drivers. See the relationship of RFID-WMS as shown in Fig. 17.

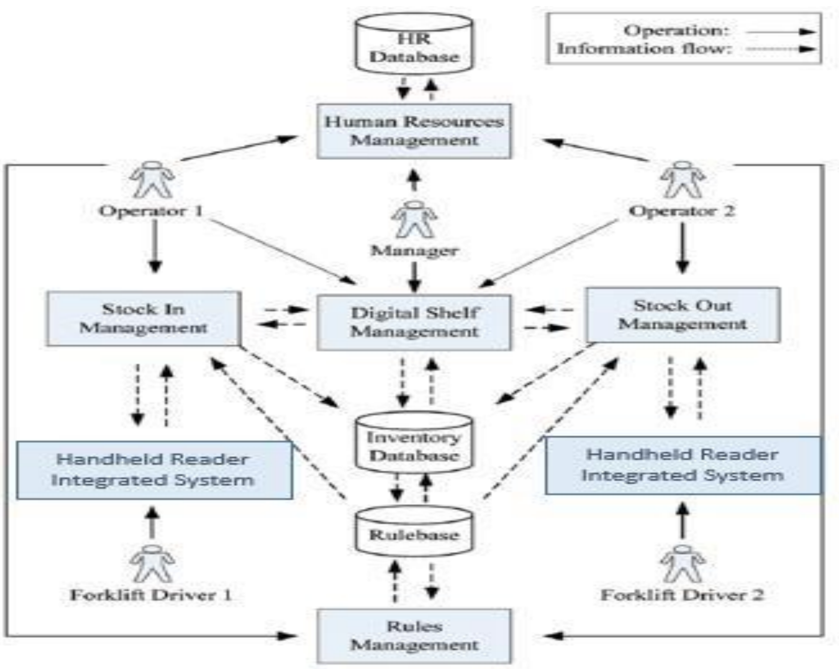

Figure 17: The Functionality of Subsystems in RFID-WMS

(iv) Shelf Management Subsystem

The shelf management helps warehouse managers to know the status of storage location and an overview of the entire warehouse inventory management process on time. Moreover, this part of the system provides the accurate inventory statistical report that contains the beginning of inventory data, receiving, ordering, and product quantities concerning the specification of each product and the operator's details and also the time it takes to complete a transaction and the end of inventory data. In addition, this function also helps in monitoring the rack's status. When there is one pallet in the passageway of drive-in racks and maybe a specific rack with an extra shelf, the system provides an alert for completing the remaining pallet to the temporary space for proper use of drive-in racks.

(v) Handheld Reader Integrated System

This subsystem is developed within the handheld UHF RFID reader. It is fixed on the forklift to assist the execution of different commands. These commands are executed when the handheld scans a pallet tag and communicates with WMS to update the information in the database. Since the items are stored in the drive-in racks, the LIFO rules help execute commands in this subsystem during ordering products. This part of the system has the added value of communicating with other subsystems with the help of a wireless network.

4.7 System Testing and Validation

The testing application was conducted to check whether any element of the system complies with its functions. Unit and integration testing are the aspects that verify the flexibility of all warehouse operations. ROK management staff, warehouse managers, and operators from the loading and offloading department tested the RFID-WMS. They approved the implementation of the system after performing some of its operations in the warehouse. Successfully tested operations are stock in, stock out, and shipping processes.

4.8 System implementation

According to the structure and the design of this system, the RFID-based warehouse management system is developed using Rich Client Platform (RCP), which facilitates visual studio plug-in architecture. It helps in developing C# applications that can be compatible with other applications developed using any other platform. With the help of a wireless network, the use of TCP/IP and socket technology contributed to analyzing the communication between subsystems.

4.9 Validation of the Operation Deliverables Before and After Using RFID-WMS

Before implementing this system, the ROK warehouse was time-consuming with a lot of workers. The packaging process is done in the provided workshop rooms, then after the items are transported into the warehouse by operators. The operators decide where to store goods based on their own experience which may cause the misuse of warehouse space. After using the RFID-based warehouse management system, the following automated features have been added to the system's functionality. These features are storage and retrieval assignment, automatic inventory management within the warehouse, forklift operations for loading and offloading, and the impact of using these new features is a lower number of workers because of the automation of most activities. For instance, the internal inventory is monitored by WMS through a handheld reader integrated system. A Drive-in rack facilitates warehouse activities. The FIFO rule helped in receiving finished goods by respecting the storage location algorithm.

As a result, the mistakes made by the operators are significantly reduced. In addition to that, warehouse managers can easily monitor inventory in real-time. Besides, there is no need for operators to move around in the warehouse locating product storage. The storage assignment is a job of a single person sitting on the front of the computer with only a single click. Since products are transported in form of a pallet, it is not necessary for the operator to check barcodes one by one and also to verify whether the picked item is the one targeted. This is the task of WMS through HRIS fixed on forklift passing by the reader and collects the necessary information. The comparison between warehouse operations before and after the implantation of RFID-WMS is summarized in the following essential elements in Table 2.

(i) Size of Warehouse

According to the Table 2, it is obvious to tell you that the distribution center space is managed by 55.5%. This is because of the utilize of drive-in racks.

(ii) Number of Workers in the Warehouse

After implementing RFID-WMS, the interactions between human being in the warehouse has been reduced by half compared to the old system operations. By clear understanding the previous warehouse operations in Section 4.2 and the new modern way of storage location assignment in Section 4.6; it is clear to announce the reduction of employees due to the following reasons: no person is carrying goods in the warehouse, goods are carried by forklift, no user in charge of storage location assignment this is done storage/location module, and none is scanning barcodes, it is the task of RFID reader through the communication with HRIS. Therefore, it's real to conclude by saying that there is a reduction of half of the labor works.

(iii) Loading and Offloading Time

Based on the mathematical calculations, it is clear that the usual loading and offloading time is reduced from 60 minutes to 20 minutes. This difference comes from the time that operator uses to move around in the warehouse looking for storage of items, scanning barcodes, and carrying products to vehicles for shipping.

(vi) Inventory Accuracy

After implementation of the RFID-WMS, the augmentation of inventory accuracy is illustrated from 80% to 99%.

Table 2: Comparison of warehousing performance without and with RFID-WMS

	Without RFID-WMS	With RFID-WMS
Capacity of warehouse	7200 cartons	10980 cartons
Loading manpower	8 persons	4 persons
Average loading time	50 minutes	18 minutes
Loading ratio	800 cartons	480 cartons
Inventory accuracy	80%	99%

This benefit is described based on misplacement and transaction errors. Figure 18 explains statistical data of the inaccuracy of the monthly inventory based on the requirement analysis of the RFID-WMS as shown in Fig. 18. Before implementing this system, the inaccuracy of the inventory management was mainly caused by misplacement as illustrated in Fig. 18 (a). This is because the operator was doing jobs manually and the transportation of the product with the warehouse. However, after using this system, Fig. 18 (b) demonstrate that the disarrangement of products within the warehouse has been reduced.

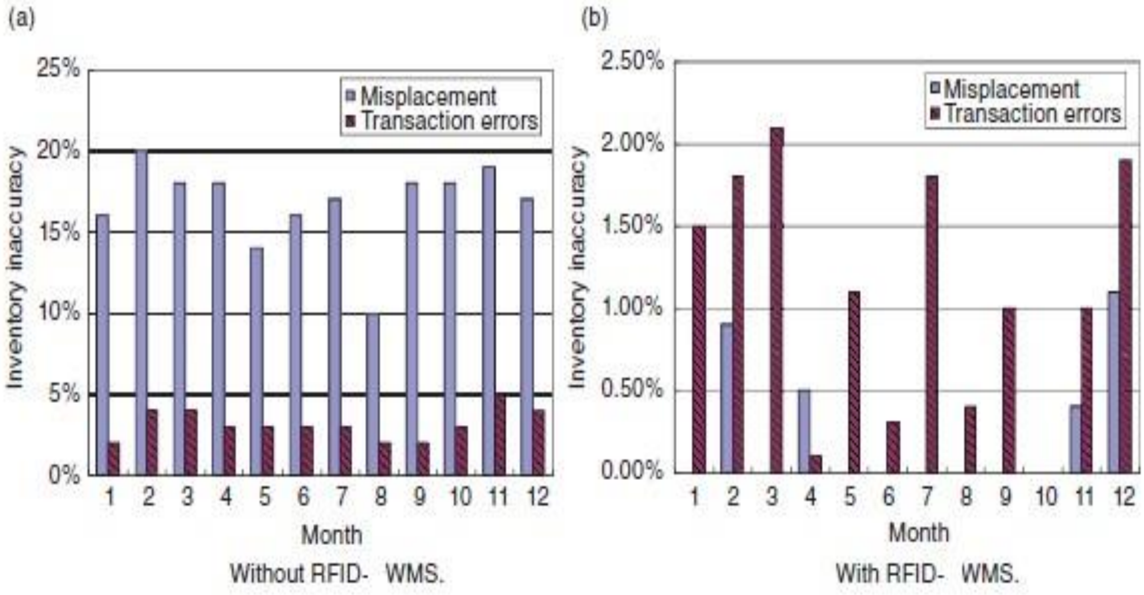

Figure 18: Comparison of Inventory Accuracy.

The comparison of the transaction errors, before implementing RFID, the author may conclude by saying that this is caused by mistakes made by the barcodes scanners at the time of inventory management or none accurate readings. The RFID-WMS illustrates an overall 97% read rate of the tag on the pallet.

The findings of the RFID_WMS shows that this system might improve traceability and visibility of products and processes, increase efficiency and speed of processes, improve information accuracy and might decrease inventory losses.

CHAPTER FIVE
CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

This project is developed to improve the inventory management and entire operations of the warehouse with the help of RFID technology. In order to achieve this goal, the RFID-WMS was proposed to reach the visualization of inventory management within the warehouse and the automatic storage and retrieval assignment. With the assistance of RFID technology, the digitalized pallet and shelf are implemented. All items and their corresponding storage location can be gathered together and trucked uniquely. Through the analysis of the functionality of the developed system, we can say that the warehouse operations, the manipulation of storage location, the increment of the precision of inventory, a small number of workforce, reduction of loading, and offloading time was improved effectively. The cost of implementation of this system is cheaper compared to its benefits. The designed system is developed based on the existing functionalities of the existing warehouse with the additional features such as handheld reader integrated system used to manage internal inventory, the clarification and differentiation of invents helped in the adaptation of the system effectively, finally, the application of Event Commands action mechanism helped a lot in defining the rules of storage/retrieval algorithm.

5.2 Recommendations

Nowadays, every business that deals with the supply of different products within the supply chain management has some limitations and challenges while trying to do their best to reach to their goal, especially successful companies that are constantly growing out of room in their warehouses and storage areas. Some innovative approaches are highly recommended. Based on the findings in RFID-WMS, it is true that RFID technology becomes a solution to warehousing operations and to solve problems most of the companies are facing today in their warehousing activities. Radio Frequency Identification technology assists to improve the proficiency of warehouse and auto recording of products during receiving and shipping. Therefore, considering evaluation conducted by the user at ROK, the RFID-WMS tool is recommended for adoption and used by ROK management in the department of loading and offloading. This work also is recommended to other industrial environments with features of regular product shapes and large throughput operations, under which digitalized shelf management is put into practice.

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APPENDICES

Appendix 1: An Interview Guide for RFID-WMS

Interview Guide for warehouse management

A. Warehouse Manager

1. What is the size of your warehouse?
2. What is the shape of your warehouse (double door, two halve with aisle, more than one exit, etc.)?
3. Is your warehouse containing some metal in building blocks?
4. What is payment methods do you use?
5. How many forklift vehicles do you have?
6. How many operators are in the warehouse?
7. Do you have any plan of increasing the number of operators in the warehouse?
8. Do you have a clear storage assignment scheme?
9. How is the registration of products done?
10. Are there any different categories for completing products registration?
11. How long does it take to register a product?
12. How do you know whether a product is successfully registered?
13. How do you maintain product records?
14. How many steps are needed to place an order?
15. How long time it takes to complete an order?
16. What are the preferred currency in your payment methods (Kesh, Us dollars, or Euro)?
17. Is there any automation system for inventory management? if yes how it works?
18. Did you previously hear about RFID technology?
19. What approximately the budget you could not exceed to implement a warehouse in your industry?

B. Warehouse Operators

1. How many cartons per pallet?
2. how many goods(cartons) will pass in and out of the warehouse (approximate) each day?
3. How do you currently assign barcodes to products?
4. Explain how the current packaging process is done
5. How goods are received in the warehouse?

Appendix 2: Sample C# Codes Used for WMS Development

```
using System;
using System.Collections. Generic;
using System.ComponentModel;
using System.Data;
using System.Drawing;
using System.Linq;
using System.Text;
using System.Windows.Forms;
using System.Data.SqlClient;
using System.IO;
using Excel = Microsoft.Office.Interop.Excel;
namespace WarehouseManagementSystem
{
    public partial class frmMainMenu : Form
    {
        SqlDataReader rdr = null;
        SqlConnection con = null;
        SqlCommand cmd = null;
        ConnectionString cs = new ConnectionString();
        public frmMainMenu ()
        {
            InitializeComponent();
        }

        private void customerToolStripMenuItem_Click(object sender, EventArgs e)
        {


        frmCustomers frm = new frmCustomers();
        frm.Show();
    }

    private void registrationToolStripMenuItem1_Click(object sender, EventArgs e)
    {
        frmRegistration frm = new frmRegistration();
        frm.Show();
    }

    private void aboutToolStripMenuItem_Click(object sender, EventArgs e)
    {
        frmAbout frm = new frmAbout();
        frm.Show();
    }

    private void registrationToolStripMenuItem_Click(object sender, EventArgs e)
    {
        frmRegistration frm = new frmRegistration();
        frm.Show();
    }

    private void profileEntryToolStripMenuItem_Click(object sender, EventArgs e)
    {
        frmCustomers frm = new frmCustomers();
        frm.Show();
    }
```

```
private void wordpadToolStripMenuItem_Click(object sender, EventArgs e)
{
    System.Diagnostics.Process.Start("Wordpad.exe");
}

private void taskManagerToolStripMenuItem_Click(object sender, EventArgs e)
{
    System.Diagnostics.Process.Start("TaskMgr.exe");
}

private void mSWordToolStripMenuItem_Click(object sender, EventArgs e)
{
    System.Diagnostics.Process.Start("Winword.exe");
}

private void categoryToolStripMenuItem_Click(object sender, EventArgs e)
{
    frmCategory frm = new frmCategory();
    frm.Show();
}

private void companyToolStripMenuItem_Click(object sender, EventArgs e)
{
    frmSubCategory frm = new frmSubCategory();
    frm.Show();
}

private void logOutToolStripMenuItem_Click(object sender, EventArgs e)
{
    this.Hide();
    frmCategory o1 = new frmCategory();
    o1.Hide();
    frmSubCategory o2 = new frmSubCategory();
    o2.Hide();
    frmProduct o3 = new frmProduct();
    o3.Hide();
    frmRegisteredUsersDetails o4 = new frmRegisteredUsersDetails();
    o4.Hide();
    frmRegistration o5 = new frmRegistration();
    o5.Hide();
    frmStockRecord o6 = new frmStockRecord();
    o6.Hide();
    frmCustomersRecord o7 = new frmCustomersRecord();
    o7.Hide();
    frmSuppliersRecord o8 = new frmSuppliersRecord();
    o8.Hide();
    frmProductsRecord2 o9 = new frmProductsRecord2();
    o9.Hide();
    frmSalesRecord2 o10 = new frmSalesRecord2();
    o10.Hide();
```

```
    frmLogin frm = new frmLogin();
    frm.Show();
    frm.txtUserName.Text = "";
    frm.txtPassword.Text = "";
    frm.ProgressBar1.Visible = false;
    frm.txtUserName.Focus();
}

private void frmMainMenu_Load(object sender, EventArgs e)
{
    if (lblUserType.Text.Trim()== "Admin")
        {
            this.masterEntryToolStripMenuItem.Enabled=true;
            this.usersToolStripMenuItem.Enabled=true;
            this.customerToolStripMenuItem1.Enabled=true;
            this.suppliersToolStripMenuItem.Enabled=true;
            this.productsToolStripMenuItem.Enabled=true;
            this.recordsToolStripMenuItem.Enabled=true;
            this.registrationToolStripMenuItem.Enabled=true;
            this.databaseToolStripMenuItem.Enabled=true;
            this.customerToolStripMenuItem.Enabled=true;
            this.supplierToolStripMenuItem.Enabled=true;
            this.productToolStripMenuItem.Enabled=true;
            this.stockToolStripMenuItem.Enabled=true;
            this.invoiceToolStripMenuItem.Enabled = true;
        }

    if (lblUserType.Text.Trim() == "Sales Person")
     {
        this.masterEntryToolStripMenuItem.Enabled = false;
        this.usersToolStripMenuItem.Enabled = false;
        this.customerToolStripMenuItem1.Enabled = true;
        this.suppliersToolStripMenuItem.Enabled = false;
        this.productsToolStripMenuItem.Enabled = false;
        this.recordsToolStripMenuItem.Enabled = false;
        this.registrationToolStripMenuItem.Enabled = false;
        this.databaseToolStripMenuItem.Enabled = false;
        this.customerToolStripMenuItem.Enabled = true;
        this.supplierToolStripMenuItem.Enabled = false;
        this.productToolStripMenuItem.Enabled = false;
        this.stockToolStripMenuItem.Enabled = false;
        this.invoiceToolStripMenuItem.Enabled = true;

     }
     if (lblUserType.Text.Trim() == "Warehouse Worker")
     {
        this.masterEntryToolStripMenuItem.Enabled = false;
        this.usersToolStripMenuItem.Enabled = false;
        this.customerToolStripMenuItem1.Enabled = false;
       this.suppliersToolStripMenuItem.Enabled = false;
        this.productsToolStripMenuItem.Enabled = false;
        this.recordsToolStripMenuItem.Enabled = false;
        this.registrationToolStripMenuItem.Enabled = false;
        this.databaseToolStripMenuItem.Enabled = false;
```

```
            this.customerToolStripMenuItem.Enabled = false;
            this.supplierToolStripMenuItem.Enabled = false;
            this.productToolStripMenuItem.Enabled = false;
            this.stockToolStripMenuItem.Enabled = false;
            this.invoiceToolStripMenuItem.Enabled = false;

        }

          if (lblUserType.Text.Trim() == "Warehouse Manager")
        {
            this.masterEntryToolStripMenuItem.Enabled = false;
            this.usersToolStripMenuItem.Enabled = false;
            this.customerToolStripMenuItem1.Enabled = false;
            this.suppliersToolStripMenuItem.Enabled = false;
            this.productsToolStripMenuItem.Enabled = false;
            this.recordsToolStripMenuItem.Enabled = false;
            this.registrationToolStripMenuItem.Enabled = false;
            this.databaseToolStripMenuItem.Enabled = false;
            this.customerToolStripMenuItem.Enabled = false;
            this.supplierToolStripMenuItem.Enabled = true;
            this.productToolStripMenuItem.Enabled = true;
            this.stockToolStripMenuItem.Enabled = true;
            this.invoiceToolStripMenuItem.Enabled = false;

        }
            ToolStripStatusLabel4.Text = System.DateTime.Now.ToString();
            GetData();


}
private void timer1_Tick(object sender, EventArgs e)
{
    ToolStripStatusLabel4.Text = System.DateTime.Now.ToString();
}
private void productsToolStripMenuItem1_Click(object sender, EventArgs e)
{
    frmProduct frm = new frmProduct();
    frm.Show();
}
private void productsToolStripMenuItem2_Click(object sender, EventArgs e)
{
    frmProductsRecord2 frm = new frmProductsRecord2();
    frm.Show();
}
    private void stockToolStripMenuItem1_Click(object sender, EventArgs e)
{
    this.Hide();
    frmStock frm = new frmStock();
    frm.lblUser.Text = lblUser.Text;
    frm.lblUserType.Text = lblUserType.Text;
    frm.Show();
}
```

```
}

private void timer1_Tick(object sender, EventArgs e)
{
  ToolStripStatusLabel4.Text = System.DateTime.Now.ToString();
}

private void productsToolStripMenuItem1_Click(object sender, EventArgs e)
{
  frmProduct frm = new frmProduct();
  frm.Show();
}

private void productsToolStripMenuItem2_Click(object sender, EventArgs e)
{
  frmProductsRecord2 frm = new frmProductsRecord2();
  frm.Show();
}


private void stockToolStripMenuItem1_Click(object sender, EventArgs e)
{
  this.Hide();
  frmStock frm = new frmStock();
  frm.lblUser.Text = lblUser.Text;
  frm.lblUserType.Text = lblUserType.Text;
  frm.Show();
}

        private void stockToolStripMenuItem_Click(object sender, EventArgs e)
        {
          this.Hide();
          frmStock frm = new frmStock();
          frm.lblUser.Text = lblUser.Text;
          frm.lblUserType.Text = lblUserType.Text;
          frm.Show();
        }

        public void GetData()
        {
          try
          {
            con = new SqlConnection(cs.DBConn);
            con.Open();
            String sql = "SELECT
 Product.ProductID,ProductName,Features,Price,sum(Quantity),sum(Price*Quantity) from
 Temp_Stock,Product where Temp_Stock.ProductID=Product.ProductID group by
 Product.productID,productname,Price,Features,Quantity having(Quantity>0)  order by
 ProductName";
            cmd = new SqlCommand(sql, con);
            rdr = cmd.ExecuteReader(CommandBehavior.CloseConnection);
            dataGridView1.Rows.Clear();
            while (rdr.Read() == true)
            {
```

```
                dataGridView1.Rows.Add(rdr[0], rdr[1], rdr[2], rdr[3], rdr[4], rdr[5]);
            }
            foreach (DataGridViewRow r in this.dataGridView1.Rows)
            {
                if (Convert.ToInt32(r.Cells[4].Value) < 10)
                {
                    r.DefaultCellStyle.BackColor = Color.Red;
                }
            }
            con.Close();
        }
        catch (Exception ex)
        {
            MessageBox.Show(ex.Message, "Error", MessageBoxButtons.OK,
MessageBoxIcon.Error);
        }
    }


     private void invoiceToolStripMenuItem_Click(object sender, EventArgs e)
     {
        this.Hide();
        frmSales frm = new frmSales();
        frm.lblUser.Text = lblUser.Text;
        frm.lblUserType.Text = lblUserType.Text;
        frm.Show();
     }

    private void salesToolStripMenuItem_Click(object sender, EventArgs e)
    {
      this.Hide();
      frmSales frm = new frmSales();
      frm.lblUser.Text = lblUser.Text;
      frm.lblUserType.Text = lblUserType.Text;
      frm.Show();
    }

    private void salesToolStripMenuItem1_Click(object sender, EventArgs e)
    {
      frmSalesRecord2 frm = new frmSalesRecord2();
      frm.Show();
    }

    private void loginDetailsToolStripMenuItem_Click(object sender, EventArgs e)
    {
      frmLoginDetails frm = new frmLoginDetails();
      frm.Show();
    }

    private void textBox1_TextChanged(object sender, EventArgs e)
    {
      try{
      con = new SqlConnection(cs.DBConn);
        con.Open();
```

```
            String sql = "SELECT
Product.ProductID,ProductName,Features,Price,sum(Quantity),sum(Price*Quantity) from
Temp_Stock,Product where Temp_Stock.ProductID=Product.ProductID and ProductName like '" +
txtProductName.Text + "%' group by product.ProductID,productname,Price,Features,Quantity
having(quantity>0) order by ProductName";
            cmd = new SqlCommand(sql, con);
            rdr = cmd.ExecuteReader(CommandBehavior.CloseConnection);
            dataGridView1.Rows.Clear();
            while (rdr.Read() == true)
            {
              dataGridView1.Rows.Add(rdr[0], rdr[1], rdr[2], rdr[3], rdr[4], rdr[5]);
            }
            foreach (DataGridViewRow r in this.dataGridView1.Rows)
            {
            if (Convert.ToInt32(r.Cells[4].Value) < 10)
            {
              r.DefaultCellStyle.BackColor = Color.Red;
            }
          }
            con.Close();
          }
          catch (Exception ex)
          {
            MessageBox.Show(ex.Message, "Error", MessageBoxButtons.OK,
MessageBoxIcon.Error);
          }
      }


  private void frmMainMenu_FormClosing(object sender, FormClosingEventArgs e)
  {
    this.Dispose();

  }

  private void profileEntryToolStripMenuItem1_Click(object sender, EventArgs e)
  {
    frmSuppliers frm = new frmSuppliers();
    frm.Show();
  }

  private void supplierToolStripMenuItem_Click(object sender, EventArgs e)
  {
    frmSuppliers frm = new frmSuppliers();
    frm.Show();
  }

  private void suppliersToolStripMenuItem1_Click(object sender, EventArgs e)
  {
    frmSuppliersRecord frm = new frmSuppliersRecord();
    frm.Show();
  }
```

```
        private void stockToolStripMenuItem2_Click(object sender, EventArgs e)
        {
            frmStockRecord frm = new frmStockRecord();
            frm.Show();
        }

        private void backupToolStripMenuItem_Click(object sender, EventArgs e)
        {
            try
            {
                Cursor = Cursors.WaitCursor;
                timer2.Enabled = true;
                if ((!System.IO.Directory.Exists("C:\\DBBackup")))
                {
                    System.IO.Directory.CreateDirectory("C:\\DBBackup");
                }
                string destdir = "C:\\DBBackup\\pos_db " + DateTime.Now.ToString("dd-MM-yyyy_HH-
mm-ss") + ".bak";
                con = new SqlConnection(cs.DBConn);
                con.Open();
                string cb = "backup database [" + System.Windows.Forms.Application.StartupPath +
"\\pos_db.mdf] to disk='" + destdir + "'with init,stats=10";
                cmd = new SqlCommand(cb);
                cmd.Connection = con;
                cmd.ExecuteReader();
                con.Close();
                MessageBox.Show("Successfully performed", "Database Backup",
MessageBoxButtons.OK, MessageBoxIcon.Information);
            }
            catch (Exception ex)
            {
                MessageBox.Show(ex.Message, "Error", MessageBoxButtons.OK,
MessageBoxIcon.Error);
            }
        }

        private void restoreToolStripMenuItem_Click(object sender, EventArgs e)
        {
            try
            {
                var _with1 = openFileDialog1;
                _with1.Filter = ("DB Backup File|*.bak;");
                _with1.FilterIndex = 4;
                //Clear the file name
                openFileDialog1.FileName = "";

                if (openFileDialog1.ShowDialog() == DialogResult.OK)
                {
                    Cursor = Cursors.WaitCursor;
                    timer2.Enabled = true;
                    SqlConnection.ClearAllPools();
                    con = new SqlConnection(cs.DBConn);
                    con.Open();
                    string cb = "USE Master ALTER DATABASE [" +
System.Windows.Forms.Application.StartupPath + "\\pos_db.mdf] SET Single_User WITH Rollback
```

```
Immediate Restore database [" + System.Windows.Forms.Application.StartupPath + "\\pos_db.mdf]
FROM disk='" + openFileDialog1.FileName + "' WITH REPLACE ALTER DATABASE [" +
System.Windows.Forms.Application.StartupPath + "\\pos_db.mdf] SET Multi_User ";
                cmd = new SqlCommand(cb);
                cmd.Connection = con;
                cmd.ExecuteReader();
                MessageBox.Show("Successfully performed", "Database Restore",
MessageBoxButtons.OK, MessageBoxIcon.Information);
                GetData();
            }
        }
        catch (Exception ex)
        {
            MessageBox.Show(ex.Message, "Error", MessageBoxButtons.OK,
MessageBoxIcon.Error);
        }
    }

    private void timer2_Tick(object sender, EventArgs e)
    {
        Cursor = Cursors.Default;
        timer2.Enabled = false;
    }

    private void btnGetData_Click(object sender, EventArgs e)
    {

        int rowsTotal = 0;
        int colsTotal = 0;
        int I = 0;
        int j = 0;


  int j = 0;
  int iC = 0;
  System.Windows.Forms.Cursor.Current = System.Windows.Forms.Cursors.WaitCursor;
  Excel.Application xlApp = new Excel.Application();

  try
  {
    Excel.Workbook excelBook = xlApp.Workbooks.Add();
    Excel.Worksheet excelWorksheet = (Excel.Worksheet)excelBook.Worksheets[1];
    xlApp.Visible = true;

    rowsTotal = dataGridView1.RowCount;
    colsTotal = dataGridView1.Columns.Count - 1;
    var _with1 = excelWorksheet;
    _with1.Cells.Select();
    _with1.Cells.Delete();
    for (iC = 0; iC <= colsTotal; iC++)
    {
      _with1.Cells[1, iC + 1].Value = dataGridView1.Columns[iC].HeaderText;
    }
```

```
            for (I = 0; I <= rowsTotal - 1; I++)
            {
               for (j = 0; j <= colsTotal; j++)
               {
                  _with1.Cells[I + 2, j + 1].value = dataGridView1.Rows[I].Cells[j].Value;
               }
            }
            _with1.Rows["1:1"].Font.FontStyle = "Bold";
            _with1.Rows["1:1"].Font.Size = 12;

            _with1.Cells.Columns.AutoFit();
            _with1.Cells.Select();
            _with1.Cells.EntireColumn.AutoFit();
            _with1.Cells[1, 1].Select();
         }
         catch (Exception ex)
         {
            MessageBox.Show(ex.Message, "Error", MessageBoxButtons.OK,
MessageBoxIcon.Error);
         }
         finally
         {
            //RELEASE ALLOACTED RESOURCES
            System.Windows.Forms.Cursor.Current = System.Windows.Forms.Cursors.Default;
            xlApp = null;
         }
      }

      private void btnReset_Click(object sender, EventArgs e)
      {
         txtProductName.Text = "";
         GetData();
      }


         private void lowStockToolStripMenuItem_Click(object sender, EventArgs e)
         {
            frmLowStockReport frm = new frmLowStockReport();
            frm.ShowDialog();
         }


      }
   }
```

Appendix 3: Sample C# Codes Used RFID System Development

```
using System;
using System.Collections.Generic;
using System.ComponentModel;
using System.Data;
using System.Drawing;
using System.Linq;
using System.Text;
using System.Windows.Forms;
using System.IO.Ports;
using System.Threading;
using System.Data.Sql;
using System.Data.SqlClient;
using ReaderB;
using System.IO;

namespace LoginApplication
{
    public partial class frmMain : Form
    {
        string str = "Data Source=.;Initial Catalog=MyDatabase;Integrated Security=True";
        private SerialPort _serialPort;
       private string DispString;
        //private byte fComAdr = 0xff;


        public frmMain()
        {
            InitializeComponent();


        InitializeComponent();
    }
    //Connection String
    string cs = @"Data
Source=(LocalDB)\MSSQLLocalDB;AttachDbFilename=|DataDirectory|\MyDatabase.mdf;Integrate
d Security=True;";
    //btn_Submit Click event

    private void btnScan_Click(object sender, EventArgs e)
    {
      // fComAdr = 0;
        _serialPort = new SerialPort();
        _serialPort.PortName = "COM3";
        _serialPort.BaudRate = 57600;
        _serialPort.DataBits = 8;
        _serialPort.Parity = Parity.None;
        _serialPort.StopBits = StopBits.One;
        _serialPort.Open();
        _serialPort.ReadTimeout = 2000;
        _serialPort.DataReceived += new SerialDataReceivedEventHandler(Fun_DataReceived);
        _serialPort.Close();
        try
        {
```

```
            if (!(_serialPort.IsOpen))
                _serialPort.Open();
            _serialPort.Write("StaticClassReaderB.ReadCard_6B(ref fComAdr, ID_6B, StartAddress,
Num, CardData, ref ferrorcode, frmcomportindex");
        }
        catch (Exception ex)
        {
            MessageBox.Show("Error opening/writing to serial port :: " + ex.Message, "Error!");
        }
    }
    string data = string.Empty;
    private delegate void setTextDeleg(string text);
    private void Fun_DataReceived(object sender, SerialDataReceivedEventArgs e)
    {
        Thread.Sleep(5000);
        data = _serialPort.ReadLine();
        this.BeginInvoke(new setTextDeleg(Fun_IsDataReceived), new object[] { data });

    }
    private void Fun_IsDataReceived(string data)
    {
        txttag.Text = data.Trim();
    }
    private byte[] HexStringToByteArray(string s)
    {
  s = s.Replace(" ", "");
  byte[] buffer = new byte[s.Length / 2];
  for (int i = 0; i < s.Length; i += 2)
     buffer[i / 2] = (byte)Convert.ToByte(s.Substring(i, 2), 16);
  return buffer;
}

private string ByteArrayToHexString(byte[] data)
{
  StringBuilder sb = new StringBuilder(data.Length * 3);
  foreach (byte b in data)
     sb.Append(Convert.ToString(b, 16).PadLeft(2, '0'));
  return sb.ToString().ToUpper();

}
/*private void RFID_DataReceived(object sender, SerialDataReceivedEventArgs e)
{

  if (txttag.Text.Length >= 12)
  {
     _serialPort.Close();

  }
  else
  {
     DispString = _serialPort.ReadExisting();
     this.Invoke(new EventHandler(DisplayText));
  }
```

```
}*/
private void DisplayText(object sender, EventArgs e)
{
   txttag.AppendText(DispString);
}
//btn_LogOut Click Event
private void btn_LogOut_Click(object sender, EventArgs e)
{
   this.Hide();
   frmLogin fl = new frmLogin();
   fl.Show();
}

private void frmMain_FormClosing(object sender, FormClosingEventArgs e)
{
   Application.Exit();
}

private void btnsubmit_Click(object sender, EventArgs e)
{
   switch (btnsubmit.Text)
   {
          case "Submit":
             if (txttag.Text.Length == 0 || txtrollno.Text.Length == 0 || txtstudname.Text.Length == 0)
             { return; }
             if (!CheckDuplicateRFID())
             {
                MessageBox.Show("Already Saved");
                txttag.Text = "";
                return;
             }
             break;
        }
        //create sql connection
        SqlConnection con = new SqlConnection(cs);
        con.Open();
        SqlCommand cmd = new SqlCommand("insert into
tbl_Student(RFID,Student_Name,RollNo,Class,Section) values
(@RFID,@Student_Name,@RollNo,@Class,@Section)", con);
        cmd.Parameters.AddWithValue("@RFID", txttag.Text);
        cmd.Parameters.AddWithValue("@Student_Name", txtstudname.Text);
        cmd.Parameters.AddWithValue("@RollNo", txtrollno.Text);
        cmd.Parameters.AddWithValue("@Section", combosec.SelectedItem.ToString());
        cmd.Parameters.AddWithValue("@Class", comboclass.SelectedItem.ToString());
        //cmd.ExecuteNonQuery();
        MessageBox.Show("Product  recorded");
        con.Close();
```

```
    }
    private bool CheckDuplicateRFID()
    {
      SqlConnection con = new SqlConnection(str);
      con.Open();
      SqlCommand cmd = new SqlCommand("select * from tbl_Studentdet where RFID='" +
txttag.Text + "'", con);
      SqlDataReader rd = cmd.ExecuteReader();


        if (rd.HasRows)
        {
          rd.Close();
          return false;
        }
        else
        {
          rd.Close();
          return true;
        }
      }
    }
  }
```

Appendix 4: Sample Arduino Codes Used for Integrating RFID System and WMS

```
#include <SoftwareSerial.h>
#define PRESET_VALUE 0xFFFF
#define POLYNOMIAL 0x8408


// software serial #1: RX = digital pin 10, TX = digital pin 11
SoftwareSerial SoftSerial1 = SoftwareSerial(10, 11);
unsigned char receiveBuffer[250];
unsigned char sendBuffer[250];
unsigned char TempEpcBuffer[40];            //tag's epc data
unsigned char TempDataBuffer[58];           //write tag's storage data
unsigned char TempResultBuffer[40];         //save data
unsigned char passwdBuffer[4] = {0x00, 0x00, 0x00, 0x00}; //default tag's access passwd
unsigned char adr = {0xFF};                 //default broadcast address
unsigned char dataLength = 0;
int len = 0;
void setup()
{

 // Arduino Nano's uart.->PC
 Serial.begin(9600);
 while (!Serial)
 {
 }
 Serial.println("start serial debug");

 // SoftSerial,ljyzn-10x reader default Baud is 57600
 SoftSerial1.begin(57600);
}

void loop()
{
 // crc16Test();
 // directSendCmdDataExample();
 // ljyznSdkExample();
 sendTest();
 delay(1000);
```

```
}

void directSendCmdDataExample()
{
 //1.
 // first test,send data directly
 // 1.1 query reader's info, directly
 int index = 0;
 sendBuffer[0] = 0x04; //len
 sendBuffer[1] = 0xFF; //adr
 sendBuffer[2] = 0x21; //cmd
 sendBuffer[3] = 0x19; //LSB-CRC16
 sendBuffer[4] = 0x95; //MSB-CRC16
 SoftSerial1.write(sendBuffer, 5);
 Serial.println("send data to reader");
 Serial.write(sendBuffer, 5);
 len = receiveData();
 if (len > 0)
 {
  Serial.println("receive data from reader");
  for (index = 0; index < len; index++)
  {
   Serial.write(receiveBuffer[index]);
  }

 Serial.println();
 len = 0;
}

// 1.2 Inventory tag's code num, directly
sendBuffer[0] = 0x04; //len
sendBuffer[1] = 0xFF; //adr
sendBuffer[2] = 0x01; //cmd
sendBuffer[3] = 0x1B; //LSB-CRC16
sendBuffer[4] = 0xB4; //MSB-CRC16
SoftSerial1.write(sendBuffer, 5);
Serial.write(sendBuffer, 5);
len = receiveData();
if (len > 0)
{
```

```
    for (index = 0; index < len; index++)
    {
     Serial.write(receiveBuffer[index]);
    }
    Serial.println();
    len = 0;
  }
}

void ljyznSdkExample()
{
  int index = 0;
  //2 ljyzn-sdk simple example
  //2.1 Inventory_G2 get epc code num
  len = Inventory_G2();
  // SoftSerial1.write(sendBuffer, len);


 Serial.println("send to reader");
 Serial.write(sendBuffer, len);
 len = receiveData();
 if (len > 0)
 {
  Serial.println("receive from reader");
  Serial.write(receiveBuffer, len);
 }
 if (len > 0)
 {
  if (DecodeInventory_G2(len) > 0)
  { //has tag's epc num
   //copy TempResultBuffer's epc data to TempEpcBuffer
   dataLength = TempResultBuffer[0];
   for (index = 0; index < dataLength; index++)
   {
    TempEpcBuffer[index] = TempResultBuffer[1 + index];
   }
```

```
    //2.2 WriteCardData 0x12345678 to epc storage 0x4 word place
    TempDataBuffer[0] = 0x12;
    TempDataBuffer[1] = 0x34;
    TempDataBuffer[2] = 0x56;
    TempDataBuffer[3] = 0x78;
    len = WriteCardData(TempEpcBuffer, 0x01, 0x04, TempDataBuffer, passwdBuffer, dataLength,
0x04);
    Serial.println("send to reader");
    Serial.write(sendBuffer, len);
    len = receiveData();
    if (len > 0)
    {
     Serial.println("receive from reader");
     Serial.write(receiveBuffer, len);
    }
    if (len > 0)
    {
     if (DecodeWriteCardData(len) == 0)
     {
      //Write success

      //2.3 ReadCardData from epc storage 0x4 word place, read 0x04 bytes
      len = ReadCardData(TempEpcBuffer, 1, 0x04, 0x04, passwdBuffer, dataLength);
      Serial.println("send to reader");
      Serial.write(sendBuffer, len);
    len = receiveData();
    if (len > 0)
    {
     Serial.println("receive from reader");
     Serial.write(receiveBuffer, len);
    }
    if (len > 0)
    {
     if (DecodeReadCardData(len) > 0)
     {
      dataLength = TempResultBuffer[0];


          Serial.println("read data");
          for (index = 0; index < dataLength; index++)
          {
           TempDataBuffer[index] = TempResultBuffer[1 + index];
           Serial.write(TempDataBuffer[index]);
          }
         }
        }
       }
      }
     }
    }
   }
```

```
int receiveData()
{
 int i = 0;
 while (SoftSerial1.available() > 0)
 {
  receiveBuffer[i] = SoftSerial1.read();
  i++;
 }
 return i;
}

///more function, please Refer User document
/// crc16 checksum
unsigned int uiCrc16Cal(unsigned char const *pucY, unsigned char ucX)
{
 unsigned char ucI, ucJ;
 unsigned short int uiCrcValue = PRESET_VALUE;

 for (ucI = 0; ucI < ucX; ucI++)
 {
  uiCrcValue = uiCrcValue ^ *(pucY + ucI);
  for (ucJ = 0; ucJ < 8; ucJ++)
   for (ucJ = 0; ucJ < 8; ucJ++)
   {
    if (uiCrcValue & 0x0001)
    {
     uiCrcValue = (uiCrcValue >> 1) ^ POLYNOMIAL;
    }
    else
    {
     uiCrcValue = (uiCrcValue >> 1);
    }
   }
  }
  return uiCrcValue;
 }

 int GetReaderInfo()
 {
  unsigned int crc16 = 0;
  sendBuffer[0] = 0x04; //len
  sendBuffer[1] = adr;  //adr default 0xFF broadcast
```

```
 sendBuffer[2] = 0x21; //cmd GetReaderInfo
 crc16 = uiCrc16Cal(sendBuffer, 3);
 // sendBuffer[3] = 0x19; //LSB-CRC16
 // sendBuffer[4] = 0x95; //MSB-CRC16
 sendBuffer[3] = (unsigned char)crc16 & 0xFF;        //LSB-CRC16
 sendBuffer[4] = (unsigned char)((crc16 >> 8) & 0xFF); //MSB-CRC16
 return 5;
}

int Inventory_G2()
{
 unsigned int crc16 = 0;
 sendBuffer[0] = 0x04; //len
 sendBuffer[1] = adr;  //adr default 0xFF broadcast
 sendBuffer[2] = 0x01; //cmd Inventory_G2
 crc16 = uiCrc16Cal(sendBuffer, 3);
 sendBuffer[3] = (unsigned char)crc16 & 0xFF;        //LSB-CRC16
 sendBuffer[4] = (unsigned char)((crc16 >> 8) & 0xFF); //MSB-CRC16
 return 5;
}

int DecodeInventory_G2(unsigned char datalen)
{
 int index = 0;
 if (uiCrc16Cal(receiveBuffer, (unsigned char)(datalen)) == 0 && receiveBuffer[2] == 0x01)
 { //crc16 pass and is Inventory_G2 return data
  if (receiveBuffer[3] == 0x01 || 0x02 || 0x03 || 0x04)
  {
   // has receiveBuffer[4] tag's epc
   // receiveBuffer[5] first tag's epc length
   if (receiveBuffer[4] > 0 && receiveBuffer[5] > 0)
   {
    //copy first tag's epc to TempEpcBuffer
    // | 1byte length | epc data |
    TempResultBuffer[0] = receiveBuffer[5];
    for (index = 0; index < receiveBuffer[5]; index++)
    {
     TempResultBuffer[1 + index] = receiveBuffer[6 + index];
    }
    return index; //first tag's epc
   }
  }
 }
 return 0;

}
/// <summary>
///
```

```
int ReadCardData(unsigned char *epc, int men, int wordptr, int num, unsigned char *passwd,
unsigned char epclen)
{
 unsigned int crc16 = 0;
 unsigned int index = 0;
 // param check
 if (epclen > 15 * 2 || epclen % 2 != 0 || men > 3 || men < 0 || num > 120 || num == 0)
 {
  return 0;
 }
 sendBuffer[0] = 12 + epclen; //len
 sendBuffer[1] = adr;       //adr default 0xFF broadcast
 sendBuffer[2] = 0x02;      //cmd ReadCardData
 sendBuffer[3] = epclen / 2;  //epc byte len to word len
 for (index = 0; index < epclen; index++)
 {
  sendBuffer[4 + index] = *(epc + index);
 }

 sendBuffer[4 + epclen] = (unsigned char)men;
 sendBuffer[5 + epclen] = (unsigned char)wordptr;
 sendBuffer[6 + epclen] = (unsigned char)(num / 2); // to word
 sendBuffer[7 + epclen] = *(passwd + 0);
 sendBuffer[8 + epclen] = *(passwd + 1);
 sendBuffer[9 + epclen] = *(passwd + 2);
 sendBuffer[10 + epclen] = *(passwd + 3);
 crc16 = uiCrc16Cal(sendBuffer, (unsigned char)(11 + epclen));
 sendBuffer[11 + epclen] = (unsigned char)crc16 & 0xFF;       //LSB-CRC16
 sendBuffer[12 + epclen] = (unsigned char)((crc16 >> 8) & 0xFF); //MSB-CRC16
 return 13 + epclen;
}
/// <summary>

int DecodeReadCardData(int datalen)
{
 int index = 0;
 int readDataLen = 0;
 if (uiCrc16Cal(receiveBuffer, (unsigned char)(datalen)) == 0 && receiveBuffer[2] == 0x02)
 { //crc16 pass and is ReadCardData return data
  if (receiveBuffer[3] == 0x00)
  {
   //copy read data to TempResultBuffer
   // | 1byte length | epc data |
   readDataLen = datalen - 6;
   TempResultBuffer[0] = readDataLen;
   for (index = 0; index < readDataLen; index++)
   {
```

```
        TempResultBuffer[1 + index] = receiveBuffer[4 + index];
       }
       return index; //read data len
     }
   }
   return 0;
 }

int WriteCardData(unsigned char *epc, int men, int wordptr, unsigned char *writeData, unsigned char
*passwd, unsigned char epclen, unsigned char writeDatalen)
{
 unsigned int crc16 = 0;
 unsigned int index = 0;
 // param check
 if (epclen > 15 * 2 || epclen % 2 != 0 || writeDatalen % 2 != 0 || men > 3 || men < 0 || writeDatalen <
1)
  {
   return 0;
  }
 sendBuffer[0] = 12 + epclen + writeDatalen; //len
 sendBuffer[1] = adr;                   //adr default 0xFF broadcast
 sendBuffer[2] = 0x02;                  //cmd WriteCardData
 sendBuffer[3] = writeDatalen / 2;        //writeData byte len to word len
 sendBuffer[4] = epclen / 2;             //epc byte len to word len
 for (index = 0; index < epclen; index++)
  {
   sendBuffer[5 + index] = *(epc + index);
  }
 sendBuffer[5 + epclen] = (unsigned char)men;
 sendBuffer[6 + epclen] = (unsigned char)wordptr;
 for (index = 0; index < writeDatalen; index++)
  {

  sendBuffer[7 + epclen + index] = *(writeData + index);
 }
 sendBuffer[7 + epclen + writeDatalen] = *(passwd + 0);
 sendBuffer[8 + epclen + writeDatalen] = *(passwd + 1);
 sendBuffer[9 + epclen + writeDatalen] = *(passwd + 2);
 sendBuffer[10 + epclen + writeDatalen] = *(passwd + 3);
 crc16 = uiCrc16Cal(sendBuffer, (unsigned char)(11 + epclen + writeDatalen));
 sendBuffer[11 + epclen + writeDatalen] = (unsigned char)crc16 & 0xFF;        //LSB-CRC16
 sendBuffer[12 + epclen + writeDatalen] = (unsigned char)((crc16 >> 8) & 0xFF); //MSB-CRC16
 return 13 + epclen + writeDatalen;
}


 int DecodeWriteCardData(unsigned char datalen)
 {
  int index = 0;
  if (uiCrc16Cal(receiveBuffer, (unsigned char)(datalen)) == 0 && receiveBuffer[2] == 0x03)
  {                  //crc16 pass and is ReadCardData return data
   return receiveBuffer[3]; //if 0x00 is success
  }
  return 0xFB; //error
 }
```

```
int WriteEpc(unsigned char *epc, unsigned char *passwd, unsigned char epclen)
{
  unsigned int crc16 = 0;
  unsigned int index = 0;
  // param check
  if (epclen > 15 * 2 || epclen % 2 != 0 || epclen < 1)
  {
   return 0;
  }
  sendBuffer[0] = 9 + epclen; //len
  sendBuffer[1] = adr;       //adr default 0xFF broadcast
  sendBuffer[2] = 0x04;      //cmd WriteEpc
  sendBuffer[3] = epclen / 2;
  sendBuffer[4] = *(passwd + 0);
  sendBuffer[5] = *(passwd + 1);
  sendBuffer[6] = *(passwd + 2);
  sendBuffer[7] = *(passwd + 3);
  for (index = 0; index < epclen; index++)
  {
   sendBuffer[8 + index] = *(epc + index);
  }

 crc16 = uiCrc16Cal(sendBuffer, (unsigned char)(11 + epclen));
 sendBuffer[8 + epclen] = (unsigned char)crc16 & 0xFF;         //LSB-CRC16
 sendBuffer[9 + epclen] = (unsigned char)((crc16 >> 8) & 0xFF); //MSB-CRC16
 return 10 + epclen;
}

/// <summary>
///
/// </summary>
/// <param name="datalen">receive data len</param>
/// <returns>0x00 success, 0xFB error, more detial read the User Manual</returns>
int DecodeWriteEpc(unsigned char datalen)
```

```
 {
  int index = 0;
  if (uiCrc16Cal(receiveBuffer, (unsigned char)(datalen)) == 0 && receiveBuffer[2] == 0x04)
  {                    //crc16 pass and is ReadCardData return data
   return receiveBuffer[3]; //if 0x00 is success
  }
  return 0xFB; //error
 }
```

```
void sendTest()
{
 len = GetReaderInfo();
 Serial.println("send to reader");
 Serial.write(sendBuffer, len);

 len = Inventory_G2();
 Serial.println("send to reader");
 Serial.write(sendBuffer, len);
 // epc 10001004
 TempEpcBuffer[0] = 0x10;
 TempEpcBuffer[1] = 0x00;
 TempEpcBuffer[2] = 0x10;
 TempEpcBuffer[3] = 0x04;

 len = ReadCardData(TempEpcBuffer, 0x01, 0x04, 58, passwdBuffer, 0x04);
 Serial.println("send to reader");
 Serial.write(sendBuffer, len);

 len = ReadCardData(TempEpcBuffer, 0x01, 0x04, 58, passwdBuffer, 0x04);
 Serial.println("send to reader");
 Serial.write(sendBuffer, len);

 TempDataBuffer[0] = 0x11;
 TempDataBuffer[1] = 0x11;
 len = WriteCardData(TempEpcBuffer, 0x01, 0x04, TempDataBuffer, passwdBuffer, 0x04, 0x02);
 Serial.println("send to reader");
 Serial.write(sendBuffer, len);

 len = WriteEpc(TempEpcBuffer, passwdBuffer, 0x04);
 Serial.println("send to reader");
 Serial.write(sendBuffer, len);
}
```

Appendix 5: Poster Presentation

RFID BASED WAREHOUSE MANAGEMENT SYSTEM. CASE STUDY: ROK INDUSTRIES

Dissertation by Fabien Ngaboyimbere
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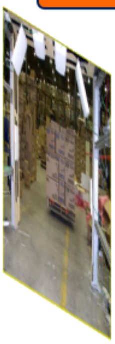
INTRODUCTION



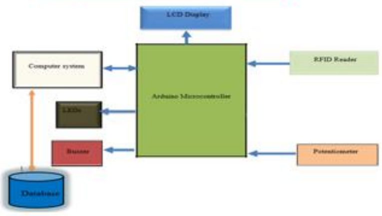
The existing warehouse management systems require human efforts, and manual recording in excel sheets and/or on paper. For huge warehouse operations, scenario is very hectic to keep track of. Use of Radio Frequency Identification known as RFID technology reduces human efforts as well as errors. So, the RFID based smart warehouse system is proposed to solve these issues. For a big warehousing, it will be an effective system. The approach in this project realizes intelligent management of an automatics warehouse. The aim of development of this system is to basically reduce human interference and apply smart technologies which are related to automation field to our day to day applications and make people in the supply chain more comfortable.

Problem statement

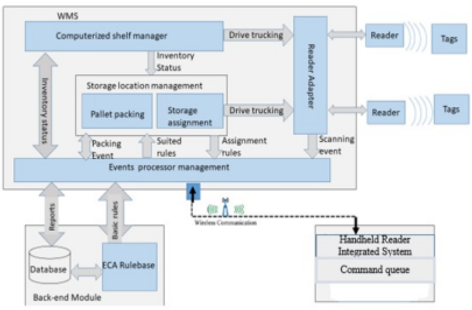
Numerous organizations nowdays have not taken the issue of warehousing into consideration, the capacity of merchandise and disseminations from the same warehouses are done without any arrangements, the completion of inventory is taking too long time due to the disorganisation and insufficient consolidation of present-day data innovation.

Methodology

1. System block diagram



2. System Architecture

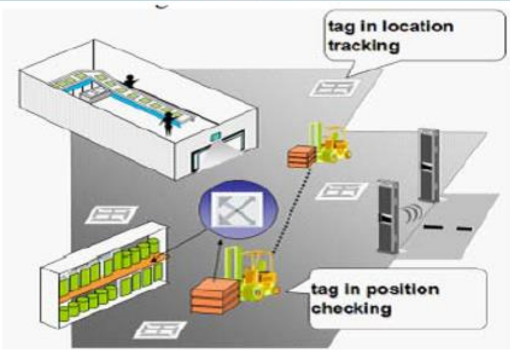


CONSTRUCTION/ALGORITHM

Prerequisites:

- **Arduino UNO**
- **UHF RFID**
- **UHF RFID cards**
- **A laptop**
- **USB cable**
- **Connecting wires**

Forklift Locating Scheme



RESULT/APPLICATION

The system is successfully developed and implemented to speed up warehouse operations. This is applicable to any warehouse not limited to ROK Industries warehouses

CONCLUSION

In this paper, a RFID-enabled intelligent warehouse management system is proposed for improving the performance of the warehouse. By automating the manual operation, close integration with current WMS, supporting forklift task scheduling and innovative 3-dimensional shelf monitoring, the efficiency and accuracy of the warehouse is increased remarkably.