DESIGN OF A SINGLE PLATFORM FOR INTEGRATING ERP AND RFID SYSTEMS FOR IMPROVED PROCUREMENT PERFORMANCE: A CASE STUDY IN THE RUBBER GLOVE MANUFACTURING INDUSTRY

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DECLARATION

I declare that this is my work. This dissertation does not incorporate without acknowledgment any material previously submitted for a Degree or Diploma in any other University or institute of higher learning. To the best of my knowledge and belief, it does not contain any previously published material written by another person except where the acknowledgment is made in the text.

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The above candidate has carried out research for the Master's Dissertation under my supervision.

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ABSTRACT

This study pertains to the limitations of existing Enterprise Resource Planning (ERP) systems and customized systems in Sri Lankan rubber glove manufacturing companies. Manual warehouse management processes lead to inventory inaccuracies leading to high disposal costs, packing material quantity adjustments after annual stock verification, and monthly disposal percentages. Therefore this research aims to design a single platform for integrating ERP and Radio-Frequency Identification (RFID) systems for improved procurement performance taking the rubber glove manufacturing industry in Sri Lanka as a case study. Since the range of inventory items handled in the warehouse is vast, the discussion is only limited to packing materials management. To achieve this aim literature review, semi-structured questionnaires, pilot tests, and semi-structured interviews are used as data collection methods. The validation framework on system performance and procurement performance was developed based on literature reviews. The design of the implemented integrated ERP and RFID system was done based on requirement analysis and literature review. A semi-structured questionnaire was distributed among the rubber glove manufacturers in Sri Lanka and their packing material suppliers, to gather feedback on their ability to attach RFID tags to products and subsequently upload the data into the system following RFID tag reading. The collected survey data were analyzed using descriptive data analysis techniques via SPSS software and the output of the implemented system was observed and recorded during the pilot test. Finally, top management feedback was gathered on the impact of the proposed system on procurement performance.

Integrating RFID technology with ERP systems in the rubber glove manufacturing industry significantly streamlines processes, enhances data accuracy, and improves efficiency. The "Supply Chain Smoother" system, tested at ABC Rubber Glove Manufacturing Company, demonstrated notable improvements in procurement performance as per the analysis and evaluation based on proposed system indicator clusters and procurement performance indicator clusters, proving its critical role in optimizing operations and reducing costs.

Keywords: ERP, RFID, Integrated systems, Procurement performance, Inventory accuracy, Rubber glove manufacturer

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

Abbreviation	**Description**
IT	Information Technology
IoT	Internet of Things
WMS	Warehouse Management Systems
ERP	Enterprise Resource Planning
CPS	Cyber-Physical Systems
AGVs	Automated Guided Vehicles
JIT	Just In Time
RFID	Radio Frequency Identification
KPI	Key Performance Indicators
GRN	Good Receipt Note
PMS	Packing Material Stores
TSP	Trimming, Sorting, and Packing
IB	Inner Bag
OB	Outer Bag
IC	Inner Carton
OC	Outer Carton
HD	Header Card
SKUs	Stock Keeping Units
PO	Purchase Orders
AI	Artificial Intelligence
UHF	Ultra High Frequency
WIP	Work-In-Progress
SCM	Supply Chain Management
AIM	Application Implementation Methodology
BAPI	Business Application Programming Interface
AMT	Advanced Manufacturing Technology
WM	Wireless Manufacturing
ES	Enterprise Systems
PI	Perpetual Inventory
DC	Distribution Center
MRP	Material Requirements Planning
API	Application Programming Interface
UI	User Interface

CHAPTER 1

INTRODUCTION

1.1 Background of Research

Sri Lanka's rubber glove industry caters to more than 5% of global demand, ranging from reusable and disposable household gloves to surgical and industrial gloves of several specifications (EDB, 2021). Sri Lanka rubber gloves are primarily used in the medical, industrial, pharmaceutical, dental, and food handling sectors, and the global healthcare sector is the largest buyer of gloves (EDB, 2021; Rathnayake, 2021). Most rubber glove manufacturing companies are export-oriented and they arrange their shipments competitively and gain more dollars to Sri Lanka's economy (S&P Global, 2021).

There are 7 export-oriented companies that play a major role in the rubber glove manufacturing industry in Sri Lanka (EDB, 2021). By combining key sourcing of raw materials, manufacturing excellence, design and development capabilities, and creative solutions in packaging and logistics, companies aspire to deliver more shipments (DPL, 2021). Companies manage their key sources to extract the best output. Due to that, the companies enhance their supply chain functions of purchasing, operations, logistics, resource management, and information workflow with Information Technology (IT), Internet of Things (IoT), Warehouse Management Systems (WMS), and ERP (Planet Together, 2021; Mostafa, Hamdy, & Elawady, 2018).

Procurement is a significant and costly business action for organizations. Hence organizations devote a huge portion (even up to 70%) of their operating budget or revenue to purchasing services and goods (Rahim, 2008). Procurement encompasses the actions undertaken by industrial and commercial entities to acquire essential materials, ultimately producing goods or facilitating business operations for societal benefit and financial gain. At its core is material procurement (Li, Zhao, & Pu, 2020).

The decisions made on purchasing will engage with the procurement performance of the organization. Measures of procurement performance can be defined as procurement effectiveness and procurement efficiency of the purchasing function. The success of an organization hinges on its procurement performance, as it plays a crucial role in securing competitive and high-quality materials. This, in turn, positions the company’s services and products advantageously in the marketplace. However, in some cases, weak procurement performance has resulted in financial loss to the private sector due to inflated prices, depreciation, and delivery of poor-quality work materials. Poor procurement performance also led to lower private-sector profitability (Barsemoi, Mwangagi, & Ode, 2014; Kakwezi & Nyeko, 2019).

The procurement process and purchasing are important to the organization. Improving quality, pursuing innovation, increasing efficiency, and achieving savings is the key importance. Procurement can control the product and service quality and it will monitor product quality against delivery times, appearance, or durability parameters. Procurement sources innovative services and goods and it will provide businesses with the competitive edge they need in terms of quality, convenience, or price. The enhanced procurement process can ensure goods and services’ on-time delivery and improve sourcing capabilities through greater efficiency. Efficient procurement permits organizations to attain immediate cost savings by procuring contracts, services, and goods at the best possible rates (SendEdge, 2023).

Inventory in manufacturing companies is the lifeblood of their operations and cost and customer satisfaction and constitutes the most important aspect of the companies. Inventory is essential to the organization for production activities, plant, and machinery maintenance as well as other operational needs (Masudin, Kamara, Zulfikarijah, & Dewi, 2018). Inventory management will critically impact an organization's success in the present competitive and dynamic market. Minimizing stock-holding expenses is achieved by maintaining an adequate inventory at the right location and time, ensuring the production of the appropriate quantity of goods (Mutinda & Paul, 2018).

A direct correlation exists between procurement success and inventory accuracy. Higher level inventory in stock adversely affects procurement performance and cash flow resulting in reduced effectiveness, efficiency, and skewed performance.

Accountability in the procurement process was enhanced if documents were verified during inventory receipt and issue. Furthermore, the act of providing inventory documents as needed conveys a sense of accountability within the organization, establishing trust in their ability to conduct business. Consequently, the outcome was an enhancement in procurement performance due to increased inventory accountability (Mutinda & Paul, 2018). Many inventory management systems suffer from overstocking, understocking, shrinkage, incorrect manual inventory adjustments, and long checkout lines due to a lack of real-time data (D'Souza, Guo, Wang, & Lee, 2013). The timeliness and increased inventory accuracy of real-time data permit sales, suppliers, customers, and distribution personnel to perform the entire spectrum of activities with self-confidence and improved profitability (Yao & Carlson, 1999).

IT infrastructure enables organizations to capture real-time data to make decisions and decrease issues with inventory-related information (Oghazi, Rad, Karlsson, & Haftor, 2018). The implementation of Information Technology (IT) has significantly improved productivity across various stages, including trend forecasting, planning, supply chain management, manufacturing, as well as planning and replenishment procedures in retail outlets. The ERP program is a cutting-edge technology that facilitates streamlined cooperation among different departments in an organization. It drives processes by providing comparative information and analysis regarding trends and forecasts. It enables efficient management of the supply chain, Just-In-Time (JIT) inventories, and information. Furthermore, it facilitates company logistics administration by guaranteeing efficient oversight and regulation, accurate order planning and scheduling, enhanced data prediction, and timely responses to inquiries, online updates, and order details.

ERP software is designed for managing business operations. Originally, it emerged as an expansion of resource planning software in the manufacturing industry, to automate the supply process for production lines to meet incoming orders. An ERP system can defined as a collection of software applications that automate the administrative tasks of a firm, including finance, manufacturing, human resources, and other modules. The prominent ERP systems are Acumatica, Sage Intacct, NetSuite, SAP ERP, and SAP S/4HANA Cloud. (G2, 2023).

An ERP system is planned to efficiently integrate and scale a company's operational IT systems, to improve the speed and flexibility of information exchange both internally and externally. This includes expanding the usefulness and durability of information, avoiding unnecessary repetition, automating repetitive tasks, and improving the adaptability of components in information systems. Usually, the limits between departments become more adaptable, improving the accessibility of data for partner businesses and customers, and ultimately, the company's ability to respond to the market is generally improved (S. Thomassey, 2016).

RFID is a form of electronic information technology that employs wireless radio waves for the transmission, identification, tracking, sequencing, and verification of diverse objects. RFID technology finds applications in various fields such as materials management, production automation, inventory assessment, parking control, car theft alarms, building entry security, and similar areas. To establish a productive and interactive information system, it is crucial to develop RFID technology that aligns with the operational processes supported by the system. RFID, an automated identification method, involves storage and remotely retrieving data through devices like RFID readers, RFID tags, and middleware (Liu & Chen, 2009).

Moreover, employing RFID enables the checking of products or materials as they traverse distinct organizational components. As RFID tags possess information-carrying capabilities, the product or material with the tag can traced at multiple places. The ERP system facilitates the transfer of data associated with these tag-attached materials or products to different sections of the organization. This ensures the provision of real-time information to diverse departments, enhancing overall planning and control (Oghazi, Rad, Karlsson, & Haftor, 2018). Figure 1 illustrates the general architecture of the RFID system.

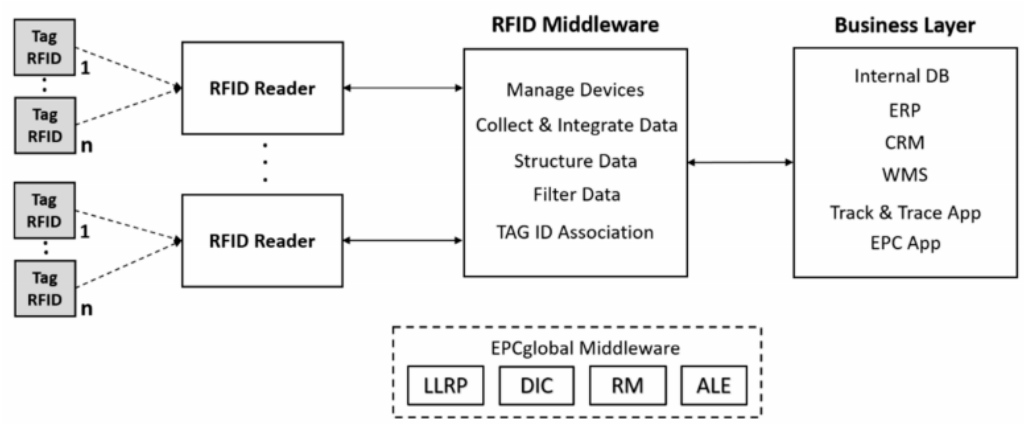

Figure 1: General architecture of RFID systems

Source: *(Figueroa, Añorga, & Arrizabalaga, 2019)*

The technological advancement and competitiveness of the rubber glove manufacturing industry or marketplace locally and globally were motivated to address enhancement of procurement performance through an inventory management approach. Improved procurement performance through integrated ERP and RFID systems in the rubber glove manufacturing industry is a new concept on which less research is available.

1.2 Research Problem

The ABC rubber glove manufacturing company in Sri Lanka maintains an ERP system and does not incorporate the latest technologies to improve its procurement performance. There were several issues identified in the existing system and problems identified by the ABC rubber glove manufacturing company which are given below.

The inaccurate inventory level was one of the main issues identified in the company's ERP system. The ERP system has an inventory management module, but it's unable to feed and monitor the movement of packing materials on time with accuracy. Currently, employees feed packing material receivable through Good Receipt Note (GRN) and they locate material lots in the warehouse through manual labeling.

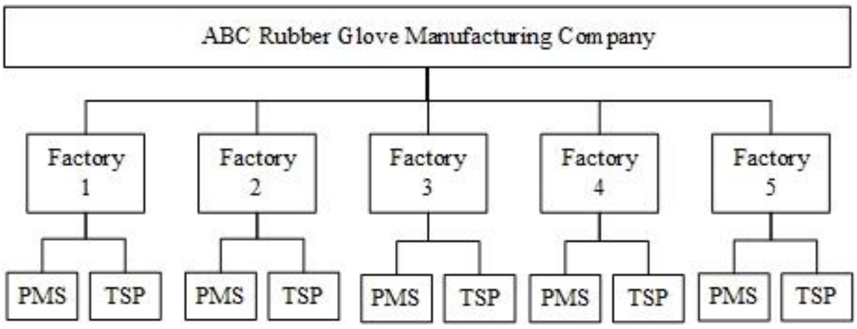

Figure 2: Material storage locations

Source: Compiled by the author based on the requirement analysis

According to Figure 2, ABC rubber glove manufacturing company has five factories and each factory includes Packing Material Stores (PMS) and Trimming, Sorting, and Packing (TSP) storage locations. All 10 major storage locations hold the packing materials required by the operation. Five types of main packing material groups (IB-Inner Bag, OB-Outer Bag, IC-Inner Carton, OC-Outer Carton, HD-Header Card) and each group consists of many Stock Keeping Units (SKUs) as mentioned in following Table 1.

Table 1: Number of material SKUs

	Packing material groups					**Total SKUs' at the factory**
	IB	OB	IC	OC	HD	
Factory 1	1677	240	37	391	47	2,392
Factory 2	385	88	17	123	25	638
Factory 3	1203	126	35	306	21	1,691
Factory 4	135	8	2	51	65	261
Factory 5	40	15	5	25	15	100
Total SKUs'						5,082

Source: Compiled by the author based on the 2021 material history report generated through the existing ERP system

Each storage area contains different quantities and types of materials. The procurement department places purchase orders from most of the SKUs 2-3 times a month. The number of manually labeled packing material lots at storage locations without a system tracing facility. All the transactions are input into the ERP system through a manual process and the probability of making errors is high.

Employees have done GRN for Purchase Orders (PO) and in the material to the warehouse on time through an existing system. However, the internal material transaction tracing function does not accurately happen. As an example, if purchase 1000 cartons for 950 requirements, the system displays 1000 quantities on the PMS location after PO GRN. 1000 quantity needs to be transferred to the TSP location to pack the finished goods with a wastage margin. After packing the finished goods, need to transfer the excess quantity to the PMS back. Finally, the actual excess quantity should be displayed on the PMS location in the system to manage accurate inventory figures, which does not happen in the existing system.

Effectively managing time-sensitive materials in inventory is crucial because of their limited shelf life. The primary focus is to ensure the constant availability of necessary materials to prevent production losses and profit declines. Unused materials can become costly if they expire, making shelf life management crucial (Mills-Harris, Soylemezoglu, & Saygin, 2005). As per Figure 3, a considerable amount of packing material quantity is adjusted after annual stock counting to match ERP or other system figures that refer to making a managerial decision in the company.

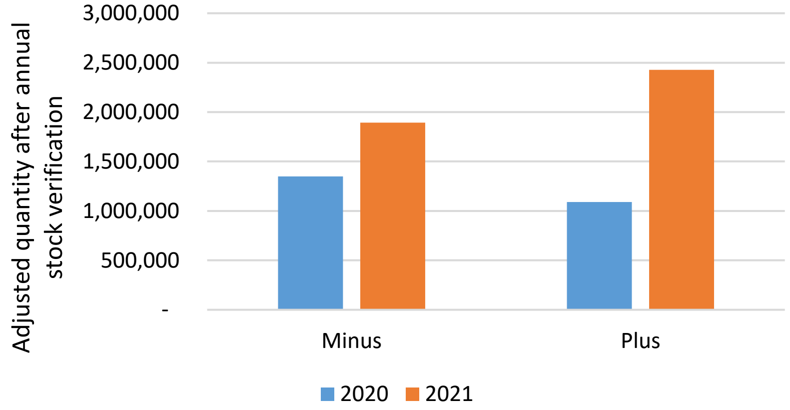

Figure 3: Adjusted packing material quantity after annual stock verification

Source: Compiled by the author based on the 2020 and 2021 packing material annual stock verification records of ABC rubber glove manufacturing company

Inaccurate inventory leads to monthly packing material disposal percentage continuing according to Figure 4 and the value of disposal will be high. The company provides a large portion of disposal materials cost or accidentally the customer will bear the cost.

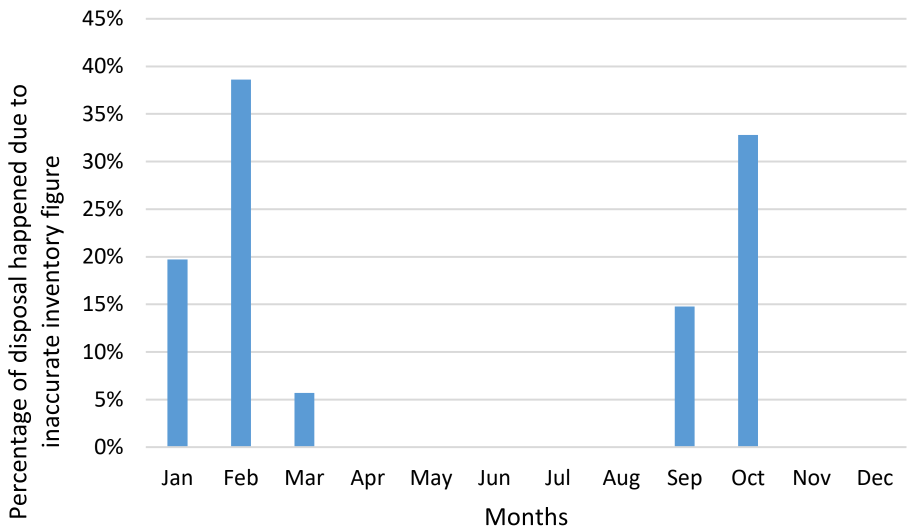

Figure 4: Percentage of PM disposal happened due to the inaccurate inventory figure

Source: Compiled by the author based on the 2021 packing material monthly stock disposal records of ABC rubber glove manufacturing company.

Inaccurate inventory figures lead to delays in the procurement process. Physically unavailability of packing material for scheduled shipment, the procurement team has to proceed with the purchasing process immediately and the process will be costly than the regular way. If there is a carton shortage, need to acquire the required board size by off-cutting the board size that is already on the supplier machine and that wastage cost should be incurred on the purchase order. The probability of getting quality packing material through immediate production from the supplier is low. Demurrage costs will be added when shipment delays happen due to inaccurate inventory figures and customer dissatisfaction making the sense of company profit.

What is a suitable system architecture to address the procurement performance issues caused by inaccurate inventory status in rubber glove manufacturing companies? That is the question that occurs during the study and the author has decided to design a single platform to integrate ERP and RFID systems addressing the above issues. The new system is proposed to have accurate inventory figures by inserting packing materials and tracing the packing material movements to improve procurement performance. Therefore, this research was focused on how to design a single platform for integrating ERP and RFID systems for improved procurement performance.

1.3 Research Questions

More precisely, the below-mentioned questions of research are set to address the aim within the context of the rubber glove manufacturing industry and their packing material suppliers,

- How to identify the current state-of-the-art integration of ERP and RFID systems in the world?
- What are the current state-of-the-art ERP and RFID systems in the Sri Lankan context?
- What factors are to be considered to design a suitable resource planning software architecture to integrate ERP and RFID systems to improve procurement performance?
- What is the impact of the integrated ERP and RFID system on procurement performance?

1.4 Research Aim and Objectives

1.4.1 Research Aim

Design of a single platform for integrating ERP and RFID systems for improved procurement performance in the industry of rubber glove manufacturers.

1.4.2 Research Objectives

The below-mentioned objectives are set to achieve the aim in the context of the rubber glove manufacturing industry,

- To identify the current state-of-the-art of integration of ERP and RFID systems in the world.
- To identify the current state-of-the-art ERP and RFID systems in the Sri Lankan context.
- To design a single platform to integrate ERP and RFID systems for improved procurement performance.
- To test the impact of the integrated ERP and RFID system on procurement performance.

1.5 Scope of the Study

The study mainly focuses on the rubber glove manufacturing company in the Sri Lanka context. The study mainly drives through the internal and external network and its resource planning architecture. Whether they have an ERP system, an RFID system to access the real-time data, an integrated system (ERP & RFID), or a manual system. Selected companies' procurement performance is considered through their inventory accuracy which includes real-time data inputs, inventory lots labeling, and transaction tracing in the study. How the procurement function is operated through existing resource planning architecture. The impact of the designed and proposed integrative approach on the selected companies' procurement performance is focused on by the study as well.

The study excluded other software components related to the supply chain executions and other functions in the supply chain such as finance, integrated transportation management, research and development, sales, professional services, and assets management. The study excluded the raw materials procured process. The study also does not look at the company system implementation details of the proposed system.

1.6 Significance of the Study

As a result of this study, rubber glove manufacturing companies require a new system that can trace real-time inventory figures to improve procurement performance. The proposed system will reduce the cost that is due to inaccurate inventory figures and be able to achieve a better financial position. It would also reduce adjustments done to the ERP or other systems after annual stock verification, monthly packing material disposal percentage, and delays in procurement performance. Improved procurement performance would be improved customer satisfaction irrespective of the manual handling functions on packing material inventory as packing material inputs, lots labeling, and transactions happen between Packing Material Store (PMS), Trimming, Sorting and Packing (TSP), and factories.

This study designs a single platform for integrating ERP and RFID systems with automated support to improve procurement performance in rubber glove manufacturing companies. The new architecture would be further enhanced to provide fully automated systems for many functions of the supply chain process. Since limited literature and technology available on integrated ERP systems with RFID technology for improving procurement performance in the Sri Lankan rubber glove context, the author expected to fill the research and technological gap through the study.

1.7 Thesis Structure

Chapter 1 of this thesis discusses the introduction to the study. The introduction includes background and primary information. Such as problem identification, aims and objectives, research gap, and scope of the research.

Chapter 2 of this thesis deliberates the literature review for the study. The concept that relates to the research will be described through the literature review. Concepts regarding multiple definitions and reasons are mentioned. Potential and existing technical capabilities are identified in this chapter.

Chapter 3 of this thesis discusses the research methodology that was used for carrying out the research. Briefly discuss how to use the mentioned methodology to explore the research objectives.

Chapter 4 of this thesis discusses the data analysis and presentation for the study. Analysis of the impact with sample scenario and discussion of the methodology applied to the scenario.

Chapter 5 of this thesis discusses the results which are obtained in Chapter 4 and the conclusion for each research question and provides recommendations for future research on future related research.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter values the relevant literature. Section 2.2 describes literature related to the ERP system. Section 2.3 describes the literature related to the RFID system. Section 2.4 explains edge computing and relevant novel technologies. Section 2.5 explains the significance of the integrated ERP and RFID system. Section 2.6 explains the history and current global context of integrated ERP and RFID systems. Section 2.7 describes the integrated ERP and RFID systems related to this case study. Section 2.8 reviews the literature and describes the inventory accuracy related to this case study. Section 2.9 describes the literature used for the procurement performance related to the case study. Chapter summary construct on section 2.9.

2.2 ERP System

The literature review, it was mainly focused on the ERP system in an organization as the major component of the proposed system. As found in much literature, ERP systems do not have a specific definition or a universally accepted definition due to the authors and scholars having defined ERPs differently. Large companies' departments use ERP systems with a large scale of functionalities. The ERP system can serve as a tool for the comprehensive planning, organization, and management of tasks across the entire company. Finance, accounting, controlling, manufacturing, research, and development functions are offered by the ERP systems (Nettsträter, Geißen, Witthaut, Ebel, & Schoneboom, 2015).

The ERP system is software designed for enterprise resource planning, consisting of interconnected modules that oversee the key business processes. The main goals of the ERP system are to facilitate the seamless integration of business processes, enhance workflow, standardize business practices, and provide access to current real-time information within and across functional and technical boundaries in the enterprise (Hamdy, Mostafa, & Elawady, 2018). According to Costa, Souza, & Júnior, (2013), ERP is a general term for a collection of activities performed by multi-modular software that aims at helping the producer or the manager of an organization in an important phase of the business, including product development, procuring items, inventory maintenance, supplier interaction, customer services, and production order follow-up. The ERP system is a customizable information system software that unifies information and information-driven processes across functional areas within an organization. These systems are specifically crafted to integrate various business functions, enabling the seamless sharing of data across multiple boundaries and divisions within the enterprise (Tarn, Yen, & Beaumont, 2002).

The main objective of an ERP system is to enhance and simplify internal company processes, often necessitating the reorganization of existing systems. This is achieved by employing multi-module systems to organize resources, control management, and oversee operations. The key elements of a developed ERP system consist of the planning and execution modules. The ERP modules are coupled in a coherent data architecture, allowing for seamless progression of a transaction via successive stages without redundant data entry, resulting in a continuous flow of information. While an ERP system provides extensive capabilities for efficiently overseeing a multifaceted operational setting, it may not fully meet the specific needs of a business. When confronted with such circumstances, the organization must decide between enhancing the existing system or developing a distinct subsystem and integrating it into the primary ERP system (Liu & Chen, 2009).

SAP S/4 HANA

SAP S/4 HANA serves as an illustration of an ERP system that can be seen as the digital cornerstone for an entire IT infrastructure within a company. The "S" denotes "simple," and the "4" indicates the 4th generation of SAP's business suite. It represents a progression from established ERPs like SAP ECC and stands out as the most capable and innovative digital core available in the market. First and foremost, SAP HANA operates at a superior speed compared to other databases, thanks to its highly efficient in-memory technology. In contrast to competing products or other database technologies, SAP HANA no longer stores data sets on slower hard drives.

Rather than conventional methods, in-memory technology enables the storage and processing of data directly in the main memory, leading to reduced overall database capacity requirements through a streamlined data model. Ultimately, this in-memory technology facilitates real-time data insights and analytics across all the administrative and transactional activities of businesses. Implementing SAP S/4 HANA brings multifaceted benefits, not only positively affecting IT landscape productivity but also resulting in significant optimization of all business processes through robust integration with SAP ERP.Better performance: Faster and real-time data access.

- Modular expandability: Machine learning, Artificial Intelligence (AI), and IoT innovative solutions can be simply implemented.
- Simplified processes: Eliminating data locks, and a data model that simplifies will streamline the processes of business and increase performance.
- Broad applicability: Possible to integrate industry-precise software extensions because SAP S/4HANA is possible to practice in every type of trade or business line.
- Global accessibility: There is a possibility to permanently access SAP ERP with the selection to operate SAP ERP on-premise in a public cloud or private cloud or as a hybrid cloud solution (NTT DATA, 2023).

2.3 RFID System

RFID technology was first introduced in the late 1940s, but its application was limited in the 1980s since it was more expensive per unit compared to the commonly used bar code. However, by efficiently streamlining data capture procedures, RFID technology not only serves tracking and identification purposes but also enhances process accuracy by minimizing or eliminating traditional error-prone manual processes (A Majeed & Rupasinghe, 2017).

RFID System Architecture

RFID is an automated identification technique utilizing devices like RFID readers, RFID tags, and middleware to store and retrieve data remotely. RFID systems comprise three key elements:

- A transponder is a small electronic device or tag that is combined with an item to identify it.

- A scanner or reader establishes communication with the tag using radio frequency signals.
- A host data processing system stores data about the identified element and shares data with other information processing systems (Liu & Chen, 2009).

A basic RFID system contains three primary elements: a reader, a tag, and a business or computer system (Figure 5). The tag comprises an antenna and a small microchip that can be either attached or embedded within various objects (such as parts, products, machinery, animals, or people). Tags display a diverse array of shapes and dimensions and can retain data in their memory. The data may include specific specifics named as product placement, a unique identification number, product cost, manufacturing date, category, current stock, dimensions, description, and further information. Tags can be categorized into two main categories: passive tags, which lack internal batteries, and active tags, which have a built-in battery and are self-powered.

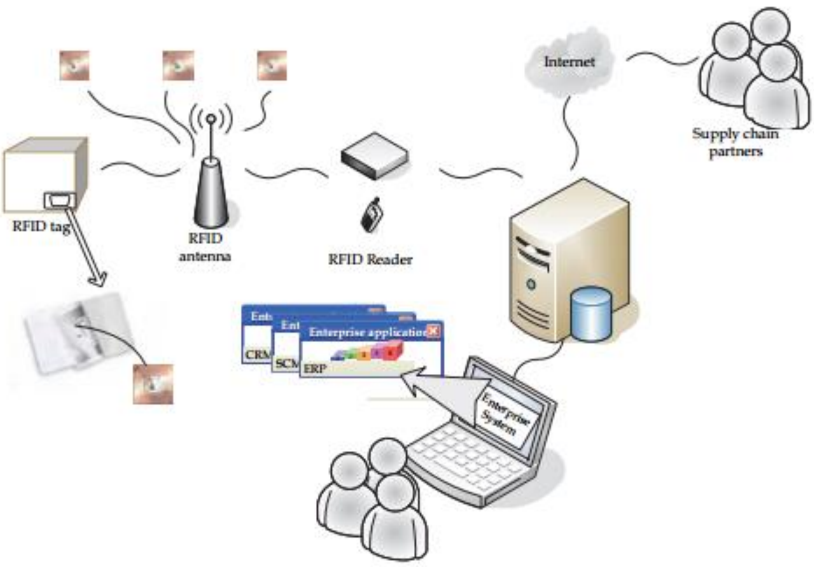

Figure 5: Elements of the RFID system

Source: (Matičević, Čičak, & Lovrić, 2011)

Active tags can both read and write data, which allows them to store more data compared to passive tags. Specifically, the Active tags are self-powered and do not rely on the electromagnetic field of the scanner to be activated. These tags utilize internal batteries as their power source, distinguishing them from passive tags that depend on the reader for power when they are within its proximity. Passive tags are triggered based on the electromagnetic field generated by the RFID reader. The RFID reader transmits radio signals through an antenna to activate the tag, allowing for the identification and recording of data.

When a tag is triggered, data is transmitted through signals generated by the antenna. Passive tags are more commonly used in a range of RFID applications since they have a longer lifespan compared to active tags. However, active tags can transmit signals over a greater distance in comparison to passive tags. Regarding supply chain applications, passive tags, particularly those operating in the Ultra High Frequency (UHF) range, are typically the most frequently utilized (Tajima, 2007). Tags also vary based on their data storage capacity, falling into two categories (Domdouzis , Kumar , & Anumba, 2007):

- Read-Only tags,
- Read/Write tags.

RFID Frequency

The frequency utilized in RFID applications is a pivotal feature of RFID technology. Differences in RFID frequency allotment regulations lead to variation, as different countries adopt their standards (Turcu, Turcu , & Graur, 2008). An obstacle of great importance in the implementation of RFID systems is the existence of diverse standards. The unequal distribution of radio frequency spectrum allocation among nations is a barrier to the global implementation of RFID systems. A key issue in RFID technology is the absence of standardized practices. At present, there are only a restricted amount of frequencies that remain the same around the globe. Operational frequency ranges vary., as outlined by Gaukler & Seifert, (2007): low frequency (LF) 125–134 kHz, high frequency (HF) 13.56 MHz, and UHF RFID operates within 868–928 MHz.

Increased frequency facilitates extended reading distances and faster communication capabilities (Gaukler & Seifert, 2007). Passive tags operating at low frequencies have an effective range of around 30 cm, whereas high-frequency passive tags are functional within approximately 1 m. UHF passive tags boast a range of about 8 m. Although active tags are more costly than passive tags, being self-powered allows them to achieve a range of up to 100 m (Matičević, Čičak, & Lovrić, 2011).

RFID Benefits

Multiple authors have emphasized that RFID technology improves supply chain operations by effectively detecting objects and delivering up-to-date information. RFID improves data accuracy, speeds up procedures, enables traceability, and boosts product visibility throughout supply chains. As a consequence, there is a boost in the velocity of physical movements and a decrease in both Work-In-Progress (WIP) and inventory quantities (Dolgui & Proth, 2008). Utilizing both RFID technology and barcodes contributes to process automation and enhances operations management by reducing workload and eliminating human errors. Nevertheless, RFID technology presents certain advantages over barcodes:

- This technology functions without requiring direct visual contact, enabling the reading of tags through various substances.
- Particularly suitable for demanding conditions involving dirt, moisture, dust, chemicals, and high temperatures.
- RFID readers can communicate with multiple tags and automatically retrieve data from them.
- RFID readers have a superior capacity for reading at longer distances.
- Tags can hold a larger amount of data in comparison to barcodes.
- Tags can exhibit variations in shape and size depending on the specific application.

Despite these benefits, RFID applications have limitations, such as physical constraints (difficulties in reading through liquids or metals) and the associated costs, although RFID prices are continuously decreasing (Matičević, Čičak, & Lovrić, 2011).

RFID Applications

RFID technology applies to a wide range of human activities. An increasing number of businesses are implementing RFID technology to improve operational efficiency and gain a competitive advantage. The novelty of RFID technology rests not only in its technical aspects but also in its efficient incorporation into real-world commercial operations. The rapid advancement in IT and the decreasing costs of RFID system components are enabling the continuous growth of its application domains. Lately, many writers have emphasized the use of RFID technology in applications related to Supply Chain Management (SCM).

In the literature, various applications of RFID have been identified, including the development of fashion products (Choy, et al., 2009), a planning system for real-time warehouse operation (Poon , et al., 2011), addressing material demand challenges in manufacturing (Huanga, Zhanga, & Jiangb, 2007; Poon , et al., 2011), hospitality (Oztaysi, Baysan, & Akpinar, 2009), and tracking vehicles in the shipment yard of an automotive manufacturing plant (Kim, Ok, Kumara, & Yee, 2010). Notably, well-known entities such as the US Department of Defense, Marks, Walmart, Metro, & Benetton, Spencer, and Gillette are among the pioneering global handlers of RFID technology within their supply chains.

RFID serves as both a technology and a physical infrastructure utilized for the identification and labeling of objects. This involves the transmission of a distinctive identifier from one device to the reader using radio waves, following a predefined code. Generally, RFID incorporates a microprocessor with memory space for information, making it a significant and versatile tool for various applications, including SCM (Oghazi, Rad, Karlsson, & Haftor, 2018). RFID facilitates the management of warehouse inventory, verifies the alignment of shipped products with the actual orders, mitigates stock shortages at the sales level, provides real-time updates to managers on production stages, minimizes paperwork, enhances productivity, and improves transparency. It streamlines the product development process across the supply chain, leading to reduced labor costs and enhanced accuracy in inventory forecasting (Oghazi, Rad, Karlsson, & Haftor, 2018).

2.4 Edge Computing and Other Relevant Novel Technologies

ERP systems are crucial for integrating various business processes, including warehouse management. Integrating novel technologies like edge computing with ERP systems can significantly enhance warehouse operations by providing real-time data, improving efficiency, and optimizing resource use.

2.4.1 Edge Computing in ERP-Integrated Warehouse Management

- Real-time data processing and analytics

Edge computing in ERP-integrated warehouse management systems processes data locally from sensors and devices, providing real-time insights into inventory levels, order status, and equipment performance. This enables ERP systems to make prompt decisions and extract actionable insights immediately, which is crucial when latency issues or limited network bandwidth prevent data transfer to centralized servers for analysis. Processing data at the edge minimizes latency, providing faster response times for crucial warehouse tasks like automated picking and sorting. This local processing approach enhances the responsiveness of real-time applications, improving user experience and operational efficiency by ensuring timely actions in IoT deployments, autonomous vehicles, and industrial automation (Modupe, et al., 2024).

- Enhanced inventory management

Enhanced inventory management, achieved through edge computing in ERP-integrated warehouse systems, leverages AI for data analysis and predictive modeling alongside IoT sensors for real-time tracking, resulting in more efficient, accurate operations, reduced waste, and improved supply chain responsiveness (Singh & Adhikari, 2023). Edge devices can track inventory movements and update the ERP system in real-time, ensuring accurate and up-to-date inventory records as local processing of inventory data. Edge computing in enhanced inventory management benefits from demand prediction and stock optimization by integrating AI and IoT within Cyber-Physical Systems (CPS), where IoT devices gather real-time data that AI algorithms analyze to optimize inventory levels and forecast future demand, enabling accurate and efficient inventory planning in dynamic market conditions (Singh & Adhikari, 2023).

Edge computing enables local analysis of historical data for demand forecasting and inventory optimization, which is then integrated into the ERP system to minimize costs and enhance customer satisfaction. The main research challenge lies in determining the timing and quantity of orders, considering supply lead time and current inventory, and developing integrated, data-driven inventory optimization models that use information on suppliers, customers, and inventory to maximize revenue and improve customer satisfaction (Mashayekhy, Babaei, Yuan, & Xue, 2022).

- Operational efficiency

A warehouse is a complex environment encompassing various processes and operations such as picking, storing, scheduling, and routing, where safety and operational efficiency are crucial metrics for successful management (Halawa, et al., 2018). Edge computing is increasingly being implemented in various IoT scenarios, such as remote equipment monitoring, predictive maintenance, and quality control (Qiu, et al., 2020). with edge devices monitoring equipment health and forecasting maintenance needs, minimizing downtime, and ensuring uninterrupted operation by integrating this data into the ERP system for seamless scheduling of maintenance activities.

Additionally, a novel Reference Architecture (RA) for industrial automation utilizes edge computing and blockchain technologies to enable flexible, scalable, and reliable configuration and orchestration of automation workflows and distributed data analytics; this approach offers significant advantages for digital automation platforms, including real-time data analysis close to the source and flexible reconfiguration of automation workflows (Isaja, Soldatos, & Gezer, 2017). , facilitating real-time control and coordination of automated systems like Automated Guided Vehicles (AGVs) and robotic arms to enhance workflow efficiency.

- Security and Compliance

In an edge computing paradigm, data from smart devices or sensors is stored on or near the device rather than being sent to the cloud. This approach is preferred over traditional cloud computing for its real-time data computation, reduced latency, faster responsiveness, and decreased network traffic, while also enhancing security by filtering sensitive data before it reaches the cloud. (Parikh, Dave, Patel, & Doshi, 2019).

Data privacy involves processing sensitive data locally to reduce the risk of breaches during transmission to central servers and ensuring compliance with data protection regulations. It encompasses the confidentiality of user data that is stored, processed, or transmitted, with any mishandling known as privacy leakage. As Multi-Access Edge Computing (MEC) facilitates Big Data applications and generates large amounts of personal data in fields like healthcare and banking, there is a significant risk to privacy due to the open service platform of MEC and the use of AI for pattern recognition, which may violate privacy without user consent (Ranaweera, Jurcut, & Liyanage, 2021).

Access control and monitoring are essential aspects of security and compliance. Edge computing enhances these functions by ensuring only authorized personnel can access specific data or areas within the warehouse, while also providing real-time data processing, data cleaning, and privacy protection at the network edge. (Lin, et al., 2021).

Other Relevant Novel Technologies

- Internet of Things (IoT)

ERP integrates with various technologies, including the Internet of Things (IoT), which uses a distinct Internet protocol for identifying, controlling, and transferring data to individuals and databases. Data collected via IoT is stored in the cloud and then extracted and managed through the ERP system (Tavanaa, Hajipour, & Oveisi, 2020). The integration of IoT and ERP offers several advantages, including automated notifications for events like re-orders, inventory replenishment, out-of-stock situations, and missed deliveries through connected sensors and devices. This integration enables real-time data access and immediate solutions by combining ERP's situational awareness with IoT's potential for generating actionable information, which ERP then processes to enhance business operations. IoT also facilitates real-time barcode scanning and data entry, reducing the need for manual intervention and improving production efficiency. Additionally, IoT enables product and equipment traceability throughout the supply chain, providing real-time information that feeds into the ERP system for tracking interdependencies between the product life cycle and material flow (Tavanaa, Hajipour, & Oveisi, 2020).

IoT devices gather and transmit data on warehouse parameters like temperature, humidity, and item location, which are then integrated into the ERP system for effective monitoring and management. IoT-enabled shelves and RFID tags offer real-time visibility into inventory levels and movements, synchronizing this information with the ERP system.

- Artificial Intelligence (AI) and Machine Learning (ML):

AI technology enables computers to think and reason like humans, drawing on fields such as robotics, computer vision, natural language processing, and cloud computing. The integration of AI in manufacturing enhances efficiency and flexibility, reduces errors, and optimizes operations in real-time, leading to significant advancements in automation within the warehouse industry in recent years. (Aggarwal, Garg, & Budhaulia, 2020).

By 2020, AI is expected to revolutionize warehouse operations through a smart warehouse ecosystem where AI manages every aspect from supply to delivery. AI can reduce errors by automating tasks such as identifying, sorting, processing, and packaging goods, while also enabling the reallocation of funds from inventory management to other growth opportunities. Additionally, RFID technology has replaced barcode scanners for better inventory control, and AI can adjust order speed and volume to boost overall productivity (Aggarwal, Garg, & Budhaulia, 2020).

Big Data Analysis techniques encompass skills in statistics, optimization, data mining, and machine learning, with machine learning algorithms designed to derive solutions by learning from data. Common methods for analyzing Big Data include parallel processing, deep learning, and support vector machines, which can handle diverse data types such as images, text, and video; however, achieving high accuracy and performance with these techniques can be time-consuming. (Wang, Pauleen , & Taskin, 2022).

AI and ML algorithms analyze warehouse data to optimize inventory levels, forecast demand, and refine order-picking strategies, with these insights being used for strategic decision-making within the ERP system. AI-driven robots also enhance picking and sorting accuracy, and their performance and operational data are integrated into the ERP system to monitor efficiency and schedule maintenance.

- Robotics and Automation

A robot is a versatile, re-programmable manipulator designed to move tools, materials, parts, or specialized devices through programmed motions to perform various tasks. In warehouses, robots work alongside associates to reduce travel time and increase productivity through innovative processes, while industrial robots handle tasks such as material handling, welding, and inspection, and mobile robots use legs, tracks, or wheels for movement, with domestic robots performing household chores (P, Sajiv, & L, 2017).

Smart automated warehouse systems are crucial components of the smart world, with Automated Guided Vehicles (AGVs) playing a key role in smart city applications and potentially saving over 40% of costs. Implementing AGVs in automated warehouses involves both management challenges, such as addressing experimental conditions, user demands, and environmental changes, and technological issues, including balancing quantity, quality, and efficiency, while AGVs themselves are extensively studied for their capabilities in autonomous planning and coordination (Zhang, Chen, & Guo, 2022).

AGVs transport goods within the warehouse, enhancing efficiency, with their real-time operational data integrated into the ERP system to synchronize logistics. Automated picking systems decrease manual labor and errors, capturing activity data that is also integrated into the ERP for precise order processing.

- Blockchain Technology

Blockchain technology will be a key tool for enhancing supply chain operations by ensuring supply commitments and visibility across manufacturing sites and contract manufacturers. It promotes supply chain transparency, reducing administrative costs and counterfeiting, and helps manufacturers innovate more quickly and affordably, address transparency issues, and meet increasing customer demands for product source and path information. (Banerjee, 2018).

Smart contracts are crucial in permission blockchains, defining the rules for processes, validations, and interactions. They enable a digital, automated record that continuously updates the status of sold and delivered goods, storing details like proof of origin and delivery in an immutable blockchain ledger to authenticate transactions and reduce disputes. By managing aspects of order management such as ordering, order changes, and fulfillment logistics, smart contracts facilitate real-time data sharing, establish engagement rules, and help identify appropriate discounts for customers (Banerjee, 2018).

Blockchain offers a secure ledger for tracking goods throughout the supply chain, ensuring both traceability and transparency. This data can be integrated with the ERP system to improve supply chain visibility, automating transactions and agreements between suppliers, warehouses, and customers for faster and more secure operations.

- Augmented Reality (AR)

Augmented Reality (AR) involves overlaying virtual elements onto the real world to enhance human senses and capabilities, making it a rapidly growing technology within the Industry 4.0 manufacturing paradigm. AR immerses users in a real-world environment augmented with virtual, computer-generated information, improving warehousing activities such as order picking, product identification, and smart palletization. AR is particularly effective in spacious warehouse layouts for increasing efficiency in order picking, reducing retrieval times, and minimizing errors, and holds great potential for advancements in product visualization, process simulation, and training for maintenance activities. (Rejeb, Keogh, Wamba, & Treiblmaier, 2020).

AR devices assist warehouse workers with picking and packing tasks, reducing errors and increasing efficiency, while the data collected is integrated into the ERP system for real-time order tracking. Additionally, AR offers interactive training for new employees and guides maintenance tasks, leading to reduced downtime and improved productivity, which is also reflected in the ERP system.

Integrating edge computing and other advanced technologies with ERP systems creates a synergistic effect that significantly improves warehouse management. By combining IoT and edge computing, real-time monitoring and rapid response to changes are achieved, with the ERP system centralizing this information for strategic decision-making. AI algorithms operating at the edge analyze data locally for immediate insights, which are then fed into the ERP system for comprehensive analysis, while edge computing ensures low-latency communication with robots and the ERP system coordinates their activities within overall warehouse operations.

2.5 Significance of the Integrated ERP and RFID System

Automated identification and data capture technologies, such as RFID, are highly beneficial for improving corporate efficiency. The integration of ERP with RFID in management enables efficient decision-making by considering consumer needs and maximizing the use of company resources. Integrating ERP systems with RFID technology allows for immediate tracking of work orders, parts, and products, guaranteeing precise data and promoting the exchange of information throughout internal and external supply chains (Matičević, Čičak, & Lovrić, 2011). Upon adopting RFID technologies, Wal-Mart and Procter & Gamble achieved a simultaneous 70% reduction in inventory levels. Additionally, they elevated their service levels from 96% to 99%, marking a substantial impact on revenue. This implementation also led to a reduction in various administrative costs by reconfiguring their supply chain processes (A Majeed & Rupasinghe, 2017).

Automated identification and data capture technologies, such as RFID, offer significant advantages in enhancing company efficiency. The incorporation of ERP with RFID in management facilitates effective decision-making by taking into account consumer demands and optimizing the utilization of firm resources. The integration of ERP systems with RFID technology ensures accurate data, enables real-time tracking of parts, goods, and work orders, and facilitates the flow of information across internal and external supply chains (Oghazi, Rad, Karlsson, & Haftor, 2018).

2.6 Brief History and Current Global Context of Integrated ERP and RFID System

According to Liu & Chen, (2009), RFID technology was utilized to optimize manufacturing efficiency in Integrated Circuits (IC) packaging facilities. The combination of RFID technology and an ERP system led to the creation of a cohesive electronic control framework. The suggested system was executed at a nearby IC packaging facility, employing Oracle Application Implementation Methodology (AIM).

The system has two modules: an inventory transaction module and an electronic reception module. The investigation findings indicate that the electronic receiving module is capable of efficiently managing check and acceptance procedures, document handling tasks, and stock-in record data processing. The module of inventory transactions effectively manages the requirements for accounting entry data, requests for inventory transaction forms, and the processing of replenishment and transaction records. The implementation of the electronic control system has led to a reduction in the time required for manual operation during the wafer-in process, effectively addressing customer complaints and preventing penalties. Furthermore, automated and paperless operations have largely replaced manual key-in activities in the inventory transaction process. Consequently, the IC packaging house has substantially reduced the workload and costs related to its operations (Liu & Chen, 2009).

As outlined by Niederman, Mathieu, Morley, & Kwon, (2011), The challenges organizations face when incorporating RFID into their existing systems vary according to the types of systems they currently employ. Four primary possibilities are anticipated to happen. Initially, organizations that have informal business processes will generate flat files by extracting data from RFID and sensor technology. Subsequently, these files can be utilized by preexisting applications. Furthermore, organizations will establish novel databases, systems, and procedures to engage with their existing Enterprise Systems (ES). These contacts can occur through both manual and automated means. Furthermore, organizations will collaborate with vendors to enhance the functionalities of their Enterprise Systems (ES) to effectively process data originating from Radio Frequency Identification (RFID) sources. Finally, organizations that possess bespoke legacy systems will seize this opportunity to migrate to ES. This shift will entail the integration of their systems while also leveraging the potential of RFID technology.

Every scenario outlined entails both risks and opportunities. Likewise, the level of investment in and optimization of bar code scanning technology will influence how costs and benefits are distributed in the transition to RFID. Over time, as RFID becomes more widespread and seamlessly integrates with other sensor data, there may be opportunities to leverage this richer information in creating innovative new business models (Niederman, Mathieu, Morley, & Kwon, 2011).

Currently, Oracle, SAP, Peoplesoft, Sun, Microsoft, and IBM are actively developing different middleware solutions to integrate RFID technology into their existing product offerings. As an illustration, SAP has created a layer of middleware known as the Auto-ID Infrastructure, which effectively transmits data from readers to applications. These applications utilize various communication and sensing types of equipment such as Bluetooth devices, RFID printers and readers, bar-code devices, and embedded systems. They initiate pertinent events by utilizing a rules engine (Niederman, Mathieu, Morley, & Kwon, 2011).

This technique aims to give priority to the reformatting of incoming data to synchronize it with different legacy systems. RFID technology will provide opportunities to build up advanced business models and revamp existing supply chain operations. For example, the capacity to monitor inventory can decrease the amount of time needed to find a product as it moves from the manufacturing area, via the storage facility, to the sales floor (Niederman, Mathieu, Morley, & Kwon, 2011). To enhance both incoming and outgoing operations, it is necessary to improve, optimize, and automate activities within an ERP system by integrating RFID technology and Business Application Programming Interface (BAPI) technology in SAP (A Majeed & Rupasinghe, 2017).

2.7 Integrated ERP and RFID System

This study evaluates the performance of ERP and RFID integration in Sri Lanka's rubber glove industry, focusing on their applications, key indicators, and integration levels. It emphasizes how combining these technologies enhances real-time data synchronization, supports JIT manufacturing, and improves operational efficiency through better information visibility and streamlined data flow. Key evaluation indicators include process automation, performance management, process control, and compliance.

Advanced Manufacturing Technology (AMT) heavily relies on Auto ID sensors and RFID as wireless devices, and wireless information networks to collect and synchronize real-time data from manufacturing workshops. The utilization of Wireless Manufacturing (WM) technology facilitates instant retrieval and monitoring of shop-floor data, hence enabling the effective implementation JIT manufacturing. As a consequence, there is a decrease in the amount of WIP inventory present on the shop floor, leading to a more streamlined and efficient operation. Moreover, it addresses common challenges faced in the workplace, such as time-consuming and mistake-prone manual data collection and input processes, hence enhancing operational effectiveness for products with a moderate range of choices and production volumes. Establishing a closed-loop production control cycle requires the critical exploration of production planning and shop-floor management, incorporating information visibility and real-time material traceability (Huanga, Zhanga, & Jiangb, 2007).

Implementing an ERP system in the organization offers managers significant insights, enabling streamlined decision-making processes. Timely, accurate, comprehensive, adequate, and reliable information about events in the supply chain, whether they are internal or external, is essential. The biggest importance lies in the sharing of real-time information and the coordination of all business process actions. The absence of accurate and current data, particularly regarding the present state of production on the shop floor (including WIP and inventory status), can significantly impair performance, particularly in JIT manufacturing and supply chain planning. RFID technology facilitates the immediate integration of tangible objects, such as materials, components, products, machinery, deliveries, and individuals, by assigning a unique identity, typically in the form of a distinct number, to each thing. The integration with the ERP system improves the visibility of information and facilitates smooth data flow in a manufacturing organization that has undergone digitalization (Matičević, Čičak, & Lovrić, 2011).

Applications of Integration

Integrating an ERP system throughout the organization offers managers crucial information, empowering them to make efficient decisions. It is crucial to have timely, accurate, comprehensive, adequate, and reliable information regarding both internal and external events in the supply chain. The primary significance is in the dissemination of up-to-date information and the synchronization of all activities of corporate operations. The lack of precise and up-to-date information, specifically regarding the current production status on the shop floor (including WIP and inventory), can greatly impede performance, especially in JIT manufacturing and supply chain planning. RFID technology enables the seamless incorporation of physical objects, such as materials, components, products, machinery, deliveries, and people, by providing a unique identifier, usually in the form of a distinct number, to each item. Integrating with the ERP system enhances information visibility and streamlines data flow in a digitally transformed industrial organization (Matičević, Čičak, & Lovrić, 2011).

Walmart and other corporations that mandate the use of RFID technology expect significant gains in their supply chains and predict long-term advantages that will also extend to their suppliers. Suppliers can potentially benefit from implementing RFID technology through reduced operational expenses, more efficiency in inventory management, and increased precision in information (Chuang & Shaw, 2007). The main benefit of using RFID technology in demand forecasting is the ability to leverage downstream data to improve the precision of forecasts. RFID technology has proven to be effective in enhancing supply chain operations by eliminating human errors and processing errors, improving operator productivity, reducing out-of-stock rates, and eliminating the need for manual input of ID codes by human operators (Angeles, 2005). Enacting internal organizational RFID provides benefits such as reduced labor expenses, mitigated human mistakes in logistics operations, and improved efficiency in inventory management across manufacturing and distribution facilities (Chuang & Shaw, 2007).

Integrating the electronic receiving module into an IC packaging facility can decrease the amount of time required for operations and minimize mistakes in data entry while receiving wafers. The inventory transaction module improves operational efficiency by decreasing the duration of inventory transactions. The module deployment produces favorable outcomes in six crucial domains: generating inquiries for released materials, handling records for released materials, generating requests for item retrieval, managing records for item retrieval, generating concise reports for stock intake, and overseeing internal grievances (Liu & Chen, 2009).

When it comes to meeting consumer demand, the benefits include a reduction in the time it takes to process information, an increase in customer satisfaction, and the elimination of errors in data processing. The advantage of inventory management lies in the improvement of methodical and electronic capabilities. When it comes to warehousing, the advantages include enhanced productivity, improved accuracy, decreased operator workloads, and speed in information processing (Liu & Chen, 2009).

Key Indicators of Integrated System

The RFID application provides four specific benefits: automation of processes, control of processes, management of performance, and adherence to regulations. RFID technology interfaces in process automation can offer useful insights for production management, especially when engaged with data from the ERP system. RFID technology in process control allows for immediate process control with visual input and evaluates causal links for ongoing enhancement in process design utilizing data-driven problem-solving tools. Well-designed measures are essential for improving operational performance. RFID technology can be used to evaluate and assess the performance of events, as well as help discover the causes of fluctuation. To ensure compliance, the most effective method entails collecting all essential data for financial, operations management, and compliance objectives via shared data collection points. (Liu & Chen, 2009). According to Figure 6, There are four main key indicators of integrated ERP and RFID systems such as process automation, performance management, process control, and compliance.

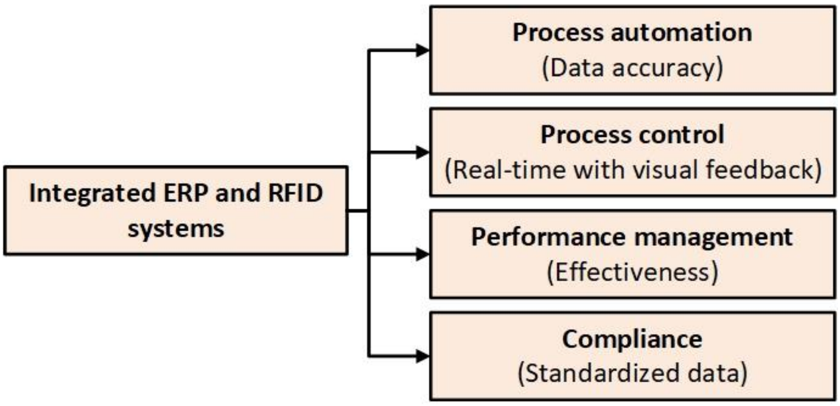

Figure 6: Key indicators of integrated ERP and RFID systems

Source: Author developed based on Liu & Chen, (2009)

Integration Levels

Integration of the supply chain is categorized into four levels, which can be facilitated through Enterprise Systems (ES) like RFID and ERP. The initial level is internal integration, where an organization without integration is typically characterized by separate departments lacking coordination with each other (Beheshti, Oghazi, Mostaghel, & Hultman, 2014). In this context, information serves as a vital tool for effective transfer and circulation within an organization, fostering enhanced coordination. According to Simchi-Levi, Kaminsky, & Simchi-Levi, (2003), the availability of standardized and reachable information within the company plays a crucial role in enabling timely and cost-effective communication and business operations. The goal of internal information integration in an organization is to attach different systems that exist in multiple departments into a cohesive information system. This involves standardizing the structure of shared information to ensure that it can be understood by all dissections within the organization (Oghazi, Rad, Karlsson, & Haftor, 2018). To achieve this objective, ERP systems offer the organization an integration opportunity through bundles situated in various divisions (Beheshti, Oghazi, Mostaghel, & Hultman, 2014).

These bundles aggregate the internal data from each department and establish connections to the central database, which is accessible and utilized by all units within the organization. ERP systems facilitate the standardization of information, allowing for the utilization of data across various departments within the organization.

Furthermore, the use of RFID enables the tracking of materials/products when they transition between different organizational departments (Oghazi, Rad, Karlsson, & Haftor, 2018). RFID tags enable the monitoring of products or materials to which they are attached at different locations, as they may store and transmit information. The ERP system enables the transmission of data about these labeled products/materials to various departments within the organization, providing real-time information to different divisions for improved planning and control.

The second tier of integration involves collaboration with suppliers. This entails establishing mutually beneficial relationships with suppliers, characterized by a robust commitment and trust. These relationships are cultivated over time, involving associated risks, shared data, incentives, and the establishment of long-term contracts (Vickery, Jayaram, Droge, & Calantone, 2003). To achieve collaboration with suppliers through the sharing of information, ERP and RFID systems can play crucial roles. When both manufacturing and supply companies possess an ERP system and establish interconnections between their respective ERP systems, it facilitates a seamless information infrastructure for exchanging data between these supply chain partners.

Through the ERP system, accurate information about inventory levels, order quantities, production rates, and more can be shared efficiently between the manufacturer and its supplier, ensuring timely and cost-effective communication. Enabling the smooth flow of information can result in increased efficiency in business operations, heightened customer satisfaction, and improved planning. Moreover, RFID can be employed to track the movement of supplies being sent to the manufacturer, offering essential details about the shipped items and their expected delivery times (Oghazi, Rad, Karlsson, & Haftor, 2018; Simchi-Levi, Kaminsky, & Simchi-Levi, 2003).

The third tier of integration involves collaboration with customers, with relationships often marked by asymmetrical power dynamics. Customers recognize that they contribute funds to the supply chain, and their indispensable role within the entire chain is acknowledged. This awareness gives customers the leverage to demand more personalized services. Therefore, addressing the integration with customers to enhance their benefits is a crucial aspect that requires comprehensive consideration (Oghazi, Rad, Karlsson, & Haftor, 2018).

To achieve this objective, numerous companies aim to improve the quality of their interactions with customers (Oghazi, Rad, Karlsson, & Haftor, 2018). One key approach for this purpose is the implementation of Customer Relationship Management (CRM). CRM entails the strategic capability and commitment of a company to fulfill the demands of its customers (Lee & Billington, 1992; Powell T. , 1995). Strengthening customer relationships can be accomplished by promptly addressing customer demands, and once closer relationships are established, companies can proactively gather data on customers' specific needs and behaviors (Stroeken, 2001). Such proximity to customers makes it challenging for competitors to effectively compete (Vickery, Jayaram, Droge, & Calantone, 2003).

In this context, Information Technology (IT), including ERP systems, plays a crucial role in fostering improved relationships with customers by bringing them closer to the company through an efficient mechanism for sharing information between customers and suppliers. Hence, the incorporation of a module within the ERP system that addresses Customer Relationship Management (CRM) factors can enhance integration between the company and its customers (Hatzithomas, Stamelos, Fotiadis, & Mylonakis, 2007; Oghazi, Rad, Karlsson, & Haftor, 2018; Simchi-Levi, Kaminsky, & Simchi-Levi, 2003). Moreover, in business-to-business connections, a customer who possesses an RFID system has the potential to obtain extensive product information from the products they receive that are connected with RFID tags. This enhances the integration between the providing firm and the client.

The fourth level of integration encompasses a completely merged supply chain, where the movement of funds, products, and information occurs seamlessly in both directions, from suppliers to downstream levels and vice versa. (Oghazi, Rad, Karlsson, & Haftor, 2018). This integration takes place within the framework of the load flows indicated. Rai, Robinson, Patnayakuni, & Seth, (2006) Information flow integration refers to the extent to which a central firm and its supply chain partners exchange operational, tactical, and strategic information. Operational information refers to specific data such as the number of inventories, the timing of delivery, and the manufacturing schedules (Oghazi, Rad, Karlsson, & Haftor, 2018). Tactical information encompasses quantitative measures of performance, the execution of specific tasks, and the resulting outcomes (Rai, Robinson, Patnayakuni, & Seth, 2006). Strategic information covers sales data (Stratman, 2007).

Integrating tactical, strategic, and operational information across a supply chain is essential for maximizing profitability across all players in the chain. This aligns with the overall purpose of Supply Chain Management (SCM). Information Technology (IT), which encompasses technologies such as RFID and ERP systems, plays a crucial role in establishing this integration. RFID tags allow for the monitoring of created and transported inventories across the chain, while ERP systems simplify the dissemination of this inventory-related information across the chain. Moreover, the ERP system allows actors at all levels of the supply chain to retrieve strategic information, including sales data. This helps to prevent the manipulation of demand information and the subsequent occurrence of the bullwhip effect. Effective dissemination of information among players in the supply chain facilitates the harmonization of production and delivery, enhanced prediction of future trends, coordination of choices relating to inventory, and a shared comprehension of obstacles that hinder performance. Within this particular framework, Information Technology (IT), encompassing technologies such as RFID and ERP systems plays a crucial role in enabling efficient communication of information among different participants in the supply chain (Rai, Robinson, Patnayakuni, & Seth, 2006).

2.8 Inventory Accuracy

This study views the precision of inventory management within the rubber glove manufacturing sector in Sri Lanka.

Importance of Inventory Precision

The accuracy of inventory is essential for maintaining an efficient and effective supply chain. Despite its importance, it is sometimes referred to as the 'missing link' in retail implementation. The accuracy of inventory data significantly impacts the performance of forecasting, ordering, and replenishment procedures, as these systems heavily rely on precise inventory records as inputs (Goyal, Aloysius, & Hardgrave, 2009). RFID implementation reduces inventory discrepancies during routine company operations that require on-hand modifications. Most shops rely on automated ordering and replenishment systems, or at the absolute least, utilize information from a system to assist their decisions regarding what, when, and how much to order. To optimize the effectiveness of these systems, businesses require precise documentation of their current inventory. Unfortunately, retailers frequently encounter difficulties in precisely monitoring the inventory levels of their products in their storefronts (Kang & Gershwin, 2007). Previous research indicates that merchants possess precise awareness of their inventory, referred to as Perpetual Inventory (PI) or the system's estimation of in-store products, for approximately 35% of their product range (Raman, DeHoratius, & Ton, 2001). Consequently, the decisions regarding ordering and replenishment are predominantly based on an inaccurate figure rather than an accurate one. Hence, inventory accuracy is often identified as the essential component that is deficient in the execution of retail operations (Heese, 2007).

Categorization of Inventory Inaccuracies

When evaluating the precision of Perpetual Inventory (PI), inaccuracies can be classified into two main categories: PI that is overestimated and PI that is underestimated. Research indicates that around 50% of the time, faulty PI tends to be exaggerated, indicating that PI shows a higher amount of goods than exists in the shop, generally known as phantom inventory. During the remaining 50% of the time, the erroneous physical inventory (PI) is underestimated, meaning that the PI reflects a lower quantity than what is present in the shop. This is sometimes referred to as hidden inventory (Gruen & Corsten, 2008). Both types of Perpetual Inventory (PI) mistakes can have a detrimental effect on the retailer. When PI is overestimated, the main problem that arises is the risk of stock depletion. This occurs when the system incorrectly indicates the presence of inventory (phantom inventory), failing to initiate new inventory orders.

On the other hand, with understated PI, the primary concern is excess inventory (hidden inventory) because the system inaccurately perceives a lower quantity than actual, resulting in unnecessary inventory orders. This surplus inventory can potentially lead to increased holding costs, heightened markdowns affecting margins, decreased inventory turnover, and disruptions in in-store execution, introducing inefficiencies and the possibility of execution-related errors such as out-of-stock incidents (Goyal, Aloysius, & Hardgrave, 2009).

Causes of Inventory Inaccuracy

Various factors contribute to inventory inaccuracies, as documented by Gruen & Corsten, 2008; Kang & Gershwin, 2007; Waller, Nachtmann, & Hunter, (2006). First and foremost, personnel making erroneous manual modifications can result in mistakes in the Perpetual Inventory (PI) system. For example, an employee might erroneously set the product inventory (PI) to zero, assuming that it is out of stock when in reality it is located in the backroom. On the other hand, an employee may mistakenly increase the PI, presuming the presence of a non-existent product case. This emphasizes the potential for erroneous manual changes to result in both underestimated and overestimated PI. Furthermore, theft can exacerbate an inflated PI (Physical Inventory) scenario, in which stolen items result in a difference between the recorded quantity in the system and the actual quantity. Furthermore, inadequate documentation of damaged or spoilt products might lead to an exaggerated Product Inventory (PI).

Improper returns, specifically those involving returned products that should be added back to the inventory system, are sometimes not accurately accounted for or are accounted for erroneously. For instance, there may be instances when product A is recorded as returned when it was product B that was returned. This can potentially result in an inaccurate representation of the physical inventory, either understating or overstating it. In the event of a mis-shipment from the distribution center, a store may receive shipments that were not supposed to be received, leading to both over and understated physical inventory. Overstated inventory occurs when products that were supposed to be received are not received, while understated inventory occurs when products that were not supposed to be received are received. Cashier errors, specifically the sixth type, can result in both over and understated inaccuracies in the PI (Point of Sale Inventory) system. For instance, in the scenario where a customer buys three units of product A and three units of product B, but the cashier erroneously inputs six units of product A, the physical inventory (PI) count for product A will be underestimated by three units, while the PI count for product B will be overestimated by three units (Goyal, Aloysius, & Hardgrave, 2009).

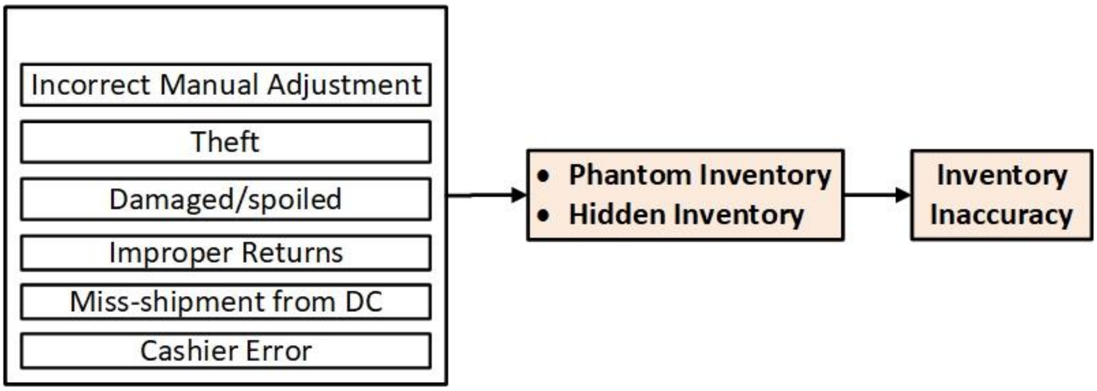

Figure 7: Causes of inventory inaccuracy

Source: Author developed based on (Goyal, Aloysius, & Hardgrave, 2009)

As depicted in Figure 7, inaccuracy in inventory can be broadly classified into two categories: phantom inventory and hidden inventory. Additionally, there are various recognized factors contributing to inventory inaccuracies, including incorrect manual adjustments, theft, damage/spoilage, improper returns, mis-shipments from distribution centers, and errors made by cashiers.

Strategies to Address Inventory Inaccuracies

To address inventory inaccuracies, companies have several potential strategies, as outlined by Kang & Gershwin, (2007) and Morey, (1985). Firstly, increasing safety stock can mitigate the impact of inaccuracies by maintaining additional inventory, and preventing out-of-stock situations. RFID technology may facilitate a reduction in the cost associated with holding this surplus inventory. Secondly, conducting frequent manual inventory counts is an option, but this approach can be disruptive, variable in accuracy, and costly. RFID-enabled improvement in Perpetual Inventory (PI) accuracy could offer a more cost-effective alternative. Thirdly, to counter overstated PI, companies can incorporate a constant decrement to account for anticipated stock loss. However, the challenge lies in accurately determining the exact stock loss, and RFID visibility may enhance accuracy compared to current estimation methods. Lastly, companies can strive to eliminate error sources through enhanced inventory management and theft reduction. Kang & Gershwin, (2007) propose autoID (RFID) as a method to assist companies in eliminating sources of errors.

PAGO's production and assembly plant is predominantly automated, with certain human jobs required for reporting and updating the IT system. These manual operations take place at the entry and exit points of high storages one and two, as well as during the entire construction process. The manual operations are prone to errors and are the main reason for inventory discrepancies. The primary ramifications of erroneous inventory for PAGO are elevated inventory levels, expedited orders (and their associated repercussions), stockouts, wastage, and protracted inventory turnover (Hellstrom & Wiberg, 2010).

Two stations are established for operators to unload products from racks at the exit points leading to high storage. An issue commonly observed at these stations involves operators mistakenly updating the quantity of products remaining on the rack, which are subsequently returned to storage at higher levels. Furthermore, at one of these stations, a further problem develops when an incorrect product category is detected on the rack. The RFID gate at each exit point plays a vital role in resolving these errors by accurately identifying the product's kind and quantity and automatically updating the information technology system. On the other hand, while dealing with high storage two, or three possible manual errors can arise: incorrectly defining the number, product category, and color.

Engaging in these tasks manually introduces a high likelihood of errors. For instance, operators must specify the color of each article, a process prone to mistakes given the multitude of colors, some of which are challenging to differentiate, particularly in a production setting. An operator often makes a mistake at the starting point of the assembly process for high storage two by unloading a greater number of articles than what is specified by the IT system. This situation commonly arises when one article is impaired or discarded, resulting in the absence of a crucial assembly that necessitates one or more articles promptly. Due to the automated adjustment of the IT system, the count on the cassette becomes inaccurate as it deducts the prescribed quantity to be unloaded, leading to improper storage levels. Hence, this disparity can result in an extra alteration of color in the paint shop, reducing production efficiency and raising production costs due to higher scrap rates and the requirement for additional labor. (Hellstrom & Wiberg, 2010).

This study examined the potential of RFID technology to improve inventory accuracy. The RFID tags used were at the case level. Implementing item-level tagging, although it offers more specific information on product movement, is currently expensive for low-value products. However, the use of data from an environment equipped with RFID technology, namely at the pallet and case levels, can improve processes and provide a strong argument for the implementation of RFID technology (Goyal, Aloysius, & Hardgrave, 2009).

RFID technology can provide limited assistance in cases of stolen items, particularly those involving unknown stock loss, at the individual case level. For example, if a case of a product is surreptitiously transported through the rear entrance, RFID technology can identify the box as it traverses the doorway, potentially signaling a theft. Subsequently, this data can be employed to modify the Perpetual Inventory (PI) by the quantities linked to the case. Likewise, when it comes to damaged or rotten items, RFID technology can assist in monitoring only if the entire case is thrown away in a garbage compactor that has an RFID reader. In such cases, modifications to the proportional-integral (PI) controller could be made accordingly. RFID technology is beneficial for recognizing individual things when they are thrown away into garbage compactors or other disposal machines (Goyal, Aloysius, & Hardgrave, 2009).

Inadequate management of returns can lead to both underestimated and overestimated Perpetual Inventory (PI) discrepancies (e.g., failure to include two returned items in the PI count). By utilizing RFID technology, the system is capable of accurately detecting and recording the return of objects and subsequently updating the inventory counts accordingly. RFID technology at the case level is effective in rectifying both overestimated and underestimated inaccuracies in physical inventory (PI) caused by mis-shipments from the Distribution Centre (DC). Let's examine two such scenarios: Firstly, in the event of an incorrect truck delivery to an incorrect store. In the absence of RFID technology, this blunder goes unnoticed until the vehicle is unloaded and the consignment is validated. Nevertheless, utilizing RFID technology enables the system to swiftly detect any mistakes when the boxes traverse an RFID portal during the unloading process. This allows for immediate rectification of receipts or issuing an alert to redirect the cargo to its intended destination. In addition, for specific instances when errors occurred on an individual basis (as opposed to the entire shipment), the system, with the assistance of RFID technology, is capable of automatically scanning and identifying the products that have been received. This eliminates the need to depend on shipment documentation from the distribution center or manual barcode scanning (Goyal, Aloysius, & Hardgrave, 2009).

By utilizing RFID technology, stores will get enhanced visibility into the status of delivered cases, determining whether they have been brought to the sales floor or stored in the back room. By combining increased visibility with point-of-sale data, a more accurate understanding of the inventory available on store shelves and in the backroom is obtained, leading to a reduction in inventory record mistakes. For example, if a truck delivers an extra amount of goods to the store, it can result in mistakes in the Perpetual Inventory (PI). This is because the store's records, which rely on shipping invoices, may not accurately reflect the surplus inventory. Using RFID technology, the system can accurately record the receipt of boxes as they are unloaded from the truck and pass through the RFID portal. This prevents any mistakes in the inventory data (Goyal, Aloysius, & Hardgrave, 2009).

Furthermore, RFID technology can be used to verify the precision of manual modifications carried out by store staff. When store staff manually modify inventory, a frequent mistake is inputting several zeros when they don't see a product on the shelf, even if there may be a case hidden in the backroom. The presence of an erroneous 'zero' number gives rise to two problems: firstly, it causes an understatement in the inventory count, and secondly, it triggers an unwanted product order in the system. By utilizing RFID technology, the system can determine with certainty whether the goods are located in the back room. As a result, decreasing incorrect manual adjustments helps to address problems associated with underestimated Perpetual Inventory (PI). By utilizing this improved visibility, businesses can automate inventory modifications by taking into account case receipts and the quantity of items in each case. RFID technology enhances the ability to track both in-store and backroom inventory, together with point-of-sale data. This enables the system to immediately correct any disparities in the system's physical inventory (Goyal, Aloysius, & Hardgrave, 2009).

2.9 Procurement Performance

The procurement performance of the rubber glove manufacturing industry in Sri Lanka is considered the validation factor of this study. Integrating RFID technology into an ERP system can significantly enhance procurement performance by providing real-time visibility, accurate tracking, and streamlined processes.

How can RFID be Used in Procurement?

The landscape of procurement processes has undergone a significant transformation with the integration of RFID technology. Through its capacity to promptly track and identify items in real-time, RFID presents numerous opportunities to elevate visibility and streamline efficiency within procurement operations.

A pivotal use of RFID in procurement lies in the domain of inventory management. Through the application of RFID tags to individual items, companies can precisely monitor their inventory levels without relying on manual interventions. This eradicates the need for time-consuming manual counts and mitigates the risk of human errors. Armed with immediate access to accurate data about stock levels, businesses can make well-informed decisions regarding the optimal timing for reordering or restocking items, thereby minimizing the occurrence of stockouts or excess inventory.

RFID technology is highly beneficial in the realm of supply chain traceability. Employing RFID tags on products or packaging materials enables companies to effortlessly track the journey of goods across the entire supply chain. This not only serves as a deterrent to counterfeiting but also guarantees adherence to regulatory mandates and quality control standards. Furthermore, RFID technology facilitates streamlined asset tracking within a procurement environment. Companies can affix RFID chips to high-value assets like machinery or equipment, enabling constant monitoring of their whereabouts and condition. This enhances asset utilization by averting loss or misplacement and facilitates the scheduling of maintenance based on real-time usage data.

Moreover, RFID technology strengthens security protocols in procurement procedures through the implementation of access control systems utilizing smart cards embedded with RFIDs, as opposed to conventional keys or passwords. These smart cards provide authorized personnel with secure access to restricted areas, effectively preventing entry by unauthorized individuals. In addition to these advantages, the incorporation of an RFID system in procurement operations leads to enhanced operational efficiency. This is achieved by minimizing the need for manual labor and streamlining processes across multiple stages, including receiving, storage management, order fulfillment, and shipping.

In general, the adoption of RFID technology offers substantial benefits to contemporary procurement methodologies. It provides organizations with heightened visibility across their supply chains, leading to improved decision-making, optimal resource allocation, and heightened customer satisfaction. The integration of this innovative solution into current workflows unleashes the considerable potential for growth, cost savings, and comprehensive process optimization within the procurement landscape (Oboloo, 2023).

The Benefits of Using RFID in Procurement

The advantages of utilizing RFID in procurement are numerous and significantly enhance visibility and monitoring across the supply chain. Real-time inventory management is made possible through RFID technology, offering precise data on stock levels. This capability empowers procurement teams to make well-informed decisions regarding the timing of supply reorders and maintaining optimal inventory quantities. Whether attached to individual items or pallets, RFID tags simplify the tracking of their movement from the supplier to the warehouse and ultimately to the end destination. This heightened visibility ensures timely delivery of goods and promotes better coordination between suppliers and buyers. Furthermore, RFID technology contributes to enhanced accuracy in receiving and shipping processes. The automation of these tasks with RFID scanners reduces human error, resulting in fewer discrepancies in orders.

Additionally, incorporating RFID in procurement serves as a deterrent to theft or loss of valuable assets. The real-time tracking features enable prompt detection of any unauthorized movement or tampering. Through the streamlining of procurement operations using RFID technology, companies can realize cost savings and enhance overall efficiency. The precise monitoring of inventory levels helps prevent both overstocking and understocking scenarios, optimizing the allocation of resources. The advantages of leveraging RFID in procurement are substantial, ranging from improved inventory management to heightened visibility across the supply chain. This innovative technology provides significant benefits for businesses seeking to streamline their procurement processes (Oboloo, 2023).

Affecting Factors for Procurement Performance

Enhancing the overall performance of the procurement system can be achieved by aligning staff competence, organizational structure, quality management systems, and information technology components with private-sector procurement processes. The objective of this alignment is to enhance the transmission of information and minimize the occurrence of delays in the processing of orders. Procurement performance, in this sense, refers to the proficient execution of personnel duties that enhance customer satisfaction, streamline information flow, and optimize procurement management. The assessment of performance enhancement will take into account factors such as the dependability of quality, reduced human error in decision-making, the uniformity of policy frameworks to facilitate the effective implementation of the procurement process, and the utilization of information technology capabilities and advantages in all purchasing activities (Barsemoi, Mwangagi, & Ode, 2014).

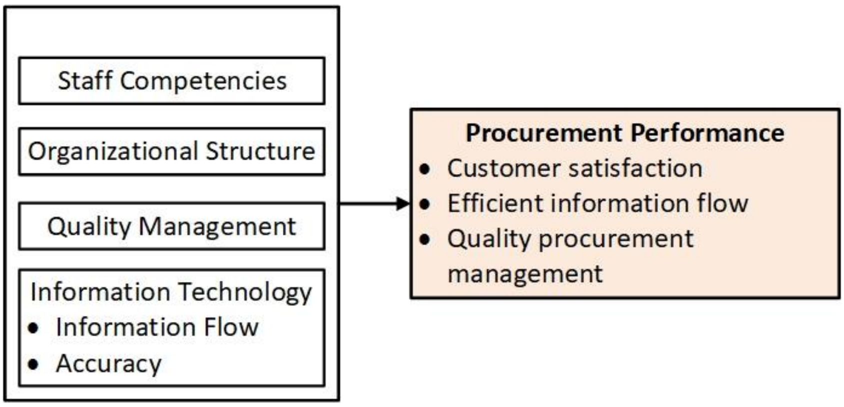

Figure 8: Information Technology Factors Affecting Procurement Performance

Source: Author developed based on (Barsemoi, Mwangagi, & Ode, 2014)

Figure 8 illustrates the substantial impact of information technology on procurement performance. The main factors that determine the impact of IT are the flow and accuracy of information, which in turn significantly influence customer satisfaction, efficient information flow, and the effective management of procurement - critical metrics for evaluating procurement performance. The figures revealed a robust positive correlation of 70.3% between the utilization of information technology (IT) and the effectiveness of procurement. This suggests that the use of information technology has a positive effect on the efficiency of procurement. Integrating IT into business operations, such as procurement, enhances procurement performance, as assessed by the company's service delivery. Information Technology (IT) plays a crucial role in reducing job completion time, enhancing operational effectiveness and efficiency, and eliminating issues with process quality and corruption (Barsemoi, Mwangagi, & Ode, 2014).

An accurate inventory stock record is obtained when the information documented in the stock record matches the actual physical inventory status (Schrady, 2016, as cited in Mutinda & Paul, 2018). The accuracy of inventory items is assessed by comparing the actual quantity on hand to the permanent inventory quantity, within set tolerances (Supply Chain Metric, 2016, as cited in Mutinda & Paul, 2018).

Accurate demand forecasting was employed to ascertain stock coverage, and the organization had established mechanisms to uphold inventory accuracy. The firm optimized its capacity effectively and responded promptly to customer inquiries, ensuring stock availability. However, there were identified areas for improvement, particularly in the proper handling of materials in cases of stockouts (Mutinda & Paul, 2018). The organization received an accurate quantity of products/services, fulfilled customer orders promptly, maintained a short cycle time for order delivery, exhibited a rapid customer response rate, ensured ample availability of goods, and effectively managed deadlines for products/services.

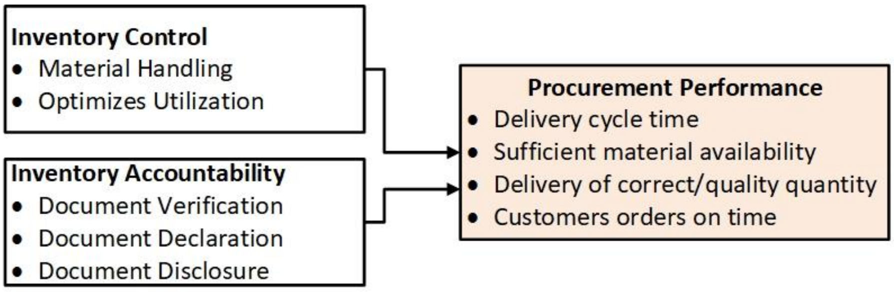

Figure 9: Inventory Control Factors Affecting Procurement Performance

Source: Author developed based on (Mutinda & Paul, 2018)

As illustrated in Figure 9, information control plays a primary role in influencing procurement performance. The key indicators of inventory control, namely material handling and optimized utilization, predominantly impact delivery cycle time, ensuring adequate material availability, delivering the correct/quality quantity, and fulfilling customer orders on time-integral components of procurement performance.

The findings on inventory control systems had a significant and favorable influence on performance. The introduction of computerized systems for monitoring inventory levels in the organization enabled the automation of management information reporting. These reports played a crucial role in providing information for inventory decisions, facilitating prompt restocking from the main shop, and immediately indicating the requirement for more products (Mutinda & Paul, 2018).

Regarding inventory control, organizations were required to guarantee precise demand forecasting for stock coverage. It was essential to establish mechanisms within the organization to ensure a prompt response to customer inquiries and proper material handling in cases of stock-related issues. Additionally, organizations were advised to collaborate with vendors to provide accurate predictions of delivery dates. The incorporation of modern technologies was recommended to enhance accuracy in predicting and monitoring stock levels (Mutinda & Paul, 2018).

Enhancing production scheduling through the implementation of Material Requirements Planning (MRP) systems has the potential to decrease inventory levels. This contributes to the establishment of lean inventory systems to a certain extent within sugar manufacturing companies in the western sugar belt, ultimately enhancing the performance of the procurement function. The utilization of IT applications in inventory management further improves the procurement function's performance in these companies. The automation of the inventory system through IT applications aids in minimizing errors and waste in the inventory, leading to increased efficiency (Mukopi & Iravo, 2015).

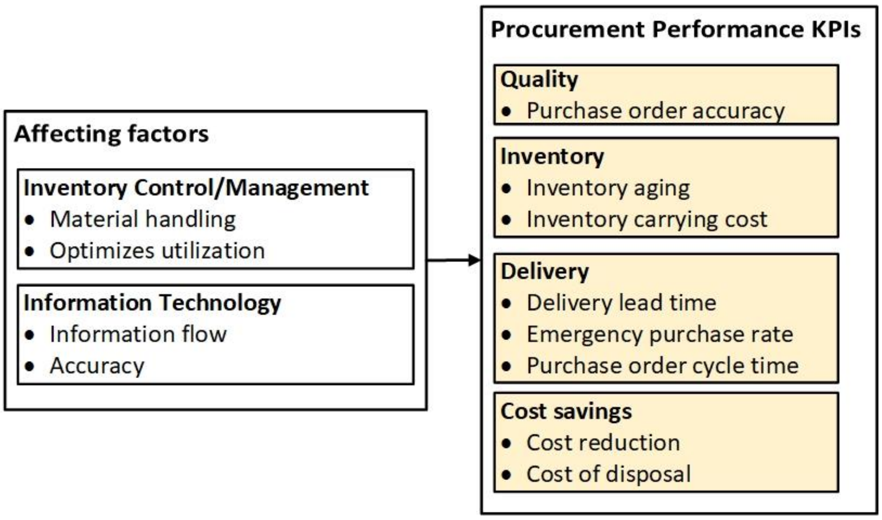

Figure 10: Affecting factors on procurement performance

Source: Author developed based on (Mutinda & Paul, 2018; Barsemoi, Mwangagi, & Ode, 2014; Robert, 2023)

According to Figure 10, inventory control and IT mainly affect procurement performance. Material handling and optimized utilization are the key indicators of inventory control. Information flow and accuracy are major indicators of IT. Those factors make changes in procurement performance through four different areas quality, inventory, delivery, and cost savings.

Purchase order accuracy entails delivering a precise and high-quality quantity of materials as per the actual requirements. An inventory aging report is a compilation of all on-hand items categorized by the time they have spent in inventory. This metric serves to pinpoint slow-moving inventory, enabling the assessment of costs associated with storing and maintaining these items before they are sold.

A substantial inventory aging level serves as an indication of capital being tied up in the form of inventory. The inventory carrying cost represents the comprehensive expenses associated with maintaining inventory, encompassing costs like rent for space, maintenance, wages, and various other overhead costs that impose a financial burden on the organization. Delivery lead time signifies the duration taken to deliver materials after the generation of the requirement. The emergency purchases rate reflects unplanned acquisitions resulting from inadequate material availability and inventory inaccuracies.

The rate can be quantified by comparing the frequency of emergency purchases to the total number of purchases conducted within a specific timeframe. Purchase order cycle time is gauged from the submission of a purchase requisition to the point when it is dispatched to a vendor, encompassing the entire ordering process and constituting the end-to-end purchase order cycle (Robert, 2023). Evaluating cost reduction involves comparing the expenses incurred through actual requirement purchases with those arising from purchases made due to inaccurate inventory (either overordering or underordering). The cost of material disposal can be assessed over a designated period. Utilizing these key indicators facilitates the measurement of procurement performance.

2.10 Chapter Summary

This chapter delves into the literature reviewed for the study, emphasizing its application to the research. It begins with a comprehensive overview of ERP systems, focusing on their essential role in organizational structures. The review highlights the significance of ERP systems, particularly SAP S/4 HANA, in enhancing efficiency and streamlining business processes. The advantages of SAP S/4 HANA, including advanced technologies, modular flexibility, and global accessibility, are positioned as state-of-the-art within the ERP domain. A detailed exploration of RFID systems follows, covering their historical development, system architecture, frequency variations, benefits, applications, and integration with ERP systems. The literature highlights the diverse applications of RFID technology across industries and its strategic importance when integrated with ERP systems, especially in supply chain management and business efficiency.

The integration of edge computing and novel technologies into ERP-integrated warehouse management is discussed, emphasizing how these advancements contribute to a more responsive, efficient, and secure operation. This results in optimized warehouse processes, improved inventory management, and enhanced overall productivity, with significant potential for further improvements as technology evolves. The chapter underscores the transformative impact of combining ERP systems with RFID technology. This integration is presented not only as a technological enhancement but also as a strategic approach that significantly improves decision-making, operational efficiency, and supply chain performance. Case studies are presented to demonstrate the tangible benefits and cost reductions achieved through the integration of ERP and RFID systems.

A brief history and the current global context of integrated ERP and RFID systems are provided, offering insights into their historical development and the present landscape. The section outlines different integration scenarios, middleware approaches adopted by major ERP vendors, and the potential for innovative business models and process optimization through RFID technology. Practical implementations and case studies are included to illustrate the tangible benefits organizations have gained from RFID-ERP integration.

Key metrics for integrated ERP and RFID systems are identified, including process automation, process control, performance management, and compliance. The literature categorizes supply chain integration into four tiers, emphasizing the role of ERP and RFID technologies in internal integration, supplier collaboration, customer engagement, and achieving a harmoniously linked supply chain. The critical importance of information sharing across supply chain members is highlighted, with IT playing a crucial role in integrating operational, tactical, and strategic information. The chapter also addresses the critical role of inventory accuracy in supply chain management (SCM). It identifies common causes of inaccuracy and explores how RFID technology can mitigate these challenges and enhance overall inventory management processes. The transformative potential of integrating RFID technology into procurement processes is emphasized, offering real-time visibility, accuracy, and streamlined operations. The benefits of RFID in improving inventory management, supply chain visibility, and preventing asset loss are highlighted, underscoring its advantages for businesses seeking to enhance procurement performance.

Finally, the chapter identifies the relationships between integrated ERP and RFID systems with inventory accuracy and procurement performance, drawing on research papers by Simchi-Levi (2003), Huang (2007), Liu & Chen (2009), Maticevic (2011), Rai (2006), Chuang & Shaw (2007), Oghazi (2009), Barsemoi (2014), Mukopi & Iravo (2015), and Mutinda & Paul (2018).

CHAPTER 3

METHODOLOGY

3.1 Introduction

This section details how the research achieves its aim and objectives. In section 3.2, research approaches were explored, and an inductive approach was chosen for this study. Section 3.3 covers the research design, including the purpose and strategy. The data collection methods are explained in section 3.4, while section 3.5 addresses the data analysis method. The method of system development is included in section 3.6. The data validation method is discussed in section 3.7. Finally, section 3.8 provides a summary of the chapter.

3.2 Research Approach

There are two research methodologies, the deductive approach and the inductive approach. The deductive approach entails the formulation of a theory and hypotheses, which are then tested through the design of a research strategy. Conversely, the inductive technique involves initially gathering facts and subsequently constructing a hypothesis through the study of the collected data (Saunders, Lewis, & Thornhill, 2009). If the primary interest lies in comprehending the reasons behind a phenomenon rather than merely describing the phenomenon itself, choosing an inductive research approach might be more suitable than a deductive one (Easterby-Smith, Thorpe, & Jackson, 2012).

An inductive research approach is used in this study to understand the reasons behind designing a single platform for integrating ERP and RFID systems. Data are collected from literature and semi-structured questionnaires to develop and evaluate the proposed system. The study compares the proposed system with the existing system and assesses its impact on procurement performance.

3.3 Research Design

The research design serves as the overarching blueprint outlining the approach to address the research question(s), with a clear emphasis on the significance of precisely defining these questions (Saunders, Lewis, & Thornhill, 2009). The transformation of research questions into a comprehensive research project is referred to as research design. This design encompasses elements such as the research purpose, research strategy, data gathering method, and data analysis (Robson, 2002, cited in Saunders, Lewis, & Thornhill, 2009).

The prevalent categorization of research purpose, commonly found in research methods literature, involves three main types: exploratory, descriptive, and explanatory An exploratory study is a powerful method for uncovering and understanding 'what is happening,' by generating new insights, raising questions, and analyzing occurrences from a novel perspective. Three main approaches to performing exploratory research include literature study, interviews with subject matter experts, and focus group interviews. Descriptive research seeks to provide an accurate depiction of individuals, events, or situations (Robson, 2002, cited in Saunders, Lewis, & Thornhill, 2009).

The selection of a particular research strategy hinges on the study's objectives, the nature of research questions, the researcher's perspective on sound research, and practical considerations like data source accessibility and time constraints (Sekaran & Bougie, 2013). Exploratory, descriptive, and explanatory research can be conducted using a range of research approaches, including experiments, surveys, ethnography, case studies, grounded theory, and action research (Yin, 2003, cited in Saunders, Lewis, & Thornhill, 2009).

Survey Research: Survey research allows for the gathering of both quantitative and qualitative data, making it adaptable for addressing a wide range of research inquiries. Surveys are frequently used in exploratory and descriptive research to gather data on individuals, occurrences, or circumstances. In addition, survey instruments may incorporate interviews and organized observation (Sekaran & Bougie, 2013).

Case Study: A case study, in this particular context, refers to a research approach that entails a systematic examination of a current occurrence within its real-world setting, utilizing various approaches to acquire empirical data (Yin, 2009, cited in Sekaran & Bougie, 2013). Case studies have the potential to provide both qualitative and quantitative data for further study and interpretation (Sekaran & Bougie, 2013).

Action Research: Consultants often use action research to drive change within organizations, starting with a pre-identified issue and gathering information to propose a temporary solution. This approach acknowledges potential unintended consequences, which are then evaluated and diagnosed. The process continues iteratively, with ongoing assessment of problems, solutions, and outcomes, leading to the development of new solutions until the issue is resolved, making action research a dynamic and evolving methodology (Sekaran & Bougie, 2013).

Figure 11 outlines the framework of this research, which aims to achieve four specific objectives. Using the literature review identify the current state-of-the-art integrated ERP and RFID systems in the world context and identify the gap between the integrated ERP and RFID systems in the rubber glove manufacturing industry in Sri Lanka. After collecting information, design an integrated ERP and RFID system called Supply Chain Smoother. Finally, the impact of the proposed system on procurement performance is tested. This research combines exploratory and descriptive purposes. It primarily focuses on designing a single platform for integrating ERP and RFID systems to enhance procurement performance in the rubber glove manufacturing industry. The development of the validation framework and the deployment of the Supply Chain Smoother system are based on data obtained from literature, surveys, and interviews. A pilot test is performed, and a descriptive analysis is conducted to compare the new system with the existing system.

In this research, surveys, case studies, and action research were employed to address the research questions and objectives outlined in chapters 1.3 and 1.4. Use structured questionnaires, semi-structured interviews, and structured observations as survey instruments. Selected rubber glove manufacturers as a specific industry to collect the information on identified problems in the supply chain process and apply the research output (Supply Chain Smoother) in the same industry to investigate the procurement performance against the existing system as a case study. This research identifies the problem of procurement performance and plans to address it through the proposed system. Develop the proposed system and evaluate through the structured observation comparing with an existing system. Follow the action research spiral model continuously to solve the identified problem by the proposed system with pilot tests.

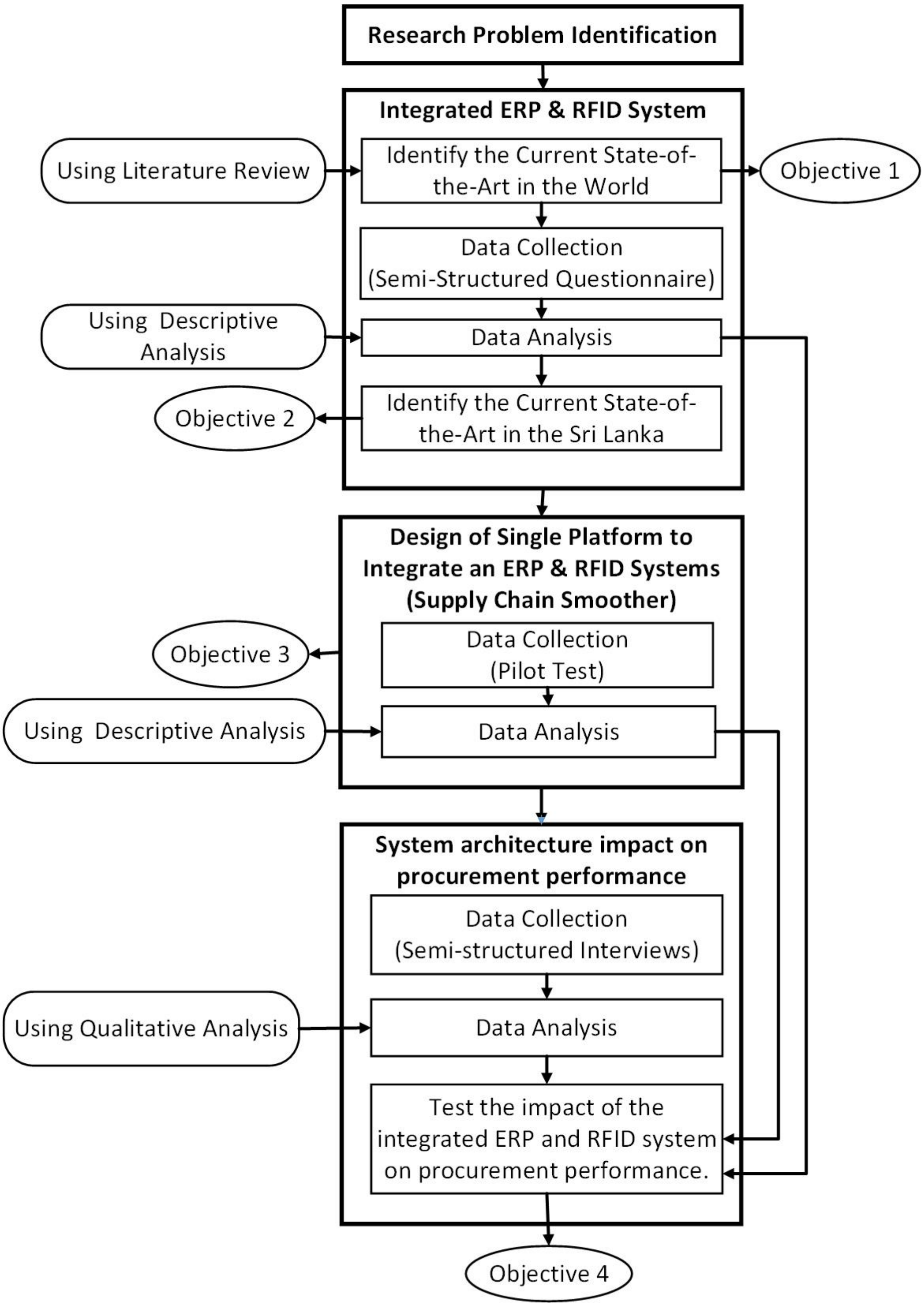

Figure 11: Research Framework

Source: Author developed based on research

3.4 Methods of Data Collection

In the field of business and management research, the terms quantitative and qualitative are frequently employed to distinguish between various approaches to data collection and data analysis techniques. Quantitative is frequently employed as a synonym for any technique of collecting data (such as a questionnaire) or examining data (such as graphs or statistics) that yields or involves numerical information. On the other hand, qualitative methods are commonly used as substitutes for acquiring information (e.g., interviews) or analyzing data (e.g., organizing data) that produces or involves non-numeric data. Qualitative research encompasses evidential material that extends beyond written language, including visual images and video recordings (Saunders, Lewis, & Thornhill, 2009).

3.4.1 Semi-Structured Questionnaire

One of the data collection techniques was the questionnaire survey. The online survey questionnaire was used to collect data for the questionnaire. According to Figure 12, existing system utilization and existing system functionality sections provide information to identify the current state-of-the-art ERP and RFID systems in the Sri Lankan context. The proposed/integrated system section provides information to measure the system performance based on process control, process automation, performance management, and compliance indicator clusters. The semi-structured questionnaire was developed with various themes in various indicators focusing on several supply chain stakeholders of the study shown in Appendix A.

Sampling techniques can be categorized into two groups: probability and non-probability. Probability sampling enables researchers to address research queries and achieve objectives that require statistical assessment of population characteristics based on the sample. Non-probability sampling is insufficient for addressing research inquiries or attaining goals that include drawing statistical inferences about population attributes. Snowball sampling is frequently employed in situations where it proves challenging to ascertain the individuals belonging to the targeted group. Snowball sampling may be the sole option for identifying populations that are challenging to ascertain (Saunders, Lewis, & Thornhill, 2009).

This survey is based on a non-probability sampling method under the snowball sampling technique. Distributed the survey among the employees of rubber glove manufacturers and their packing material suppliers through initial contact identified further contact and collected the data. The same target sample group was employed to collect data for understanding the current state-of-the-art ERP and RFID systems within the Sri Lankan context and to evaluate the performance of the proposed system,

- Production and warehousing of rubber glove manufacturing company- Data operators, executives, managers,
- Procurement and logistics of rubber glove manufacturing company - Executives, managers,
- IT/ERP consultant of rubber glove manufacturing company,
- Marketing of packing materials suppliers - Exective, managers,

According to the Sri Lanka Export Development Board, over 7 rubber glove manufacturing companies in Sri Lanka are in the gloves sector and more than 50 packing material suppliers in Sri Lanka. Five export-oriented rubber glove manufacturing companies' employees and eight packing material suppliers' employees participated in the survey as responders (EDB, 2021).

The online survey was conducted to collect responses using Google Forms. The survey questionnaire was distributed among 300 respondents using different methods such as email, Linked In, Facebook, WhatsApp, Email, etc. In responses, 95 completed responses were received. And 11 responses were ineligible. So the total response rate can be calculated as follows for this study (Saunders, Lewis, & Thornhill, 2009).

$$\text{Total Response Rate} = \frac{\text{Total Number of Responses}}{\text{Total number of sample} - \text{ineligible}}$$

$$37\% = \frac{106}{300 - 11}$$

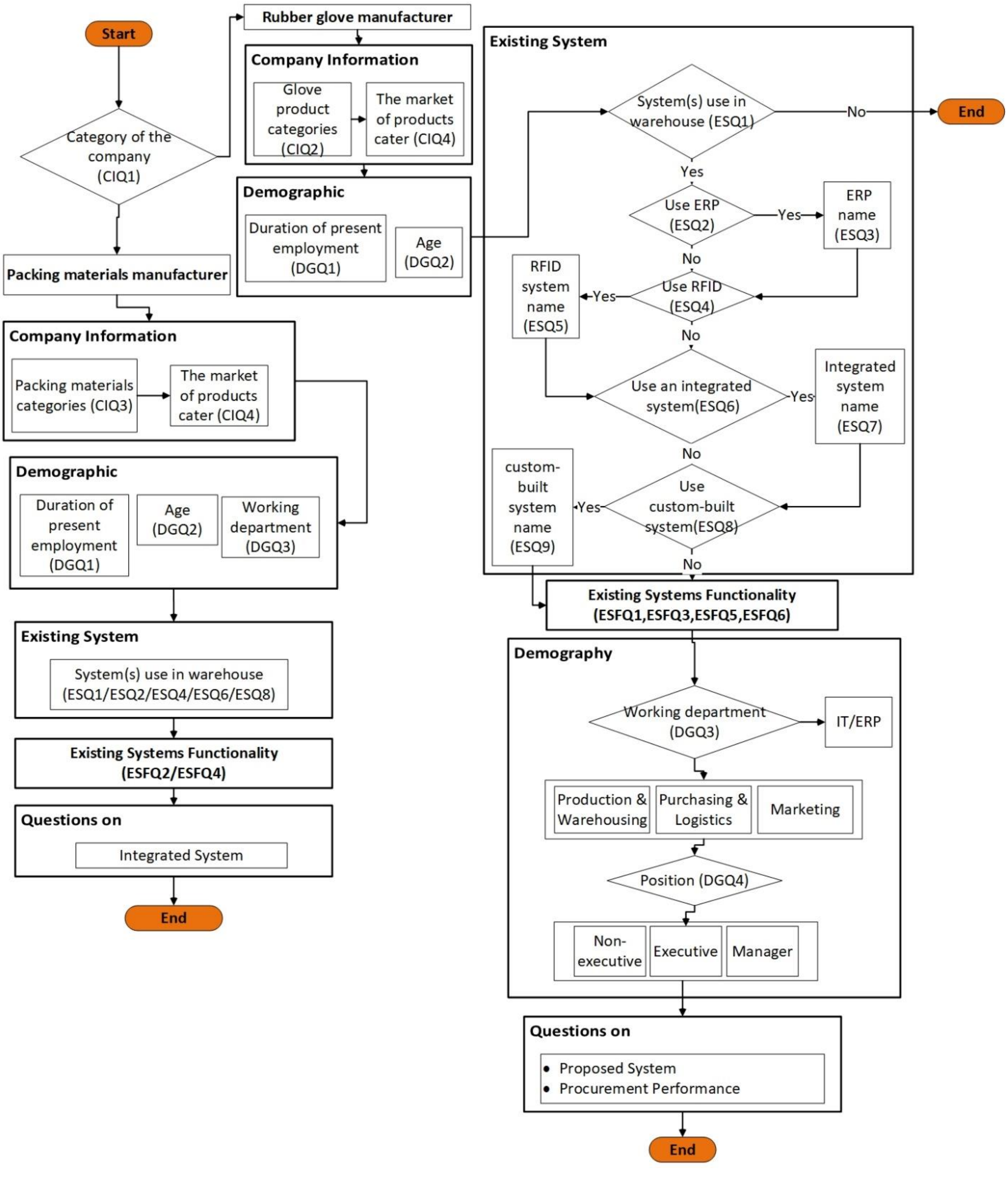

Figure 12: Semi-structured questionnaire structure

Source: Author developed based on literature review

3.4.2 Pilot Test (Structured Observation)

A structured observational study occurs when the observer has a predetermined set of categories for studying activities or phenomena. Structured observation is generally characterized by its quantitative nature. Customized formats for documenting observations can be created for each study to correspond with the research aims. Structured observation typically entails documenting many characteristics of the focal attribute, such as the duration and frequency of an occurrence, as well as the precise actions that precede and follow it. The observations, documented in worksheets or field notes, are subsequently subject to systematic analysis (Sekaran & Bougie, 2013).

Structured observation serves as the data collection method in this research to evaluate the functionality of the proposed system in comparison to the existing system, and to assess the impact of the proposed system on procurement performance, focusing on quality, delivery, inventory management, and cost savings. Data analysis procedure like statistical data was used to generate numerical data. The structured format used to collect data on existing systems and proposed systems' (Supply Chain Smoother) pilot tests is shown in Appendix B. Structured observation was done with pilot tests at five warehouse locations in one week period for each location of a rubber glove manufacturing company.

3.4.3 Semi-Structured Interviews

In semi-structured interviews, use the same set of question lists for the selected sample group. The question list was prepared based on procurement performance indicator clusters such as quality, delivery, inventory management, and cost savings. This interview is based on a non-probability sampling method under the purposive sampling technique. Conducted semi-structured interviews among the managers of rubber glove manufacturers. The target sample group was managers in

- Production and warehousing of rubber glove manufacturing company
- Procurement and logistics of rubber glove manufacturing
- IT/ERP consultant of a rubber glove manufacturing company,

Managers from one export-oriented rubber glove manufacturing company, who are permanent employees with over five years of experience, participated in the interviews. These face-to-face, one-on-one interviews were conducted using a non-standardized approach. Semi-structured interviews were conducted to obtain feedback from the company's management regarding the impact of the proposed system on procurement performance, as analyzed from the structured observation data. A total of five semi-structured interviews were completed, with the interview structure detailed in Appendix I.

3.5 Methods of Data Analysis

In business and management research, quantitative and qualitative terms are used to describe data collection and analysis methods, focusing on numeric and non-numeric data, respectively. This study used a mixed methods approach, combining both quantitative and qualitative data collection and analysis. In mixed methods research, these techniques can be applied concurrently or consecutively but are not integrated during analysis. Quantitative data undergoes quantitative analysis, while qualitative data undergoes qualitative analysis, with the research design potentially prioritizing one method over the other (Saunders, Lewis, & Thornhill, 2009).

3.5.1 Quantitative Data Analysis

Descriptive statistics analysis was used in data analysis to meet the objectives of this research. Data cleaning was done by checking the outliers. The normality test did check whether the data were normally distributed or not. Skewness values and kurtosis values were used in the normality test. Cronbach’s Alpha was used as the statistical measure to check the internal consistency (Pallant, 2017). A descriptive statistic is a statistical analysis process that can explain what information can be obtained from the data that we gathered from the survey questionnaire (Kemp, Hort, & Hollowood, 2018). The data collected from the semi-structured questionnaire were analyzed using SPSS version 29. The analysis involved conducting a frequency analysis to identify the current state-of-the-art integrated ERP and RFID systems in rubber glove manufacturing companies in Sri Lanka.

Summarizing data for individual variables can be done using a frequency distribution table, which lists the number of cases in each category for categorical data. When dealing with a large number of categories or numerical values, it's necessary to group the data into categories that align with the research questions and objectives. Quantitative descriptions for samples and populations typically include measures of central tendency (mode, median, mean) to provide an impression of common or average values. Additionally, describing the dispersion of data around the central tendency is important, with interquartile range and standard deviation being common methods for this purpose (Saunders, Lewis, & Thornhill, 2009). The data collected from the pilot test were analyzed using Microsoft Excel 2016. Test the impact of an integrated system on procurement performance by conducting a comparative descriptive analysis of the pilot test data from the proposed system against the existing system. Frequency distribution, central tendency, and dispersion measures are used as descriptive statistics when analyzing the pilot test data from the proposed system against the existing system.

3.5.2 Qualitative Data Analysis

Qualitative analysis encompasses four general steps: summarizing, categorizing, and structuring data using narratives. Summarizing condenses large amounts of text into fewer words to identify the main themes, helping researchers become familiar with key themes, explore them further in future data collection, and identify relationships between themes while noting any relevant observations about the interview setting or participants. Categorizing involves creating categories and attaching these to meaningful data chunks, with categories acting as codes to group data and provide a structure for the research project. Unitizing data assigns relevant units such as words, lines, sentences, or paragraphs to appropriate categories, facilitating the search for key themes, patterns, and relationships. Structuring using narratives involves sequencing accounts of experiences to convey meaning, highlighting the significance of related events for the narrator and the researcher (Saunders, Lewis, & Thornhill, 2009).

To assess the impact of the integrated ERP and RFID system on procurement performance, four themes quality, delivery, inventory, and cost savings were identified as key indicators from the literature. Interviews were conducted and the responses were summarized according to these themes, categorizing the data to identify patterns and relationships, and structuring the findings into a coherent narrative to provide meaningful insights into how the integrated system influences these procurement performance indicators.

3.6 Methodology of System Development

The methodology of Supply Chain Smoother (software application and hardware device) development consists of six steps. Such as identifying problems and motivation, defining objectives of the research, designing and developing solutions, building simulation/demonstration, and testing and conclusion (see Figure 13).

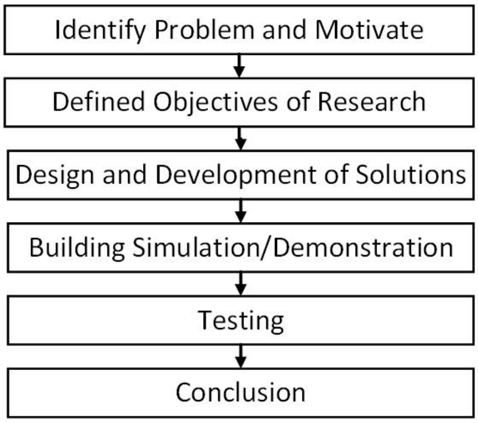

Figure 13: Flowchart of research methodology for system development

Source : (Pane, Awangga, & Azhari , 2018)

Problem identification is discussed in the 1.2 section of the research and objectives are defined in the 1.4 section of the research. The design and development of the solution are in section 4.4.1, building simulation/demonstration is in section 4.4.5, testing/pilot test results are included in section 4.4.6, and the conclusion is discussed in section 5.2.

3.7 Methods of Data Validation

Two frameworks are employed as methods of data validation in this research. The first framework assesses the performance of the proposed system against the existing system, focusing on process control, process automation, performance management, and compliance. The second framework evaluates the impact of the proposed system on procurement performance, emphasizing quality, delivery, inventory management, and cost savings.

3.7.1 Validation Framework Based on System Performance Indicators (Objective 2)

According to Figure 14, a validation framework is designed to identify and validate the existing system and proposed integrated ERP and RFID system performance based on process control, process automation, performance management, and compliance indicator clusters.

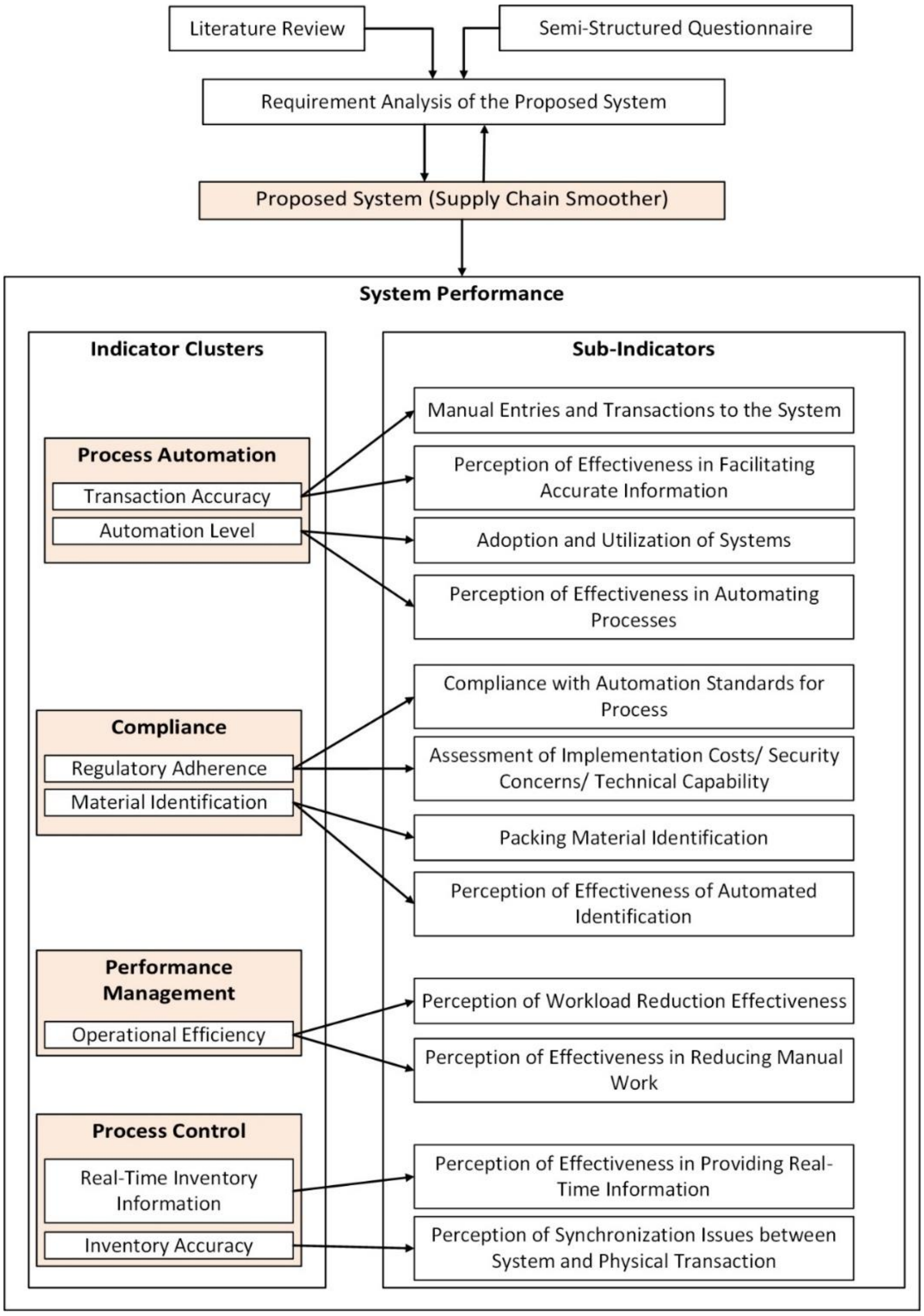

Figure 14: Validation framework based on system performance indicators
Source: Author developed based on literature review

- Operationalization of variables

Operationalizing refers to the process of making abstract concepts measurable and tangible. Operationalizing involves investigating the behavioral features, aspects, or facets associated with the notion. These features are further converted into quantifiable and visible components to theory a measurement index for the notion. Implementing a notion requires an order of actions. Preliminarily, it is important to formulate a precise and comprehensive specification of the construct that is intended to be quantified. Next, it is imperative to consider the substance of the measure, which entails creating an instrument (consisting of one or more items or questions) that accurately assesses the desired idea. Afterward, it is necessary to establish a response format, such as a seven-point ranking scale with endpoints labeled as "strongly disagree" and "strongly agree". Lastly, the measuring scale must undergo an evaluation to determine its validity and reliability (Sekaran & Bougie, 2013).

The operationalization of the variables table was developed based on the literature review. The five-point Likert scale was used as the measurement tool for identifying current state-of-the-art ERP and RFID integrated systems in rubber glove manufacturing companies and the capability of their packing material suppliers to engage with the proposed system as a supply chain stakeholder. The following five-point Likert scale was used in the questionnaire in this research. One indicates strongly agree; two means agree, three indicates neutral, four standards disagree, and five shows strongly disagree.

The operationalization of the variables (variable table) for this validation model can be seen in Table 2. Five sections are included in the questionnaire company information, existing system utilization, existing system functionalities, proposed system, and procurement performance..

Respond where,

RGMC: Rubber Glove Manufacturing Company
- PMS: Packing Material Supplier
- Non-Exec: Non-Executive
- Exec: Executive
- Mgr: Manager
- IT: IT/ERP Conusultant
- Common: All responders

Table 2: Operationalize Table

Section	Indicator Cluster	Sub-Indicator	Respond	Variable	Label	Measure	Source of literature
Company Information	-	-	Common	Category of the company	CIQ1	Nominal	Author Developed
				The market of Companies' products cater	CIQ4		
			RGMC	Glove product categories	CIQ2		
			PMS	Packing materials categories	CIQ3		
Demographic	-	-	Common	Duration of present employment	DGQ1		
				Age	DGQ2		
				Working department	DGQ3		
				Position/role in the company	DGQ4		
Existing System Utilization	Process Automation (Automation Level)	Adoption and Utilization of Systems	Common	System(s) to manage packing materials/finished goods in a warehouse	ESQ1	Nominal	Author Developed
				ERP system to manage packing materials/finished goods	ESQ2		
				RFID system to manage packing materials/finished goods	ESQ3		
				Integrated ERP and RFID systems to manage packing materials/finished goods	ESQ4		
				Custom-built system (internally or externally developed) to manage packing materials/finished goods	ESQ5		
			RGMC	Name of the ERP system	ESQ6	-	
				Name of the RFID system	ESQ7		
				Name of the integrated system	ESQ8		
				Name of the custom-built system	ESQ9	Nominal	(Chuang & Shaw, 2007)
Existing Systems Functionality	Process Automation (Transaction Accuracy)	Manual Entries and Transactions to the System	PMS	Manual Entry of AOD	ESFQ2		
			RGMC	Manual Entry of GRN	ESFQ1		
				Manual Material Transfer Transactions	ESFQ5		
				Manual Material Return Transactions	ESFQ6		

Section	Indicator Cluster	Sub-Indicator	Respond	Variable	Label	Measure	Source of literature
Existing Systems Functionality	Compliance (Material Identification)	Packing Material Identification	PMS	Identification of received items	ESFQ3	Nominal	(Huanga, Zhanga, & Jiangb, 2007; Dolgui & Proth, 2008; Liu & Chen, 2009; Matičević, Čičak, & Lovrić, 2011)
			RGMC	Identification of dispatched items	ESFQ4		
Proposed System	Process Automation (Transaction Accuracy)	Perception of Effectiveness in Facilitating Accurate Information	RGMC (Exec)	Generate accurate and summarized reports for top management.	GESPAQ1	Likert Scale	
				Enhance customer satisfaction by enabling a quick response to customer demand.	GESPAQ2		
			RGMC (Mgr)	Accurate decision-making and enhanced forecasting capabilities.	GMSPAQ1		
			RGMC (Non-Exec)	Accurate quantity records	GNESPAQ1		
	Process Automation (Automation Level)	Perception of Effectiveness in Automating Processes	RGMC (IT)	Perception of Effectiveness in Automating Processes	GITSPAQ1		
	Compliance (Regulatory Adherence)	Compliance with Automation Standards for Process	RGMC (IT)	Compliance with RFID Data Capturing and Automation Processes	GITSCQ1	Likert Scale	(Mukopi & Iravo, 2015; A Majeed & Rupasinghe, 2017)
				Compliance with Automation Standards for Inbound and Outbound Tasks	GITSCQ2		
				Recommendation of integrating an ERP system with RFID technology in the company.	GITSCQ9	Nominal	
				Additional comments or insights regarding your recommendation.	GITSCQ10	-	

Section	**Indicator Cluster**	**Sub-Indicator**	**Respond**	**Variable**	**Label**	**Measure**	**Source of literature**
Proposed System	Compliance (Regulatory Adherence)	Assessment of Implementation Costs/ Security Concerns/ Technical Capability	RGMC (IT)	Assessment of Implementation Costs for RFID and ERP Integration	GITSCQ4	Nominal	(Gruen & Corsten, 2008; Dolgui & Proth, 2008; Liu & Chen, 2009; Matičević, Čičak, & Lovrić, 2011; Barsemoi, Mwangagi, & Ode, 2014; Oghazi, Rad, Karlsson, & Haftor, 2018; Mutinda & Paul, 2018)
				Assessment of Security Concerns Related to ERP and RFID Integration	GITSCQ5		
				Specified security issue	GITSCQ6	-	
				Assessment of Technical Challenges in ERP and RFID Integration	GITSCQ7	Nominal	
				Specified technical issue	GITSCQ8	-	
	Compliance (Material Identification)	Perception of Effectiveness of Automated Identification	PMS	Identification of finished goods that are ready for dispatch from the warehouse.	SSCQ1	Likert Scale	
				Handling and tracing finished good lots until it will be dispatched.	SSCQ2		
			RGMC (Exec)	Standardized information to all stakeholders for prompt decisions and accurate forecasting.	GESCQ1		
			RGMC (Non-Exec)	Standardized information on packing material lots	GNESCQ1		
			RGMC (IT)	Mostly weighted sub-tasks of operation that can be automated by RFID.	GITSCQ3	Nominal	
	Performance Management (Operational Efficiency)	Perception of Effectiveness in Reducing Manual Work	RGMC (Exec)	Need for manual Excel-based tasks.	GESPMQ2	Likert Scale	
			RGMC (IT)	Processing time by data capturing	GITSPMQ1		
		Perception of Workload Reduction Effectiveness	RGMC (Mgr)	Reduce employee workload, freeing up time for other tasks.	GMSPMQ1		
			RGMC (Non-Exec)	Operator workload	GNESPMQ1		

Section	Indicator Cluster	Sub-Indicator	Respond	Variable	Label	Measure	Source of literature
Proposed System	Process Control (Real-Time Inventory Information)	Perception of Effectiveness in Providing Real-Time Information	PMS	Real-time information with visual feedback on relevant purchase orders (PO)	SSPCQ1	Likert Scale	(Chuang & Shaw, 2007; Dolgui & Proth, 2008; Liu & Chen, 2009; Matičević, Čičak, & Lovrić, 2011; Mukopi & Iravo, 2015; A Majeed & Rupasinghe, 2017; Gruen & Corsten, 2008)
			RGMC (Exec)	Provide real-time inventory information to make decisions.	GESPCQ1		
			RGMC(IT)	Provides real-time information	GITSPCQ2		
	Process Control (Inventory Accuracy)	Perception of Synchronization Issues between System and Physical Transaction	RGMC (Non-Exec)	Packing materials transfers in the system and physically at the same time	GNESPCQ1		
			RGMC (Non-Exec)	Packing materials returns in the system and physically at the same time	GNESPCQ2		
	-	-	PMS	Possibility of RFID code insertion	SSQ1	Nominal	
				Cost of RFID tags	SSQ2		
			RGMC(IT)	Awareness on RFID	GITSQ1		
				RFID be a technology diver for the future of supply chains	GITSQ2		
			RGMC(IT)	Experience in ERP and RFID integration	GITSQ3		
			RGMC(IT)	Well-knowledge about the ERP BAPI technology.	GITSQ4		
Procurement Performance	Quality	Purchase order accuracy	RGMC (Exec)	Reducing Overordering or Underordering	GEPPQQ1	Likert Scale	
		Inventory discrepancy	RGMC(IT)	Demand Visibility Improvement	GITPPQQ1		

Section	Indicator Cluster	Sub-Indicator	Respond	Variable	Label	Measure	Source of literature
Procurement Performance	Delivery	GRN Cycle Time	RGMC (Mgr)	Lead Time Reduction	GMPPDQ1	Likert Scale	(Barsemoi, Mwangagi, & Ode, 2014; Oghazi, Rad, Karlsson, & Haftor, 2018; Mutinda & Paul, 2018)
		Emergency Purchase Rate due to the inventory figure	RGMC (Exec)	Reducing Information Processing Time	GEPPDQ1		
			RGMC(IT)	Impact of Real-Time Data on Process Efficiency	GITPPDQ1		
			RGMC (Non-Exec)	Elimination of Data Processing Time	GNEPPDQ1		
	Inventory Management	Inventory Adjustment Rate (Quantity)	RGMC(Exec)	Reducing Manual Adjustments	GEPPIMQ1		
			RGMC(IT)	Inventory shrinkage	GITPPIMQ1		
				Stock out	GITPPIMQ2		
				Inventory management	GITPPIMQ3		
				Inventory adjustments	GITPPIMQ4		
				Complexity and Accuracy of Manual Entry	GITPPIMQ5		
			RGMC (Mgr)	Real-time inventory updates.	GMPPIMQ1		
			RGMC (Non-Exec)	Impact of Manual Transfers on Inventory Accuracy	GNEPPIMQ1		
				Impact of Manual Returns on Inventory Accuracy	GNEPPIMQ2		
	Cost saving	-	RGMC (Mgr)	Labor costs	GMPPCSQ1	Likert Scale	
		Inventory Discrepancy Rate		Precise inventory figures and decrease disposal costs.	GMPPCSQ3		
				Precise inventory figures and reduce stock-holding costs.	GMPPCSQ2		
				Precise inventory figures and decrease provision amounts.	GMPPCSQ4		

3.7.2 Validation Framework Based on Procurement Performance KPIs

A validation framework (see Figure 15) is designed to identify and measure the procurement performance based on its KPIs.

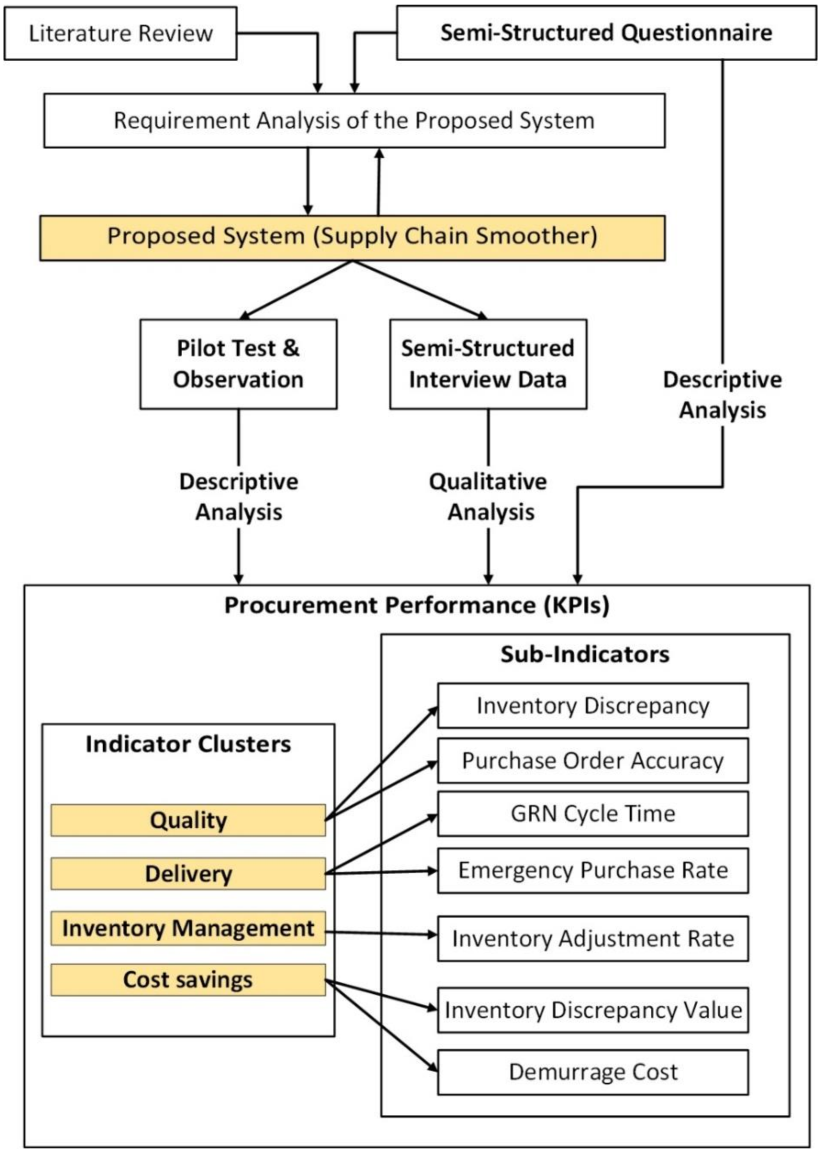

Figure 15: Validation framework based on procurement performance KPIs
Source: Author developed based on literature review

According to the literature, key indicators of procurement performance include quality, delivery, inventory management, and cost savings, with specific metrics such as inventory discrepancy, purchase order accuracy, GRN cycle time, emergency purchase rate, inventory adjustment rate, inventory discrepancy value, and demurrage cost (Robert, 2023; Barsemoi, Mwangagi, & Ode, 2014). Detailed KPIs are provided in Table 3.

Table 3: Indicators definition table

Indicator	Sub Indicators	Measures	Explanation	Source from Literature
Quality	Inventory discrepancy	$(RecInv - AInv)$	Measures the difference between recorded GRN, transferred and returned quantities, and physical stock.	(Pajić, Andrejić, & Kilibarda, 2021), (Robert, 2023)
	Purchase order accuracy	$\frac{\lvert (AReq + Wtge) - POQty \rvert}{(AReq + Wtge)} \times 100\%$	The actual total requirement is determined after allocating physical inventory to pending sales order requirements and adding the wastage quantity. The purchase order quantity is calculated after allocating system inventory figures to pending sales order requirements and adding the wastage quantity. The percentage of relative difference between the actual total requirement and the purchase order quantity is measured through this function.	
Delivery	GRN cycle time	$(GRNDT - GRDT) \times (60 \times 24)$ $(GRNDT - GRDT) \times (60 \times 60 \times 24)$	Measure the difference between the date and time when a Goods Receipt Note (GRN) is created in the system and the date and time when the goods are received at the location.	(Dunham, 2024) (Jenkins, 2023) (Robert, 2023)
	Emergency purchase rate due to the inventory figure	$\frac{NumEP}{TNumPO} \times 100\%$	Percentage of the relative difference between the number of emergency purchases due to the inaccurate inventory figure and the total number of purchase orders.	

Indicator	Sub Indicators	Measures	Explanation	Source from Literature
Inventory Management	Inventory adjustment rate (Quantity)	$\frac{TInvAdj}{TPICount} \times 100\%$	Percentage of the relative difference between total inventory adjustment (to match system inventory figure and physical stock figure) and total physical inventory figure.	(Gergely, 2024) (Robert, 2023)
Cost Saving	Inventory discrepancy value	$(RecInv - AInv) \times UCost$	Measures the value of the difference between recorded GRN, transferred and returned quantities, and physical stock by multiplying per unit cost.	(Katrych, 2022) (Robert, 2023)
	Demurrage cost due to the emergency purchases	$(ActDW - AFTim) \times DemRate$	Measures the cost of the difference between the total time that the shipment, vehicle, or container spends at the specified location due to the emergency purchases and the predefined amount of time that a shipment, vehicle, or container is allowed to stay at the location without incurring extra costs.	

Measures where;

- Recorded Inventory = RecInv
- Actual Inventory = AInv
- Actual Requirement = AReq
- Wastage = Wtge
- Purchase Order Quantity = POQty
- Date and Time of GRN Creation = GRNDT
- Date and Time of Goods Receipt = GRDT
- Number of Emergency Purchases = NumEP
- Total Number of Purchase Orders = TNumPO
- Total Inventory Adjustments (Quantity) = TInvAdj
- Total Physical Inventory Count = TPICount
- Unit Cost = UCost
- Actual Dwell Time = ActDW
- Allowed Free Time = AFTim
- Demurrage Rate = DemRate

3.8 Chapter Summary

This chapter outlines the methodology to achieve the research aims, focusing on an inductive approach to understanding phenomena. It includes research design, data collection, analysis, system development, and validation, employing semi-structured questionnaires and interviews to explore the integration of ERP and RFID systems in Sri Lanka's rubber glove manufacturing industry. The study uses exploratory and descriptive methods, combining literature reviews, surveys, and observational methods during pilot testing to evaluate the impact on procurement performance.

Quantitative methods involve collecting numerical data via questionnaires, analyzed with tools like SPSS, while qualitative methods gather non-numeric data through interviews. A semi-structured questionnaire was distributed online to employees of rubber glove manufacturers and packing material suppliers, achieving a 37% response rate. Structured observations and semi-structured interviews provided qualitative insights, targeting professionals in production, warehousing, procurement, logistics, IT/ERP consulting, and marketing.

A mixed methods approach was used, combining quantitative and qualitative data collection and analysis. Quantitative data from the questionnaire were analyzed using SPSS, while pilot test data were analyzed with Excel to compare the proposed Supply Chain Smoother against existing systems. Qualitative data from interviews were summarized and categorized to assess the integrated ERP and RFID system's impact on procurement performance, focusing on quality, delivery, inventory, and cost savings. Data validation employed two frameworks: descriptive analysis of semi-structured questionnaires and pilot test data, and semi-structured interviews analyzed using procurement performance KPIs. Key indicators include inventory discrepancy, purchase order accuracy, GRN cycle time, emergency purchase rate, inventory adjustment rate, and demurrage cost.

CHAPTER 4

DATA ANALYSIS, RESULTS, AND DISCUSSION

4.1 Introduction

This chapter explains the analysis of the data gathered in the study. The proposed system design, approach, analysis and design, implementation, and demonstration are discussed in this chapter. In this chapter, the data analysis, results, and discussion are systematically organized according to the main research objectives.

This comprehensive study focuses on the rubber glove manufacturing industry in Sri Lanka, addressing issues within ABC Rubber Glove Manufacturing Company's ERP system, particularly related to inaccurate inventory levels impacting procurement performance. The proposed solution, integrating ERP and RFID systems, aims to enhance supply chain functions and improve operational efficiency. The study's findings, supported by data analysis and pilot tests, indicate that the integrated system significantly reduces processing times and errors, enhances inventory accuracy, and optimizes procurement performance, demonstrating the critical role of technology integration in the industry.

4.2 Objective 1

Objective 1 is to identify the current state-of-the-art integration of ERP and RFID systems in the world using a critical review of the literature.

There are several scenarios discussed in Chapter 2, regarding integrating the ERP and RFID systems in the world. Most manufacturing companies integrate their ERP system with automatic data capturing technology (RFID) to manage their warehouse to eliminate errors that occur due to the manual data entering the system.

4.3 Objective 2

Objective 2 is to identify the current state-of-the-art ERP and RFID systems in the rubber glove manufacturing industry in the Sri Lankan context using descriptive analysis of the semi-structured questionnaire.

4.3.1 Frequency Distribution Analysis

Frequency analysis was done for the company information, demographics, existing systems, existing systems functionality, and suppliers' feedback on the proposed integrated ERP system described in this section.

A. Company Information

a. Company Category

Figure 16 shows the percentage of the value of rubber glove manufacturers and packing material suppliers participants in the survey. As a percentage, 80% were rubber glove manufacturers respondents, and 20% were packing material suppliers respondents.

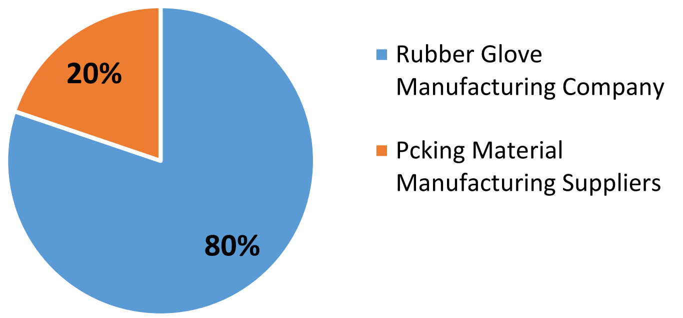

Figure 16: Company Category

b. Glove Product Composition

Table 4 shows the percentage of the value of rubber glove manufacturers’ categories of glove products in the survey. As a percentage, 20% were produced disposal gloves, 11.2% produced arm sleeves, 18.2% were produced sports gloves, 25.3% produced supported gloves, and 25.3% produced unsupported gloves.

Table 4: Glove product composition

		Responses		Percent of Cases
		N	Percent	
Glove_Type	**Disposable Gloves**	57	20.0%	75.0%
	Arm Sleeves	32	11.2%	42.1%
	Sports	52	18.2%	68.4%
	Supported Gloves	72	25.3%	94.7%
	Unsupported Gloves	72	25.3%	94.7%
Total		285	100.0%	375.0%

c. Packing Material Composition

Table 5 shows the percentage of the value of suppliers' categories of packing materials in the survey. As a percentage, 15% produced outer bags, 15% produced inner bags, 17.5% produced outer cartons, 17.5% produced inner cartons, 20% produced display boxes, and 15% produced header cards.

Table 5: Packing Material Composition

		Responses		Percent of Cases
		N	Percent	
Packing_Material_Type	**Outer Bag (OB)**	6	15.0%	31.6%
	Inner Bag (IB)	6	15.0%	31.6%
	Outer Cartons (OC)	7	17.5%	36.8%
	Inner Cartons (IC)	7	17.5%	36.8%
	Display Boxes (DB)	8	20.0%	42.1%
	Header Cards (HD)	6	15.0%	31.6%
Total		40	100.0%	210.5%

d. Composition of Retail Market

Figure 17 shows the percentage of the value of the product market of rubber glove manufacturers and packing material suppliers participants in the survey. As a percentage, 81% of respondents were catering to export and local markets, 11% of respondents were catering to local markets, and 8% of respondents were catering to solely export-oriented markets.

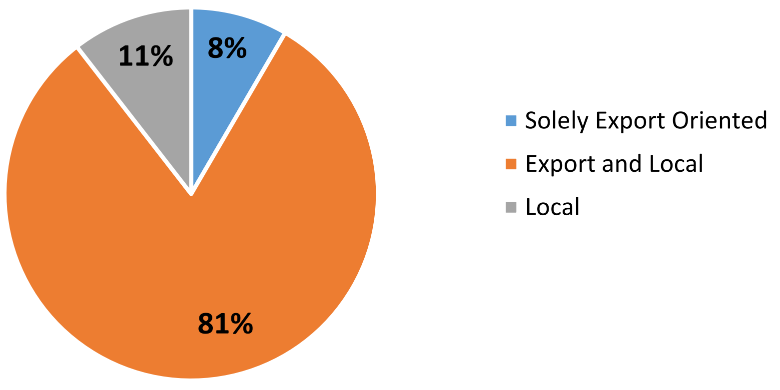

Figure 17: Composition of the Retail Market

B. Demographic

a. Employment Period

Figure 18 shows the percentage of the value of the duration of present employment of participants in the survey. As a percentage, 60% of respondents were working 3-5 years in the company, 35% of respondents were working more than 5 years in the company, 3% of respondents were working 1-2 years in the company, and 1% respondents were working below one year in the company.

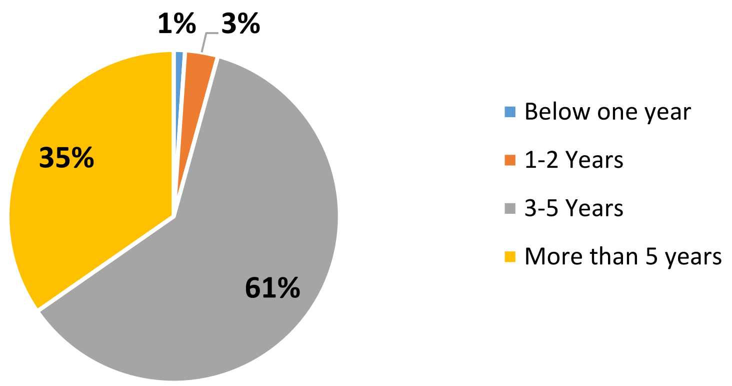

Figure 18: Employment Period

b. Age Distribution

Figure 19 shows the percentage of the value of the age of participants in the survey. As a percentage, 74% of respondents were 20-35 years, 24% of respondents were 35-50 years, and 2% of respondents were 50-65 years.

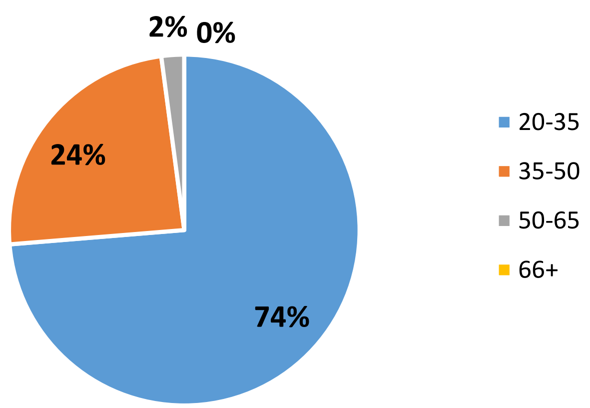

Figure 19: Age Distribution

c. Working Department

Figure 20 shows the percentage of the value of the working department of participants in the survey. As a percentage, 49% of respondents were in the production and warehousing department, 25% of respondents were purchasing and logistics department, 20% of respondents were marketing department, and 6% of respondents were IT/ERP department.

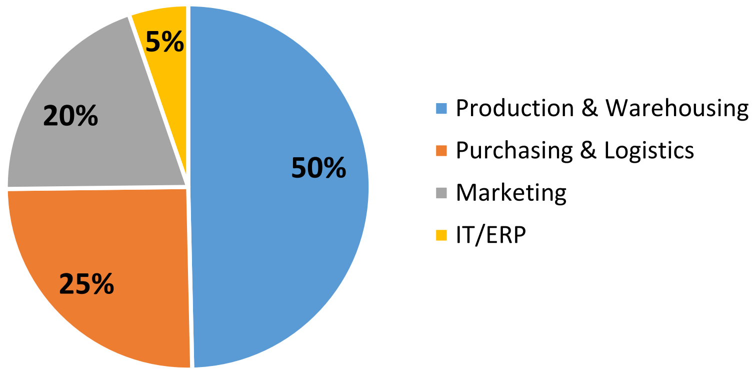

Figure 20: Working Department

d. Job Position

Figure 21 shows the percentage of the value of the job position of participants in the survey. As a percentage, 40% of respondents were managers, 36% of respondents were executives, 18% of respondents were non-executive, and 6%of respondents were IT/ERP consultants.

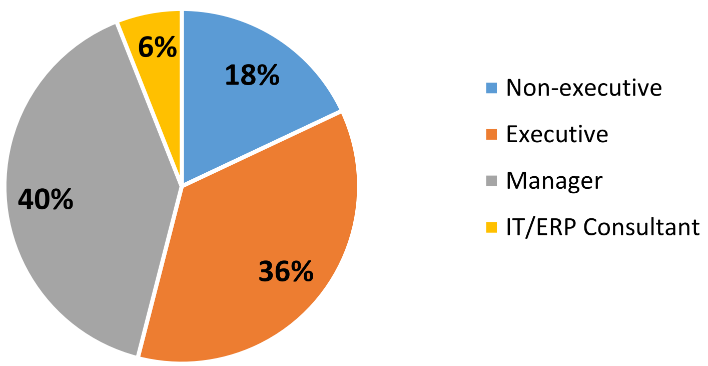

Figure 21: Job Position

C. Existing System Utilization

Table 6 and Figure 22 show the percentage of the value of the existing systems usage in the company of participants in the survey. As a percentage, 100% of respondents use systems to manage packing materials in the warehouse, 95% of respondents use ERP systems to manage packing materials in their warehouse, and 1% of respondents use RFID systems to manage their packing materials in the warehouse. 1% of respondents use integrated ERP and RFID systems to manage packing materials in the warehouse. 66% of respondents use the custom build system to manage packing materials in the warehouse of rubber glove manufacturer and their packing material suppliers.

Table 6: Frequency Analysis of Existing Systems

Response	**Systems for managing packing materials in a warehouse**	**ERP system usage**	**RFID technology usage**	**Integrated ERP and RFID system usage**	**Customized system usage**
Yes	100%	95%	1%	1%	66%
No	0%	5%	99%	99%	34%

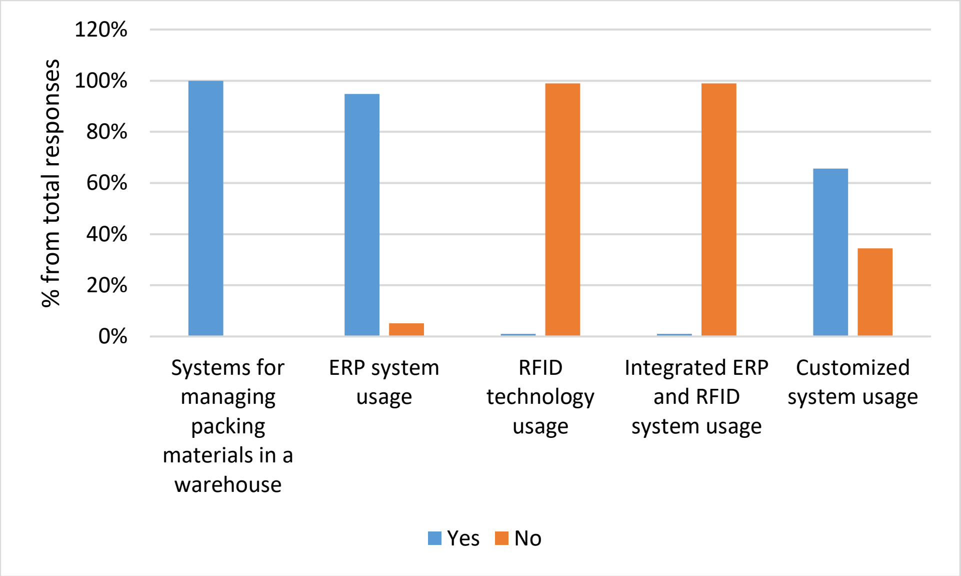

Figure 22: Frequency Analysis of Existing Systems

According to Figure 23, 66% of rubber glove manufacturer respondents use the ERP_Commercial System to manage packing materials in their warehouse, 33% of respondents use the ERP_Local system to manage packing materials in their warehouse, and 1% of respondents do not use ERP systems to manage packing materials in their warehouse.

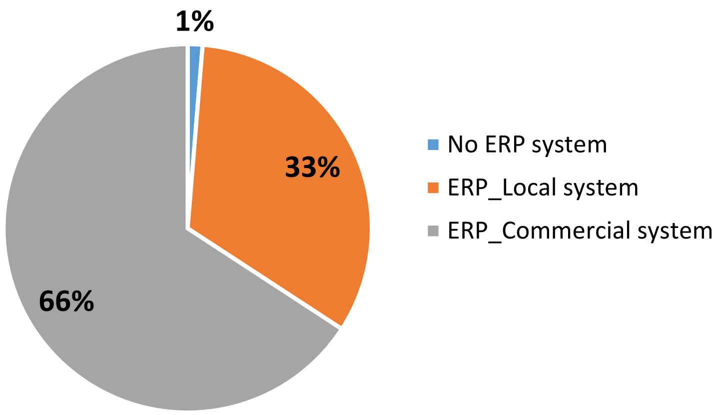

Figure 23: Existing ERP System

According to Figure 24, 42% of rubber glove manufacturer respondents use the Custom-Build System as a custom-build system to manage packing materials in their warehouse, 33% of respondents use the ERP_Local system as a custom-build system to manage packing materials in their warehouse, and 25% of respondents do not use a custom-build system to manage packing materials in their warehouse.

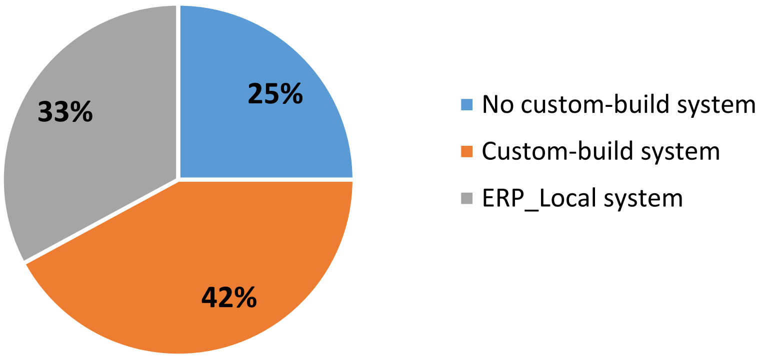

Figure 24: Existing Custom-Build System

D. Existing System Functions

Table 7 and Figure 25 show the percentage of the value of the functions of the existing system in the company of participants in the survey. As a percentage, 97% of rubber glove manufacturer respondents manually enter the received material quantity and create a Goods Receipt Note (GRN) in the existing system, 99% of respondents process system transactions when materials transfer from PMS (Packing Material Store) to TSP (Trimming, Sorting, and Packing), and 97% of respondents process system transactions when materials return to PMS (Packing Material Store) from TSP (Trimming, Sorting, and Packing). As a percentage, 95% of packing material suppliers respondents manually enter the dispatched packing material quantity and create an Advice of Dispatched (AOD) in the existing system.

Table 7: Frequency Analysis of Existing System Functions

Response for manual data input	**GRN**	**Packing materials transfer from PMS to TSP**	**Packing materials return to PMS from TSP**	**AOD**
Yes	97%	99%	97%	95%
No	3%	1%	3%	5%

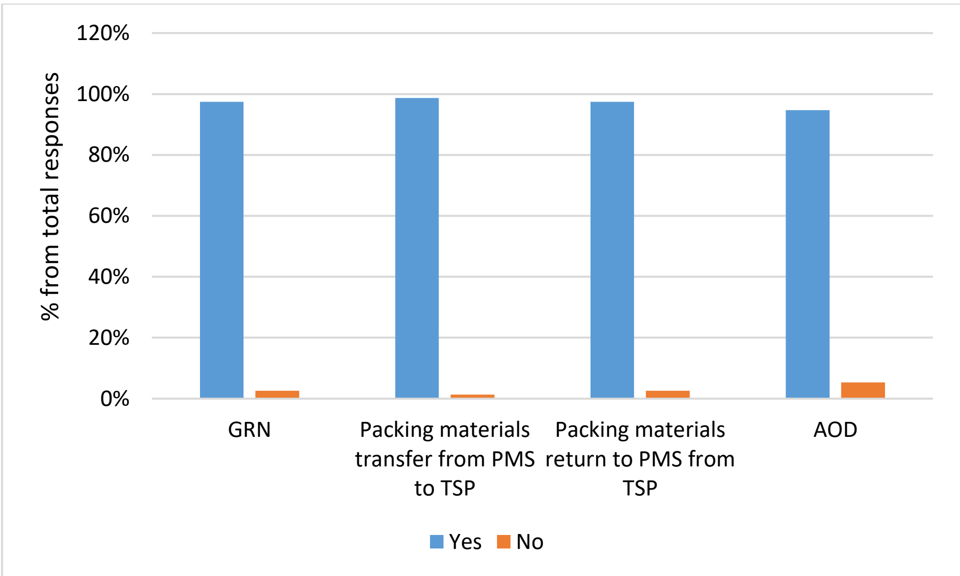

Figure 25: Frequency Analysis of Existing System Functions

According to Figure 26, 99% of rubber glove manufacturer respondents store the received packing materials in a warehouse with manual labeling, and 1% of respondents store the received packing materials in a warehouse with barcode pasting.

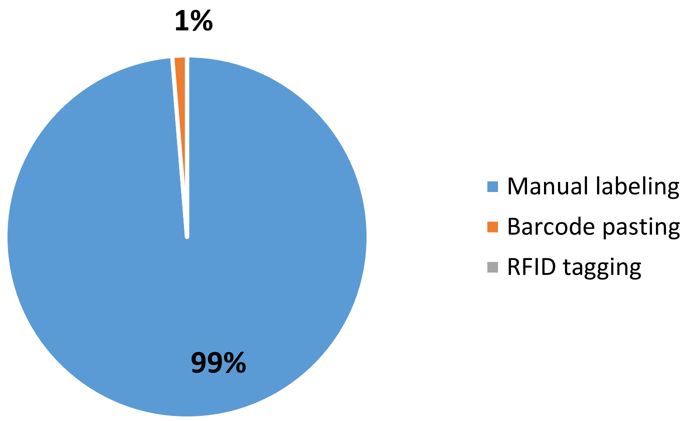

Figure 26: Received packing materials identification

According to Figure 27, 95% of packing material suppliers respondents store and dispatch packing materials from the warehouse with manual labeling, and 5% of respondents store and dispatch packing materials from the warehouse.

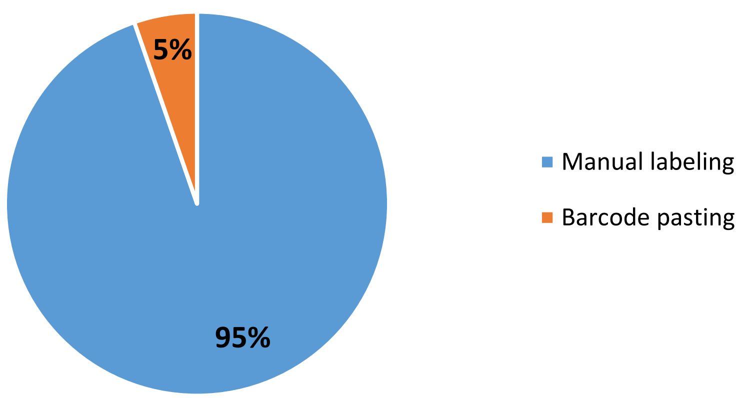

Figure 27: Dispatched packing materials identification

E. Supplier Feedback for the Proposed Integrated System

According to Table 8 and Figure 28, 74% and 21% of packing material suppliers strongly agree and agree an integrated RFID system is simpler and more standardized than manually labeling finished goods that are ready for dispatch from the warehouse. 79% and 16% of packing material suppliers strongly agree and agree on the possibility of viewing real-time information with visual feedback on relevant purchase orders (PO) by accessing integrated ERP and RFID systems of rubber glove manufacturers. 68% and 26% of packing material suppliers strongly agree or agree on easy-to-handle and trace finished goods lots until it will be dispatched from their warehouse.

Table 8: Supplier Feedback For the Proposed Integrated System

	Identification of finished goods that are ready for dispatch from the warehouse.	**Real-time information with visual feedback on relevant purchase orders (PO)**	**Handling and tracing finished good lots until it will be dispatched from the warehouse.**
Strongly Agree	74%	79%	68%
Agree	21%	16%	26%
Neutral	5%	5%	5%
Disagree	0%	0%	0%
Strongly Disagree	0%	0%	0%

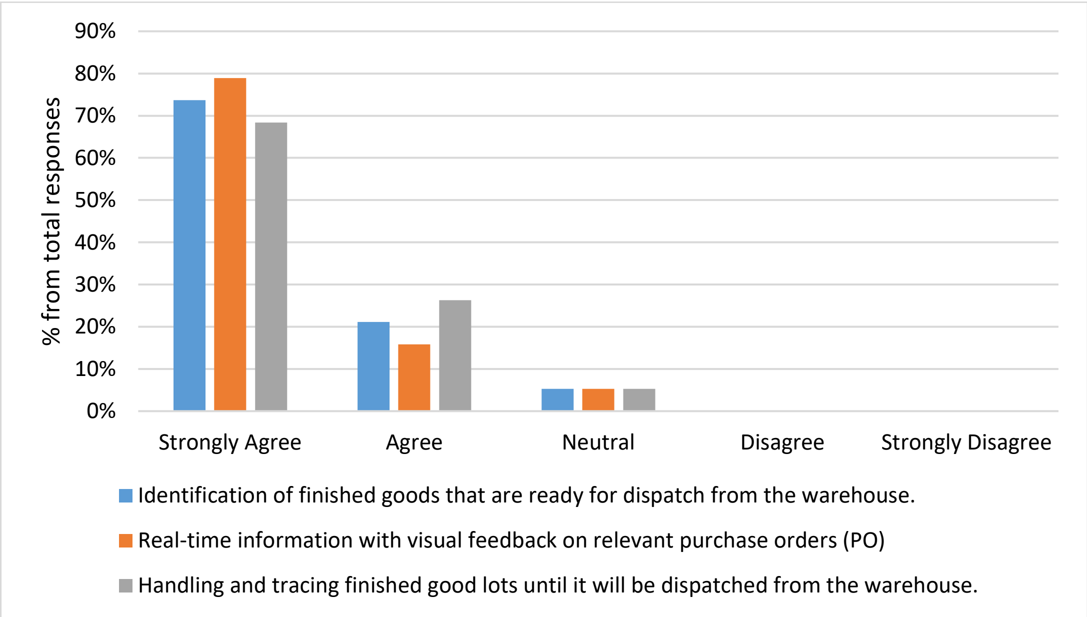

Figure 28: Supplier Feedback For the Proposed Integrated System

According to Figure 29, 74% of packing material suppliers respond that they have a high level of ability to input RFID codes into the rubber glove manufacturers' integrated ERP and RFID system interface using their system access. 21% of suppliers respond with a strongly high level of ability, and 5% of suppliers respond with a medium level of ability.

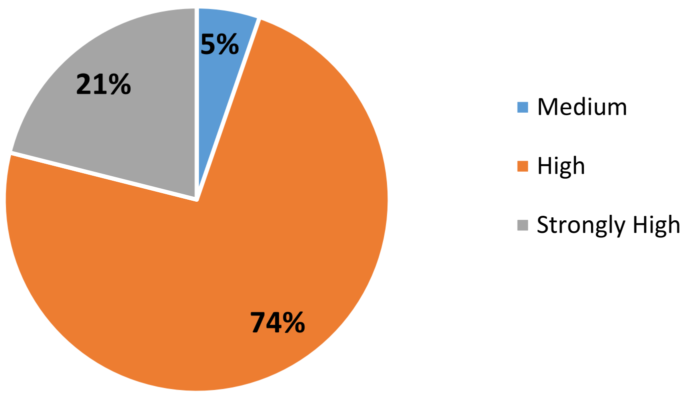

Figure 29: Ability to Enter RFID Code into the Customer System

According to Figure 30, 95% of packing material suppliers respond the cost of RFID tags should be borne by the customer by adding per unit packing material cost. 5% of suppliers agree to accept the cost of the RFID tag.

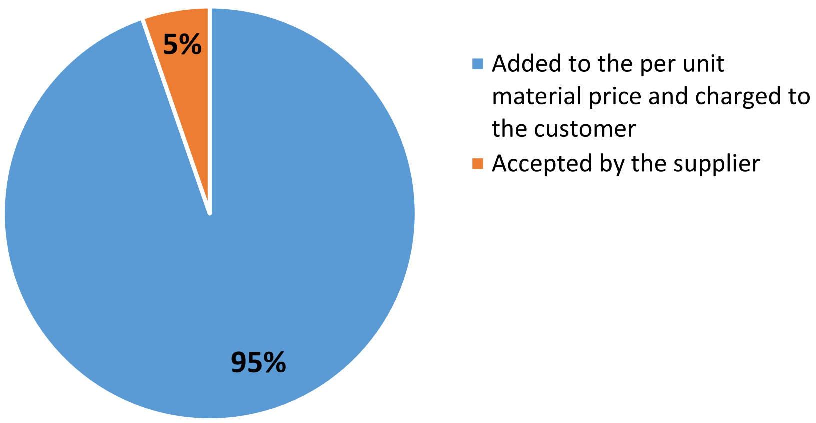

Figure 30: Cost of RFID Tags Bearing Party

4.3.2 Descriptive Statistics for System Performance Indicator Clusters (Mean, Mode, Median, and Standard Deviation)

A. Process Automation Indicator Cluster

a. Transaction Accuracy (Manual Entries and Transactions to the System)

According to Table 9, the 19 responders' mean, mode, median, and standard deviation in the answer is "Yes" and packing material suppliers manually enter the dispatched packing material quantity and create an AOD in the existing system. Of the 77 responders on mean, mode, median, and standard deviation the answer is "Yes" and the rubber glove manufacturing company manually creates a Goods Receipt Note (GRN) in the existing system for received material quantity, manually processes the system transactions when materials transfer from PMS to TSP, and manually process system transactions when materials return to PMS from TSP.

Table 9: Manual Entries and Transactions to the System

		AOD Creation (PMS)	GRN Creation (RGMC)	Material Transfer (RGMC)	Material Returns (RGMC)
N	**Valid**	19	77	77	77
	Missing	0	0	0	0
Mean		1.05	1.03	1.00	1.03
Median		1.00	1.00	1.00	1.00
Mode		1	1	1	1
Std. Deviation		0.229	0.160	0.162	0.160
Answer		"Yes"=1, "No"=2			

The survey results reveal a clear trend in which both packing material suppliers and the rubber glove manufacturing company heavily rely on manual processes. This reliance on manual methods underscores the potential for efficiency improvements through automation and the implementation of automatic data-capturing technology.

b. Transaction Accuracy (Perception of Effectiveness in Facilitating Accurate Information)

According to Table 10, the 26 responders' mean, mode, median, and standard deviation answers are "Strongly Agree" and "Agree" and executives of the rubber glove manufacturing company strongly agreed that the proposed system can generate accurate and summarized reports for top management and enhances customer satisfaction by enabling a quick response to customer demand. Of the 28 responders' mean, mode, median, and standard deviation answers are "Strongly Agree" and

“Agree” and managers of the rubber glove manufacturing company agreed that the proposed system facilitates accurate decision-making and enhances forecasting capabilities. Of 17 responders on mean, mode, median, and standard deviation answer is “Strongly Agree” and non-executives of the rubber glove manufacturing company strongly agreed that manual insertion of packing materials into the system can lead to inaccurate quantity records.

Table 10: Perception of Effectiveness in Facilitating Accurate Information

		Generate Accurate & Summarized Reports (RGMC-Exec)	Quick Response to Customer Demand (RGMC-Exec)	Accurate Decision-Making & Enhanced Forecasting Capabilities (RGMC-Mgr)	Accurate quantity records (RGMC-Non-Exec)
N	**Valid**	26	26	28	17
	Missing	0	0	0	0
Mean		1.77	1.69	1.79	1.41
Median		1.00	1.00	2.00	1.00
Mode		1	1	1	1
Std. Deviation		1.142	1.011	1.067	0.507
Answer		“Strongly Agree”=1, “Agree”=2, “Neutral”=3, “Disagree”=4, “Strongly Disagree”=5			

The survey results indicate strong agreement among different groups within the rubber glove manufacturing company regarding the proposed system's effectiveness. There is a consensus on the proposed system's benefits and the issues associated with manual data entry of the existing system.

c. Automation Level (Adoption and Utilization of Systems)

According to Table 11, the 96 responders’ mean, mode, median, and standard deviation answer is “Yes” and packing material suppliers and rubber glove manufacturing companies use systems to manage packing materials in their warehouses and most respondents use an ERP system to manage packing materials in their warehouse, as indicate in Figure 23, ERP_Commercial System and ERP_Local System is the mostly used ERP system in the responders' company. Most respondents use a custom-built system (either internally or externally developed) to manage packing materials in their warehouse, as indicated in Figure 24, Custom-Build System and ERP_Local System are the most used custom-built systems in the responders' company. Of the 96 responders’ mean, mode, median, and standard deviation answer is “No” and packing material suppliers and rubber glove manufacturing companies do not use an RFID system or integrated ERP and RFID system to manage packing materials in their warehouses.

Table 11: Adoption and Utilization of Systems

		Systems for Managing Packing Materials	Utilization of ERP System	Utilization of RFID System	Utilization of Integrated ERP and RFID Systems	Utilization of Custom-Built Systems
N	**Valid**	96	96	96	96	96
	Missing	0	0	0	0	0
Mean		1.00	1.05	1.99	1.99	1.34
Median		1.00	1.00	2.00	2.00	1.00
Mode		1	1	2	2	1
Std. Deviation		0.000	0.223	0.102	0.102	0.477
Answer		"Yes"=1, "No"=2				

All 96 respondents confirmed that packing material suppliers and rubber glove manufacturing companies use systems to manage packing materials in their warehouses. Most respondents use an ERP system for this purpose. However, the majority of respondents reported that they do not use an RFID system or an integrated ERP and RFID system to manage packing materials in their warehouses.

d. Automation Level (Perception of Effectiveness in Automating Processes)

According to Table 12, the 6 responders' mean, mode, median, and standard deviation answer is "Strongly Agree" and IT/ERP consultants of rubber glove manufacturing companies proposed system can automate the supply chain process.

Table 12: Perception of Effectiveness in Automating Processes

		Automates the Processes (RGMC-IT)
N	**Valid**	6
	Missing	0
Mean		1.50
Median		1.50
Mode		1
Std. Deviation		0.548
Answer		"Strongly Agree"=1, "Agree"=2, "Neutral"=3, "Disagree"=4, "Strongly Disagree"=5

The data from the 6 responders show a strong consensus that the proposed system can effectively automate the supply chain process. The low variation in responses further supports the conclusion that the IT/ERP consultants' proposed system is well-regarded for automating supply chain processes in rubber glove manufacturing companies.

B. Compliance Indicator Cluster

a. Regulatory Adherence (Compliance with Automation Standards for Process)

According to Table 13, the 6 responders' mean, mode, median, and standard deviation in the answer is "Strongly Agree" and IT/ERP consultants of rubber glove manufacturing companies are highly positive about the RFID systems' capability to capture data, send it to the BAPI, and automate processes and generally in strong agreement that the automation of both inbound and outbound tasks is feasible. Of the 6 responders' mean, mode, median, and standard deviation the answer is "Yes" and all IT/ERP consultants of rubber glove manufacturing companies recommend integrating an ERP system with RFID technology in their company. As a summary, 3 of the IT/ERP consultants of rubber glove manufacturing companies give additional comments as leveraging RFID technology can provide valuable benefits by enhancing inventory management and overall supply chain operations.

Table 13: Compliance with Automation Standards for Process

		Compliance with RFID Data Capturing and Automation Processes (RGMC-IT)	Compliance with Automation Standards for Inbound and Outbound Tasks (RGMC-IT)	Recommendation of Proposed System (RGMC-IT)
N	**Valid**	6	6	6
	Missing	0	0	0
Mean		1.33	1.50	1.00
Median		1.00	1.50	1.00
Mode		1	1	1
Std. Deviation		0.516	0.548	0.000
Answer		"Strongly Agree"=1, "Agree"=2, "Neutral"=3, "Disagree"=4, "Strongly Disagree"=5		"Yes"=1, "No"=2

The conclusion is that the feedback from the IT/ERP consultants in rubber glove manufacturing companies is overwhelmingly positive regarding RFID technology. The majority of responders strongly agree that RFID systems are effective for data capture, integration with BAPI, and process automation. They also unanimously support the integration of ERP systems with RFID technology. Additionally, the consultants believe that RFID technology offers significant benefits for improving inventory management and overall supply chain operations.

b. **Regulatory Adherence (Assessment of Implementation Costs/ Security Concerns/ Technical Capability)**

According to Table 14, the 6 responders' mean, mode, median, and standard deviation in the answer is "Neutral" and IT/ERP consultants of rubber glove manufacturing companies have a neutral view on the cost of implementing RFID and ERP system integration, with some perceiving it as neither particularly low nor high. Of the 6 responders' the mean is "Yes", and the mean, mode, median, and standard deviation in the answer are "No". The IT/ERP consultants have some concerns about security in ERP and RFID system integration, but most respondents do not perceive it as a significant issue. One responder indicates security concerns "If integration happening between third-party App, then BAPI will open up the ERP environment for external. Also depends on the applications used for RFID readers". Of the 6 responders' mean, mode, median, and standard deviation the answer is "No" and all IT/ERP consultants of rubber glove manufacturing companies do not perceive any technical issues with integrating ERP and RFID systems.

Table 14: Implementation Costs/ Security Concerns/ Technical Capability

		Implementation Costs for RFID and ERP Integration (RGMC-IT)	Security Concerns Related to ERP and RFID Integration (RGMC-IT)	Technical issues can occur during the ERP and RFID system integration (RGMC-IT)
N	**Valid**	6	6	6
	Missing	0	0	0
Mean		3.333	1.83	2.00
Median		3.00	2.00	2.00
Mode		3	2	2
Std. Deviation		0.516	0.408	0.000
Answer		"Low"=1, "Medium Low"=2, "Neutral"=3, "Medium High"=4, "High"=5	"Yes"=1, "No"=2	

The six IT/ERP consultants from rubber glove manufacturing companies expressed a neutral stance on the cost of implementing RFID and ERP integration. Most do not consider security a major issue, though one mentioned concerns with third-party applications and RFID readers. All consultants reported no significant technical issues with the integration process.

c. **Material Identification (Packing Material Identification)**

According to Table 15, the 19 responders' mean, mode, median, and standard deviation in the answer is "Manual Labeling" and packing material suppliers store and identify dispatch packing materials using manual labeling. Of the 77 responders mean, mode, median, and standard deviation in the answer is "Manual Labeling" and rubber glove manufacturing companies store and identify received materials in their warehouses using manual labeling.

Table 15: Packing Material Identification

		Identification of Dispatched Materials (PMS)	Identification of Received Materials (RGMC)
N	**Valid**	19	77
	Missing	0	0
Mean		1.05	1.01
Median		1.00	1.00
Mode		1	1
Std. Deviation		0.229	0.114
Answer		"Manual Labeling"=1, "Barcode Pasting"=2, "RFID Tagging"	

Packing material suppliers and rubber glove manufacturing companies predominantly use manual labeling to store and identify packing materials. For both dispatch and received materials, the majority of respondents indicated that manual labeling is the most common method used for identification and storage.

d. **Material Identification (Perception of Effectiveness of Automated Identification)**

According to Table 16, the 19 responders' mean, mode, median, and standard deviation in the answer is "Strongly Agree" and packing material suppliers strongly agree that using automated identification (like data capturing tags or barcodes) is simpler and more standardized than manually labeling finished goods for dispatch from the warehouse and using automated identification makes it easy to handle and trace finished good lots until they are dispatched from the warehouse. Of the 26 responders' mean, mode, median, and standard deviation the answer is "Strongly Agree" and executives of rubber glove manufacturing companies strongly agree that using automated identification for packing materials provides standardized information to all supply chain stakeholders, which helps in prompt decision-making and accurate forecasting. Of the 17 responders' mean, mode, median, and standard deviation the answer is “Agree” and non-executives of rubber glove manufacturing companies agree that using automated identification delivers more standardized information for packing material lots compared to manual labeling. Of the 6 responders’ mean, mode, median, and standard deviation the answer is “Both” and IT/ERP consultants of rubber glove manufacturing companies prioritize automating both inbound and outbound operations with RFID technology.

Table 16: Perception of Effectiveness of Automated Identification

		Simplified and Standardized with Automated ID (PMS)	Easy Handling and Tracing with Automated ID (PMS)	Standardized Information for Decisions and Forecasts (RGMC-Exec)	Effectiveness of Automated Identification (RGMC-Non-Exec)	Prioritization of Operations for RFID Automation (RGMC-IT)
N	**Valid**	19	19	26	17	6
	Missing	0	0	0	0	0
Mean		1.32	1.37	1.35	1.71	2.67
Median		1.00	1.00	1.00	2.00	3.00
Mode		1	1	1	2	3
Std. Deviation		0.582	0.597	0.485	0.588	0.816
Answer		“Strongly Agree”=1, “Agree”=2, “Neutral”=3, “Disagree”=4, “Strongly Disagree”=5				“Inbound”=1, “Outbound”=2, “Both”=3, “None”=4

Packing material suppliers strongly agree that automated identification (such as barcodes or data tags) is easier and more standardized than manual labeling, making it simpler to handle and trace goods. Executives of rubber glove manufacturing companies also strongly agree that this system provides consistent information, aiding in decision-making and forecasting. IT/ERP consultants prioritize using RFID technology for both inbound and outbound operations, while non-executives agree that automated identification offers better standardization than manual methods.

C. Performance Management Indicator Cluster

a. Operational Efficiency (Perception of Workload Reduction Effectiveness)

According to Table 17, the 28 responders’ mean, mode, median, and standard deviation in the answer is “Agree” and managers of rubber glove manufacturing companies agree that the proposed system effectively reduces employee workload, allowing more time for other tasks. Of the 17 responders’ mean, mode, median, and standard deviation, the answer is “Agree” and non-executives of rubber glove manufacturing companies agree that the proposed system reduces operator workload.

Table 17: Perception of Workload Reduction Effectiveness

		Workload Reduction Effectiveness	Reduction in Operator Workload
N	Valid	28	17
	Missing	0	0
Mean		2.04	1.65
Median		2.00	2.00
Mode		2	2
Std. Deviation		1.071	0.493
Answer		"Strongly Agree"=1, "Agree"=2, "Neutral"=3, "Disagree"=4, "Strongly Disagree"=5	

Both managers and non-executives of rubber glove manufacturing companies generally agree that the proposed system effectively reduces employee workload.

b. Operational Efficiency (Perception of Effectiveness in Reducing Manual Work)

According to Table 18, the 26 responders' mean, mode, median, and standard deviation in the answer is "Strongly Agree" and executives of rubber glove manufacturing companies strongly agree that the proposed system reduces the need for manual Excel-based tasks. Of the 6 responders' mean, mode, median, and standard deviation the answer is "Strongly Agree" and IT/ERP consultants of rubber glove manufacturing companies strongly agree that the proposed system with data capturing improves processing time. Both executives and IT/ERP consultants from rubber glove manufacturing companies strongly agree that the proposed system significantly reduces the need for manual Excel-based tasks and improves processing time.

Table 18: Perception of Effectiveness in Reducing Manual Work

		Effectiveness in Reducing Manual Excel-Based Tasks	Improvement in Processing Time Due to Data Capturing
N	Valid	26	6
	Missing	0	0
Mean		1.73	1.33
Median		1.00	1.00
Mode		1	1
Std. Deviation		1.002	0.516
Answer		"Strongly Agree"=1, "Agree"=2, "Neutral"=3, "Disagree"=4, "Strongly Disagree"=5	

D. Process Control Indicator Cluster

a. Real-Time Inventory Information (Perception of Effectiveness in Providing Real-Time Information)

According to Table 19, the 19 responders' mean, mode, median, and standard deviation in the answer is "Strongly Agree" and packing material suppliers strongly agree that the proposed system allows for viewing real-time information and visual feedback on purchase orders. Of the 26 responders' the mean, mode, median, and standard deviation in the answer is "Agree" and executives of the rubber glove manufacturing company agree that the proposed system effectively provides real-time inventory information, aiding in decision-making. Of the 6 responders' mean, mode, median, and standard deviation the answer is "Strongly Agree" and IT/ERP consultants in the rubber glove manufacturing company strongly agree that the proposed system provides real-time information.

Table 19: Perception of Effectiveness in Providing Real-Time Information

		Providing Real-Time Visual Feedback on Purchase Orders (PMS)	Providing Real-Time Inventory Information (RGMC-Exec)	Providing Real-Time Information (RGMC-IT)
N	Valid	19	26	6
	Missing	0	0	0
Mean		1.26	1.88	1.33
Median		1.00	2.00	1.00
Mode		1	1	1
Std. Deviation		0.562	0.993	0.516
Answer		"Strongly Agree"=1, "Agree"=2, "Neutral"=3, "Disagree"=4, "Strongly Disagree"=5		

Packing material suppliers and IT/ERP consultants strongly agree that the proposed system provides real-time information and visual feedback, while executives agree that it effectively supports decision-making with real-time inventory data. Overall, all groups recognize the system's benefits in delivering timely and accurate information.

b. Inventory Accuracy (Perception of Synchronization Issues between System and Physical Transaction)

According to Table 20, the 17 responders' mean, mode, median, and standard deviation in the answer is "Agree" and non-executives of rubber glove manufacturing companies agree that manual transfers of packing materials and physical transfers do not always happen simultaneously and manual returns of packing materials and their physical transfers do not always happen at the same time.

Table 20: Perception of Synchronization Issues between System and Physical Transaction

		Transfers in the System and Physically at the Same Time (RGMC-Non-Exec)	Returns in the System and Physically at the Same Time (RGMC-Non-Exec)
N	**Valid**	17	17
	Missing	0	0
Mean		1.88	1.82
Median		2.00	2.00
Mode		2	2
Std. Deviation		0.697	0.636
Answer		"Strongly Agree"=1, "Agree"=2, "Neutral"=3, "Disagree"=4, "Strongly Disagree"=5	

Non-executives of rubber glove manufacturing companies generally agree that manual transfers of packing materials and their physical transfers do not always occur simultaneously, and the same issue applies to manual returns of packing materials.

4.4 Objective 3

Objective 3 is to design a single platform to integrate ERP and RFID systems for improved procurement performance. Successfully design and implement the system with minimum and low-cost requirements. According to the pilot test result analysis, the implemented system (Supply Chain Smoother) reduces the time allocated for GRN, transfers, returns, and material identification (labeling) process and increases the accuracy of the inventory figure which has a significant positive relationship with procurement performance.

4.4.1 Design and Development of Solutions

A. Hardware Components

The hardware component features a NodeMcu WiFi Module for economical and flexible internet connectivity and IoT solution prototyping, including Wi-Fi and programming capabilities. The RFID-RC522 reader module communicates with RFID tags using an electromagnetic field. Additional components include jumper wires, RFID tags, and a breadboard for temporary implementation. Specifications for these components and the Arduino IDE 1.8.1.9 are detailed in Appendix C.

B. Middleware (API) and Software Components

HTML, CSS, PHP, and JavaScript are used for software development. phpMyAdmin, paired with MySQL, manages the database for Supply Chain Smoother. NodeJS, combined with JavaScript, creates the system's API. The NetBeans IDE is used for programming, debugging, profiling, and deploying software components. XAMPP, a web server solution stack, includes MySQL Database, Apache HTTP Server, and PHP interpreters. Appendix D provides further details on these technologies.

4.4.2 Overall Approach

A. Hardware Component

The main section of the proposed system, Supply Chain Smoother, involves creating a hardware component and enabling data transmission to the system. This requires a NodeMcu WiFi module connected to an RFID RC522 reader module, which detects RFID tags and captures RFID codes. The data is then sent through an HTTP POST request and stored in a MySQL database. Subsequently, the web application accesses and uses this data. The module has two main functions: building the hardware component and managing data transmission.

a. Build Up the Hardware Component

The hardware setup involves connecting a NodeMcu WiFi module and an RFID RC522 reader module using jumper wires. The NodeMcu is powered by a 5V supply via a USB cable and programmed with Arduino IDE 1.8.1.9. The RFID RC522 reader captures RFID codes and sends them to the NodeMcu module. According to Table 21, there are three RFID reading stations: Station 1 at the packing material warehouse entrance, Station 2 at the TSP entrance for lots transferred from PMS, and Station 3 at the TSP exit for lots returning to PMS.

Table 21: RFID reading stations

Hardware Unit	Location	Action
Station 1	Entrance of PMS	Automatically input received packing materials into the system
Station 2	Entrance of TSP	Automatically input transfer packing materials into the system from PMS to TSP
Station 3	Exit of TSP	Automatically input return packing materials into the system from TSP to PMS

b. Data Transmission

Data transmission involves sending analog or digital data between devices or networks. In rubber glove manufacturing warehouses in Sri Lanka, RFID technology is used to scan packaging material codes with an RFID RC522 module. This data is sent to a NodeMcu module, which uses a POST request to store the information in a MySQL database via Node.js. The stored data can then be accessed and used by a web-based application.

B. Software Components

According to Table 22, Web-based applications consist of the following 4 modules with 19 functions. 7 functions are allowed for both rubber glove manufacture and packing material suppliers. 11 functions are allowed only for rubber glove manufacturers and one function only allowed for packing material suppliers.

Table 22: Modules of software component

Module	Functions	Rubber Glover Manufacturer	Packing Material Supplier
User Log	User Sign-up	Yes	Yes
	User Log-in	Yes	Yes
	Display user details	Yes	Yes
	Edit user details	Yes	Yes
	Delete user	Yes	Yes
	User Log-out	Yes	Yes
Material Log	Create packing material	Yes	No
	Edit packing material	Yes	No
	Delete packing material	Yes	No
Purchase Order Log	Create purchase order	Yes	No
	Display purchase order details	Yes	Yes
	Edit purchase order	Yes	No
	Add RFID code for lots of purchase orders	No	Yes
	Delete purchase order	Yes	No
	GRN – Input (Station 1)	Yes	No
Inventory Log	Search and view the inventory of materials	Yes	No
	Transfer materials from PMS to TSP – Input (Station 2)	Yes	No
	Materials issue for the order	Yes	No
	Return materials from TSP to PMS – Input (Station 3)	Yes	No

a. User Log

This module includes user sign-up, login, display, editing, deletion, and logout functions, accessible to both rubber glove manufacturers and packing material suppliers. User creation occurs after data validation, with error messages for invalid inputs. Each registered user is assigned a unique ID generated by the MySQL database, enabling login with a valid username and password.

b. Material Log

This module consists of creating packing material, editing packing material, and deleting packing material functions which only can be accessed by rubber glover manufacturers. When creating the Material Code in the system Material Group (Table 23) and the Supplier pre-defined need to be selected from the drop-down menu. Spec Number, Material description, and Price should be input to create the Material Code. After submitting the material form random number is generated with “MC” letters as a unique number. Editing and deleting functions happen by referring to the unique number of the Material Code and ID which is generated from the MySQL database.

Table 23: Packing Material Groups

Material Grop	**Packing Material Type**
PM0010	Printed Inner Bag
PM0015	Plain Inner Bag
PM0020	Printed Outer Bag
PM0025	Plain Outer Bag
PM0030	Printed Inner Carton
PM0035	Plain Inner Carton
PM0040	Printed Outer Carton
PM0045	Plain Outer Carton
PM0050	Header Card

c. Purchase Order Log

This module includes functions for creating, editing, deleting purchase orders, and generating GRNs (Input at Station 1), accessible only by rubber glove manufacturers. Both manufacturers and packing material suppliers can display purchase order details, while only suppliers can add RFID codes to each lot of the purchase order. When creating a purchase order, details such as Material Group, Spec Number, Material Code, Material Description, Supplier, and Price are referenced from the database, and only Location, Required Quantity, and Wastage Margin are inputted. Calculated values (Table 24) are stored in the database upon form submission. The system handles the Required Quantity and Wastage Quantity separately. A unique purchase order number is generated with “PO” letters after form submission. Editing and deleting are done by referencing the unique Purchase Order Number and ID from the MySQL database.

Table 24: Calculated inputs for database

Calculation	**Material Group**	
	PM0040 /PM0045	PM0010/PM0015/PM0020/PM0025 /PM0030/PM0035/PM0050
1	No. of Req. Lots.= Req. Qty. / 100	No. of Req. Lots.= Req. Qty. / 1000
2	Wst. Qty. = Req. Qty. * Wst. Mgn.	
3	No. of WL. = Wst. Qty. / 100	No. of WL. = Wst. Qty. / 1000
4	PO Qty. = Req. Qty. + Wst. Qty.	
5	Tot PO Val. = PO Qty. * Pr.	

Where;

- No of Requirement Lots = No. of Req. Lots.
- No of Wastage Lots = No. of WL.
- Total PO Value = Tot PO Val.
- Required Quantity = Req. Qty.
- Wastage Quantity = Wst. Qty.
- Wastage Margin = Wst. Mgn.
- PO Quantity = PO Qty.
- Price = Pr.

After a packing material supplier completes a purchase order, they attach RFID tags to each lot and input the RFID codes into the web-based system by editing the purchase order. These details are stored in the database and are accessible to the rubber glove manufacturer. When RFID-tagged lots arrive at the packing material warehouse, they are processed at Station 1, located at the PMS entrance. At Station 1, the RFID reader captures and sends the codes to the database via the API’s first request. The system maps these codes and generates a GRN for the relevant purchase order based on the number of lots and the pre-defined quantity of the Material Group (Table 25). The inventory log is then updated with the GRN quantities, recorded separately in the PMS required and wastage quantity columns.

Table 25: Calculated GRN quantity input

Calculation	**Material Group**	
	PM0040 /PM0045	PM0010/PM0015/PM0020/PM0025 /PM0030/PM0035/PM0050
1	GRN Req. Qty. = No. of Req. Lots.* 100	GRN Req. Qty. = No. of Req. Lots.* 1000
2	GRN Wstg. Qty. = No. of WL.* 100	GRN Wstg. Qty. = No. of WL.* 1000

Where;

- GRN Required Quantity = GRN Req. Qty.
- GRN Wastage Quantity = GRN Wstg. Qty.
- No of Requirement Lots (RFID read by Station 1)= No. of Req. Lots.
- No of Wastage Lots (RFID read by Station 1)= No. of WL.

d. Inventory Log

This module allows rubber glove manufacturers to search and view material inventory, transfer materials from PMS to TSP, issue materials for sales orders, and return materials from TSP to PMS. Inventory can be searched by Material Code, and details for each location are displayed on the user interface. When RFID-tagged lots are transferred to TSP from PMS, they pass through Station 2 at the TSP entrance, where the RFID reader captures and sends the data to the database via the API's second request. The system maps these RFID codes and generates transfers by multiplying the number of lots by the pre-defined quantity of the Material Group (Table 26). The inventory log is updated by removing the RFID codes from PMS and adding them to TSP, adjusting the required and wastage quantities accordingly.

Table 26: Calculated transferred quantity

Calculation	**Material Group**	
	PM0040 /PM0045	PM0010/PM0015/PM0020 /PM0025 /PM0030/PM0035/PM0050
1	Trans. Req. Qty. PMS-TSP. = No. of Req. Lots.* 100	Trans. Req. Qty. PMS-TSP. = No. of Req. Lots.* 1000
2	Trans. Wst. Qty. PMS-TSP. = No. of WL.* 100	Trans. Wst. Qty. PMS-TSP. = No. of WL.* 1000

Where;

- Transferred Required Quantity from PMS to TSP = Trans. Req. Qty. PMS-TSP.
- Transferred Wastage Quantity from PMS to TSP = Trans. Wst. Qty. PMS-TSP.
- No of Requirement Lots (RFID read by Station 2)= No. of Req. Lots.
- No of Wastage Lots (RFID read by Station 2)= No. of WL.

A special function that consists of an inventory log is to issue packing materials to the sales order. Quantity included in TSP Required Quantity or TSP Wastage Quantity can be issued for sales orders by referring RFID code. The number of RFID codes that are issued for sales orders is calculated according to Table 27. Those issued RFID codes with calculated quantities were removed from the TSP table of the database. Update inventory table reducing that issued quantity from TSP required and wastage quantity.

Table 27:Calculated issued quantity

Calculation	Material Group	
	PM0040 /PM0045	PM0010/PM0015/PM0020/PM0025 /PM0030/PM0035/PM0050
1	Iss. Qty. SO. = No. of Req. Lots.* 100	Iss. Qty. SO. = No. of Req. Lots.* 1000
2	Iss. Qty. SO. = No. of WL.* 100	Iss. Qty. SO. = No. of WL.* 1000

Where;

- Issued Quantity for Sales Order = Iss. Qty. SO.
- No of Requirement Lots (Issued)= No. of Req. Lots.
- No of Wastage Lots (Issued)= No. of WL.

When the RFID tag attaches lots returned to the PMS from TSP, it goes through the hardware component fixed TSP exit called Station 3. At Station 3, the reader reads the RFID code and sends that data to the database through the hardware component and the API 3rd requests call. There is RFID code mapping using API and generating returns by multiplying the number of lots from the pre-defined quantity of Material Group as per Table 28. At the same time, the returned lot' RFID code was removed from TSP and added to the PMS database. After the transaction, the inventory log is updated by reducing the TSP required and wastage quantities and adding that quantity into the PMS required and wastage quantity.

Table 28:Calculated returned quantity

Calculation	Material Group	
	PM0040 /PM0045	PM0010/PM0015/PM0020/PM0025 /PM0030/PM0035/PM0050
1	Rtn. Req. Qty. PMS-TSP. = No. of Req. Lots.* 100	Rtn. Req. Qty. PMS-TSP. = No. of Req. Lots.* 1000
2	Rtn. Wst. Qty. PMS-TSP. = No. of WL.* 100	Rtn. Wst. Qty. PMS-TSP. = No. of WL.* 1000

Where;

- Returned Required Quantity from PMS to TSP = Rtn. Req. Qty. PMS-TSP.
- Returned Wastage Quantity from PMS to TSP = Rtn. Wst. Qty. PMS-TSP.
- No of Requirement Lots (RFID read by Station 3)= No. of Req. Lots.
- No of Wastage Lots (RFID read by Station 3)= No. of WL.

4.4.3 Analysis and Design

The analysis and design phase of the project is essential for its success. This phase begins with a thorough examination of requirements, which is documented using mind maps. It involves identifying and understanding necessary specifications and designing a conceptual model for the system. Key components of the analysis include:

- Literature review: Investigating global advancements in integrated system
- Questionnaire: Assessing current ERP and RFID systems in the Sri Lankan rubber glove manufacturing industry through survey frequency analysis.
- Observation: Reviewing existing systems and operations.

These activities help define the system's structure and functionality, ensuring the design addresses the identified needs effectively. The literature review, questionnaire, and observation of the current system globally and in Sri Lanka revealed several problems: the warehouse lacks an RFID or RFID-integrated system, and relies on manual data entry for receiving materials, which causes inventory inaccuracies due to the absence of visual feedback. Manual labeling without standardized identification leads to delays in the supply chain, impacting customer satisfaction. Most rubber glove manufacturers handle inventory transfers and returns through manual data entry, which increases stock holding costs, disposal costs, and provision amounts, and reduces decision-making capability, accurate purchase order creation, and forecasting. The research problem is discussed in Section 1.2, and the system is divided into two major modules and two sub-modules as detailed in Figure 31.

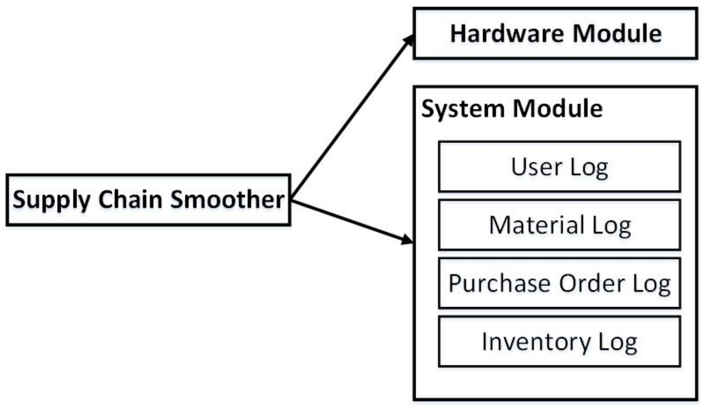

Figure 31: Deviation of overall Supply Chain Smoother

Source: Compiled by the author based on the requirement analysis

A. Hardware Component

According to Figure 32, the hardware module consists of the NodeMcu WiFi Module, RFID RC522 reader module, and WiFi. The RFID RC522 Module reads RFID tags within 50 milliseconds. The NodeMcu WiFi Module connects to WiFi and uploads code to the ESP8266 WiFi-enabled chip via the Arduino IDE, using C++ language. This code reads RFID tags and sends the RFID codes to the database through a defined service URL on the LAN by running an API built on Node.js. The data is then stored in the database following the 1st, 2nd, and 3rd request calls of the API.

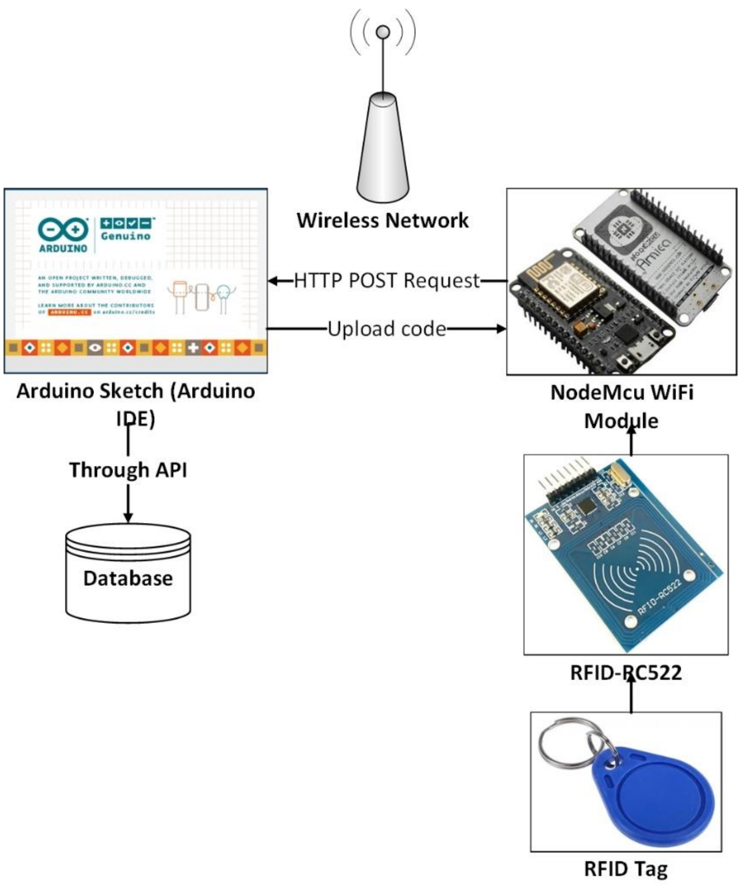

Figure 32: Hardware module

Source: Compiled by the author based on the requirement analysis

B. Software Components

This is implemented to view and manage real-time inventory received from the hardware devices. There are four sub-modules included in the system module. The overall design of the Web Based Application is depicted in the Figure 33,

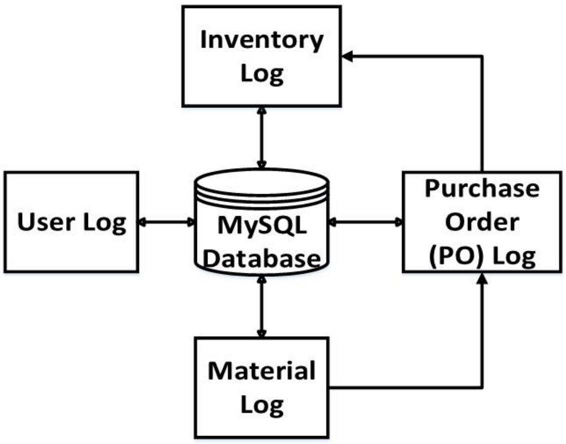

Figure 33: System module

Source: Compiled by the author based on the requirement analysis

a. **User Log**

According to Figure 34, two categories of users can sign into the system as rubber glove manufacturers and packing material suppliers. New users need to fill out the User Signup form and submit it, and then the system validates the data and creates a user in the database. After the registered user can log into the system with username and password. The system-logged users can view, edit, and delete their details and the system updates the user data according to that by automatically generated ID.

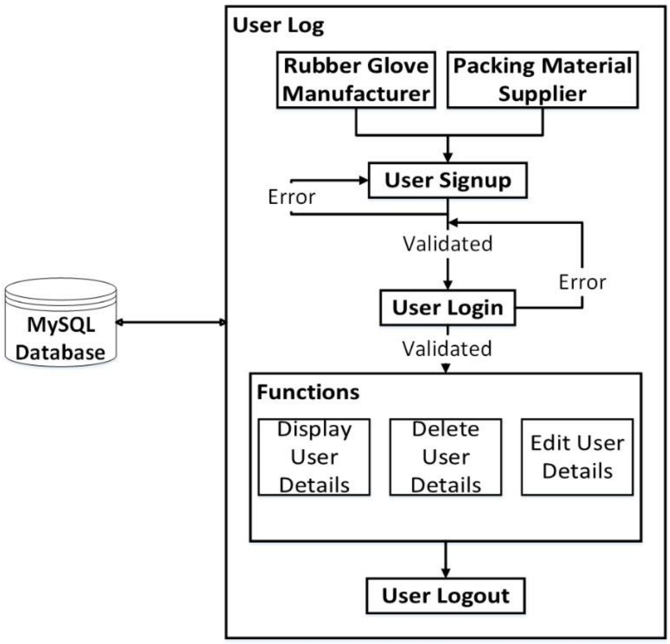

Figure 34: User log

Source: Compiled by the author based on the requirement analysis

b. Material Log

According to Figure 36, a logged-in user at a rubber glove manufacturer can create material by submitting a form. As outlined in Table 23, the system includes pre-defined material groups and suppliers. After form submission, the system automatically generates a unique code starting with "MC." Users can edit or delete material details or proceed to the purchase order creation dashboard. Any changes to material details are updated in the system database using the automatically generated ID.

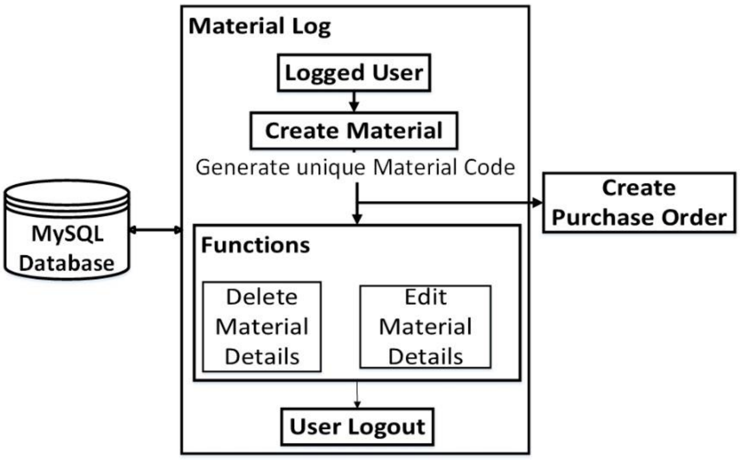

Figure 35: Material Log

Source: Compiled by the author based on the requirement analysis

c. Purchase Order Log

According to Figure 36, logged-in users of the rubber glove manufacturing company can create purchase orders (PO) by inputting material codes and data. Upon submission, the system performs five calculations, generates a unique "PO" code, and saves the data. Users can view, edit, and delete PO details, while packing material suppliers can add RFID codes to the relevant purchase orders. At Station 1, an RFID reader transmits the code to the database via hardware and an API call, mapping the RFID code and generating a Goods Receipt Note (GRN) for the PO through the calculated data.

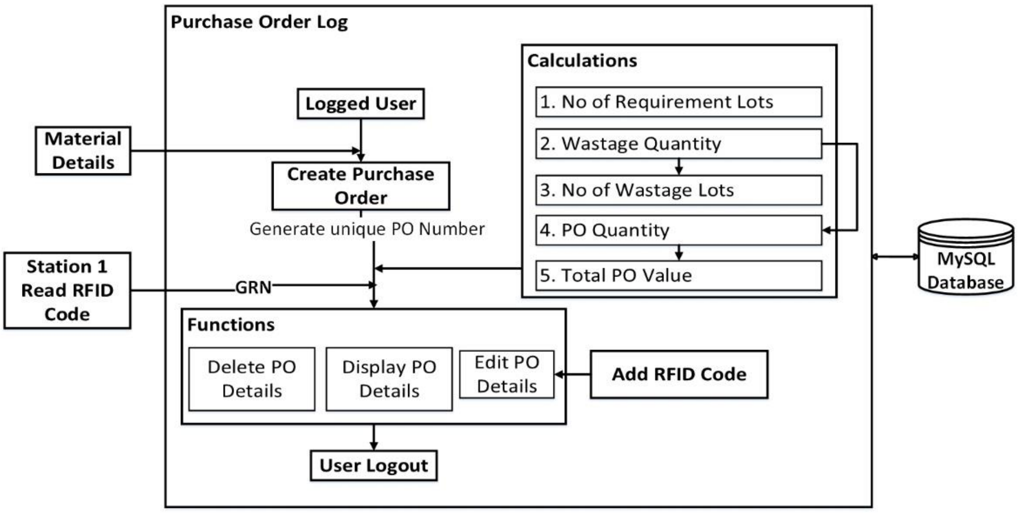

Figure 36: Purchase order log

Source: Compiled by the author based on the requirement analysis

d. Inventory Log

According to Figure 37, inventory can be searched and viewed by "Material Code". Transfers and returns are automatically updated in the inventory log with the input of Station 2 and Station 3. When TSP Required Quantity and TSP Wasatage quantity are the inventory, can issue for sales orders referring RFID code of lots.

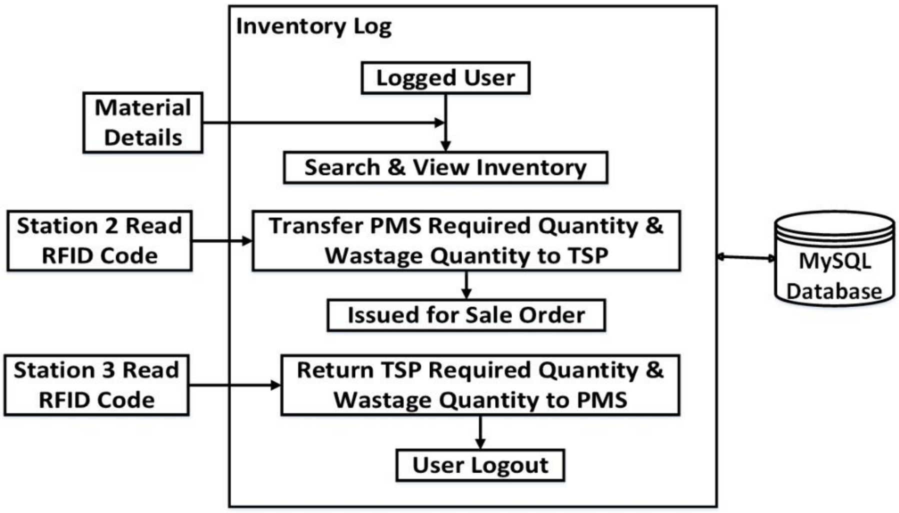

Figure 37: Inventory Log

Source: Compiled by the author based on the requirement analysis

Figure 38, describes the technical architecture of the proposed solution as a combination of software module and hardware module. The software module consists of a user log, material log, purchase order log, and inventory log.

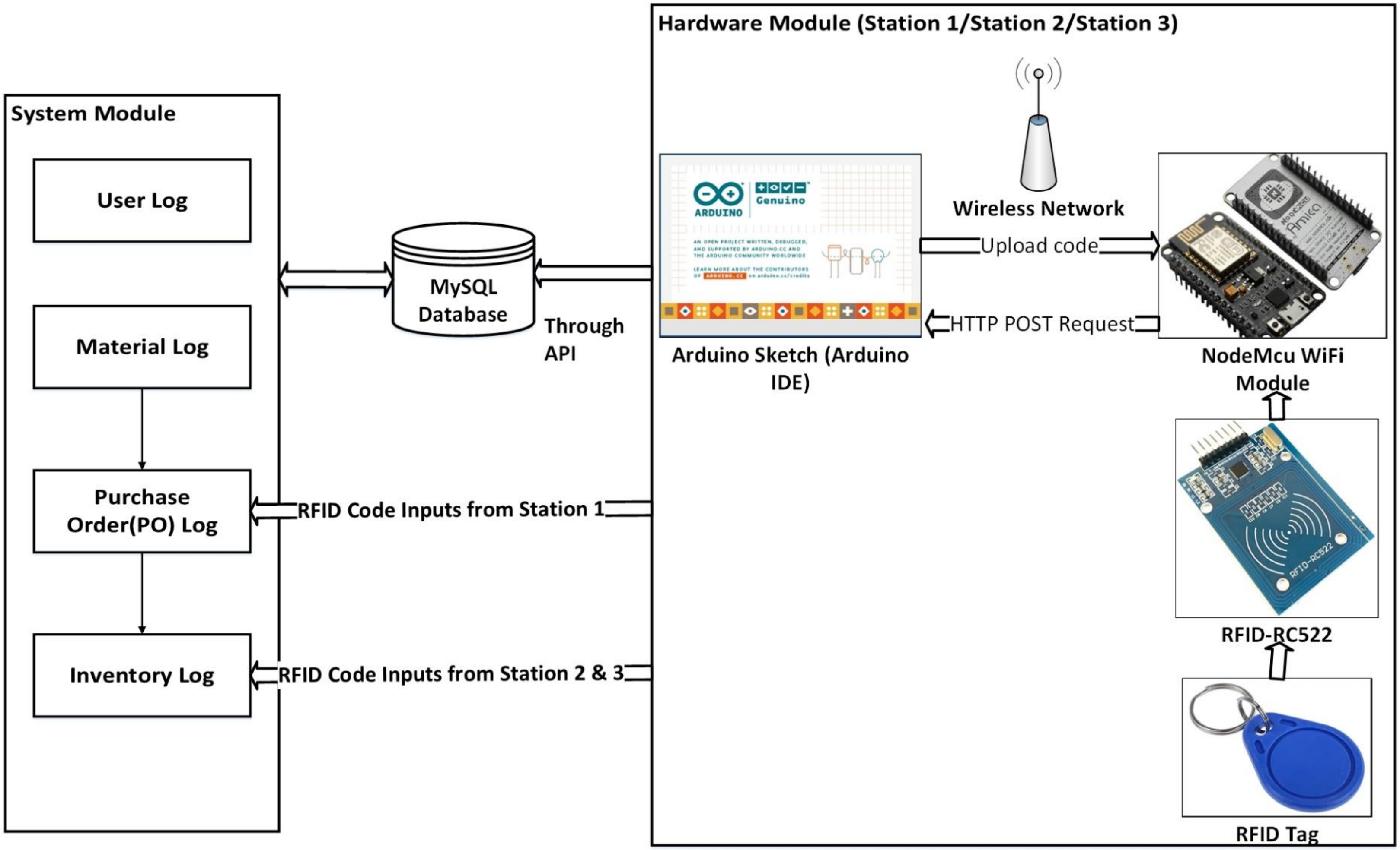

Figure 38: High-Level Architecture

Source: Compiled by the author based on the requirement analysis

4.4.4 Implementation

A. Hardware Component

There are several steps followed to implement the hardware module. Firstly prepare the requirements that are needed to implement the hardware module. NodeMcu Wifi Module, RFID-RC522, Arduino RFID Library for MFRC522 (SPI), Arduino IDE, Arduino Core for NodeMCU ESP-12E Using Arduino Boards Manager, Jumper Wires, and XAMPP are the main requirements which need to prepare for hardware module implementation. Secondly, connect the NodeMcu and RFID RC522 modules. According to Table 29 and Figure 39, connect the RFID RC522 Module to the NodeMcu WiFi Module.

Table 29: Connected pin details

RFID	NodeMcu	Jumper Wire Color
SDA/SS	D8	Orange
SCK	D5	Green
MOSI	D7	Purple
MISO	D6	Blue
IRQ	-	-
GND	GND	Black
RST	D1	Yellow
3V	3V	Red

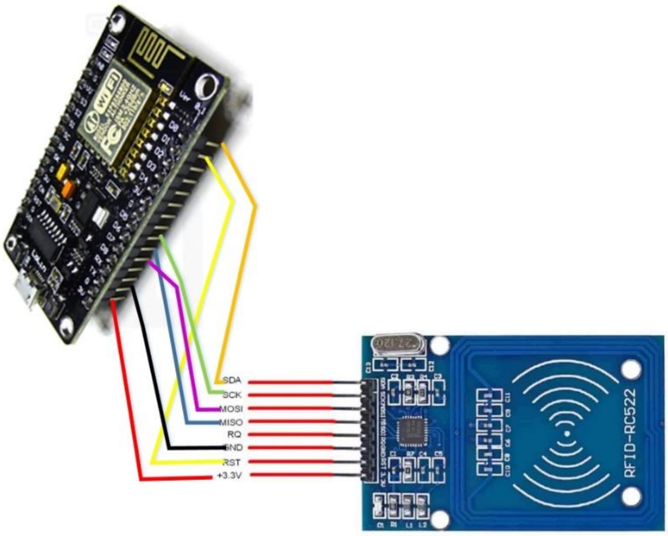

Figure 39: Pin diagram

Source: (Cedcraftscodes, 2019)

According to Figure 40, three units implemented are named Station 1, Station 2, and Station 3.

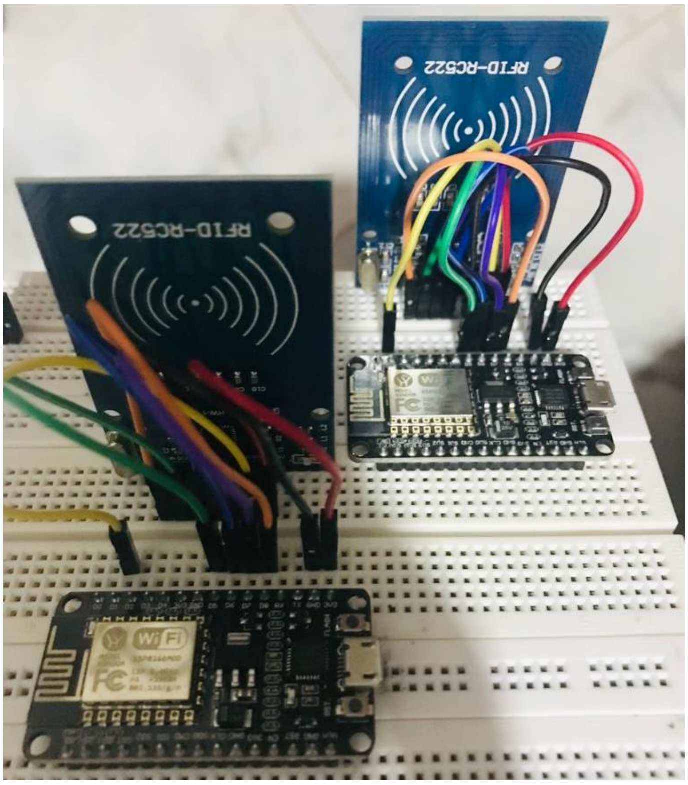

Figure 40: Connected NodeMcu & RFID RC522

Source: Compiled by the author based on the requirement analysis

Thirdly set up the ardino and add an RFID library. According to Figure 41, add the ESP8266 board manager URL and according to Figure 42, install the ESP8266.

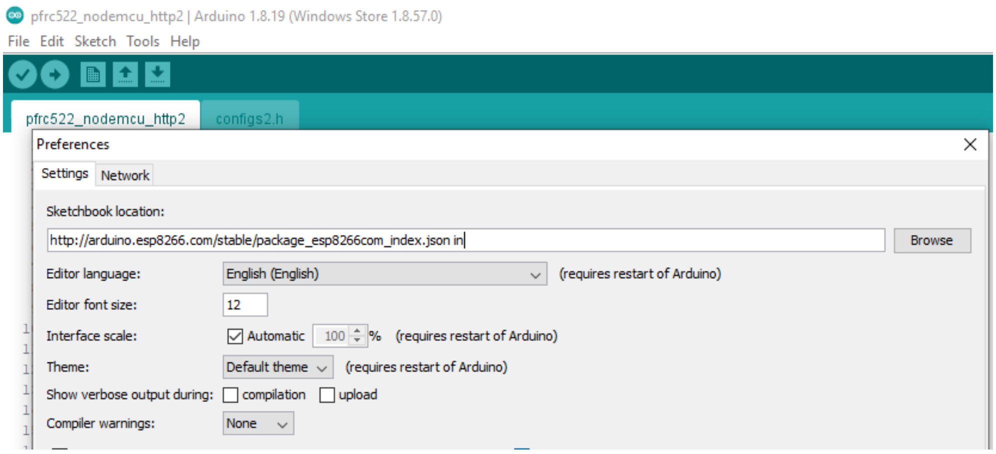

Figure 41: Adding ESP8266

Source: (Cedcraftscodes, 2019)

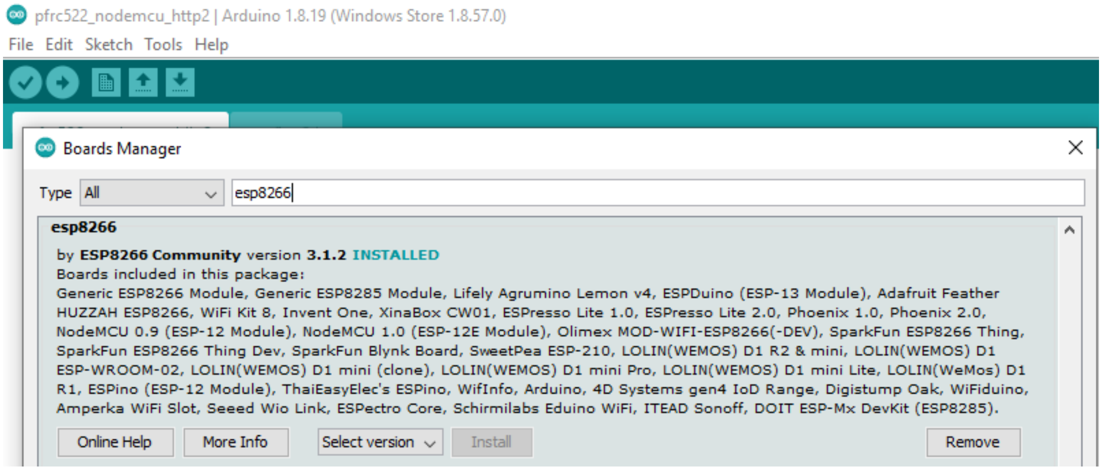

Figure 42:Install ESP8266

Source: (Cedcraftscodes, 2019)

Fourthly, select the port and board by plugging in NodeMcu to the computer as shown in Figure 43, after plugging the NodeMce into the computer and RFID scanner will light up. According to Figure 44, install the CP2102 driver on the computer and select the detected Port (Ex: COM3)

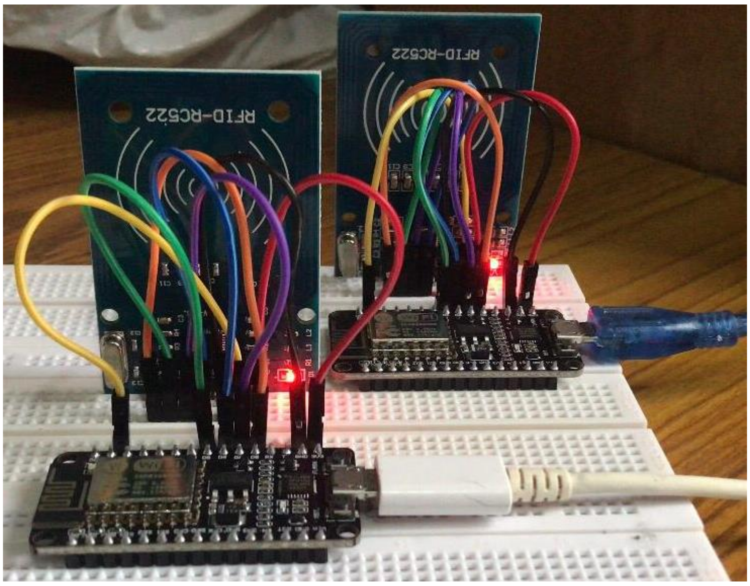

Figure 43: The device connected to power

Source: Compiled by the author based on the requirement analysis

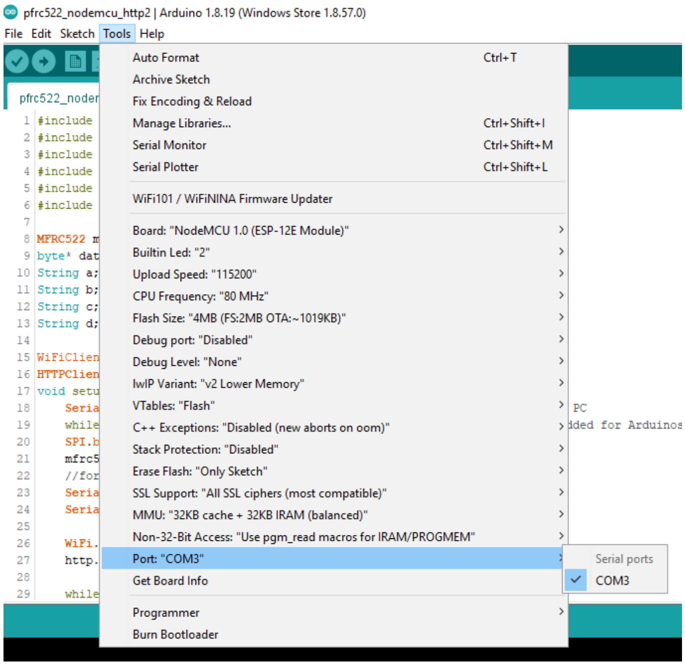

Figure 44: Port selection

Source: (Cedcraftscodes, 2019)

Lastly, upload the .ino file and .h file to NodeMcu, the source code is included which was written in C++ language in Appendix E.

B. Middleware (API)

According to Figure 45, API runs using the Open PowerShell window. First, need to install Node.js by the “npm install” command and run the API by node server.js command. The code you provided is written in JavaScript and is designed to run in a Node.js environment. It uses the Express.js framework for building web applications and APIs.

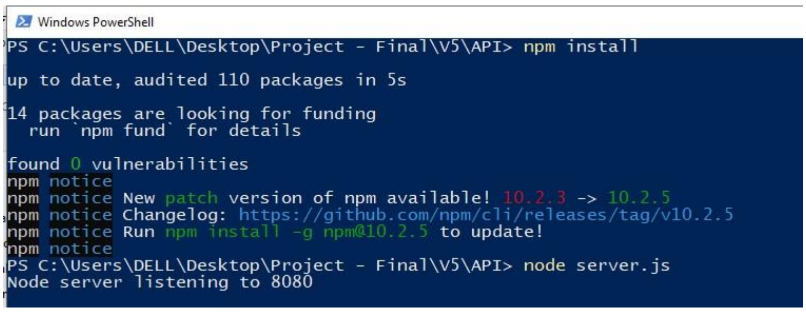

Figure 45: Run the API

Source: Compiled by the author

The Node.js API includes three main files: app.js, db-connect.js, and server.js. The app handles HTTP POST requests for GRN updates, material transfers from PMS to TSP, material returns from TSP to PMS, and inventory management, triggering asynchronous database operations and sending responses back to clients. The db-connect.js module manages database interactions using connection pooling for efficient communication with the MySQL database. The JavaScript source code for GRN transfers from PMS to TSP and returns from TSP to PMS is provided in Appendix F.

C. Software Components

PHP language is used as a core language of a web-based application. CSS, HTML, and JavaScript are used to implement the web-based application. XAMPP 3.3.0 web server solutions (Figure 46) and NetBeans IDE 8.0.2 (Figure 47) are used to implement the software. Database developed with MySQL in phpMyAdmin (Figure 48).

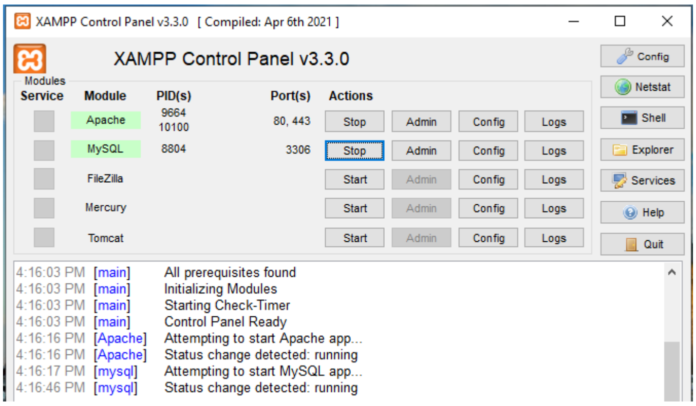

Figure 46: XAMPP control panel

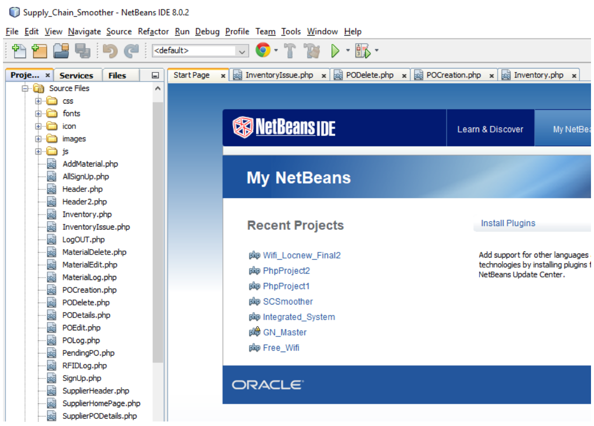

Figure 47: NetBeans IDE

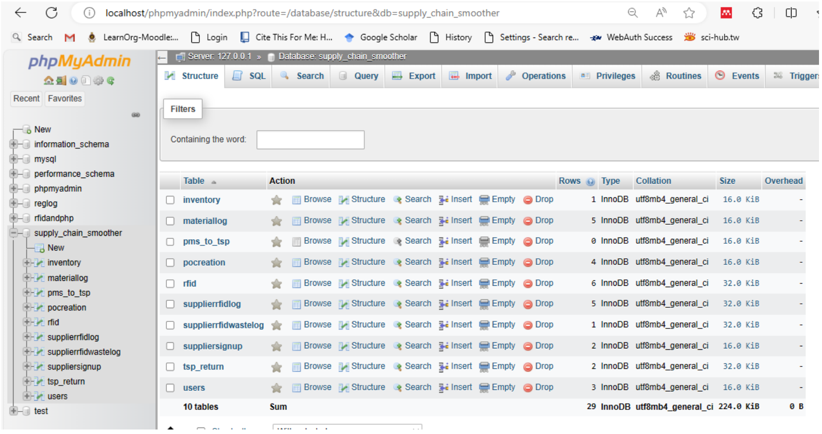

Figure 48: phpMyAdmin

The web-based system's database comprises nine tables, as shown in Figure 48, with a database map illustrated in Figure 50. All tables except the inventory table have an auto-increment ID, serving as a unique identifier. The PHP code provided initiates a session using `session_start()` and connects to a MySQL database using the `mysqli_connect` function (Figure 49).

```
<?php
session_start();
$conn=  mysqli_connect("localhost", "root","");
mysqli_select_db($conn, "supply_chain_smoother");

?>
```

Figure 49: mysqli_connect function

User information for rubber glove manufacturing companies is stored in the "users" table, while packing material suppliers' user data is in the "supplier_sign_up" table. Packing material details are managed in the "material_log" table, and purchase order details are stored in the "po_creation" table. RFID codes related to purchase orders are stored in the "supplier_rfid_log" and "supplier_rfid_waste_log" tables, input by suppliers using the edit purchase order function. The "RFID" table manages RFID code data from a hardware device called Station 1, mapping these codes with the "supplier_rfid_log" and "supplier_rfid_waste_log" tables via the API. Data from Station 2 is saved in the "pms_to_tsp" table, with RFID codes mapping to the "RFID" table's "uid" column, removing them from the "RFID" table and adding them to "pms_to_tsp". Similarly, data from Station 3 updates the "RFID" table, removing codes from "pms_to_tsp" and adding them back to "RFID". Inventory tables are updated simultaneously during transfers and returns.

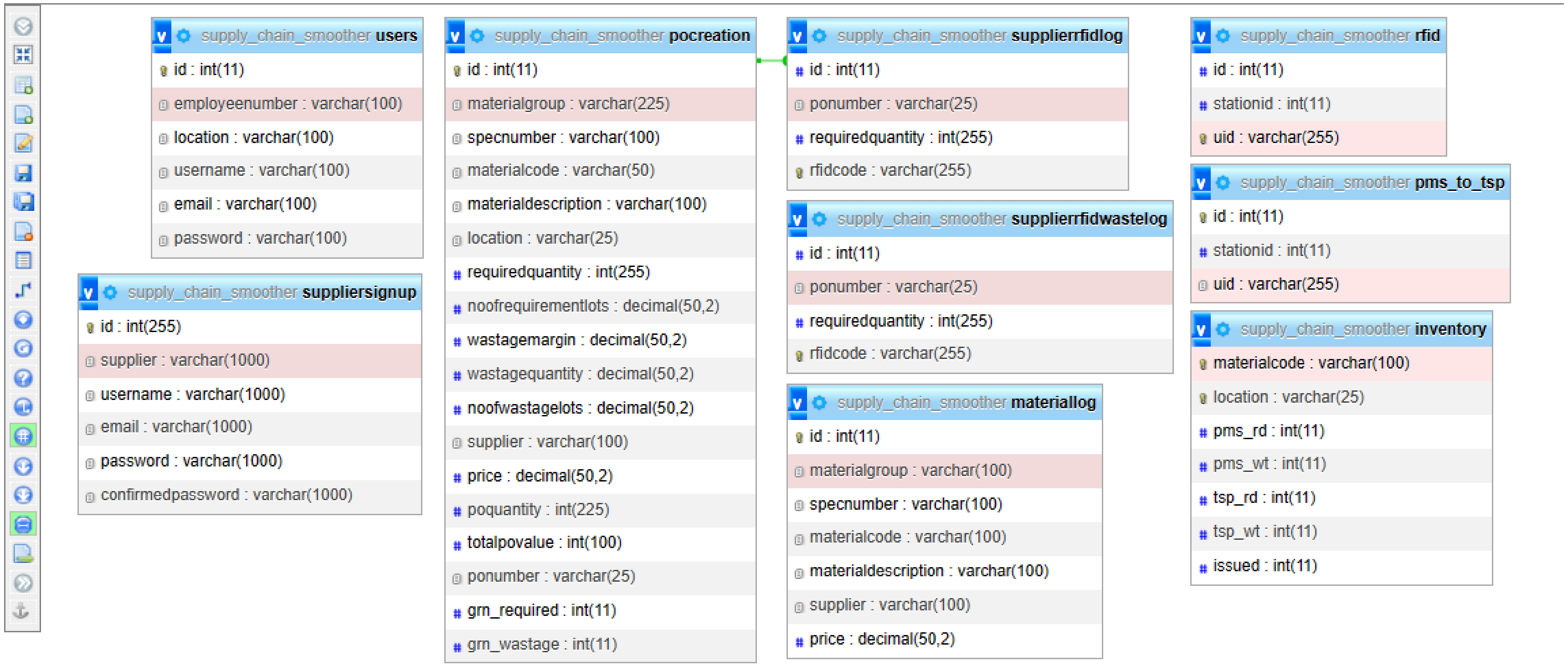

Figure 50: Database Map

a. User Log

This module consists of user sign-up, user log-in, display of user details, editing user details, deleting user functions, and user log-out functions. All the functions of this module can be accessed by both rubber glove manufacturers and packing material suppliers. The user creates after validation of data input by the user and if not enter valid data as an input, the system pops up the message. Source code for user sign-up is given in Figure 51,

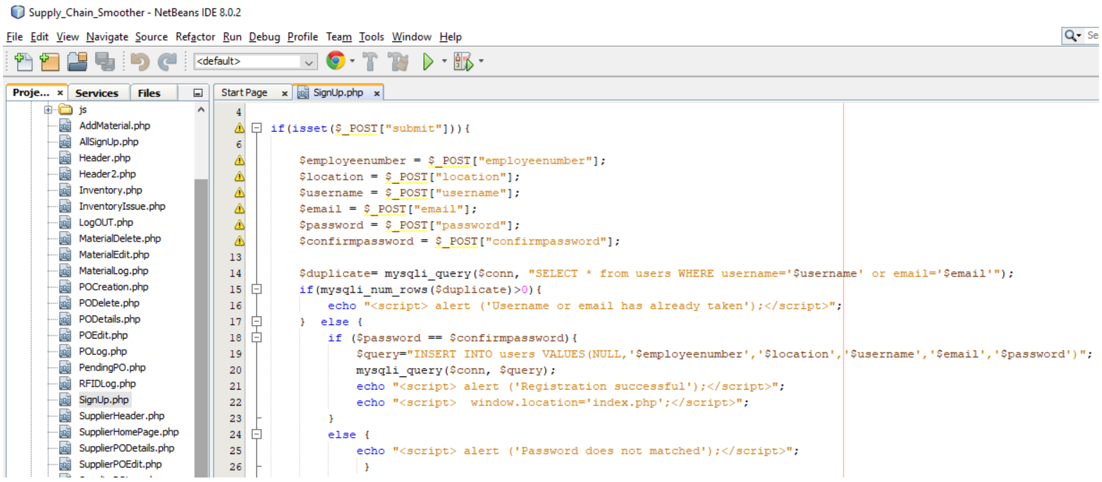

Figure 51: Source code- User sign-up

Check the login details with the database saved sign-up details and allow for login to the system, else the system generates an error message as a popup window. Logged user can view their details in the system, and can edit and update their details through the system. Logged user can delete their account through the database. The source code for user log-in, displaying user details, updating the user details, and deleting the user is given in User Log in Appendix G.

b. Material Log

This module consists of creating packing material, editing packing material, and deleting packing material functions which only can be accessed by rubber glover manufacturers. When creating the Material Code in the system Material Group (Table 23) and the Supplier pre-defined need to be selected from the drop-down menu. The source code for create material code is given in Figure 52,

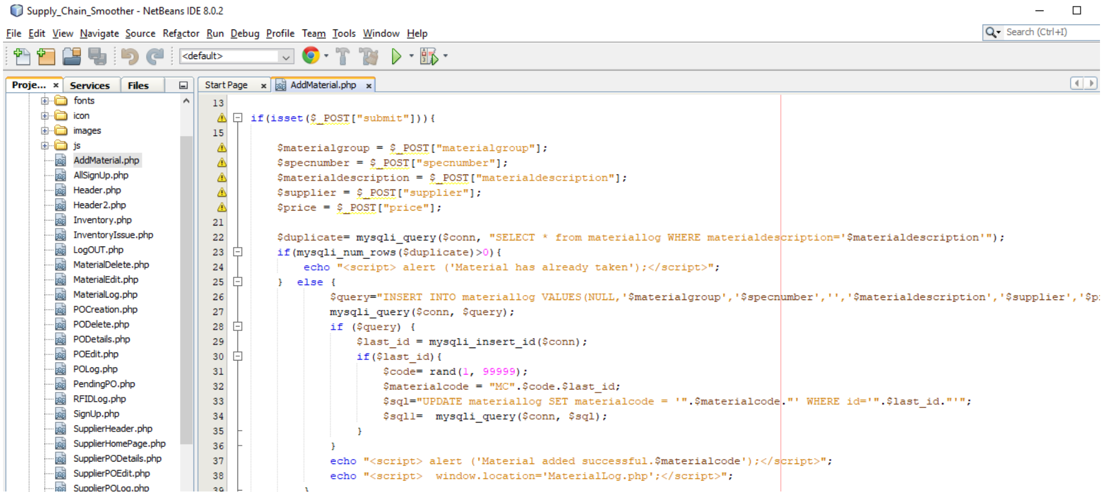

Figure 52: Source code- Material code creation

The material log can be viewed by a user and all the created material details against material code are included in one table. Material log details can be edited and updated by referring to the unique “id”. Material log details can be deleted by referring to the unique “id”. The source code for displaying the material log, updating the material details, and deleting the material details is given in the Material Log in Appendix G.

c. Purchase Order Log

This module consists of creating a purchase order, editing the purchase order, deleting the purchase order, and Generate GRN – Input (Station 1) functions which only can be accessed by rubber glove manufacturers, and displaying purchase order details function can access both rubber glove manufacturer and packing material suppliers, and RFID code adding for each lot of the purchase order function can only access by packing material supplier. When creating a purchase order Material Group, Spec Number, Material Code, Material Description, Supplier, and Price details refer from the database and input only Location, Required Quantity, and Wastage Margin. There are some calculated values (Table 24) input into the database when submitting the purchase order creation form. The source code for creating a purchase order is given in Figure 53,

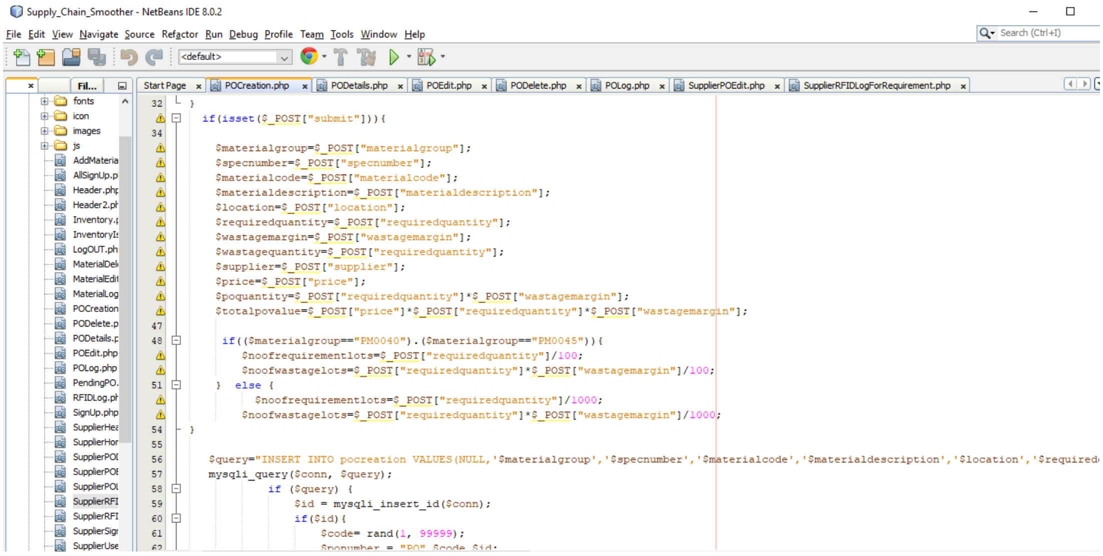

Figure 53: Source code- Purchase order creation

Users can access all the purchase orders which have in the database in one table called the purchase order log. The packing material supplier can edit and update the purchase order with the RFID code addition only. Rubber glove manufacturers can edit or update other details of the purchase order by referring to a unique “id”. A purchase order can be deleted by referring to the unique “id”. The source code for displaying the purchase order log, and adding the RFID code for the purchase order, updating the purchase order is given in the Purchase Order Log in Appendix G.

Using API update the GRN quantity in the “po_creation” table. The source code for updating the purchase order is given in Figure 54,

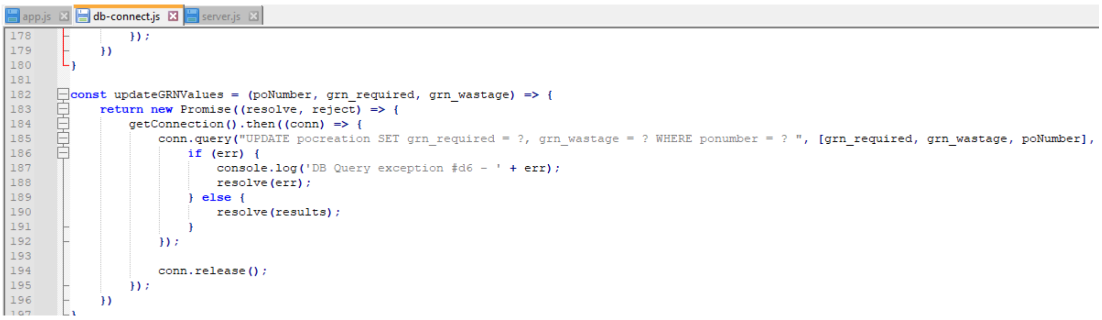

Figure 54: Source code - GRN of purchase order

d. Inventory Log

This module consists of searching and viewing the inventory of materials, transferring materials from PMS to TSP, materials issues for the sales order, and returning materials from TSP to PMS functions which only can be accessed by rubber glove manufacturers. The inventory search by Material Coode and all the details of each inventory location are displayed in the user interface. The source code for searching inventory is given in Figure 55,

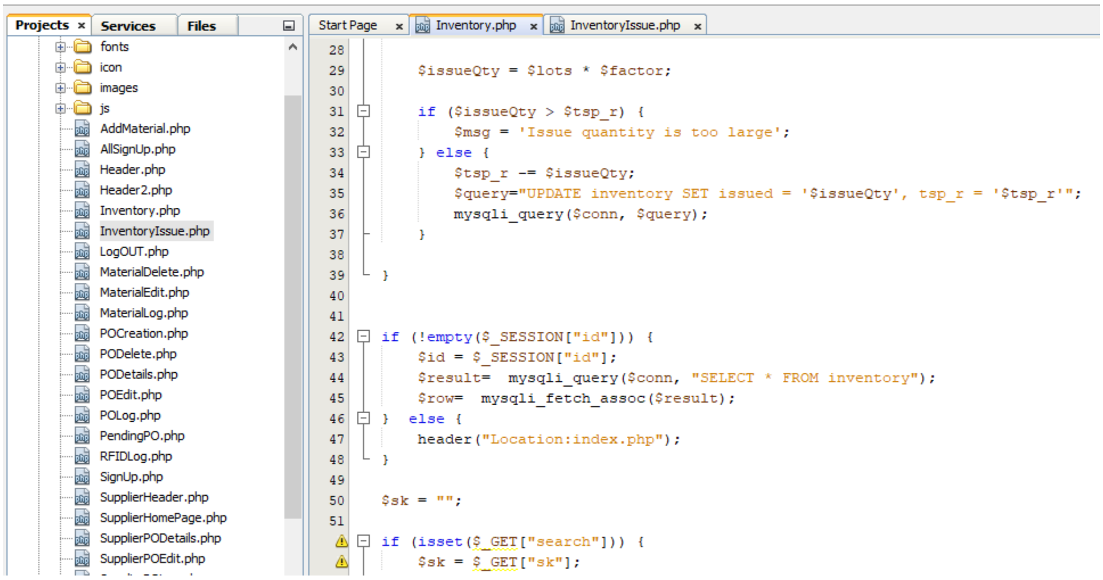

Figure 55: Source code - Search Inventory

Using API transfer the inventory from PMS to TSP. The source code for transferring the inventory from PMS to TSP is given in Figure 56,

```
const pmsRfIdRegistration = (id, stationId, uid) => {
    return new Promise((resolve, reject) => {
        getConnection().then((conn) => {
            conn.query("INSERT INTO pms_to_tsp (stationid, uid) VALUES (?, ?)", [stationId, uid], (err, results, fields) => {
                if (err) {
                    console.log('DB Query exception #d1 - ' + err);
                    resolve(err);
                } else {
                    resolve(results);
                }
            });

            conn.release();
        });
    })
}
```

Figure 56: Source code - Inventory transfer from PMS to TSP

Using API transfer the inventory from TSP to PMS. The source code for transferring the inventory from TSP to PMS is given in Figure 57,

```
const tspRfIdRegistration = (id, stationId, uid) => {
    return new Promise((resolve, reject) => {
        getConnection().then((conn) => {
            conn.query("INSERT INTO tsp_return VALUES (?, ?, ?)", [id, stationId, uid], (err, results, fields) => {
                if (err) {
                    console.log('DB Query exception #d10 - ' + err);
                    resolve(err);
                } else {
                    resolve(results);
                }
            });

            conn.release();
        });
    })
}
```

Figure 57: Source code- Inventory return from TSP to PMS

The inventory quantities can be issued for sales orders. The source code for issuing inventory for sales orders is given in Figure 58,

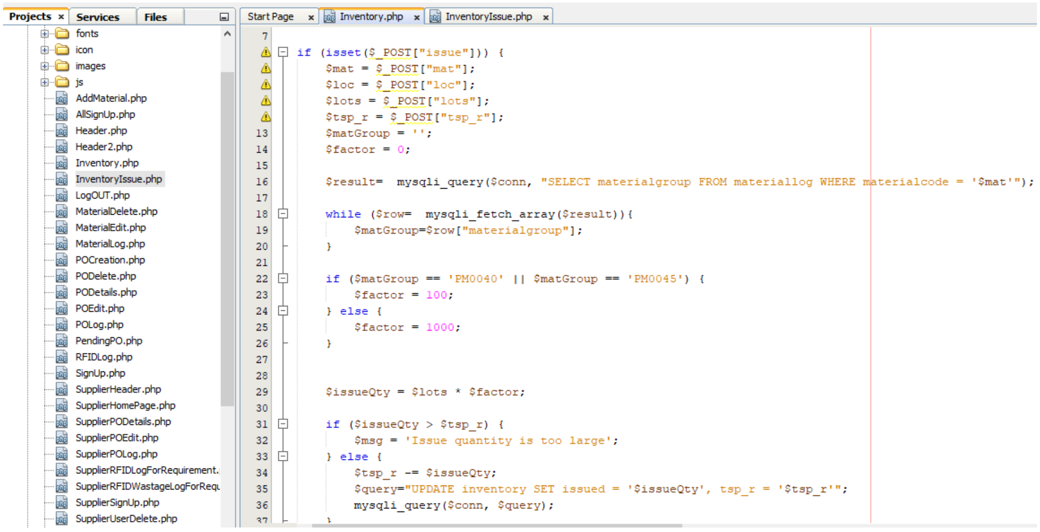

Figure 58: Source code - Issuing inventory for sales order

4.4.5 Building Simulation/Demonstration

A. User Log

There is a snapshot of the User Interface (UI) relevant to the User sign-up of the user log given in Figure 59. Other snapshots of the UI relevant to the user log are given in the User Log in Appendix H.

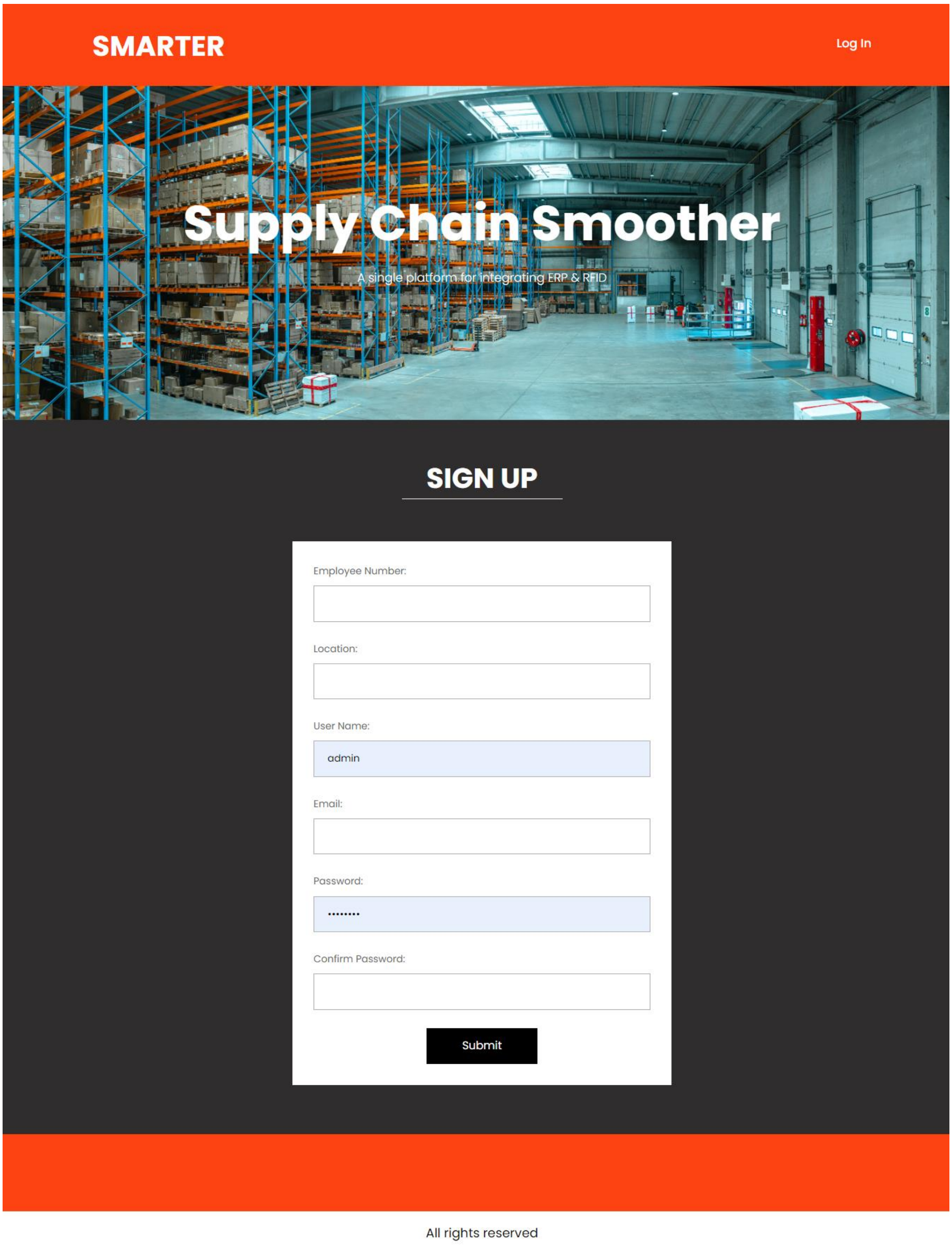

Figure 59: User Sign-up-Software

B. Material Log

There is a snapshot of the User Interface (UI) relevant to the Create packing material of the material log given in Figure 60. Other snapshots of the UI relevant to the material log are given in the Material Log in Appendix H.

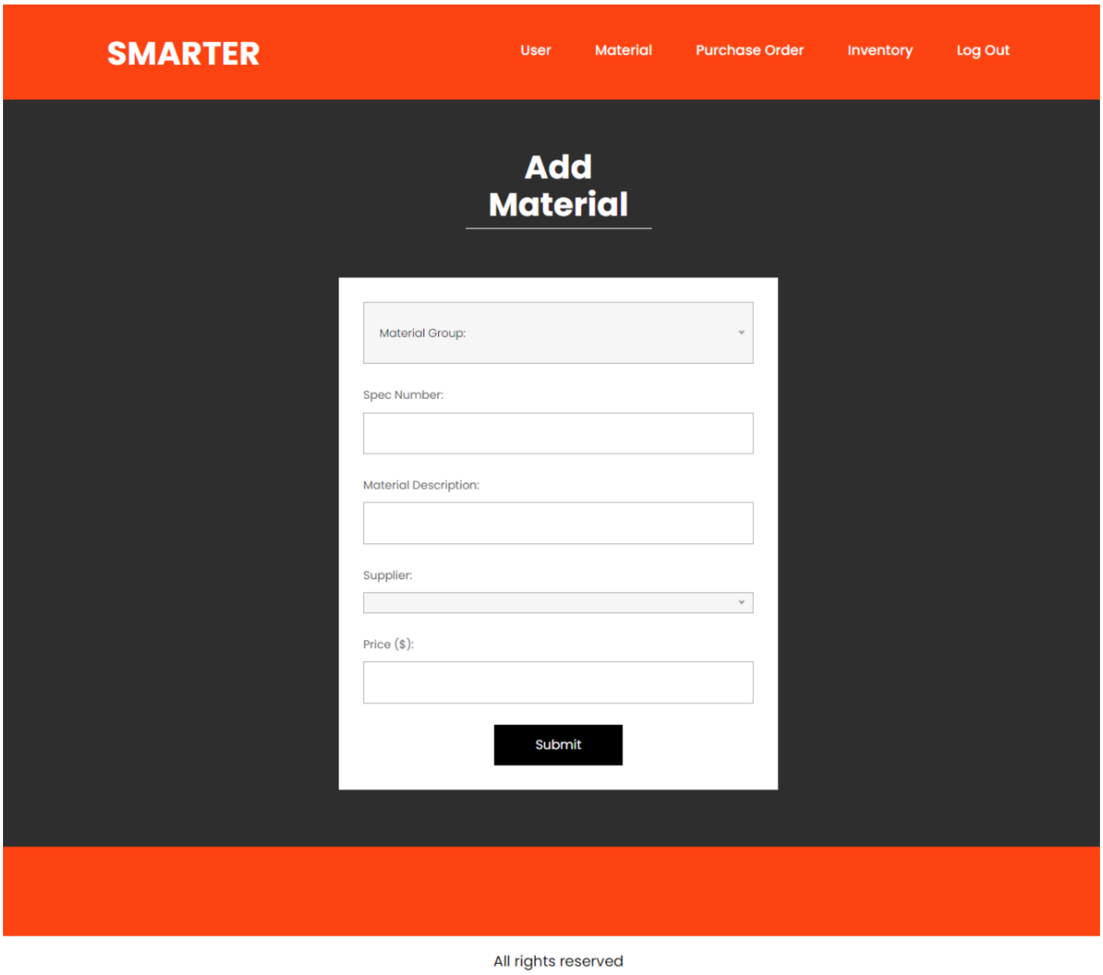

Figure 60: Create packing material- Software

C. Purchase Order Log

There is a snapshot of the User Interface (UI) relevant to the Create purchase order of the purchase order log given in Figure 61. Other snapshots of the UI relevant to the purchase order log are given in the Purchase Order Log in Appendix H.

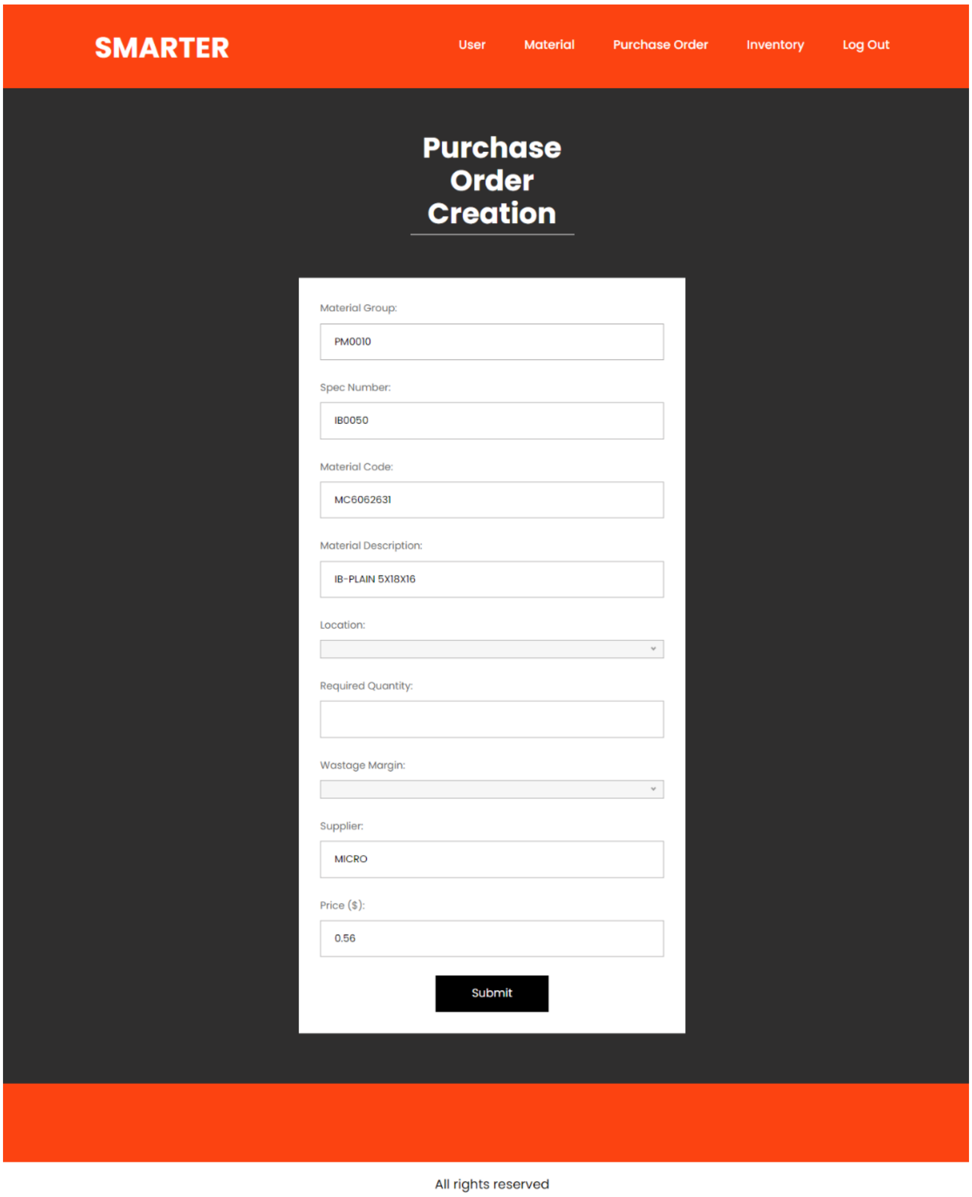

Figure 61: Create purchase order- Software

GRN function has combinations of the connected output of Arduino IDE, Windows PowerShell, phpMyAdmin (rfid table), phpMyAdmin(inventory table), and updated inventory table after GRN and relevant UI output is given in the GRN Function in Purchase Order Log in Appendix H.

D. Inventory Log

There is a snapshot of the User Interface (UI) relevant to the Search and view of the inventory in the inventory log given in Figure 62. Other snapshots of the UI relevant to the inventory log are given in the Inventory Log in Appendix H.

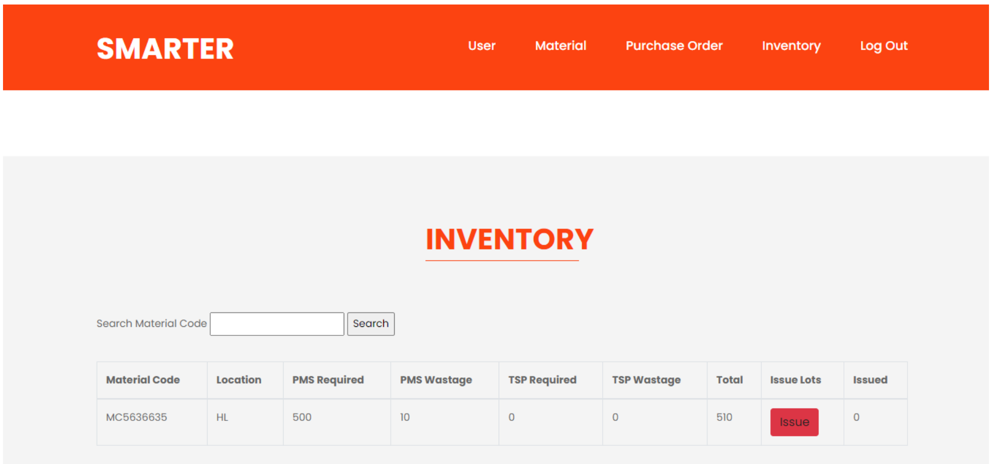

Figure 62: Search and view the inventory of materials- Software

Transfer materials from PMS to TSP function have combinations of the connected output of Arduino IDE, Windows PowerShell, phpMyAdmin (pms_to_tsp table), phpMyAdmin(inventory table), phpMyAdmin (rfid table), and updated inventory table after transferred and relevant UI output is given in the Transfer Materials from PMS to TSP Function in Inventory Log in Appendix H.

There is a snapshot of the User Interface (UI) relevant to the Material issue for order in the inventory log given in Figure 63.

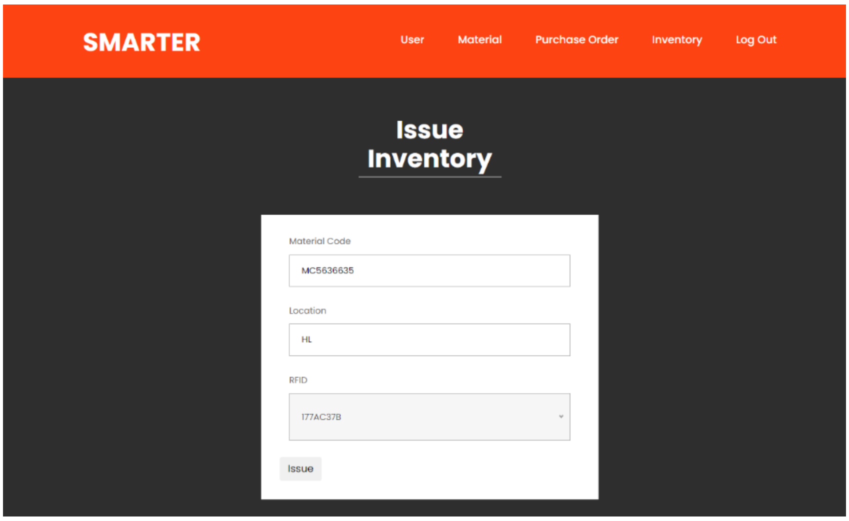

Figure 63: Materials issue for the order- Software

Materials issue for the order function has combinations of the connected output of phpMyAdmin (inventory table), phpMyAdmin (pms_to_tsp table), and updated inventory table after issued and relevant UI output is given in the Material Issue for Order Function in Inventory Log in Appendix H.

Return materials from TSP to PMS function have combinations of the connected output of Arduino IDE, Windows PowerShell, phpMyAdmin (rfid table), phpMyAdmin(inventory table), and updated inventory table after returned and relevant UI output is given in the Return Materials from TSP to PMS Function in Inventory Log in Appendix H.

4.4.6 Pilot Test

The structured format used to collect data on existing systems and proposed systems' (Supply Chain Smoother) pilot tests is shown in Appendix B. Structured observation was done with pilot tests at five warehouse locations in one week period for each location and the head office of a rubber glove manufacturing company. Table 30 displays the details of the existing system operation. The summary of data gathered from a pilot test is shown in Table 31,

Where;

Measurement

- Number of times the process is done per day = W
- Time spent on the per-process (minutes) = X
- Number of steps = Y
- The number of errors that occurred per day = Z
- Number of times the process is tested= V
- The number of errors occurred at the testing times = U

Process

- GRN = A
- Packing materials transfer from PMS to TSP location in the system and physically = B
- Packing materials returns from TSP to the PMS location in the system and physically = C.
- Inventory figure adjustments were done by the operator = D
- Generate identification for received packing material lots = E

Table 30: Process at Production and warehousing (Existing)

Factory	Proces	Monday				Tuesday				Wednesday				Thursday				Friday				Saturday			
	s	**W**	**X**	**Y**	**Z**	**W**	**X**	**Y**	**Z**	**W**	**X**	**Y**	**Z**	**W**	**X**	**Y**	**Z**	**W**	**X**	**Y**	**Z**	**W**	**X**	**Y**	**Z**
Factory 1	**A**	10	2	8	2	12	2	8	1	11	2	8	7	16	2	8	5	18	2	8	6	6	2	8	0
	B	100	10	9	10	98	10	9	8	76	10	9	5	88	10	9	6	96	10	9	11	56	10	9	4
	C	1	10	9	1	0	10	9	0	2	10	9	1	3	10	9	1	1	10	9	1	0	10	9	0
	D	1	0.5	6	1	0	0.5	6	0	0	0.5	6	0	1	0.5	6	0	1	0.5	6	0	0	0.5	6	0
	E	40	2	2	3	48	2	2	3	44	2	2	2	64	2	2	5	72	2	2	9	24	2	2	2
Factory 2	**A**	18	1.7	8	4	20	1.7	8	7	24	1.7	8	3	15	1.7	8	0	21	1.7	8	7	8	1.7	8	0
	B	72	9.5	9	6	81	9.5	9	9	78	9.5	9	8	73	9.5	9	5	83	9.5	9	12	42	9.5	9	0
	C	2	10	9	1	1	10	9	0	3	10	9	1	0	10	9	0	1	10	9	0	0	10	9	0
	D	3	0.5	6	1	0	0.5	6	0	0	0.5	6	0	1	0.5	6	0	2	0.5	6	1	0	0.5	6	0
	E	72	2.5	2	5	80	2.5	2	9	96	2.5	2	6	60	2.5	2	2	84	2.5	2	10	32	2.5	2	3
Factory 3	**A**	20	2	8	6	24	2	8	8	21	2	8	4	18	2	8	0	23	2	8	6	5	2	8	1
	B	84	9	9	11	72	9	9	5	68	9	9	2	76	9	9	4	81	9	9	13	24	9	9	2
	C	5	9.5	9	3	0	9.5	9	0	2	9.5	9	0	1	9.5	9	0	6	9.5	9	3	0	9.5	9	0
	D	2	0.7	6	1	0	0.7	6	0	1	0.7	6	0	0	0.7	6	0	1	0.7	6	0	0	0.7	6	0
	E	80	1.8	2	12	96	1.8	2	12	63	1.8	2	9	68	1.8	2	8	97	1.8	2	17	25	1.8	2	0
Factory 4	**A**	11	2.3	8	2	14	2.3	8	0	16	2.3	8	3	13	2.3	8	1	15	2.3	8	3	5	2.3	8	0
	B	56	10	9	4	73	10	9	8	62	10	9	4	46	10	9	2	57	10	9	8	25	10	9	0
	C	3	9.5	9	0	0	9.5	9	0	2	9.5	9	2	0	9.5	9	0	0	9.5	9	0	0	9.5	9	0
	D	2	0.5	6	1	1	0.5	6	1	3	0.5	6	1	0	0.5	6	0	0	0.5	6	0	0	0.5	6	0
	E	42	2.2	2	8	48	2.2	2	11	42	2.2	2	7	49	2.2	2	5	75	2.2	2	15	30	2.2	2	6
Factory 5	**A**	4	2.5	8	1	5	2.5	8	0	3	2.5	8	0	7	2.5	8	1	10	2.5	8	2	3	2.5	8	0
	B	30	10	9	5	22	10	9	3	10	10	9	0	38	10	9	4	40	10	9	11	10	10	9	0
	C	0	11	9	0	0	11	9	0	0	11	9	0	1	11	9	1	0	11	9	0	0	11	9	0
	D	0	1	6	0	0	1	6	0	0	1	6	0	0	1	6	0	0	1	6	0	0	1	6	0
	E	16	2.5	2	3	20	2.5	2	2	12	2.5	2	0	32	2.5	2	4	30	2.5	2	7	24	2.5	2	2

Table 31: Process of Production and Warehousing (Proposed System - Supply Chain Smoother)

Factory	Process	Monday				Tuesday				Wednesday				Thursday				Friday				Saturday			
		V	**X**	**Y**	**U**	**V**	**X**	**Y**	**U**	**V**	**X**	**Y**	**U**	**V**	**X**	**Y**	**U**	**V**	**X**	**Y**	**U**	**V**	**X**	**Y**	**U**
Factory 1	**A**	2	0.1	2	0	2	0.1	2	0	1	0.1	2	0	1	0.1	2	0	2	0.1	2	0	1	0.1	2	0
	B	6	0.1	2	0	8	0.1	2	0	4	0.1	2	0	4	0.1	2	0	6	0.1	2	0	7	0.1	2	0
	C	1	0.1	2	0	1	0.1	2	0	1	0.1	2	0	1	0.1	2	0	1	0.1	2	0	1	0.1	2	0
	E	10	0	0	0	8	0	0	0	6	0	0	0	8	0	0	0	5	0	0	0	4	0	0	0
Factory 2	**A**	2	0.1	2	0	2	0.1	2	0	1	0.1	2	0	1	0.1	2	0	2	0.1	2	0	1	0.1	2	0
	B	6	0.1	2	0	8	0.1	2	0	4	0.1	2	0	4	0.1	2	0	6	0.1	2	0	7	0.1	2	0
	C	1	0.1	2	0	1	0.1	2	0	1	0.1	2	0	1	0.1	2	0	1	0.1	2	0	1	0.1	2	0
	E	10	0	0	0	8	0	0	0	6	0	0	0	8	0	0	0	5	0	0	0	4	0	0	0
Factory 3	**A**	2	0.1	2	0	2	0.1	2	0	1	0.1	2	0	1	0.1	2	0	2	0.1	2	0	1	0.1	2	0
	B	6	0.1	2	0	8	0.1	2	0	4	0.1	2	0	4	0.1	2	0	6	0.1	2	0	7	0.1	2	0
	C	1	0.1	2	0	1	0.1	2	0	1	0.1	2	0	1	0.1	2	0	1	0.1	2	0	1	0.1	2	0
	E	10	0	0	0	8	0	0	0	6	0	0	0	8	0	0	0	5	0	0	0	4	0	0	0
Factory 4	**A**	2	0.1	2	0	2	0.1	2	0	1	0.1	2	0	1	0.1	2	0	2	0.1	2	0	1	0.1	2	0
	B	6	0.1	2	0	8	0.1	2	0	4	0.1	2	0	4	0.1	2	0	6	0.1	2	0	7	0.1	2	0
	C	1	0.1	2	0	1	0.1	2	0	1	0.1	2	0	1	0.1	2	0	1	0.1	2	0	1	0.1	2	0
	E	10	0	0	0	8	0	0	0	6	0	0	0	8	0	0	0	5	0	0	0	4	0	0	0
Factory 5	**A**	2	0.1	2	0	2	0.1	2	0	1	0.1	2	0	1	0.1	2	0	2	0.1	2	0	1	0.1	2	0
	B	6	0.1	2	0	8	0.1	2	0	4	0.1	2	0	4	0.1	2	0	6	0.1	2	0	7	0.1	2	0
	C	1	0.1	2	0	1	0.1	2	0	1	0.1	2	0	1	0.1	2	0	1	0.1	2	0	1	0.1	2	0
	E	10	0	0	0	8	0	0	0	6	0	0	0	8	0	0	0	5	0	0	0	4	0	0	0

4.4 Objective 4

Objective 4 is to measure the impact of the integrated ERP and RFID system on procurement performance in the rubber glove manufacturing industry in Sri Lanka using descriptive analysis through collected data from pilot test data from the proposed system against the existing system, semi-structured questionnaires, and semi-structured interviews.

4.4.1 Frequency Distribution Analysis on Pilot Test Data

According to the ABC rubber glove manufacturing company's pilot test result analysis, the implemented system (Supply Chain Smoother) reduces the time allocated for GRN, transfers, returns, and material identification (labeling) process and increases the accuracy of the inventory figure which has a significant positive relationship with procurement performance. As per the case study, it is necessary to integrate ERP and RFID systems to improve the procurement performance of the rubber glove manufacturing industry in Sri Lanka.

According to Table 30, There is data gathering done from the existing system process, before the pilot test. Pilot test data is summarized in Table 31. The following processes are tested in both existing and Supply Chain Smoother systems on five warehouse locations in a 6 working days period for each location in ABC rubber glove manufacturing company. According to Figure 64, Good Receipt Note (GRN), material transfer from Packing Material Store (PMS) to Trimming. Sorting and Packing (TSP), materials returned from TSP to the PMS, and generating identification for received packing material lots take more time in the existing system than the Supply Chain Smoother. The operator has to follow several steps to complete each process in the existing system and takes more time to complete the process. However, the proposed system automatically captures the data and conveys it to the database and the user can display the real-time values in 6 seconds.

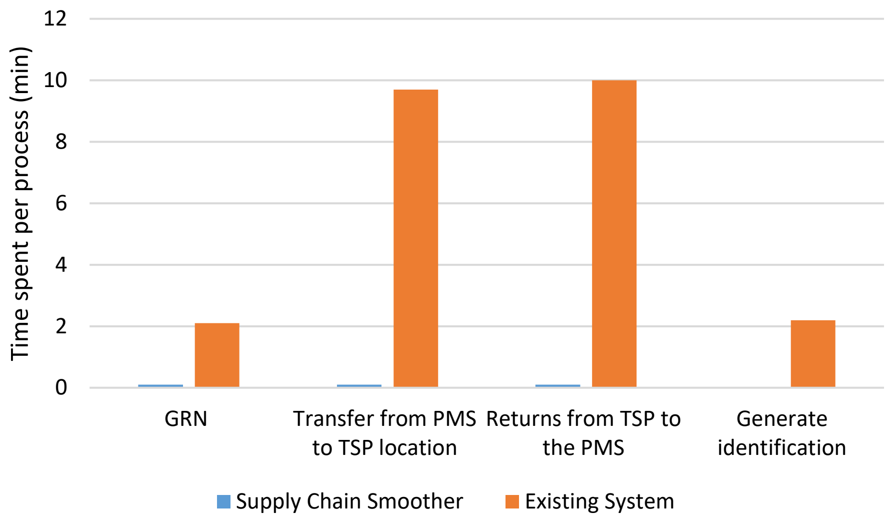

Figure 64: Time spent per process in existing Vs supply chain smoother

Source: Author developed based on data analysis

According to Figure 65, the average GRN per day at all five locations can be completed in less time using RFID technology than the existing system. The operator has to pass the the lot through RFID Station only. However, the proposed system automatically captures the data and conveys it to the database and the user can do all the GRN transactions of the day in less time when comparing the total time allocated to do the GRN process per day using the existing system.

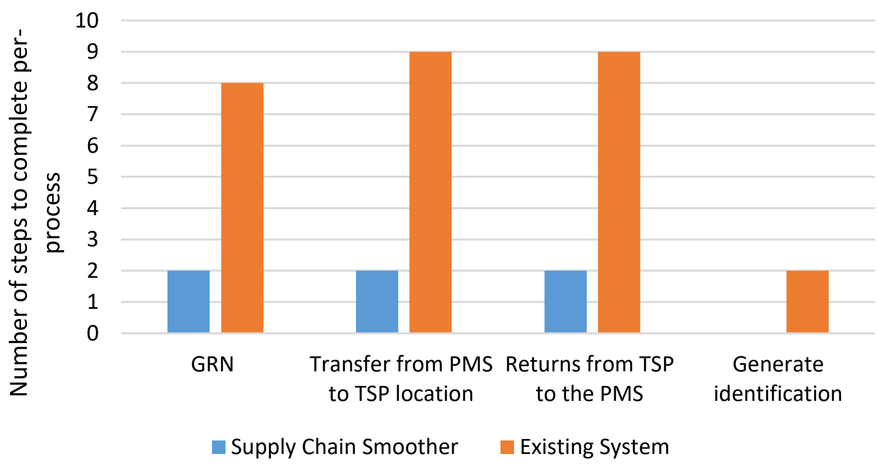

Figure 65: Number of steps to complete the process in existing Vs supply chain smoother

Source: Author developed based on data analysis

According to Figure 66, some errors occurred during each process in the existing system due to the manual data inputs.

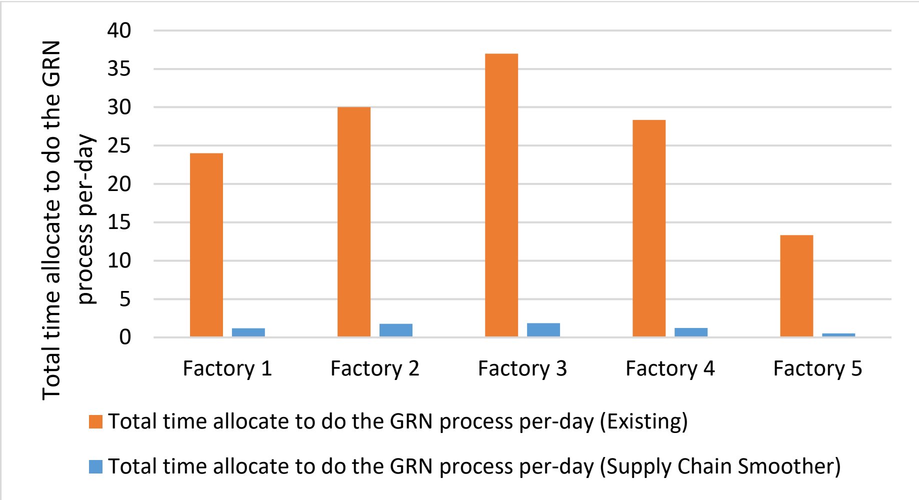

Figure 66: Average error occurred during each process per day

Source: Author developed based on data analysis

During the pilot test, there was no error countered on the process and inventory figure. According to Figure 67, at least one system adjustment was done to correct the inventory figure at all four locations except one location.

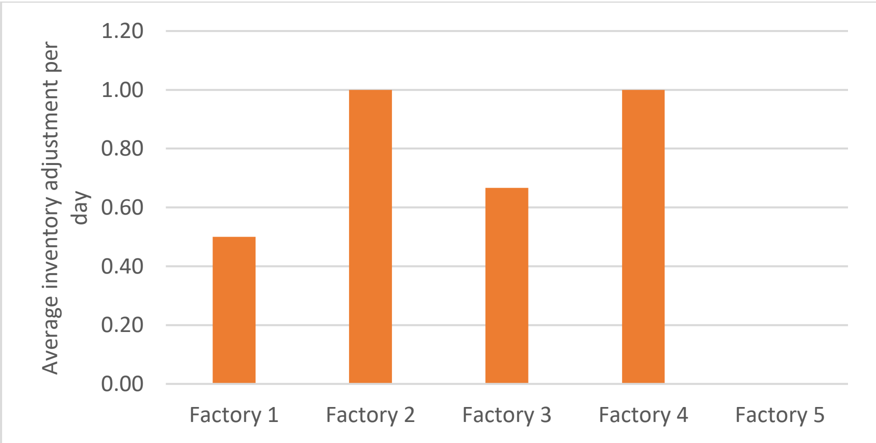

Figure 67: Average inventory adjustment per day

Source: Author developed based on data analysis

When comparing the existing system and the proposed system (Supply Chain Smoother), there are significant advantages of an RFID-integrated system due to the auto data input capability. It will make real-time accurate data figures within less amount of time.

4.4.2 Descriptive Statistics for Procurement Performance Indicator Clusters Based on Semi-Structured Questionnaire

A. Quality Indicator Cluster

According to Table 32, the 26 responders’ mean, mode, median, and standard deviation in the answer is “Strongly Agree” and executives of rubber glove manufacturing companies strongly agree that the proposed system helps reduce overordering or underordering compared to actual requirements. Of the 6 responders’ mean, mode, median, and standard deviation, the answer is “Agree” and IT/ERP consultants of rubber glove manufacturing companies agree that the proposed system enhances demand visibility.

Table 32: Quality Indicator Cluster

		Reducing Overordering or Underordering (RGMC-Exec)	Demand Visibility Improvement (RGMC-IT)
N	**Valid**	26	6
	Missing	0	0
Mean		1.38	1.67
Median		1.00	2.00
Mode		1	2
Std. Deviation		0.983	0.516
Answer		“Strongly Agree”=1, “Agree”=2, “Neutral”=3, “Disagree”=4, “Strongly Disagree”=5	

The majority of executives of rubber glove manufacturing companies strongly agree that the proposed system effectively reduces overordering or underordering, ensuring inventory aligns with actual requirements. Additionally, IT/ERP consultants agree that the proposed system enhances demand visibility, further supporting improved inventory management and purchase order accuracy. Overall, the feedback indicates strong support for the proposed system's ability to minimize inventory discrepancies and improve the accuracy of purchase orders which impact procurement performance.

B. Delivery Indicator Cluster

According to Table 33, the 26 responders’ mean, mode, median, and standard deviation in the answer is “Agree” and executives of rubber glove manufacturing companies agree that the proposed system decreases information processing time. Of the 6 responders’ mean, mode, median, and standard deviation the answer is “Strongly

Agree" and IT/ERP consultants of rubber glove manufacturing companies strongly agree that real-time data is important for improving process efficiency. Of the 28 responders' the mean, mode, median, and standard deviation in the answer is "Agree" and managers of rubber glove manufacturing companies agree that the proposed system reduces the lead time in the procurement and logistics process. Of the 17 responders' the mean, mode, median, and standard deviation in the answer is "Agree" and non-executives of rubber glove manufacturing companies agree that the proposed system eliminates data processing time, with a significant number strongly agreeing.

Table 33: Delivery Indicator Cluster

		Decreasing Information Processing Time (RGMC-Exec)	Real-Time Data in Enhancing Process Efficiency (RGMC-IT)	Reducing Lead Time (RGMC-Mgr)	Elimination of Data Processing Time (RGMC-Non-Exec)
N	**Valid**	26	6	28	17
	Missing	0	0	0	0
Mean		1.77	1.33	1.79	1.59
Median		1.00	1.00	1.50	2.00
Mode		1	1	1	1
Std. Deviation		1.032	0.516	1.101	0.618
Answer		"Strongly Agree"=1, "Agree"=2, "Neutral"=3, "Disagree"=4, "Strongly Disagree"=5			

The feedback indicates that the system has a positive impact on several key procurement performance areas. Executives of rubber glove manufacturing companies generally agree that the system decreases information processing time. IT/ERP consultants strongly agree on the importance of real-time data for enhancing process efficiency. Managers also agree that the system reduces lead times in procurement and logistics. Non-executives agree that the system effectively eliminates data processing time, with a notable number strongly agreeing. Overall, the proposed system is seen as beneficial in reducing GRN cycle time and reducing the need for emergency purchases by streamlining information processing and enhancing operational efficiency.

C. Inventory Management Indicator Cluster

According to Table 34, the 6 responders' mean, mode, median, and standard deviation in the answer is "Agree" and IT/ERP consultants of rubber glove manufacturing companies agree that the proposed system helps reduce inventory shrinkage, helps reduce stockouts, data capturing helps reduce the need for manual inventory adjustments, and manual data entry into the ERP system is complex and prone to inaccuracies, with many strongly agreeing. Most respondents strongly agree that the system improves inventory management.

Table 34: Inventory Management Indicator Cluster (IT/ERP Consultant)

		Inventory Shrinkage (RGMC-IT)	Stock-Out (RGMC-IT)	Inventory Management (RGMC-IT)	Inventory Adjustments (RGMC-IT)	Impact of Manual Data Entry Complexity on Accuracy (RGMC-IT)
N	**Valid**	6	6	6	6	6
	Missing	0	0	0	0	0
Mean		1.50	1.67	1.33	1.50	1.50
Median		1.50	2.00	1.00	1.50	1.50
Mode		1	2	1	1	1
Std. Deviation		0.548	0.516	0.516	0.548	0.548
Answer		"Strongly Agree"=1, "Agree"=2, "Neutral"=3, "Disagree"=4, "Strongly Disagree"=5				

According to Table 35, the 26 responders' mean, mode, median, and standard deviation in the answer is "Agree" and non-executives, executives, and managers of rubber glove manufacturing companies agree that the proposed system helps reduce the need for manual adjustments to correct inventory figures, provides real-time inventory updates with visual feedback, manual transfers of packing materials can lead to inventory inaccuracies and manual returns of packing materials can lead to inventory inaccuracies, with a consensus of agreement.

Table 35: Inventory Management Indicator Cluster (Non-Exec/Exec/Mgr)

		Reducing Manual Adjustments (RGMC-Exec)	Real-Time Inventory Updates (RGMC-Mgr)	Inventory Inaccuracies due to Manual Transfers (RGMC-Non-Exec)	Inventory Inaccuracies due to Manual Returns (RGMC- Non-Exec)
N	**Valid**	26	28	17	17
	Missing	0	0	0	0
Mean		1.81	1.89	1.59	1.76
Median		2.00	2.00	2.00	2.00
Mode		2	2	2	2
Std. Deviation		0.801	1.031	0.507	0.562
Answer		"Strongly Agree"=1, "Agree"=2, "Neutral"=3, "Disagree"=4, "Strongly Disagree"=5			

IT/ERP consultants of rubber glove manufacturing companies agree that the proposed system significantly reduces inventory shrinkage, stockouts, and the need for manual inventory adjustments, with many strongly agreeing that it improves inventory management. Non-executives, executives, and managers also agree that the system minimizes manual adjustments required to correct inventory figures, provides real-time updates with visual feedback, and addresses issues related to manual transfers and returns of packing materials leading to inaccuracies. Overall, the proposed system is seen as effective in reducing inventory adjustment rates and enhancing overall inventory management while improving procurement performance.

D. Cost Savings Indicator Cluster

According to Table 36, the 28 responders' mean, mode, median, and standard deviation answer is "Agree" and managers of rubber glove manufacturing companies agree that the proposed system is beneficial in reducing labor costs and improving inventory accuracy while decreasing disposal cost, stock-holding cost, and provision amount.

Table 36: Cost Savings Indicator Cluster

		Reducing Labor Costs (RGMC-Mgr)	Decreasing Disposal Costs (RGMC-Mgr)	Reducing Stock-Holding Costs (RGMC-Mgr)	Decreasing Provision Amounts (RGMC- Mgr)
N	**Valid**	28	28	28	28
	Missing	0	0	0	0
Mean		1.93	2.14	2.07	1.89
Median		2.00	2.00	2.00	2.00
Mode		2	2	2	2
Std. Deviation		1.052	1.208	1.152	1.197
Answer		"Strongly Agree"=1, "Agree"=2, "Neutral"=3, "Disagree"=4, "Strongly Disagree"=5			

The proposed system is effective in improving inventory accuracy and reducing labor costs. Additionally, the system helps decrease disposal costs, stock-holding costs, and provision amounts. This consensus indicates that the system positively impacts inventory discrepancy values and demurrage costs by enhancing accuracy and reducing associated expenses by improving procurement performance.

4.4.3 Descriptive Statistics for Procurement Performance Measures Based on Existing and Proposed System Data

Descriptive statistics for procurement performance measures based on existing and proposed system data are summarized in Table 37, with findings derived from the sample calculations in Table 38, using the same reference numbers.

Table 37: Findings From Sample Calculation Summary

Indicator	**Sub Indicators**	**No Of Cases**	**Findings**		**Discussion**
			Existing System	**Proposed System**	
Quality	Inventory discrepancy	GRN: 100 purchase orders	1. 1380 $Quantity$	2. 0 $Quantity$	There is a significant discrepancy (GRN:1380, Transfers: 1180, Returns: 3007) between recorded GRN, transfers, and returns versus the actual quantities in the existing system. Users manually enter transactions into the system, often resulting in missing records. Frequently, users do not return the remaining quantities to the packing material stores after fulfilling relevant sales orders. Additionally, physical transactions and system transactions sometimes do not occur simultaneously. These factors contribute to a significant difference between recorded inventory and actual inventory, referred to as inventory discrepancy. In the proposed system, there is no significant difference between recorded GRN, transfers, and returns and the actual quantities. The RFID reader automatically captures the packing material lot identification. The proposed system provides traceability from the entry of packing material lots into the warehouse until they are issued for sales orders. Consequently, there is no significant discrepancy between recorded inventory and actual inventory, resulting in a null inventory discrepancy.
		Transfers: 99 times	3. 1,180 $Quantity$	4. 0 $Quantity$	
		Returns: 99 times	5. 3,007 $Quantity$	6. 0 $Quantity$	

Indicator	Sub Indicators	No Of Cases	Findings		Discussion
			Existing System	Proposed System	
Quality	Purchase order accuracy	88 sales order requirements	7. -7%	8. -0.04%	The actual total requirement is determined after allocating physical inventory to pending sales order requirements and adding the wastage quantity. The purchase order quantity is calculated after allocating system inventory figures to pending sales order requirements and adding the wastage quantity. Inventory discrepancy quantity that is generated after GRN, transfer, and returns will make an error on the recorded/system inventory. The -7% relative difference between the actual total requirement and the purchase order quantity when using the existing system. In the proposed system, there is no significant difference between actual and recorded inventory. This improvement is due to the RFID reader automatically capturing the packing material lot identification, ensuring real-time and accurate tracking of inventory movements. As a result, system/recorded inventory and actual inventory figures are nearly identical. This results in a negligible -0.04% relative difference between the actual total requirement and the purchase order quantity. This -0.04% difference is primarily due to the packing material suppliers' Minimum Order Quantity (MOQ) rather than errors in the system. The proposed system's enhanced accuracy reduces inventory discrepancies. The proposed system can generate more accurate purchase orders than the existing system, demonstrating its effectiveness in minimizing inventory discrepancies and optimizing order accuracy.

Indicator	Sub Indicators	No Of Cases	Findings		Discussion
			Existing System	Proposed System	
Delivery	GRN cycle time	GRN: 100 purchase orders	9. Average cycle time $= 4min$	10. Average cycle time $= 0.15min$	The GRN cycle time is the time difference between when a Goods Receipt Note (GRN) is created in the system and when the goods are received at the location. In the existing system, the average GRN cycle time for 100 purchase orders is 4 minutes. This extended cycle time is due to the manual identification process for packing material lots, which involves 8 steps. These manual steps are time-consuming and contribute to the longer cycle time. In the proposed system, the average GRN cycle time is significantly reduced to 0.15 minutes (9 seconds). This improvement is achieved by automatically capturing the packing material lot identification using RFID technology. The proposed system requires only two steps to complete the GRN process and automatically updates the system database. As a result, the GRN cycle time is drastically reduced, enhancing efficiency and streamlining the process. This improvement demonstrates the proposed system's effectiveness in reducing operational time and improving delivery processes.

Indicator	Sub Indicators	No Of Cases	Findings		Discussion
			Existing System	Proposed System	
Delivery	Emergency purchase rate due to the inventory figure	88 sales order requirements	11. 6%	12. 0%	In the existing system, there is a 6% emergency purchase rate due to inaccurate inventory figures. This discrepancy is caused by significant differences between recorded GRNs (1380), transfers (1180), and returns (3007) compared to actual quantities. Although the system indicates that pending sales order requirements can be fulfilled, the physical stock shows otherwise, leading to packing material shortages. These inaccuracies necessitate emergency purchases, incurring extra costs for sales orders. For instance, when making emergency purchases for outer cartons, the ideal board size cannot be utilized, often requiring selection from available sizes in the production plant. This results in additional costs for off-cuts, delivery charges, and potential demurrage costs due to delays. The proposed system eliminates emergency purchase rates due to inaccurate inventory figures by maintaining accurate inventory data through RFID technology. With this system, there is no inventory discrepancy, ensuring that physical and system records match precisely. This accuracy prevents packing material shortages and avoids the extra costs associated with emergency purchases, such as off-cut costs, delivery charges, and demurrage fees. The proposed system's reliable inventory management enhances overall efficiency and cost-effectiveness in the production and delivery processes.

Indicator	Sub Indicators	No Of Cases	Findings		Discussion
			Existing System	Proposed System	
Inventory Management	Inventory adjustment rate (Quantity)	88 Stock-Keeping Units (SKUs)	13. 10%	14. 0%	In the existing system, there is a 10% relative difference between the total inventory adjustment and the total physical inventory. This discrepancy arises due to significant differences between recorded GRNs (1380), transfers (1180), and returns (3007) compared to actual quantities. These discrepancies necessitate frequent adjustments to reconcile the system inventory with physical stock, leading to a 10% adjustment rate. The need for these adjustments results in additional time and effort spent by users to correct and reconcile SKUs, thereby causing inefficiencies and potential delays in inventory management. In the proposed system, there is no need for inventory adjustments to reconcile physical and system inventory. The system achieves a 0% relative difference between the total inventory adjustment and total physical inventory. This accuracy is ensured by the RFID reader, which automatically captures packing material lot identification and updates the system database in real-time. Consequently, there are no inventory discrepancies, and users do not need to spend time on manual adjustments. This improvement enhances efficiency, reduces the time spent on inventory management, and ensures accurate and reliable inventory records. The proposed system demonstrates significant improvements in inventory accuracy and management, minimizing the need for manual interventions and adjustments.

Indicator	Sub Indicators	No Of Cases	Findings		Discussion
			Existing System	Proposed System	
Cost Saving	Inventory discrepancy value	GRN: 100 purchase orders	15. USD 76.675	16. USD 0	In the existing system, there is a significant discrepancy between the recorded and actual values of GRNs (USD 76,675), transfers (USD 26,536), and returns (USD 152,627). Users manually enter transactions, leading to missing records and discrepancies. Additionally, users often fail to return the remaining quantities to the packing material stores after fulfilling sales orders. These factors contribute to a substantial difference between recorded and actual inventory, resulting in a high inventory discrepancy value. This discrepancy incurs additional costs and negatively impacts profitability. The proposed system eliminates significant discrepancies between recorded and actual quantities of GRNs, transfers, and returns. This is achieved through the use of RFID technology, which automatically captures packing material lot identification and provides complete traceability from the warehouse entry to issuance for sales orders. As a result, there is no discrepancy between recorded and actual inventory, resulting in a null inventory discrepancy value. This accuracy eliminates the additional costs associated with discrepancies, leading to significant cost savings when compared to the existing system. The proposed system's precise tracking and automatic updating ensure reliable inventory management and enhance overall cost efficiency.
		Transfers: 99 times	17. USD 26.536	18. USD 0	
		Returns: 99 times	19. USD 152.627	20. USD 0	

<table>
<tr><th rowspan="2">Indicator</th><th rowspan="2">Sub Indicators</th><th rowspan="2">No Of Cases</th><th colspan="2">Findings</th><th rowspan="2">Discussion</th></tr>
<tr><th>Existing System</th><th>Proposed System</th></tr>
<tr><td rowspan="5">Cost Saving</td><td rowspan="5">Demurrage cost due to the emergency purchases</td><td rowspan="5">5 Cases happened due to the PM delays</td><td>21.
LKR 2,600</td><td rowspan="5">26.
LKR 0</td><td rowspan="5">In the existing system, inaccuracies in inventory figures often necessitate urgent purchases of packing material. These emergency purchases frequently result in delivery delays beyond the shipment cut-off time due to supplier production lead times. The allowed free time for a container is 24 hours; beyond this, demurrage costs are incurred, which are calculated based on the container type (20ft/40ft) and the duration the container remains in a specific location. During the testing period, a total of LKR 31,550 was paid in demurrage costs due to these emergency purchases. This highlights the inefficiencies and additional costs incurred due to inventory discrepancies.
The proposed system eliminates the need for emergency purchases due to packing material shortages by ensuring accurate and real-time inventory management with no discrepancies between actual and recorded inventory figures. This accurate inventory management allows for the precise allocation of pending sales order requirements from the actual inventory, preventing delays and additional costs associated with emergency purchases. Consequently, the proposed system incurs no demurrage costs, leading to significant cost savings and enhanced operational efficiency.</td></tr>
<tr><td>22.
LKR 20,800</td></tr>
<tr><td>23.
LKR 800</td></tr>
<tr><td>24.
LKR 2,800</td></tr>
<tr><td>25.
LKR 4,550</td></tr>
</table>

Table 38: Sample Calculation Summary

Measures	Sample Calculation	
	Existing System	**Proposed System**
$(RecInv - AInv)$	1.$(176{,}005 - 174{,}625)$	2.$(176{,}005 - 176{,}005)$
	3.$(829{,}414 - 828{,}234)$	4.$(875{,}071 - 875{,}071)$
	5.$(21{,}512 - 18{,}505)$	6.$(61{,}311 - 61{,}311)$
$\frac{\lvert(AReq + Wtge) - POQty\rvert}{(AReq + Wtge)} \times 100\%$	7.$\frac{\lvert(997{,}081) - 1{,}069{,}838\rvert}{(997{,}081)} \times 100\%$	8.$\frac{\lvert(981{,}704) - 982{,}105\rvert}{(981{,}704)} \times 100\%$
$(GRNDT - GRDT) \times (60 \times 24)$ $(GRNDT - GRDT) \times (60^2 \times 24)$	9.$((12/11/23\ 10{:}28\ AM) - (12/11/23\ 10{:}25\ AM)) \times 1440$	10.$((12/13/2023\ 15{:}42{:}02) - (12/13/2023\ 15{:}42{:}00)) \times 86{,}400$
$\frac{NumEP}{TNumPO} \times 100\%$	11.$\frac{5}{88} \times 100\%$	12.$\frac{0}{88} \times 100\%$
$\frac{TInvAdj}{TPICount} \times 100\%$	13. $\frac{(43{,}359 - 39{,}126)}{43{,}359} \times 100\%$	14. $\frac{(61{,}311 - 61{,}311)}{61{,}311} \times 100\%$
$(RecInv - AInv) \times UCost$	15. $(1{,}380 \times UCost)$	16. USD 0 = $(0 \times UCost)$
	17. $(1180 \times UCost)$	18. USD 0 = $(0 \times UCost)$
	19. $(3007 \times UCost)$	20.USD 0 = $(0 \times UCost)$
$(ActDW - AFTim) \times DemRate$ DemRate, If the container type is 20ft: ActDW<24 = LKR 400 per hour ActDW>24 = LKR 450 per hour If the container type is 40ft: ActDW<24 = LKR 600 per hour ActDW>24 = LKR 800 per hour	21.$(28 - 24) \times 650)$	26. $(24 - 24) \times DemRate)$
	22.$(50 - 24) \times 800)$	
	23.$(26 - 24) \times 400)$	
	24.$(31 - 24) \times 400)$	
	25.$(31 - 24) \times 650)$	

Recorded Inventory = RecInv, Actual Inventory = AInv, Actual Requirement = AReq, Wastage = Wtge, Purchase Order Quantity = POQty, Date and Time of GRN Creation = GRNDT, Date and Time of Goods Receipt = GRDT, Number of Emergency Purchases = NumEP, Total Number of Purchase Orders = TNumPO, Total Inventory Adjustments (Quantity) = TInvAdj, Total Physical Inventory Count = TPICount, Unit Cost = UCost, Actual Dwell Time = ActDW, Allowed Free Time = AFTim

4.4.4 Qualitative Analysis of Semi-Structured Interview Responses

A. Summarizing

The semi-structured interviews with procurement and IT managers, as well as warehouse managers, consistently highlighted significant improvements in key procurement performance indicators following the integration of ERP and RFID systems. The main themes extracted from the interviews are,

- Quality: Inventory discrepancies and purchase order accuracy.
- Delivery: GRN cycle time and emergency purchase rate due to inventory figures.
- Inventory Management: Inventory adjustment rate (quantity).
- Cost Savings: Inventory discrepancy value and demurrage costs due to emergency purchases.

B. Categorizing

Quality: Inventory Discrepancy

- Reduced Discrepancies: All respondents reported that the integration of ERP and RFID systems has virtually eliminated inventory discrepancies.
- Improved Reconciliation: Manual reconciliation has become almost unnecessary due to accurate, real-time tracking provided by the RFID system.

Quality: Purchase Order Accuracy

- Enhanced Accuracy: Purchase order accuracy has significantly improved, with discrepancies dropping from 7% to nearly zero.
- Real-Time Updates: Real-time data updates ensure that purchase orders accurately reflect actual requirements.

Delivery: GRN Cycle Time

- Reduced Cycle Time: The GRN cycle time has decreased dramatically, from several minutes to mere seconds.
- Automated Management: System logs are used to track and manage the GRN cycle time, reducing the need for manual intervention.

Delivery: Emergency Purchase Rate Due to Inventory Figures

- Eliminated Emergency Purchases: Accurate inventory figures have eliminated the need for emergency purchases.
- Better Resource Planning: When emergency purchases are necessary, they are handled more efficiently due to better planning.

Inventory: Inventory Adjustment Rate (Quantity)

- Decreased Adjustments: The need for inventory adjustments has decreased significantly, indicating the system's enhanced accuracy.
- Real-Time Alignment: Real-time tracking ensures alignment between physical stock and system inventory.

Cost Savings: Inventory Discrepancy Value

- Zero Costs: The cost associated with inventory discrepancies has dropped to zero, resulting in significant savings.
- Continued Accuracy: Regular audits and staff training ensure ongoing accuracy and minimal financial impact.

Cost Savings: Demurrage Costs Due to Emergency Purchases

- Eliminated Costs: Accurate inventory records have eliminated demurrage costs associated with emergency purchases.
- Avoiding Emergency Purchases: By maintaining precise inventory records, the need for emergency purchases is avoided, preventing demurrage costs.

C. Structuring Using Narratives

Impact of ERP and RFID Systems on Procurement Performance

The integration of ERP and RFID systems has brought substantial improvements to the procurement process across multiple dimensions.

Quality Improvements: The implementation has nearly eradicated inventory discrepancies, thanks to real-time data tracking. This advancement has made manual reconciliations almost redundant, enhancing overall accuracy. Additionally, purchase order accuracy has seen a notable improvement, with discrepancies reducing from 7%

to nearly zero. This improvement ensures that purchase orders align perfectly with actual requirements, optimizing the procurement process.

Delivery Efficiency: The GRN cycle time has been dramatically reduced from several minutes to mere seconds. This reduction streamlines operations and enhances efficiency. The use of system logs to monitor and manage the cycle time ensures that the process remains swift and requires minimal manual intervention. Furthermore, the accurate inventory figures provided by the integrated systems have eliminated the need for emergency purchases, facilitating better resource planning and management.

Inventory Management: The frequency of inventory adjustments has dropped significantly, indicating the accuracy of the integrated system. Real-time tracking ensures that physical stock always matches the system inventory, reducing the need for adjustments and improving inventory management efficiency.

Cost Savings: The integration of ERP and RFID systems has led to substantial cost savings. The cost associated with inventory discrepancies has been reduced to zero, resulting in significant financial benefits for the company. Regular audits and ongoing staff training ensure continued accuracy and minimal financial impact. Additionally, demurrage costs due to emergency purchases have been eliminated, as accurate inventory data prevents the need for such purchases. By maintaining precise inventory records, the company avoids the costs associated with emergency purchases, contributing to overall cost savings.

D. Conclusion

The qualitative analysis of the interviews reveals that the integration of ERP and RFID systems has positively influenced procurement performance. The improvements in quality, delivery, inventory management, and cost savings demonstrate the system's effectiveness in optimizing procurement processes and enhancing operational efficiency. The feedback from various managers highlights the significant benefits of adopting advanced technologies for better resource planning, accurate data tracking, and efficient inventory management

4.5 Discussion

Objective 1: To identify the current state-of-the-art of integration of ERP and RFID systems in the world.

The integration of ERP and RFID systems is essential for achieving real-time data accuracy, process automation, and enhanced operational efficiency. To fully grasp the current state-of-the-art in this integration, it's important to review recent case studies, industry reports, and technological advancements, especially in global contexts like SAP S/4 HANA. While the literature offers a solid understanding of RFID's role and its integration with ERP systems, a comprehensive analysis must also consider challenges such as costs, standardization, and RFID's physical limitations.

Technological advancements like edge computing have significantly advanced the integration, particularly in enhancing real-time data processing, inventory management, and warehouse efficiency. These innovations represent key milestones in modern warehouse management, aligning well with the objective of understanding the current state-of-the-art.

The discussion in section 2.7 provides a thorough exploration of ERP and RFID integration, detailing benefits, challenges, and global applications. It effectively aligns with the objective by offering a detailed and nuanced understanding of the integration's impact on manufacturing and supply chain operations, showcasing how these technologies are modernizing industry practices.

Objective 2: To identify the current state-of-the-art ERP and RFID systems in the Sri Lankan context.

The data reveals that ERP systems are widely adopted (95%) in Sri Lankan warehouses, while RFID systems are scarcely used (1%). This low RFID adoption indicates that, although ERP systems are common, their integration with RFID technology is still nascent. Additionally, the high use of custom-built systems (66%) shows a trend toward tailored solutions for specific needs. The proposed system's performance evaluation will need to address these factors, demonstrating clear advantages in integrating ERP and RFID technologies to offer improvements over existing practices. The current state of technology use in Sri Lanka underscores the need for effective strategies to promote RFID adoption and showcase the benefits of integrated systems to enhance overall warehouse management performance.

The high reliance on manual data entry and processing (97% for GRN and 95% for AOD) in current systems indicates inefficiencies, such as increased errors and slow operations. Similarly, extensive manual labeling (99% for received materials and 95% for dispatched materials) reflects outdated practices prone to mistakes. The proposed ERP and RFID systems aim to automate these tasks, reduce errors, and improve processing speed and accuracy, addressing the limitations of current manual processes and enhancing real-time tracking and overall efficiency. The proposed system aims to automate manual tasks, such as data entry and material identification, which are currently handled manually. The integration of ERP and RFID systems promises to reduce manual errors, speed up processing times, and provide more accurate data, addressing the inefficiencies identified in the current systems. With 99% of respondents relying on manual labeling, the integration of RFID could transform material handling by providing real-time tracking and automated updates. This would mitigate the issues related to manual errors and enhance overall operational efficiency.

Supplier feedback is highly positive about the proposed integrated ERP and RFID systems, highlighting their simplicity, real-time data access, and ease of handling. This feedback supports the system's potential to address current limitations and enhance operational efficiency. However, managing RFID tag costs is crucial for widespread acceptance and successful implementation. The data aligns well with the proposed system’s capabilities, indicating it can effectively address inefficiencies and modernize practices in Sri Lanka.

Objective 3: To design a single platform to integrate ERP and RFID systems for improved procurement performance.

The design and development approach outlined in Section 4.4.1 provides a solid foundation for an integrated ERP and RFID platform, but additional considerations for scalability, security, and ERP integration are necessary to fully achieve improved procurement performance. Section 4.4.2 shows alignment with the objective by integrating hardware for efficient data capture and software for seamless ERP integration. However, technical challenges and potential single points of failure must be addressed.

Section 4.4.3's analysis and design phase supports the development of a comprehensive solution, with a thorough examination of requirements and technical architecture. Success hinges on managing hardware compatibility, software complexity, and robust testing. Section 4.4.4's implementation plan aligns well with the objective, detailing hardware, middleware, and software setup. Challenges such as hardware complexity and API errors need to be managed, with a focus on thorough testing and user-friendly design. The Building Simulation/Demonstration phase provides valuable UI insights but requires a more comprehensive demonstration of real-time performance and integration to validate effectiveness.

Pilot test results indicate improvements in efficiency, accuracy, and simplicity, aligning with the objective. However, further validation on ERP and RFID integration, scalability, and user feedback is needed to ensure the system meets procurement performance goals in real-world scenarios.

Objective 4: To test the impact of the integrated ERP and RFID system on procurement performance

The pilot test results strongly support the objective of testing the impact of an integrated ERP and RFID system on procurement performance. The key findings demonstrate are,

- Time Efficiency: The integrated system substantially reduces processing time.
- Accuracy: The system improves inventory accuracy by eliminating manual errors.
- Process Streamlining: Fewer steps and reduced errors lead to more efficient operations.
- Error Reduction: A decreased need for manual adjustments indicates improved reliability.

The integration of ERP and RFID systems has a positive impact on procurement performance, as evidenced by the improvements in time efficiency, accuracy, process steps, and error reduction. The pilot test results effectively align with the objective and highlight the advantages of adopting such technology in the procurement process.

The descriptive statistics for the indicator clusters provide strong evidence that the integrated ERP and RFID systems positively impact procurement performance. The system shows,

- Quality Improvement: Enhanced demand visibility and reduced overordering/underordering contribute to better inventory alignment with actual needs.
- Delivery Efficiency: Reduced information processing time and lead times, along with elimination of data processing time, improve operational efficiency.
- Inventory Management: Improved accuracy, reduced shrinkage, and stockouts, and minimized manual adjustments support better inventory management.
- Cost Savings: Reduction in labor, disposal, stock-holding, and provision costs highlights the system’s financial benefits.

The feedback from various respondents supports the objective by demonstrating that the integrated ERP and RFID system effectively enhances procurement performance through improved efficiency, accuracy, and cost savings. The integrated ERP and RFID system exhibits a significant positive impact on procurement performance. The proposed system outperforms the existing system across all measured indicators, including quality, delivery, inventory management, and cost savings. The use of RFID technology has addressed critical issues such as inventory discrepancies, purchase order inaccuracies, and high processing times, resulting in improved efficiency, accuracy, and cost-effectiveness.

The proposed system's RFID integration provides clear benefits in procurement performance, supporting the objective of testing its impact effectively. The improvements in inventory accuracy, reduced cycle times, and cost savings validate the effectiveness of the integrated ERP and RFID system in enhancing overall procurement processes.

The qualitative analysis confirms that the integration of ERP and RFID systems has led to substantial improvements in procurement performance. The findings across quality, delivery, inventory management, and cost savings demonstrate that the systems have effectively optimized procurement processes and enhanced operational efficiency. The feedback from procurement, IT, and warehouse managers highlights the significant positive impact of the ERP and RFID systems on procurement performance. The improvements in inventory accuracy, delivery efficiency, inventory management, and cost savings align to test the impact of these integrated systems. The qualitative evidence supports the assertion that the systems provide substantial benefits and effectively address key challenges in procurement.

The analysis of the pilot test results, survey data, and qualitative feedback confirms that the integration of ERP and RFID systems significantly impacts procurement performance. Key findings indicate that the integrated systems enhance time efficiency, accuracy, and process streamlining while reducing errors and manual adjustments. Descriptive statistics further support these conclusions, showing improvements in quality, delivery efficiency, inventory management, and cost savings. Specifically, the systems have improved demand visibility, reduced overordering and underordering, minimized processing times, and decreased costs associated with labor and inventory management. The qualitative analysis reinforces these findings by highlighting the positive impact of ERP and RFID systems on procurement efficiency, accuracy, and overall cost-effectiveness.

4.6 Chapter Summary

Chapter 4 provides a detailed analysis of efforts to improve procurement performance in Sri Lanka's rubber glove manufacturing sector by integrating ERP and RFID systems. The chapter outlines the proposed system's design, implementation, and effectiveness, highlighting how the integration addresses issues like inaccurate inventory levels at ABC Rubber Glove Manufacturing Company. The integration of ERP and RFID systems is shown to significantly reduce processing times and errors, enhance inventory accuracy, and optimize procurement performance. This is supported by data analysis and pilot tests, underscoring the importance of technology in boosting operational efficiency. A review of current literature also emphasizes the role of ERP and RFID systems in reducing manual data entry errors in warehouse management.

Objective 2 explores the state-of-the-art ERP and RFID systems in Sri Lanka's rubber glove manufacturing industry through a descriptive analysis of a semi-structured questionnaire. The analysis covers company demographics, existing systems, and supplier feedback. Results reveal that 95% of companies use ERP systems, but only 1% use RFID, indicating a heavy reliance on manual processes. The survey shows strong support for integrating ERP and RFID systems to improve accuracy, real-time information, and process automation. Key findings include the dominance of supported and unsupported gloves, a mix of export and local markets, and a workforce mostly aged 20-35.

The "Supply Chain Smoother" system integrates hardware and software to improve supply chain management. Hardware components include a NodeMcu WiFi Module and RFID-RC522 reader, while the software uses HTML, CSS, PHP, JavaScript, and MySQL. The system captures and processes data through RFID modules at critical points, with software modules for user management, material logging, and inventory updates. The implementation involved setting up hardware, configuring middleware with Node.js, and developing software with PHP and JavaScript. Pilot tests at five warehouse locations and the head office demonstrated significant improvements in process time and error reduction.

Objective 4 evaluates the impact of the ERP and RFID integration on procurement performance. The assessment shows that the new system significantly reduces processing times for Goods Receipt Notes, material transfers, and returns, and improves inventory accuracy. Survey and interview feedback indicates strong agreement among stakeholders that the system enhances inventory management, reduces overordering and underordering, and provides better real-time data visibility. The system also achieves cost savings by minimizing inventory discrepancies, reducing emergency purchase rates, and lowering demurrage costs, thus proving its effectiveness in improving procurement efficiency and accuracy.

CHAPTER 5

CONCLUSIONS, RECOMMENDATIONS AND FURTHER RESEARCH

5.1 Introduction

The conclusion derived from the data analysis from Chapter 4, which is related to the objectives of this research, will be discussed in this chapter. Recommendations and discussions to improve the integrated ERP and RFID system and procurement performance will be discussed in this chapter later. Limitations of this research and further research areas will be elaborated on in the last part of this chapter.

5.2 Conclusions and Implications

In conclusion, this comprehensive study focuses on the rubber glove manufacturing industry in Sri Lanka and addresses issues within ABC rubber glove manufacturing company's ERP system, particularly related to inaccurate inventory levels impacting procurement performance. The proposed solution involves the integration of ERP and RFID systems to enhance supply chain functions. The literature review emphasizes the pivotal role of ERP systems, with SAP S/4 HANA as a state-of-the-art platform, and explores the historical development and global context of integrating RFID technology with ERP systems.

The research methodology employs both deductive and inductive approaches, utilizing surveys, case studies, and action research. The data analysis and discussion chapter utilizes statistical methods to assess the impact of integrated ERP and RFID systems on procurement performance in the specified industry. The Supply Chain Smoother project, consisting of hardware and software components, is designed to enhance supply chain efficiency.

The discussion includes insights from the pilot test of the integrated system. The data analysis covers various aspects, including company information, demographics, existing systems, and supplier feedback. Descriptive statistics and qualitative data analysis methods are used to analyze and reach the objectives.

The study's findings suggest that the implemented system positively impacts procurement performance in the rubber glove manufacturing industry in Sri Lanka. The Supply Chain Smoother reduces processing time and errors compared to the existing system, emphasizing the potential benefits of integrating ERP and RFID systems. Overall, this research fills a technological and research gap in the Sri Lankan context, providing valuable insights for companies in the rubber glove industry and contributing to the broader understanding of ERP and RFID system integration in supply chain management.

Based on the data analysis in Chapter 4, The findings indicate a strong potential for integrating automation in the industry. Implementing RFID technology alongside ERP systems could streamline processes, enhance data accuracy, and improve overall efficiency. The identified concerns about costs and security should be addressed proactively. Engaging stakeholders in discussions about potential solutions and demonstrating the long-term benefits of automation will be key to overcoming these barriers. Given the current reliance on manual processes, a strategic approach to transitioning to automated systems will be necessary. This includes training, phased implementation, and continuous monitoring to ensure a smooth adoption process. Further studies could explore the specific benefits and challenges experienced by companies that have already implemented RFID systems, providing additional insights into best practices and potential pitfalls.

The integration of the ERP and RFID system, as demonstrated in the pilot test at ABC Rubber Glove Manufacturing Company, has shown substantial improvements in procurement performance. The pilot results indicate a marked reduction in processing times and errors, with significant enhancements in inventory accuracy and procurement efficiency. The automated data capture and real-time updates provided by the Supply Chain Smoother system lead to near-zero discrepancies between recorded and actual inventory, a sharp contrast to the existing system's substantial discrepancies and inefficiencies. Feedback from stakeholders, including executives and IT consultants, reinforces the system's efficacy in reducing overordering, improving demand visibility, and decreasing information processing time. Moreover, the new system eliminates emergency purchase rates and associated costs, including demurrage, by ensuring precise inventory management. Overall, these improvements underscore the critical role of integrating ERP and RFID technologies in optimizing procurement performance, reducing costs, and enhancing operational efficiency in the rubber glove manufacturing industry.

5.3 Recommendations to improve integrated ERP and RFID system and procurement performance

1. Hardware component improvement

The implemented hardware module is not user-friendly and it should be converted as a covered circuit-based device that can be used anywhere at any time. There are need for more devices to capture the RFID codes.

2. Fine-tune the integrated system

This system builds up due to the not having existing system access to integrate with RFID technology. Continuously monitor and fine-tune the integrated system based on feedback and performance metrics and regularly update the ERP and RFID systems to leverage any new features or improvements.

3. Employee training

Implement comprehensive training programs for employees to ensure they are proficient in using the integrated system and provide ongoing training and support to address any issues or challenges faced by users.

4. RFID integrated system for suppliers

As discussed in Section 3.2.4.2, the input of the RFID code of the relevant purchase order should be manually entered by the supplier into the proposed system. Due to that recommend to implement the integrated ERP and RFID system with suppliers as well.

5. Scalability planning

Consider scalability aspects to accommodate potential business growth or changes in the future. Evaluate the system's ability to handle an increasing number of transactions, suppliers, and inventory items.

6. Data security and privacy

Implement robust security measures to protect sensitive data, especially as the integrated system involves the exchange of information across various components. Comply with data protection regulations and ensure that privacy concerns are adequately addressed.

7. Benchmarking

Compare the performance of the integrated system against industry benchmarks to ensure it remains competitive and efficient. Benchmarking can help identify areas where further improvements are needed.

8. Review and enhance the Supply Chain Smoother project

Regularly review the Supply Chain Smoother project and assess its effectiveness. Explore opportunities to enhance the project by incorporating new technologies or refining existing processes.

Implementing these recommendations should contribute to the ongoing success and optimization of the integrated ERP and RFID system in the context of rubber glove manufacturing in Sri Lanka.

5.4 Limitations of Research

Because of the limited time, capability, cost, and resources this research was conducted only for non-executives, executives, managers, and IT/ERP consultants working in rubber glove manufacturing companies and their packing material suppliers.

Questionnaires were distributed through an online platform and distributed in English language only. The number of respondents in the sample is 95 responses. This study is limited to assessing procurement performance. However, there are several other supply chain functions related to the inventory and stakeholders that closely affect their job role. The integrated ERP and RFID system was developed by using minimum and low-cost requirements and the performance of the system was somewhat limited.

5.5 Future Research Areas

Explore the integration of emerging technologies beyond RFID, such as IoT, blockchain, or artificial intelligence, and assess their impact on ERP systems in the rubber glove manufacturing industry. Investigate how these technologies can further enhance supply chain efficiency and overall performance.

Extend the research to focus on improving the user interface and experience of the integrated system. Investigate the design aspects of the hardware and software components to make them more user-friendly, efficient, and accessible for different users within the organization.

Conduct a comparative analysis of the integrated ERP and RFID systems across different industries to understand their adaptability and effectiveness in diverse business environments. Explore whether modifications are required for successful implementation in industries other than rubber glove manufacturing.

Further, investigate the integration of RFID systems with suppliers. Explore mechanisms for seamless communication and information exchange between the organization and its suppliers to enhance collaboration, streamline processes, and improve overall supply chain performance.

REFERENCES

A Majeed, M. , & Rupasinghe, T. . (2017). Internet of Things (IoT) Embedded Future Supply Chains for Industry 4.0: An Assessment from an ERP-based Fashion Apparel and Footwear Industry. *International Journal of Supply Chain Management*, 25-40.

Aggarwal, K., Garg, S., & Budhaulia, P. (2020). TRANSFORMING MANUFACTURING PROCESSES WITH THE HELP OF AI. *International Journal of Mechanical Engineering and Technology (IJMET)*, 9-20.

Angeles, R. (2005). RFID technologies: Supply-Chain applications and implementation issues. *Information Systems Management*, 51-65.

Banerjee, A. (2018). Blockchain Technology: Supply Chain Insights from ERP. *Advances in Computers*, 1-30.

Baron, R., & Kenny, D. (1986). The Moderator-Mediator Variable Distinction in Social Psychological Research. Conceptual, Strategic, and Statistical Considerations. *Journal of Personality and Social Psychology*, 1173-1182.

Barsemoi, H., Mwangagi, P., & Ode, B. (2014). Factors influencing procurement performance in private sector in Kenya. *International Journal of Innovation and Applied Studies*, 632-641.

Beheshti, H., Oghazi, P., Mostaghel, R., & Hultman, M. (2014). Supply chain integration and firm performance: an empirical study of Swedish manufacturing firms. *Competitiveness Review Vol. 24 No. 1, 2014 pp. 20-31*, 20-31.

Bermana, J., & Smyth, R. (2015). Conceptual frameworks in the doctoral research process: a pedagogical model. *Innovations in Education and Teaching International, 2015*, 125-136.

Cedcraftscodes. (2019, January 29). *Connecting RFID Scanner to PHP using NodeMcu Wifi Module*. Retrieved from Dev Craze: https://devcraze.com/tutorials/connecting-rfid-scanner-to-php-using-nodemcu-wifi-module/

Choy, K., Chowa, K. H., Moon , K. L., Zeng, X., Lau, H., Chan, F., & Ho, G. (2009). A RFID-case-based sample management system for fashion product development. *Engineering Applications of Artificial Intelligence 22*, 882-896.

Chuang, M.-L., & Shaw, W. (2007). RFID: Integration Stages in Supply Chain Management. *80 IEEE ENGINEERING MANAGEMENT REVIEW, VOL. 35, NO. 2, SECOND QUARTER 2007*, 80-87.

Coldwell, D., & Herbst, F. (2004). *Business Research.* Cape Town: JUTA Acdaemic.

Costa, W. A., Souza, F. M., & Júnior, J. A. (2013). How the Warehouse Management System (WMS) can contribute to the management of a Distribution Center (DC) in a furniture retail enterprise. *Journal of Chemical Information and Modeling*, 1689-1699.

D'Souza, P., Guo, M., Wang, D., & Lee, I. (2013). Real-time Inventory Management with RFIDash Dept. *Dept. of CIS - Senior Design 2012-2013*, 1-10.

Dolgui, A., & Proth, J. –M. (2008). RFID TECHNOLOGY IN SUPPLY CHAIN MANAGEMENT: STATE OF THE ART AND PERSPECTIVES. In A. Dolgui , & J.–M. Proth , *17th IFAC World Congress (IFAC'08)* (pp. 4464-4475). Seoul: IFAC Proceedings Volumes.

Domdouzis , K., Kumar , B., & Anumba, C. (2007). Radio-Frequency Identification (RFID) applications: A brief introduction. *Advanced Engineering Informatics 21*, 350-355.

DPL. (2021, November 11). *Who We Are*. Retrieved from DPL: https://www.dplgroup.com/about-us/who-we-are/

Dunham, A. (2024, February 5). *Procurement KPIs: 22 Essential Metrics for Tracking and Visualizing Procurement Performance*. Retrieved from pipefy procure-to-pay : https://www.pipefy.com/blog/procurement-kpis/

Easterby-Smith, M., Thorpe, R., & Jackson, P. (2012). *MANAGEMENT RESEARCH.* Singapore: SAGE Publications Ltd.

EDB. (2021, November 11). *INDUSTRIAL & SURGICAL GLOVES OF RUBBER*. Retrieved from Sri Lanka Export Development Board: https://www.srilankabusiness.com/exporters-directory/rubber-exporters-in-sri-lanka/finished-rubber-products-exporters/industrial-surgical-gloves-suppliers/

EDB. (2021, November 11). *RUBBER GLOVES FROM SRI LANKA*. Retrieved from Sri Lanka Export Development Board: https://www.srilankabusiness.com/rubber/rubber-glove-industry-sri-lanka.html

ElectronicWings. (2023, December 12). *Introduction to NodeMCU*. Retrieved from ElectronicWings: https://www.electronicwings.com/nodemcu/introduction-to-nodemcu

Figueroa, S., Añorga, J., & Arrizabalaga, S. (2019). An Attribute-Based Access Control Model in RFID Systems Based on Blockchain Decentralized Applications for Healthcare Environments. *Computers 2019*, 1-19.

G2. (2023, January 21). *Best ERP Systems*. Retrieved from G2: https://www.g2.com/categories/erp-systems

Gaukler , G., & Seifert, R. (2007). Applications of RFID in Supply Chains. *Applications of RFID in Supply Chains*, 29-48.

Gergely, S. (2024, February 14). *Essential KPIs for Measuring Procurement Performance*. Retrieved from Veridion: https://veridion.com/blog-posts/procurement-performance-kpis/

Goyal, S., Aloysius, J., & Hardgrave, B. (2009). Using RFID to Improve Inventory Accuracy. *15th Americas Conference on Information Systems 2009, AMCIS 2009*, 4316-4322.

Gruen, T., & Corsten, D. (2008). *A Comprehensive Guide To Retail Out-of-Stock Reduction In the Fast-Moving Consumer Goods Industry.* Colorado Springs: GMA, FMI, NACDS, P&G or the University of Colorado at Colorado Springs.

Halawa, F., Daoud, H., Lee, I., Li, Y., Yoon, S. W., & Chung, S. H. (2018). Introduction of a Real Time Location System to Enhance the Warehouse Safety and Operational Efficiency. *International Journal of Production Economics*, 1-42.

Hamdy, W., Mostafa, N., & Elawady, H. (2018). Towards a Smart Warehouse Management System. *Proceedings of the International Conference on Industrial Engineering and Operations Management*, 2555-2563.

Hatzithomas, L., Stamelos, I., Fotiadis, T., & Mylonakis, J. (2007). Quality And Effectiveness Of Enterprise Resource Planning – Customer Relationship Management Systems: Implications For Information Systems Marketing Strategies. *The Journal of Applied Business Research – Third Quarter 2007*, 33-52.

Heese, H. (2007). Inventory Record Inaccuracy, Double Marginalization, and RFID Adoption. *Production and Operations Management*, 542-553.

Hellstrom, D., & Wiberg, M. (2010). Improving inventory accuracy using RFID technology: a case study. *Assembly Automation*, 345-351.

Huanga, G., Zhanga, Y., & Jiangb, P. . (2007). RFID-based wireless manufacturing for walking-worker assembly islands with fixed-position layouts. *Robotics and Computer-Integrated Manufacturing 23 (2007)*, 469-477.

Isaja, M., Soldatos, J., & Gezer, V. (2017). Combining Edge Computing and Blockchains for Flexibility and Performance in Industrial Automation. *The*

Eleventh International Conference on Mobile Ubiquitous Computing, Systems, Services and Technologies, 159-164.

Jenkins, A. (2023, January 26). *What Is Shrinkage in Inventory?* Retrieved from ORACLE NetSuite: https://www.netsuite.com/portal/resource/articles/inventory-management/shrinkage.shtml

John W., C. (1994). *Research Design.* Washington: Sage Publications.

Kakwezi, P., & Nyeko, S. (2019). PROCUREMENT PROCESSES AND PERFORMANCE: EFFICIENCY AND EFFECTIVENESS OF THE PROCUREMENT FUNCTION. *Int Journal of Social Sciences Management and Entrepreneurship 3(1)*, 172-182.

Kang, Y., & Gershwin, S. (2007). Information inaccuracy in inventory systems: stock loss and stockout. *IIE Transactions (Institute of Industrial Engineers)*, 843-859.

Katrych, T. (2022, October 10). *Procurement KPIs & Metrics: What To Focus on and How To Measure*. Retrieved from PRECORO: https://precoro.com/blog/procurement-kpis-metrics/#quality-kpis

Kemp, S., Hort, J., & Hollowood, T. (2018). *Descriptive Analysis in Sensory Evaluation.* West Sussex: John Wiley & Sons Ltd.

Kim, J., Ok, C.-S., Kumara, S., & Yee, S.-T. (2010). A market-based approach for dynamic vehicle deployment planning using radio frequency identification (RFID) information. *Int. J. Production Economics 128 (2010)*, 235-247.

Koyanagi, F. (2023, December 12). *NodeMCU ESP8266: Details and Pinout*. Retrieved from Autodesk Instructables: https://www.instructables.com/NodeMCU-ESP8266-Details-and-Pinout/

Lee, H., & Billington, C. (1992, April 15). *Managing Supply Chain Inventory: Pitfalls and Opportunities*. Retrieved from MIT Sloan Management Review: https://sloanreview.mit.edu/article/managing-supply-chain-inventory-pitfalls-and-opportunities/

Li, X., Zhao, X., & Pu, W. (2020). A novel approach to measuring enterprise procurement decision process: an information distance perspective. *Enterprise Information Systems*, 58-82.

Lin, S., Huang, J., Chen, W., Zhou, W., Xu, J., Liu, Y., & Yao, J. (2021). Intelligent warehouse monitoring based on distributed system and edge computing. *International Journal of Intelligent Robotics and Applications*, 130-142.

Liu, C., & Chen, L. (2009). Applications of RFID technology for improving production efficiency in an integrated-circuit packaging house. *International Journal of Production Research*, 2203-2216.

Mashayekhy, Y., Babaei, A., Yuan, X.-M., & Xue, A. (2022). Impact of Internet of Things (IoT) on Inventory Management:A Literature Survey. *Logistics*, 1-19.

Masudin, I., Kamara, M., Zulfikarijah, F., & Dewi, S. (2018). Impact of Inventory Management and Procurement Practices on Organization's Performance. *Singaporean Journal of Business Economics, and Management Studies (SJBEM)*, 32-39.

Matičević, G., Čičak, M., & Lovrić, T. (2011). RFID and Supply Chain Management for Manufacturing Digital Enterprise. *Supply Chain Management - New Perspectives*, 517-536.

Mills-Harris, M. , Soylemezoglu, A., & Saygin, C. . (2005). RFID Data-Based Inventory Management of Time-Sensitive Materials. *0-7803-9252-3*, 2302-2307.

Modupe, O. T., Oladapo, O. J., Otitoola, A. A., Abiona, O. O., Oyeniran, O. C., Adewusi, A. O., & Komolafe, A. M. (2024). REVIEWING THE TRANSFORMATIONAL IMPACT OF EDGE COMPUTING ON REAL-TIME DATA PROCESSING AND ANALYTICS. *Computer Science & IT Research Journal*, 694-702.

Morey, R. (1985). Estimating Service Level Impacts from Changes in Cycle Count, Bder Stock, or Corrective Action. *JOURNAL OF OPERATIONS MANAGEMENT vol. 5, No. 4. August 1985*, 411-418.

Mostafa, N., Hamdy, W., & Elawady, H. (2018). Towards a Smart Warehouse Management System. *Proceedings of the International Conference on Industrial Engineering and Operations Management*, 2555-2563.

Mukopi, C. M., & Iravo, A. M. (2015). An Analysis of the Effects of Inventory Management on the Performance of the Procurement Function of Sugar Manufacturing Companies in the Western Kenya Sugar Belt. *International Journal of Scientific and Research Publications, Volume 5, Issue 5, May 2015*, 809-822.

Mutinda, L. N., & Paul, S. N. (2018). Role of Inventory Management Strategies on Procurement Performance in State Corporations in Kenya. *American Based Research Journal*, 39-51.

Navarro, D. (2022). Learning statistics with R:A tutorial for psychology students and other beginners. *Gastronomía ecuatoriana y turismo local.*, 5-24.

Nettsträter, A., Geißen, T., Witthaut, M., Ebel, D., & Schoneboom, J. (2015). Logistics Software Systems and Functions: An Overview of ERP, WMS, TMS and SCM

Systems. *M. ten Hompel et al. (eds.), Cloud Computing for Logistics, Lecture Notes in Logistics, DOI 10.1007/978-3-319-13404-8_1*, 1-11.

Niederman, F., Mathieu, R., Morley, R., & Kwon, I.-W. (2011). EXAMINING RFID APPLICATIONS IN SUPPLY CHAIN MANAGEMENT. *COMMUNICATIONS OF THE ACM*, 6-6.

NTT DATA. (2023, February 25). *SAP S/4HANA - Learn All the Details in Our ERP Wiki*. Retrieved from NTT DATA Business Solutions: https://nttdata-solutions.com/us/sap-s-4hana-erp-wiki/

Oboloo. (2023, November 19). *RFID Applications In Procurement: Enhancing Visibility And Tracking*. Retrieved from oboloo Articles: https://oboloo.com/blog/rfid-applications-in-procurement-enhancing-visibility-and-tracking/

Oghazi, P., Rad, F. F., Karlsson, S., & Haftor, D. (2018). RFID and ERP systems in supply chain management. *European Journal of Management and Business Economics*, 171-182.

Oztaysi, B., Baysan, S., & Akpinar, F. (2009). Radio frequency identification (RFID) in hospitality. *Technovation 29 (2009)*, 618-624.

P, G., Sajiv, G., & L, M. L. (2017). Warehouse Management System using Microprocessor Based Mobile Robotic Approach. *2017 Third International Conference on Science Technology Engineering & Management (ICONSTEM)*, 868-872.

Pajić, V., Andrejić, M., & Kilibarda, M. (2021). EVALUATION AND SELECTION OF KPI IN PROCUREMENT AND DISTRIBUTION LOGISTICS USING SWARA-QFD APPROACH. *International Journal for Traffic and Transport Engineering (IJTTE)*, 267-29.

Pallant, J. (2017). *A Step by Step Guide to Data Analysis using SPSS for Windows third edition.* New York: Open University Press.

Pane, S. F., Awangga, R. M., & Azhari , B. R. (2018). Qualitative evaluation of RFID implementation on warehouse management system. *Telecommunication Computing Electronics and Control) (2018) 16(3) 1303-1308*, 1303-1307.

Parikh, S., Dave, D., Patel, R., & Doshi, N. (2019). Security and Privacy Issues in Cloud, Fog and Edge Computing. *The 3rd International workshop on Recent advances on Internet of Things:Technology and Application Approaches(IoT-T&A 2019)* , 735-739.

Planet Together. (2021, April 2). *The 5 Functions of Supply Chain Management*. Retrieved from planet together: https://www.planettogether.com/blog/the-five-functions-of-supply-chain-management

Poon , T., Choy , K., Chan , F., Ho, G., Gunasekaran, A., Lau, H., & Chow, H. (2011). A real-time warehouse operations planning system for small batch replenishment problems in production environment. *Expert Systems with Applications 38 (2011) 8524–8537*, 8524-8537.

Powell, T. (1995). TOTAL QUALITY MANAGEMENT AS COMPETITIVE ADVANTAGE: A REVIEW AND EMPIRICAL STUDY. *Strategic Management Journal, Vol. 16, 15-37 (1995)*, 15-37.

Powell, Z. (2023, December 12). *Node.js vs PHP: A Head-to-Head Comparison*. Retrieved from kinsta: https://kinsta.com/blog/node-js-vs-php/#:~:text=Close-,Node.,side%20and%20server-side%20development.

Qiu, T., Chi, J., Zhou, X., Ning, Z., Atiquzzaman, M., & Wu, D. O. (2020). Edge Computing in Industrial Internet of Things:Architecture, Advances and Challenges. *IEEE Communications Surveys & Tutorials*, 2462-2488.

Rahim, M. (2008). Identifying Factors Affecting Acceptance of E-procurement Systems: An Initial Qualitative Study at an Australian City Council. *Innovation and Knowledge Management in Business Globalization: Theory and Practice - Proceedings of the 10th International Business Information Management Association Conference*, 219-229.

Rai, A., Robinson, J., Patnayakuni, R., & Seth, N. (2006). Firm Performance Impact of Digitally Enabled Supply Chain Integration Capabilities. *Digitally Enabled Supply Chain Integration Capabilities*, 226-246.

Raman, A., DeHoratius, N., & Ton, Z. (2001). Execution: The Missing Link in Retail Operations. *CALIFORNIA MANAGEMENT REVIEW VOL. 43, NO. 3 SPRING 2001*, 136-152.

Ranaweera, P., Jurcut, A. D., & Liyanage, M. (2021). Survey on Multi-Access Edge Computing Security and Privacy. *IEEE COMMUNICATIONS SURVEYS & TUTORIALS*, 1078-1124.

Randolph, K., & Myers, L. (2013). *Basic statistics in multivariate analysis.* New York: OUP USA.

Rathnayake, D. (2021, July 7). *SL rubber gloves cater to 5% of global demand*. Retrieved from theMorning: https://www.themorning.lk/articles/148177

Rejeb, A., Keogh, J., Wamba, S. F., & Treiblmaier, H. (2020). The potentials of augmented reality in supply chain management: a state-of-the-art review. *Management Review Quarterly*, 1-38.

Robert. (2023, December 10). *Procurement Key Performance Indicators and Metrics*. Retrieved from prokuria: https://www.prokuria.com/post/procurement-key-performance-indicators-and-metrics

S&P Global. (2021, November 11). *Sri Lankan Manufacturers of rubber gloves and Suppliers of rubber gloves*. Retrieved from Panjiva: https://panjiva.com/Sri-Lankan-Manufacturers-Of/rubber+gloves

S. Thomassey, B. (2016). Enterprise resource planning systems for use in apparel supply chains. In B. S. Thomassey, *Information Systems for the Fashion and Apparel Industry* (pp. 235-261). Roubaix: Elsevier Ltd.

Sanketh, R. (2020, May 26). *An Introduction to RFID*. Retrieved from AUTONOMOUS ROBOTICS: https://medium.com/autonomous-robotics/an-introduction-to-rfid-dc6228767691#:~:text=The%20RC522%20RFID%20Reader%20module,maximum%20data%20rate%20of%2010Mbps.

Saunders, M., Lewis, P., & Thornhill, A. (2009). *Research methods for business students.* New Delhi: Dorling Kindersley.

Sekaran, U., & Bougie, R. (2013). *Research Methods for Business.* West Sussex: John Wiley & Sons Ltd.

SendEdge. (2023, November 4). *How Purchasing and Procurement Can Impact the Efficacy of Businesses?* Retrieved from SendEdge: https://www.spendedge.com/blogs/purchasing-procurement-can-impact-efficacy-businesses/

Simchi-Levi, D., Kaminsky, P., & Simchi-Levi, E. (2003). *Design and Managing The Supply Chain Concepts Strategies and Case Studies.* United States of America: Jeffrey J. Shelstad.

Singh, N., & Adhikari, D. (2023). AI and IoT: A Future Perspective on Inventory Management. *International Journal for Research in Applied Science & Engineering Technology (IJRASET)* , 2753-2757.

Stratman, J. (2007). Realizing Benefits from Enterprise Resource Planning: Does Strategic Focus Matter? *Production and Operations Management Society*, 203-216.

Stroeken, J. (2001). Information technology, innovation and supply chain structure. *International Journal of Services, Technology and Management*, 269-288.

Tajima, M. (2007). Strategic value of RFID in supply chain management. *Journal of Purchasing & Supply Management 13*, 261-273.

Tarn, J. , Yen, D. , & Beaumont, M. (2002). Exploring the rationales for ERP and SCM integration. *Industrial Management & Data Systems*, 26-34.

Tavanaa, M., Hajipour, V., & Oveisi, S. (2020). IoT-based enterprise resource planning: Challenges, open issues, applications, architecture, and future research directions. *Internet of Things 11 (2020) 100262*, 1-27.

Turcu, C., Turcu , C., & Graur, A. (2008). Improvement of Supply Chain Performances Using RFID Technology. *Supply Chain, The Way to Flat Organisation*, 339-354.

Vickery, S., Jayaram, J., Droge, C., & Calantone, R. (2003). The effects of an integrative supply chain strategy on customer service and financial performance: an analysis of direct versus indirect relationships. *Journal of Operations Management 21 (2003) 523–539*, 523-539.

Waller, M., Nachtmann, H., & Hunter, J. (2006). Measuring the impact of inaccurate inventory information on a retail outlet. *The International Journal of Logistics Management Vol. 17 No. 3, 2006*, 355-376.

Wang, W. Y., Pauleen , D., & Taskin, N. (2022). Enterprise systems, emerging technologies, and the data-driven knowledge organisation. *KNOWLEDGE MANAGEMENT RESEARCH & PRACTICE*, 1-13.

Wilson, J. (2010). *Essentials of Business Research: A Guide to Doing Your Research Project.* SAGE Publications.

Wullt, J., & Smihily, M. (2010). Radio Frequency Identification (RFID) used by 3% of enterprises in 2009. *E-commerce accounted for 12% of enterprises' turnover in the EU27 in 2008*, 1-4.

Yao, A., & Carlson, J. (1999). The impact of real-time data communication on inventory management. *Int. J. Production Economics 59 (1999)*, 213-219.

Zhang, Z., Chen, J., & Guo, Q. (2022). Application of Automated Guided Vehicles in Smart Automated Warehouse Systems: A Survey. *Computer Modeling in Engineering & Sciences*, 1530-1563.

APPENDICES

Appendix A: Semi-Structured Questionnaire

Design of a single platform for integrating ERP & RFID systems for improved procurement Performance: A case study in the rubber glove manufacturing industry

This study aims to design a single platform for integrating Enterprise Resource Planning (ERP) and Radio-Frequency Identification (RFID) systems for improved procurement performance as a case study in the rubber glove manufacturing industry.

The survey should only take less than 15 minutes, and your responses are confidential.

Your participation is very much appreciated.

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<table>
<tr><td colspan="5">Section 1</td></tr>
<tr><td colspan="5">If you want the results of this study only, please provide your Email address.</td></tr>
<tr><td colspan="5">1. Please select the category to which your company belongs*</td></tr>
<tr><td colspan="2">Rubber glove manufacturing company</td><td colspan="3">Packing materials manufacturing company</td></tr>
<tr><td colspan="5">Section 2 – Rubber glove manufacturing company</td></tr>
<tr><td colspan="5">2. What type of latex-based gloves does your company manufacture?*</td></tr>
<tr><td>Disposable Gloves</td><td>Arm Sleeves</td><td>Sports</td><td>Supported Gloves</td><td>Unsupported Gloves</td></tr>
<tr><td colspan="5">3. Which market are you catering to?*</td></tr>
</table>

Solely export-oriented	Export & local	Local	
4. What is the duration of your present employment?*			
Below one year	1-2 Years	3-5 Years	More than 5 years
5. What's your age?*			
20-35	35-50	50-65	66+
6. Do you use system(s) to manage packing materials in your warehouse?*			
Yes	No		
7. Does your warehouse use an Enterprise Resource Planning (ERP) system to manage packing materials? - The system can be used as a tool for comprehensive planning, coordination, and management of company-wide tasks such as finance, accounting, controlling, manufacturing, research, and development functions.*			
Yes	No		
8. If the answer is "Yes" for Q8, Please specify the name of the ERP system*			
9. Does your warehouse use a Radio-Frequency Identification (RFID) system to manage packing materials? - The system can be used as an automatic identification method that automatically captures and stores data using devices such as RFID tags, RFID readers, and middleware.*			
Yes	No		
10. If the answer is "Yes" for Q10, Please specify the name of the RFID system*			
11. Does your warehouse use an integrated ERP and RFID system to manage packing materials? - The system can automatically capture data and store data with automatic identification in the ERP system to manage company-wide tasks.*			
Yes	No		
12. If the answer is "Yes" for Q12, Please specify the name of the integrated ERP and RFID system*			
13. Does your warehouse use a custom-built system (internally or externally developed) to manage packing materials?*			
Yes	No		

14. If the answer is "Yes" for Q14, Please specify the name of the custom-built system*				
15. Do you manually (without using automatic data capturing technology) enter the received material quantity and create a Goods Receipt Note (GRN) in the existing system?*				
Yes		No		
16. How do you store the received materials in your warehouse with identification?*				
Manual labeling	Barcode pasting	RFID tagging		
17. Do you manually (without using automatic data capturing technology) process system transactions when materials transfer from PMS (Packing Material Store) to TSP (Trimming, Sorting, and Packing)?*				
Yes		No		
18. Do you manually (without using automatic data capturing technology) process system transactions when materials return to PMS (Packing Material Store) from TSP (Trimming, Sorting, and Packing)*				
Yes		No		
19. Which of the following best describes the department you work in?*				
Production & Warehousing	Purchasing & Logistics	Marketing	IT/ERP	
20. What is your position/role in the company?*				
Non-executive	Executive	Manager	IT/ERP Consultant	
Section 2.1 – Non-executive				
21. Manual (without using automatic data capturing technology) insertion of packing materials into the system can result in inaccurate quantity records.*				
Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
22. Manual (without using automatic data capturing technology) transfers of packing materials into the system from PMS to TSP can cause inventory inaccuracies.*				
Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree

23. Manual (without using automatic data capturing technology) returns of packing materials into the system from TSP to PMS can cause inventory inaccuracies.*

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
24. Manual (without using automatic data capturing technology) transfers of packing materials into the system from PMS to TSP and physical transfers do not happen at the same time.*				
Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
25. Manual (without using automatic data capturing technology) returns of packing materials into the system from TSP to PMS and physical transfers do not happen at the same time.*				
Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
Automated insertion and transfers (using automatic data capturing technology) of packing materials into the system, (Q26 to Q27)				
26. Reduce operator workload.*				
Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
27. Eliminate data processing time.*				
Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
28. Automated identification (using automatic data capturing tag or barcode) for packing material lots can deliver more standardized information than manual labeling.*				
Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
Section 2.2 – Executive				
Automated insertion and transfers (using automatic data capturing technology) of packing materials into the system, (Q21 to Q27)				
21. Reduce overordering or underordering compared to the actual requirements.*				
Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree

22. Reduce manual adjustments to correct the inventory figures.*				
Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
23. Generate accurate and summarized reports for top management.*				
Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
24. Provide real-time inventory information to make decisions.*				
Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
25. Decrease information processing time.*				
Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
26. Enhance customer satisfaction by enabling a quick response to customer demand.*				
Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
27. Decrease the need for manual Excel-based tasks.*				
Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
28. Automated identification (using automatic data capturing tag or barcode) of packing materials can deliver standardized information to all supply chain stakeholders, facilitating prompt decision-making and accurate forecasting.*				
Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
Section 2.3 – Manager				
Automated insertion and transfers (using automatic data capturing technology) of packing materials into the system, (Q21 to Q27)				
21. Facilitate accurate decision-making and enhance forecasting capabilities.*				

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
22. Offer real-time inventory updates with visual feedback.*				
Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
23. Reduce employee workload, freeing up time for other tasks.*				
Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
24. Reduce labor costs.*				
Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
25. Reduce the lead time of the procurement and logistics process.*				
Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
26. Facilitate precise inventory figures and decrease disposal costs.*				
Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
27. Facilitate precise inventory figures and reduce stock-holding costs.*				
Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
28. Facilitate precise inventory figures and decrease provision amounts.*				
Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
Section 2.4 – IT/ERP Consultant				
21. Do you have any idea what an RFID is?*				
Yes	No			
22. From your understanding can RFID be a technology diver for the future of supply chains?*				
Yes	No	May be		

23. Have you implemented any ERP solutions for companies that use RFID for efficient process optimization?*				
Yes		No		
The integration of ERP and RFID systems, (Q24 to Q31)				
24. Enhances demand visibility*				
Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
25. Reduced inventory shrinkage*				
Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
26. Reduced stock out*				
Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
27. Automates the processes*				
Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
28. Provides real-time Information*				
Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
29. Improves inventory management*				
Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
30. Improved processing time by data capturing*				
Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
31. Reduce the need for manual inventory adjustments by data capturing*				
Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
32. Well-knowledge about the ERP BAPI (Business Application Programming Interface) technology* (Low – High)				

1	2	3	4	5
33. RFID systems support capturing data and sending it to the BAPI and then automating the processes*				
Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
34. Tasks in both receiving goods (inbound delivery) and sending them out (outbound cycle) can be automated*				
Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
35. Manual data entering into the ERP system is complex and leads to inaccuracies *				
Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
36. Real-time data is important to improve process efficiency*				
Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
37. From the following operations, what would you weigh mostly to have RFID automate various sub-tasks?*				
Inbound	Outbound	Both	None	
38. Cost of implementation for RFID and ERP system integration* (Low – High)				
1	2	3	4	5
39. Is there any security concern on ERP and RFID system integration?*				
Yes	No			
40. If the answer is “Yes” for Q39, Please specify the security issue*				
41. Are there any technical issues with ERP and RFID system integration?*				
Yes	No			
42. If the answer is “Yes” for Q41, Please specify the technical issue*				
43. Do you recommend integrating an ERP system with RFID technology in your company?*				

Yes			No		
44. Please provide any additional comments or insights regarding your recommendation (Q43)*					
Section 3 – Packing materials manufacturing company					
2. What type of packing materials does your company manufacture?*					
Outer Bag (OB)	Inner Bag (IB)	Outer Cartons (OC)	Inner Cartons (IC)	Display Boxes (DB)	Header Cards (HD)
3. Which market are you catering to?*					
Solely export-oriented		Export & local		Local	
4. What is the duration of your present employment?*					
Below one year	1-2 Years		3-5 Years	More than 5 years	
5. What's your age?*					
20-35	35-50		50-65	66+	
6. Which of the following best describes the department you work in?*					
Production & Warehousing	Purchasing & Logistics		Marketing	IT/ERP	
7. Do you use system(s) to manage finished goods in your warehouse?*					
Yes			No		
8. Does your warehouse use an Enterprise Resource Planning (ERP) system to manage finished goods? - The system can be used as a tool for comprehensive planning, coordination, and management of company-wide tasks such as finance, accounting, controlling, manufacturing, research, and development functions.*					
Yes			No		
9. Does your warehouse use a Radio-Frequency Identification (RFID) system to manage finished goods? - The system can be used as an automatic identification method that automatically captures and stores data using devices such as RFID tags, RFID readers, and middleware.*					
Yes			No		
10. Does your warehouse use an integrated ERP and RFID system to manage finished goods? - The system can automatically capture data and store data with automatic identification in the ERP system to manage company-wide tasks.*					

Yes		No		
11. Does your warehouse use a custom-built system (internally or externally developed) to manage finished goods? *				
Yes		No		
12. What is your position/role in the company?*				
Non-executive	Executive	Manager	IT/ERP Consultant	
13. Do you manually (without using automatic data capturing technology) enter the dispatched packing material quantity and create an Advice of Dispatched (AOD) in the existing system?*				
Yes		No		
14. How do you store the dispatch packing materials from your warehouse with identification?*				
Manual labeling	Barcode pasting	RFID tagging	None	
15. Automated identification (using automatic data capturing tag or barcode) is simpler and more standardized than manually labeling finished goods that are ready for dispatch from your warehouse.*				
Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
16. Possible to view real-time information with visual feedback on relevant purchase orders (PO) by accessing integrated ERP and RFID systems of customer*				
Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
17. Automated identification (using automatic data capturing tag or barcode) can be easy to handle and trace finished good lots until it will be dispatched from your warehouse*				
Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
18. Ability to input RFID codes (automatic data capturing tag code) into the customer's integrated ERP and RFID system interface using their system access (Low-High)*				
1	2	3	4	5

19. How should the cost of an RFID tag (automatic data capturing tag code) be handled?*		
Added to the per unit material price and charged to the customer	Accepted by the supplier	Other:

Appendix B: Structured Observation (Pilot Test)

B.1.1 Process of Production and Warehousing

Category	Process	Number of times the process is done per day	Time spent on the process (minutes)	Number of screens to iterate/steps	The number of errors that occurred per day
Process automation	Generate Good Receipt Note (GRN)				
	Packing materials transfer from PMS to TSP location in the system and physically				
	Packing materials returns from TSP to the PMS location in the system and physically.				
Performance management	Inventory figure adjustments done by the operator				
Compliance	Generate identification for received packing material lots.				

Appendix C: Hardware Components (Technical Details)

C.1.1 NodeMcu Wifi Module

NodeMCU is an open-source LUA-based firmware developed for the ESP8266 wifi chip. By exploring functionality with the ESP8266 chip, NodeMCU firmware comes with the ESP8266 Development board/kit i.e. NodeMCU Development board.

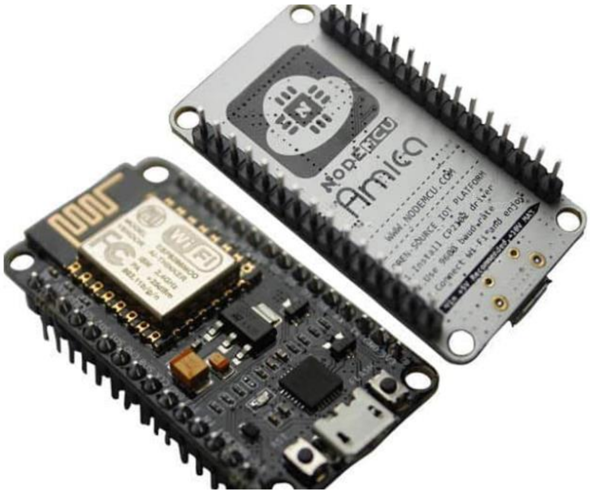

Figure 68: NodeMCU Development Board/kit v1.0 (Version2)

Source: (ElectronicWings, 2023)

Since NodeMCU is an open-source platform, its hardware design is open for editing/modification/building. NodeMCU Dev Kit/board consists of an ESP8266 wifi-enabled chip. The ESP8266 is a low-cost Wi-Fi chip developed by Espressif Systems with TCP/IP protocol. For more information about ESP8266, refer to the ESP8266 WiFi Module. There is Version2 (V2) available for NodeMCU Dev Kit i.e. NodeMCU Development Board v1.0 (Version2), which usually comes in black colored PCB (Figure 71).

NodeMCU Development board is featured with wifi capability, analog pins, digital pins, and serial communication protocols. To get started with using NodeMCU for IoT applications first need to know how to write/download NodeMCU firmware in NodeMCU Development Boards. And before that where this NodeMCU firmware will get as per our requirement. There are online NodeMCU custom builds available using which we can easily get our custom NodeMCU firmware as per our requirement

(ElectronicWings, 2019). According to Figure 72, the RC522 module has a total of 8 pins that interface it to the outside world. The connections are as follows:

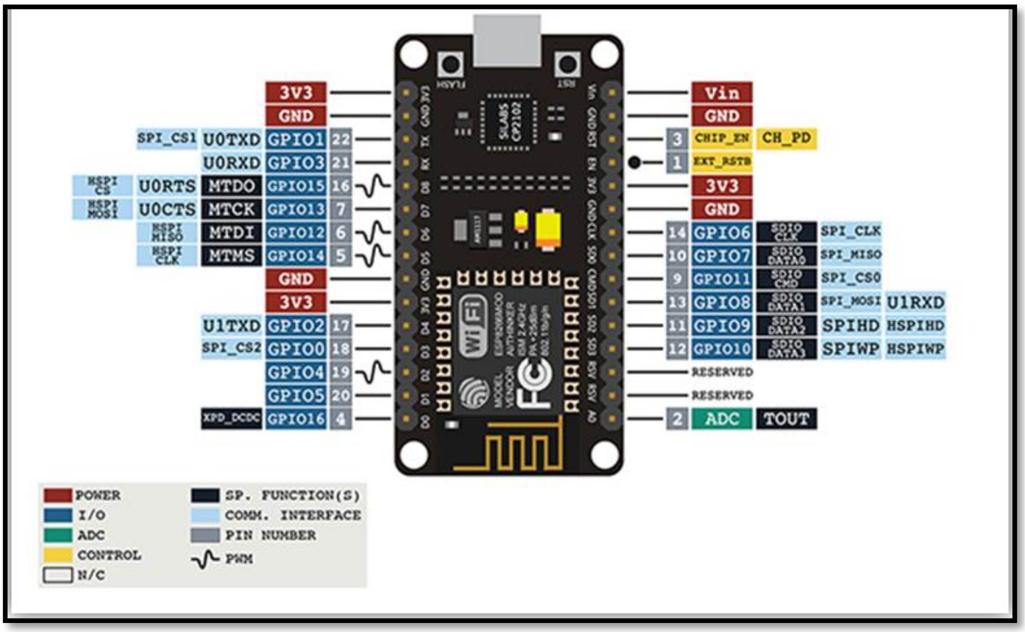

Figure 69: Connections of NodeMCU Development Board

Source: (Koyanagi, 2023)

C.1.2 RFID-RC522 Card Reader Module, RFID Card Tag, and Key Fob Tag

The RC522 RFID module based on MFRC522 IC from NXP is one of the most inexpensive RFID options. According to Figure 73, it usually comes with an RFID card tag and key fob tag having 1KB of memory. The RC522 RFID Reader module is designed to create a 13.56MHz electromagnetic field that it uses to communicate with the RFID tags. The reader can communicate with a microcontroller over a 4-pin Serial Peripheral Interface (SPI) with a maximum data rate of 10Mbps. The operating voltage of the module is from 2.5 to 3.3V, but the logic pins are 5-volt tolerant, so it can be easily connected to NodeMcu Wifi Module or any 5V logic microcontroller without using any logic level converter.

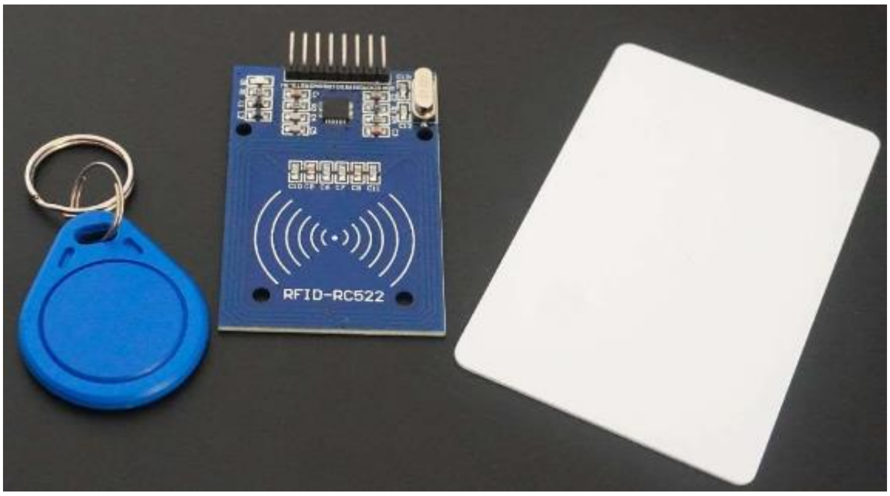

Figure 70: RFID-RC522, RFID Card Tag, and Key Fob Tag

Source: (Sanketh, 2020)

According to Figure 74, the RC522 module has a total of 8 pins that interface it to the outside world. VCC supplies power for the module. This can be anywhere from 2.5 to 3.3 volts. RST is an input for Reset and power-down. When this pin goes low, hard power-down is enabled. This turns off all internal current sinks including the oscillator and the input pins are disconnected from the outside world. On the rising edge, the module is reset. GND is the Ground Pin and needs to be connected to the GND pin on the NodeMcu Wifi Module. IRQ is an interrupt pin that can alert the microcontroller when an RFID tag comes into its vicinity.

MISO / SCL / Tx pin acts as Master-In-Slave-Out when SPI interface is enabled, acts as serial clock when I2C interface is enabled, and acts as serial data output when UART interface is enabled. MOSI (Master Out Slave In) is SPI input to the RC522 module. SCK (Serial Clock) accepts clock pulses provided by the SPI bus Master i.e. NodeMcu Wifi Module. SS / SDA / Rx pin acts as Signal input when the SPI interface is enabled, acts as serial data when the I2C interface is enabled, and acts as serial data input when the UART interface is enabled. This pin is usually marked by encasing the pin in a square so it can be used as a reference for identifying the other pins (Sanketh, 2020).

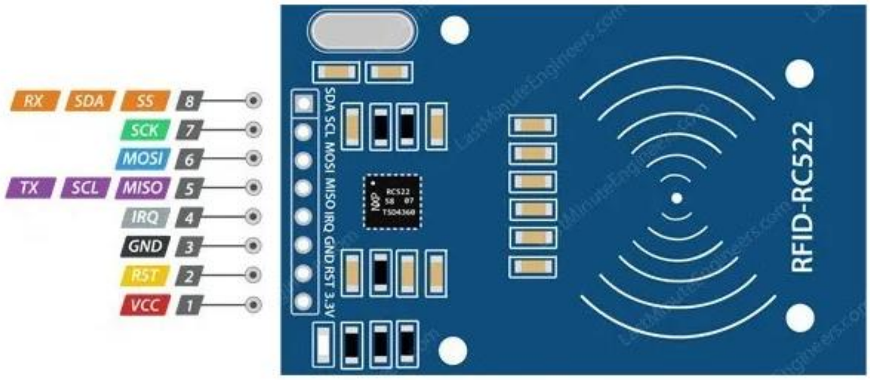

Figure 71: Connections of RFID-RC522

Source: (Sanketh, 2020)

C.1.3 Arduino IDE 1.8.1.9

Arduino IDE 1.8.1.9 is used to program the NodeMcu Wifi Module (Cedcraftscodes, 2019), and follow the steps as connect the NodeMcu to a PC or laptop with a micro USB cable, download and install the drivers, add the board manager URL, install the board and restart, port and select the COM Port of NodeMcu, and upload and program the NodeMcu to setup the Arduino IDE with NodeMcu Wifi Module.

Appendix D: Middleware (API) and Software Components (Developing Languages and Tools)

D.1.1 Developing languages of Supply Chain Smoother

HTML serves as the foundational language for creating user interfaces on the web. It acts as the primary markup language, forming the basis for most web pages and interfaces. HTML enables the creation of structured documents by providing semantic elements for text, such as lists, links, quotes, headings, and paragraphs. It supports the embedding of objects, images, and interactive forms. Additionally, HTML allows the integration of scripts written in languages like JavaScript, influencing the characteristics of HTML pages.

Cascading Style Sheets (CSS) is a language designed to define the presentation semantics of documents written in markup languages like HTML or XHTML. It separates document content from presentation, allowing for greater flexibility in specifying the appearance of elements such as colors, layout, and fonts. CSS can be applied to various XML documents, including SVG, plain XML, and XUL. This separation of content and presentation enhances accessibility, facilitates the sharing of formatting techniques across multiple pages, and reduces complexity in structural content. CSS also enables the adaptation of the same markup page to different styles based on rendering methods, screen size, or the device on which it is viewed.

PHP, initially an acronym for Personal Home Page, is a server-side scripting language designed for web development and used as a general-purpose programming language. The PHP acronym now stands for PHP (Hypertext Preprocessor), reflecting its recursive nature. On the other hand, JavaScript (JS) is employed within web browsers, allowing client-side scripts to interact with users, control the browser, communicate asynchronously, and dynamically modify displayed document content. JavaScript is a multi-paradigm language, utilizing prototype-based scripting with dynamic typing and first-class functions.

D.1.2 Database of Supply Chain Smoother

MySQL is an open-source relational database management system, accessible through Structured Query Language (SQL), which serves as a programming language for interacting with and managing data in relational databases. It is widely employed to store information for efficiently running large, intricate websites and is compatible with various programming languages like Python, PHP, and JavaScript, making it versatile across different platforms and operating systems. Additionally, phpMyAdmin, a free software tool written in PHP, facilitates web-based administration of MySQL. With support for a broad spectrum of operations on MySQL and MariaDB, phpMyAdmin allows users to perform common tasks through its user interface while also enabling the direct execution of SQL statements.

D.1.3 NodeJS

Node.js serves both client-side and server-side development, offering a single-threaded, open-source, cross-platform runtime environment for the creation of fast and scalable server-side and networking applications. Featuring an event-driven, non-blocking I/O architecture and utilizing the Google V8 JavaScript runtime engine, Node.js proves to be efficient for real-time application development (Powell Z. , 2023). The platform efficiently handles numerous client requests by queuing them in EventQueue, owing to its event-driven architecture. With its EventLoop-an endless loop that seamlessly receives and processes requests-Node. js optimizes computation power. If a request can be processed without I/O blocking, the event loop manages it independently, delivering the response back to the client. Furthermore, Node.js supports the parallel processing of multiple requests through the use of the cluster module or worker_threads, enhancing its capability to handle concurrent operations (Powell Z. , 2023) (Figure 75).

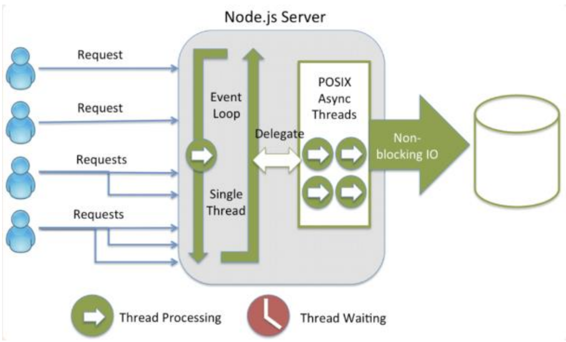

Figure 72: Node.js request handling

Source: (Powell Z. , 2023)

D.1.4 NetBeans IDE

NetBeans IDE is a free and open-source integrated development environment (IDE) designed for the development of desktop, mobile, and web applications across various programming languages, including Java, HTML5, PHP, and C++. Supporting the entire development cycle, from project creation to debugging, profiling, and deployment, the IDE is compatible with Windows, Linux, Mac OS X, and other UNIX-based systems. NetBeans IDE offers extensive support for JDK 7 technologies and the latest Java enhancements, making it the first IDE to provide support for JDK 7, Java EE 7, and JavaFX 2. Additionally, the IDE fully supports Java EE, adhering to the latest standards for Java, XML, web services, and SQL, and it is fully compatible with the GlassFish Server, serving as the reference implementation of Java EE.

D.1.5 XAMPP

XAMPP is a free and open-source cross-platform web server solution stack package, encompassing the Apache HTTP Server, MySQL Database, and interpreters for scripting in PHP and Perl programming languages. Primarily designed as a development tool, XAMPP enables web designers to program and test their work on personal computers without internet access. This comprehensive package not only includes the necessary components for web server functionality but also provides tools for creating and manipulating databases in MySQL, offering a convenient and self-contained environment for web development and testing.

Appendix E: C++ Source Code (NodeMcu)

E.1.1 .ino source code

```
#include <SPI.h>
#include <MFRC522.h>
#include <ESP8266WiFi.h>
#include <ESP8266HTTPClient.h>
#include <string.h>
#include "configs.h"

MFRC522 mfrc522(SS_PIN, RST_PIN);
byte* data;
String a;
String b;
String c;
String d;

WiFiClient client;
HTTPClient http;
void setup() {
  Serial.begin(115200);      // Initialize serial communications with the PC
  while (!Serial);           // Do nothing if no serial port is opened (added for Arduinos
based on ATMEGA32U4)
  SPI.begin();               // Init SPI bus
  mfrc522.PCD_Init();        // Init MFRC522 card
//for wifi
  Serial.print("Connecting to ");
  Serial.println(ssid);

  WiFi.begin(ssid, password);
  http.begin(client, serverName);

  while(WiFi.status() !=WL_CONNECTED)
  {
   delay(500);
   Serial.print(".");
  }
  Serial.println();
  Serial.println("Wifi connected");
  Serial.println("IP adress: ");
  Serial.println(WiFi.localIP());
  Serial.println("NesMask: ");
  Serial.println(WiFi.subnetMask());
  Serial.println("Getway: ");
  Serial.println(WiFi.gatewayIP());
  //End

  Serial.println(F("RFID Read: "));
}
```

```
void loop() {
//Connection to server
  Serial.print("Connecting to: ");
  Serial.println(host);

  const int httpPort= 8080;
  if(!client.connect(host,httpPort))
  {
    Serial.println("Connection failed");
    return;
  }


  // Look for new cards
  if ( ! mfrc522.PICC_IsNewCardPresent()) {
    delay(50);
    return;
  }
  // Select one of the cards
  if ( ! mfrc522.PICC_ReadCardSerial()) {
    delay(50);
    return;
  }


  // Show some details of the PICC (that is: the tag/card)
  Serial.print(F("Card UID:"));
  dump_byte_array(mfrc522.uid.uidByte, mfrc522.uid.size);
  Serial.println();

  data = mfrc522.uid.uidByte, mfrc522.uid.size;
  for(int i=0; i<4; i++)
  {
    Serial.print(data[i],HEX);
  }
  a=String(data[0],HEX);
  b=String(data[1],HEX);
  c=String(data[2],HEX);
  d=String(data[3],HEX);
  a.toUpperCase();
  b.toUpperCase();
  c.toUpperCase();
  d.toUpperCase();
```

```
//============ HTTP POST ============
  http.addHeader("Content-Type", "application/json");
  String payload =  "{\"station_id\": \"" + String(station_id) + "\", \"uid\": \"" + String(a) + String(b) + String(c) + String(d) + "\"}";
  Serial.println(payload);
  int httpResponseCode = http.POST(payload);
  //==================================
  delay(1000);

  while(client.available()){
   String line = client.readStringUntil('\r');
   Serial.print(line);
  }
  Serial.println();
  Serial.println("Closing connection");
  delay(1000);
}

// Helper routine to dump a byte array as hex values to Serial
void dump_byte_array(byte *buffer, byte bufferSize) {
  for (byte i = 0; i < bufferSize; i++) {
    Serial.print(buffer[i] < 0x10 ? " 0" : " ");
    Serial.print(buffer[i], HEX);
  }
}
```

E.1.2 .h source code

```
#define RST_PIN 5
#define SS_PIN 15

const char* ssid = "Dialog 4G 075";
const char* password = "4643c5c3";
const char* host="192.168.8.159"; //IP adress of host computer
const char* station_id="01";
const char* serverName = "http://192.168.8.159:8080/supply-chain-backend-service/api/v1/rfidRegistration"; //service URL in LAN
```

Appendix F: JavaScript Source Code (API)

F.1.1 app.js (GRN function)

```
app.post('/supply-chain-backend-service/api/v1/rfidRegistration', async (req, res) => {
    let id = req.body.id;
    let stationId = req.body.station_id;
    let uid = req.body.uid;
    let result = await db.getpoNumberAndLotSizeFromRFID(uid);
    let result2 = await db.getpoNumberAndLotSizeFromRFIDWastage(uid);
    let PONumber = '';
    let lotSize = 0;
    let location = '';
    let materialCode = '';
    let pms_r = 0;
    let pms_w = 0;
    let tsp_r = 0;
    let tsp_w = 0;
    let new_pms_r = 0;
    let new_pms_w = 0;
    let grn_required = 0;
    let grn_wastage = 0;
    let new_gran_required = 0;
    let new_gran_wastage = 0;

    if (result.length) {
        PONumber = result[0]['ponumber'];
        lotSize = result[0]['requiredquantity'];

        const result3 = await db.rfIdRegistration(id, stationId, uid);

        if (result3.affectedRows > 0) {
            const result4 = await
db.getLocationAndMaterialCodeFromPONumber(PONumber);

            if (result4.length) {
                location = result4[0]['location'];
                materialCode = result4[0]['materialcode'];

                const result5 = await db.getInventoryValues(location, materialCode);
                console.log(result5);
             if (result5.length) {
                    pms_r = result5[0]['pms_rd'];
                    tsp_r = result5[0]['tsp_rd'];
                    new_pms_r = pms_r + lotSize;

                    const result6 = await db.updateInventory(new_pms_r, tsp_r, location,
             materialCode);
             if (result6.affectedRows > 0) {

                        const result7 = await db.getGRNValues(PONumber);
```

```
if (result7.length) {
                grn_required = result7[0]['grn_required'];
                grn_wastage = result7[0]['grn_wastage'];
                new_gran_required = grn_required + lotSize;

                const result8 = await db.updateGRNValues(PONumber,
new_gran_required, grn_wastage);

                if (result8.affectedRows > 0) {
                    res.send({sts: 'success'});
                }
            }
        } else {
            res.send({sts: 'failed', reason: 'Insertion failed'});
        }
    } else {
        pms_r = lotSize
        tsp_r = 0;
        pms_w = 0;
        tsp_w = 0;

        const result6 = await db.insertToInventory(pms_r, tsp_r, pms_w,
tsp_w, location, materialCode);

        if (result6.affectedRows > 0) {
            const result7 = await db.getGRNValues(PONumber);

            if (result7.length) {
                grn_required = result7[0]['grn_required'];
                grn_wastage = result7[0]['grn_wastage'];
                console.log(grn_required);
                console.log(grn_wastage);
                new_gran_required = grn_required + lotSize;

                const result8 = await db.updateGRNValues(PONumber,
new_gran_required, grn_wastage);

                if (result8.affectedRows > 0) {
                    res.send({sts: 'success'});
                }
            }
        } else {
            res.send({sts: 'failed', reason: 'Insertion failed'});
        }
    }
}
```

```
        } else {
            res.send({sts: 'failed', reason: 'Insertion failed'});
        }

    } else if (result2.length) {
        PONumber = result2[0]['ponumber'];
        lotSize = result2[0]['requiredquantity'];

        const result3 = await db.rfIdRegistration(id, stationId, uid);

        if (result3.affectedRows > 0) {
            const result4 = await
db.getLocationAndMaterialCodeFromPONumber(PONumber);

            if (result4.length) {
                location = result4[0]['location'];
                materialCode = result4[0]['materialcode'];


                const result5 = await db.getInventoryValues(location, materialCode);
                console.log(result5);

                if (result5.length) {
                    pms_w = result5[0]['pms_wt'];
                    tsp_w = result5[0]['tsp_wt'];
                    new_pms_w = pms_w + lotSize;

                    const result6 = await db.updateInventoryWastage(new_pms_w,
tsp_w, location, materialCode);

                    if (result6.affectedRows > 0) {

                        const result7 = await db.getGRNValues(PONumber);

                        if (result7.length) {
                            grn_required = result7[0]['grn_required'];
                            grn_wastage = result7[0]['grn_wastage'];

                            new_gran_wastage = grn_wastage + lotSize;

                            const result8 = await db.updateGRNValues(PONumber,
grn_required, new_gran_wastage);

                            if (result8.affectedRows > 0) {
                                res.send({sts: 'success'});
                            }
```

```
}
                } else {
                    res.send({sts: 'failed', reason: 'Insertion failed'});
                }
            } else {
                pms_r = 0
                tsp_r = 0;
                pms_w = lotSize;
                tsp_w = 0;

                const result6 = await db.insertToInventory(pms_r, tsp_r, pms_w,
tsp_w, location, materialCode);

                if (result6.affectedRows > 0) {
                    const result7 = await db.getGRNValues(PONumber);

                    if (result7.length) {
                        grn_required = result7[0]['grn_required'];
                        grn_wastage = result7[0]['grn_wastage'];

                        new_gran_wastage = grn_wastage + lotSize;

                        const result8 = await db.updateGRNValues(PONumber,
grn_required, new_gran_wastage);

                        if (result8.affectedRows > 0) {
                            res.send({sts: 'success'});
                        }
                    }
                } else {
                    res.send({sts: 'failed', reason: 'Insertion failed'});
                }
            }
        }

    } else {
        res.send({sts: 'failed', reason: 'Insertion failed'});
    }

  } else {
    res.send({sts: 'failed', reason: 'RFID not found'});
  }

});
```

F.1.2 app.js (Transfer from PMS to TSP function)

```
app.post('/supply-chain-backend-service/api/v1/rfidRegistrationPms', async (req,
res) => {
    let id = undefined;
    let stationId = req.body.station_id;
    let uid = req.body.uid;
    // let results = await db.pmsProcess(stationId, uid);
    // res.send({sts: results});
    let result = await db.getpoNumberAndLotSizeFromRFID(uid);
    let result2 = await db.getpoNumberAndLotSizeFromRFIDWastage(uid);
    let PONumber = ''
    let lotSize = 0;
    let location = '';
    let materialCode = '';
    let pms_r = 0;
    let tsp_r = 0;
    let pms_w = 0;
    let tsp_w = 0;
    let new_pms_r = 0;
    let new_pms_w = 0
    let new_tsp_r = 0;
    let new_tsp_w = 0;
    console.log('test');
    if (result.length) {

        PONumber = result[0]['ponumber'];
        lotSize = result[0]['requiredquantity'];

        const result3 = await db.pmsRfIdRegistration(id, stationId, uid);

        if (result3.affectedRows > 0) {
            const result4 = await db.rfIdDeregistration(uid);

            if (result4.affectedRows > 0) {
                const result5 = await
db.getLocationAndMaterialCodeFromPONumber(PONumber);
                if (result5.length) {
                    location = result5[0]['location'];
                    materialCode = result5[0]['materialcode'];

                    console.log(location);
                    console.log(materialCode);
                    const result6 = await db.getInventoryValues(location, materialCode);
                    console.log('inventory values');
                    console.log(result6);
```

```
if (result6.length) {
            pms_r = result6[0]['pms_rd'];
            tsp_r = result6[0]['tsp_rd'];
            console.log(pms_r);
            console.log(tsp_r);

            new_pms_r = pms_r - lotSize;
            new_tsp_r = tsp_r + lotSize;

            console.log('-----');
            console.log(new_pms_r);
            console.log(new_tsp_r);

            const result7 = await db.updateInventory(new_pms_r, new_tsp_r,
location, materialCode);

            if (result7.affectedRows > 0) {
              res.send({sts: 'success', reason: 'Inventory updated'});
            }
          }
        }

      } else {
        res.send({sts: 'failed', reason: 'RFID deletion failed'});
      }
    } else {
      res.send({sts: 'failed', reason: 'PMS RFID insertion failed'});
    }

  } else if (result2.length) {

    PONumber = result2[0]['ponumber'];
    lotSize = result2[0]['requiredquantity'];

    const result3 = await db.pmsRfIdRegistration(id, stationId, uid);

    if (result3.affectedRows > 0) {
      const result4 = await db.rfIdDeregistration(uid);

      if (result4.affectedRows > 0) {
        const result5 = await
db.getLocationAndMaterialCodeFromPONumber(PONumber);
```

```
if (result5.length) {
            location = result5[0]['location'];
            materialCode = result5[0]['materialcode'];

            const result6 = await db.getInventoryValues(location, materialCode);
            console.log('inventory values');
            console.log(result6);

            if (result6.length) {
              pms_w = result6[0]['pms_wt'];
              tsp_w = result6[0]['tsp_wt'];
              console.log(pms_w);
              console.log(tsp_w);
              console.log('-------');

              new_pms_w = pms_w - lotSize;
              new_tsp_w = tsp_w + lotSize;

              console.log(new_pms_w);
              console.log(new_tsp_w);

              const result7 = await db.updateInventoryWastage(new_pms_w,
new_tsp_w, location, materialCode);

              if (result7.affectedRows > 0) {
                res.send({sts: 'success', reason: 'Inventory updated'});
              }


            }
          }

        } else {
          res.send({sts: 'failed', reason: 'RFID deletion failed'});
        }
      } else {
        res.send({sts: 'failed', reason: 'PMS RFID insertion failed'});
      }

    } else {
      res.send({sts: 'failed', reason: 'RFID not found'});
    }



});
```

F.1.3 app.js (Return from TSP to PMS function)

```
app.post('/supply-chain-backend-service/api/v1/rfidRegistrationTsp', async (req,
res) => {
    let id = req.body.id;
    let stationId = req.body.station_id;
    let uid = req.body.uid;
    let result = await db.getpoNumberAndLotSizeFromRFID(uid);
    let result2 = await db.getpoNumberAndLotSizeFromRFIDWastage(uid);
    let PONumber = ''
    let lotSize = 0;
    let location = '';
    let materialCode = '';
    let pms_r = 0;
    let tsp_r = 0;
    let pms_w = 0;
    let tsp_w = 0;
    let new_pms_r = 0;
    let new_pms_w = 0
    let new_tsp_r = 0;
    let new_tsp_w = 0;

    console.log(result);

    if (result.length) {
        PONumber = result[0]['ponumber'];
        lotSize = result[0]['requiredquantity'];

        const result3 = await db.rfIdRegistration(id, stationId, uid);

        if (result3.affectedRows > 0) {
            const result4 = await db.pmsRfIdDeregistration(uid);

            if (result4.affectedRows > 0) {
                const result5 = await
db.getLocationAndMaterialCodeFromPONumber(PONumber);

                if (result5.length) {
                    location = result5[0]['location'];
                    materialCode = result5[0]['materialcode'];

                    const result6 = await db.getInventoryValues(location, materialCode);

                    if (result6.length) {
                        pms_r = result6[0]['pms_rd'];
                        tsp_r = result6[0]['tsp_rd'];

                        new_pms_r = pms_r + lotSize;
                        new_tsp_r = tsp_r - lotSize;
```

```
const result7 = await db.updateInventory(new_pms_r, new_tsp_r, location,
materialCode);

            if (result7.affectedRows > 0) {
              res.send({sts: 'success', reason: 'Inventory updated'});
            }
          }
        }

      } else {
        res.send({sts: 'failed', reason: 'RFID deletion failed'});
      }
    } else {
      res.send({sts: 'failed', reason: 'PMS RFID insertion failed'});
    }

  } else if (result2.length) {
    PONumber = result2[0]['ponumber'];
    lotSize = result2[0]['requiredquantity'];

    const result3 = await db.rfIdRegistration(id, stationId, uid);

    if (result3.affectedRows > 0) {
      const result4 = await db.pmsRfIdDeregistration(uid);

      if (result4.affectedRows > 0) {
        const result5 = await
db.getLocationAndMaterialCodeFromPONumber(PONumber);

        if (result5.length) {
          location = result5[0]['location'];
          materialCode = result5[0]['materialcode'];

          const result6 = await db.getInventoryValues(location, materialCode);

          if (result6.length) {
            pms_w = result6[0]['pms_wt'];
            tsp_w = result6[0]['tsp_wt'];

            new_pms_w = pms_w + lotSize;
            new_tsp_w = tsp_w - lotSize;

            const result7 = await db.updateInventoryWastage(new_pms_w,
new_tsp_w, location, materialCode);
```

```
if (result7.affectedRows > 0) {
                        res.send({sts: 'success', reason: 'Inventory updated'});
                    }
                }
            }

        } else {
            res.send({sts: 'failed', reason: 'RFID deletion failed'});
        }
    } else {
        res.send({sts: 'failed', reason: 'PMS RFID insertion failed'});
    }

} else {
    res.send({sts: 'failed', reason: 'RFID not found'});
}

});
```

Appendix G: PHP Source Code (Web-based application)

G.1.1 User Log

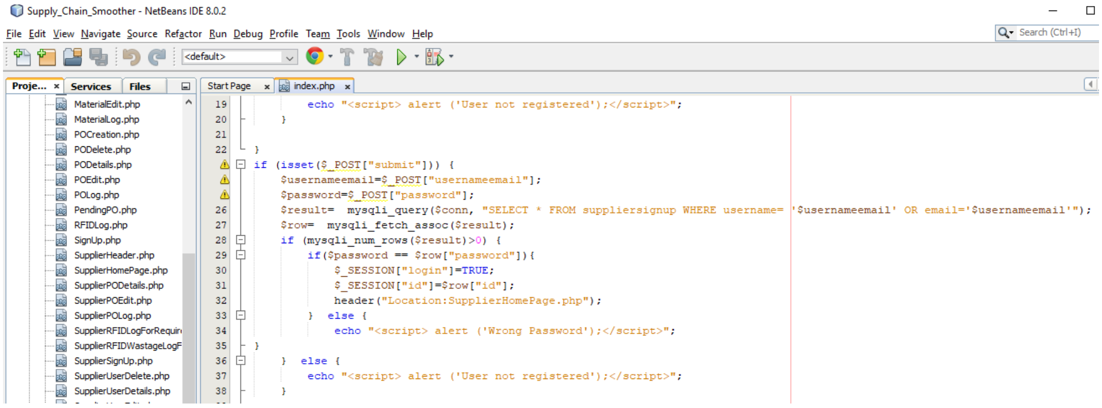

Figure 73: Source code-User log-in

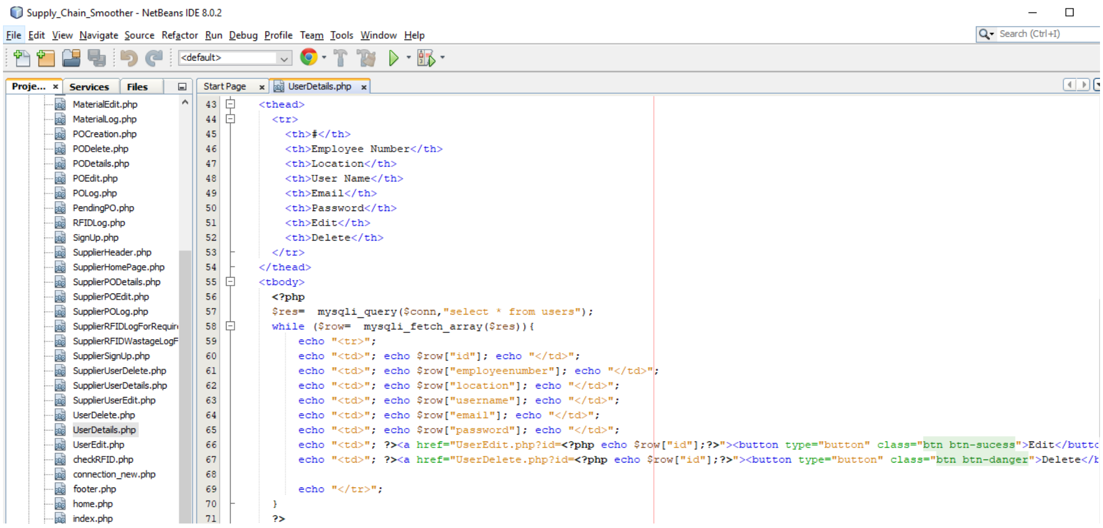

Figure 74: Source code - Display user details

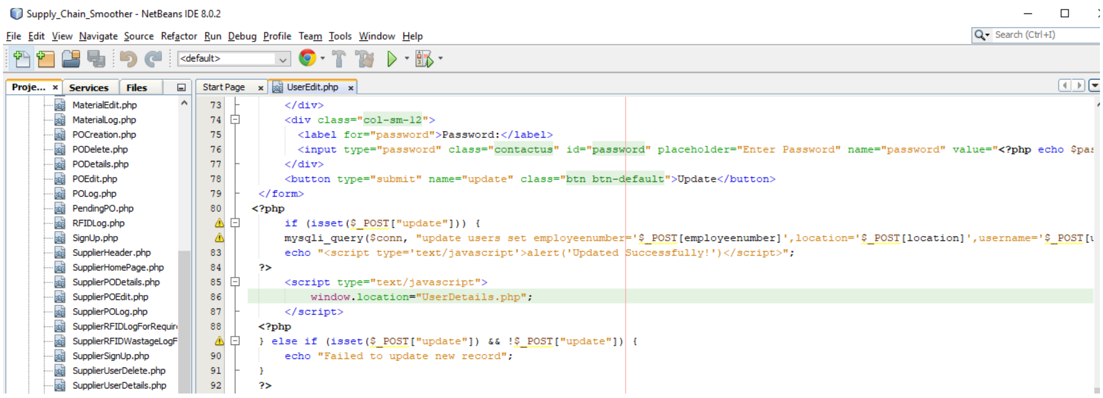

Figure 75: Source code-Update user details

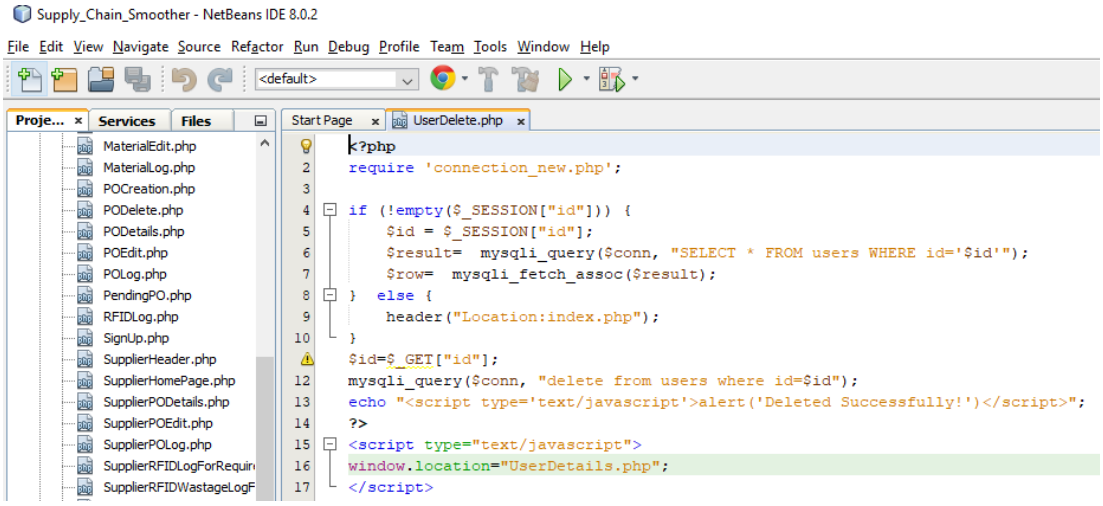

Figure 76: Source code-Delete user

G.1.2 Material Log

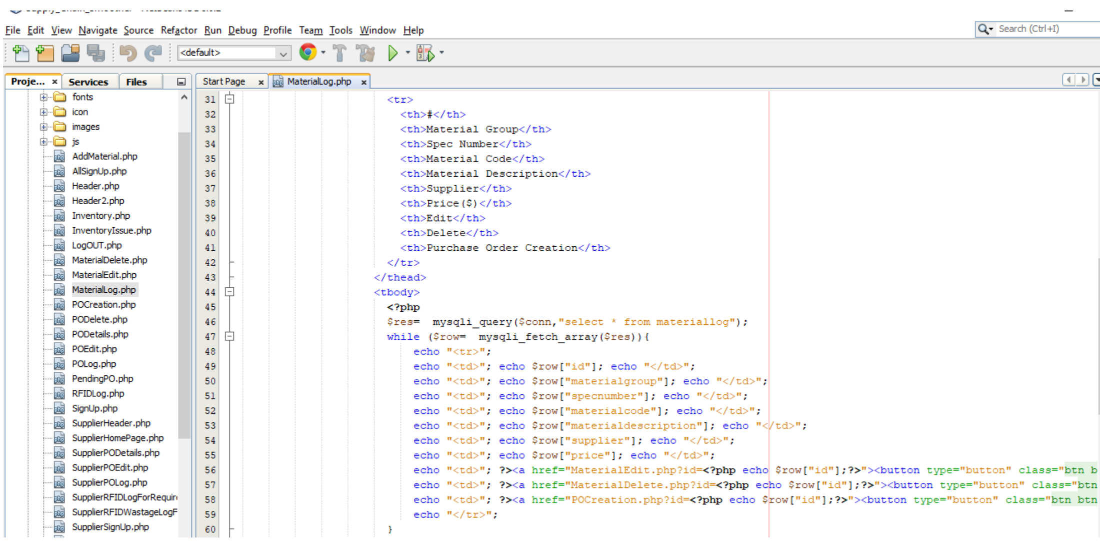

Figure 77: Source code-Display material log

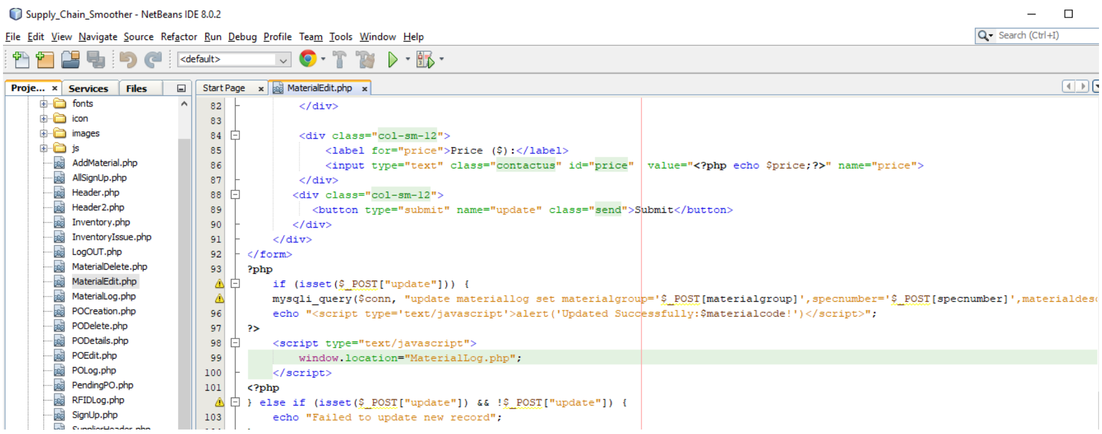

Figure 78: Source code-Update material details

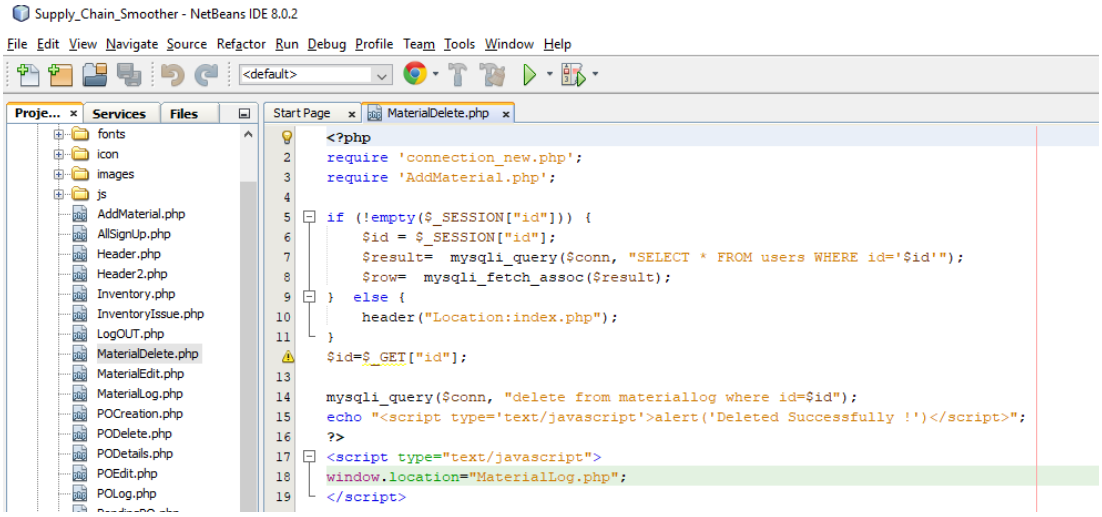

Figure 79: Source code - Delete material details

G.1.3 Purchase Order Log

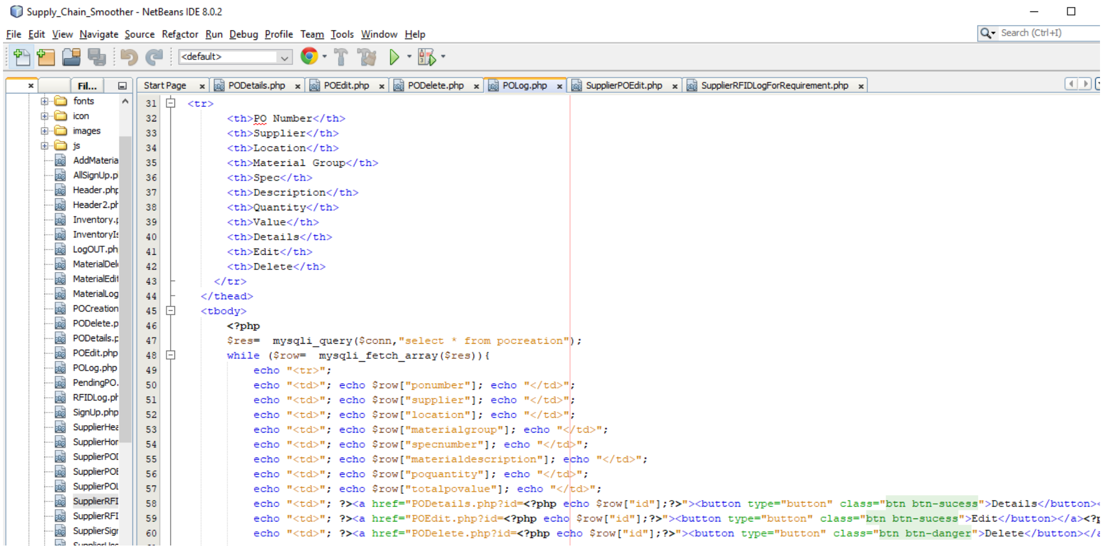

Figure 80: Source code - View purchase order log

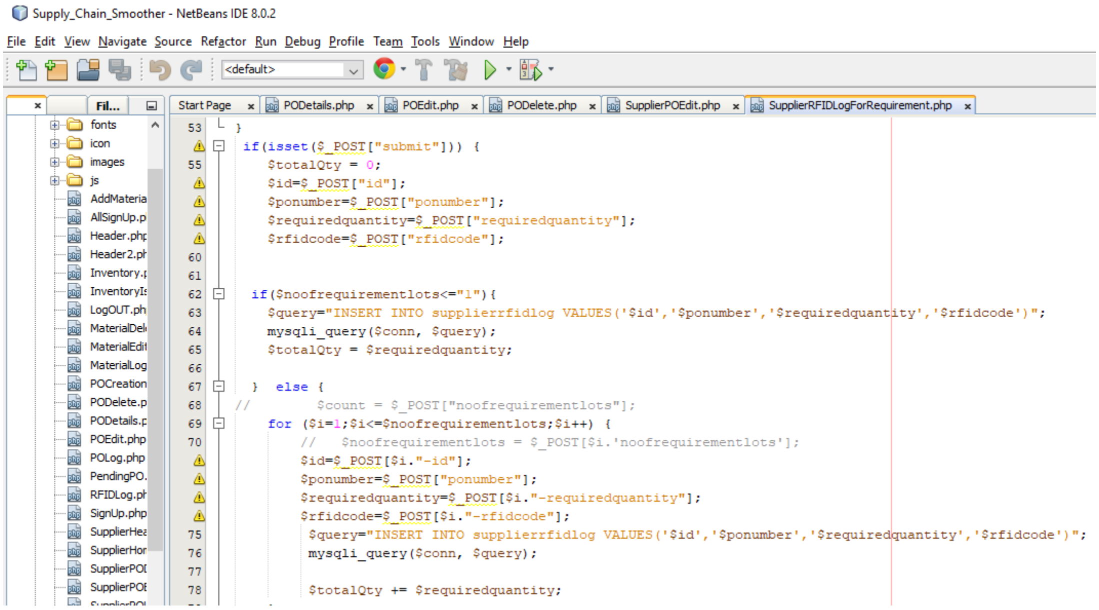

Figure 81: Source code -RFID code addition

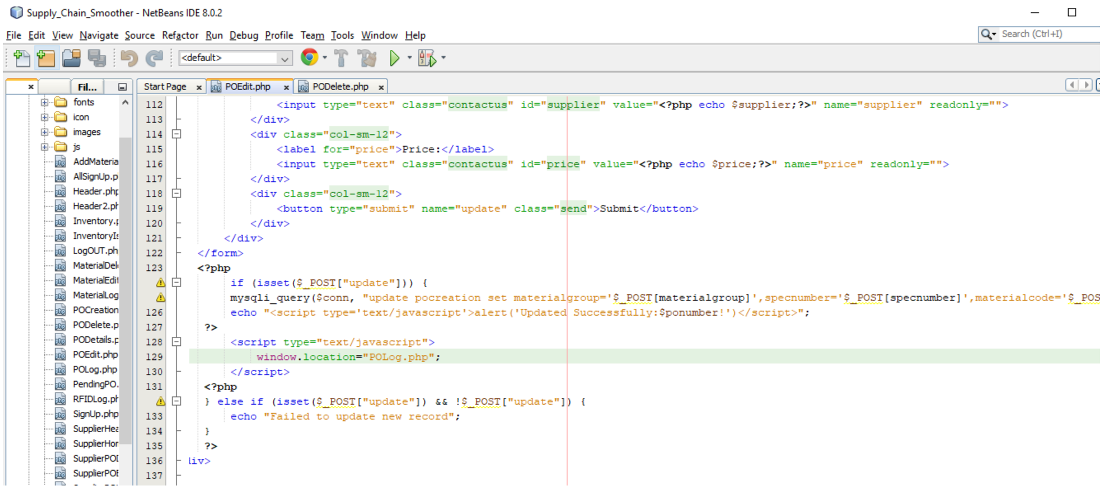

Figure 82: Source code - Updating purchase order

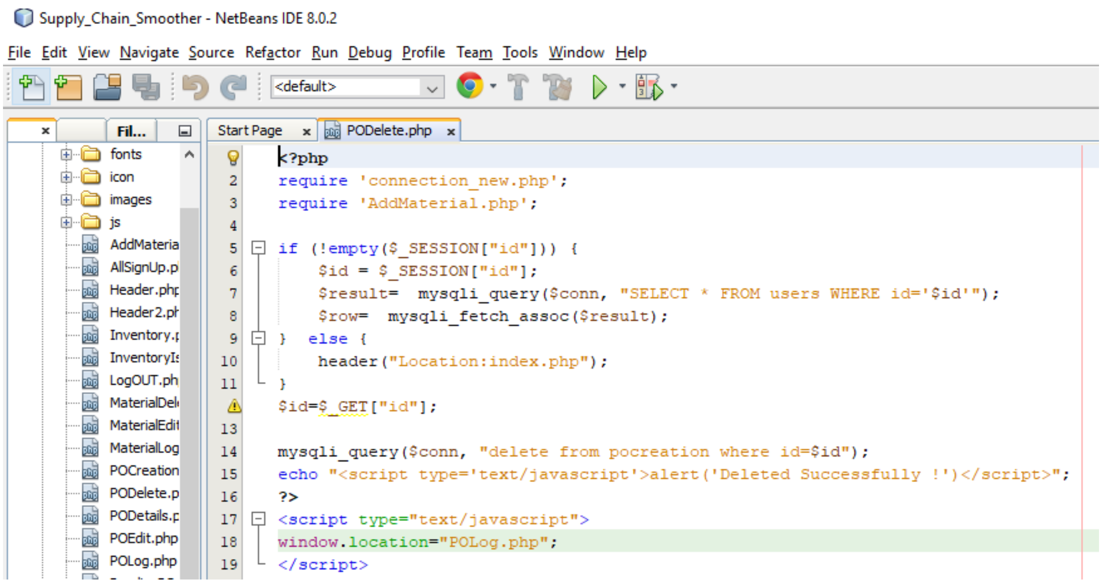

Figure 83: Deleting purchase order

Appendix H: UI Snapshots (Web-based application)

H.1.1 User Log

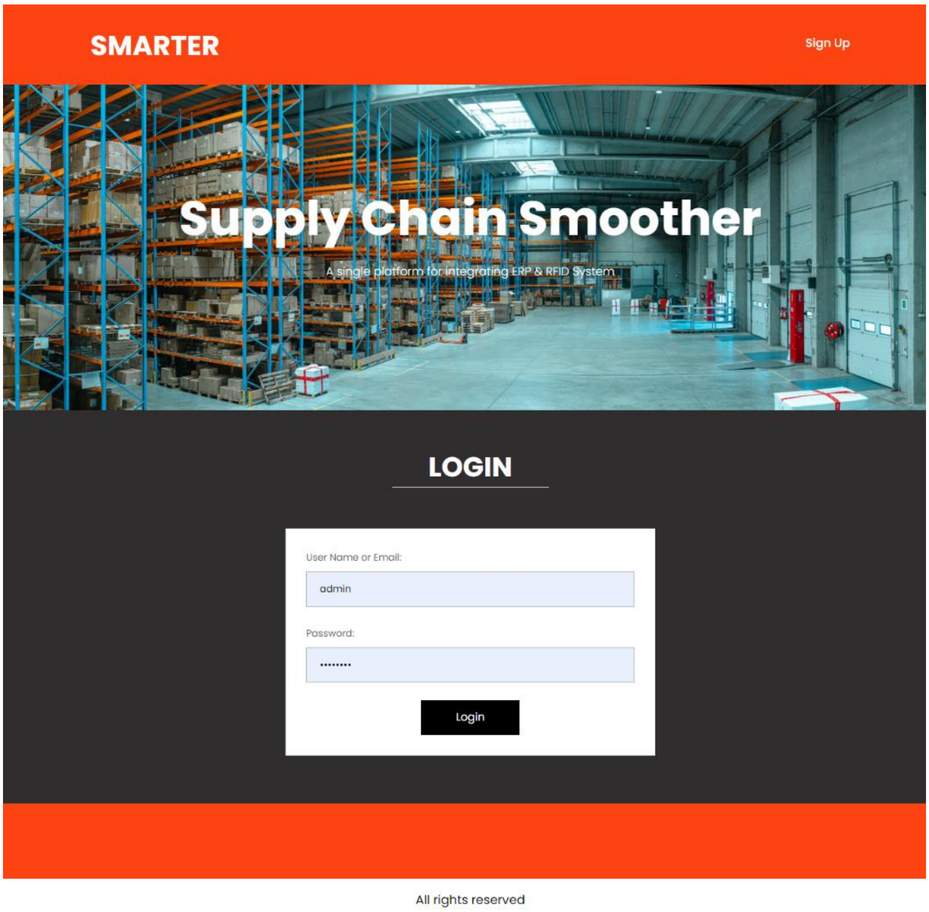

Figure 84: User Log-in- Software

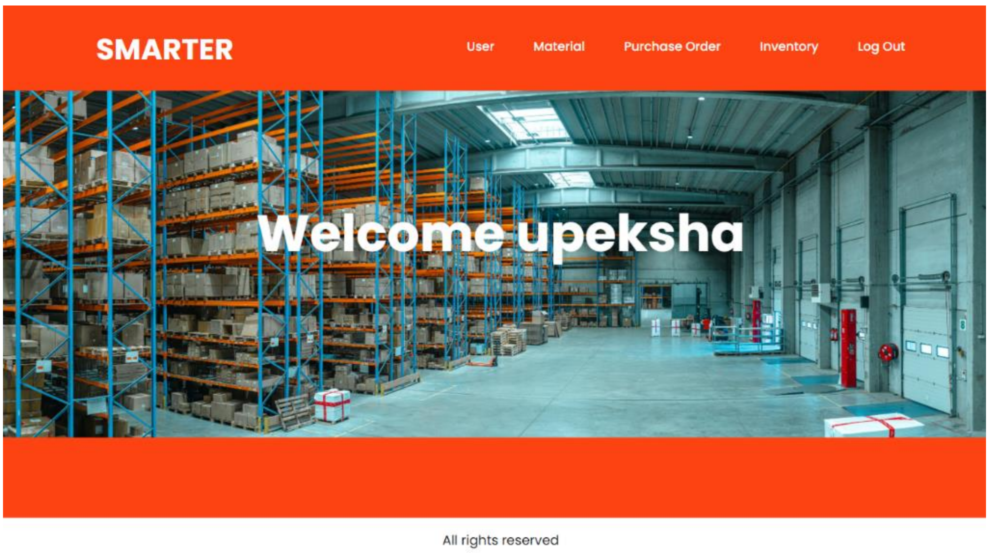

Figure 85: Home Page- Software

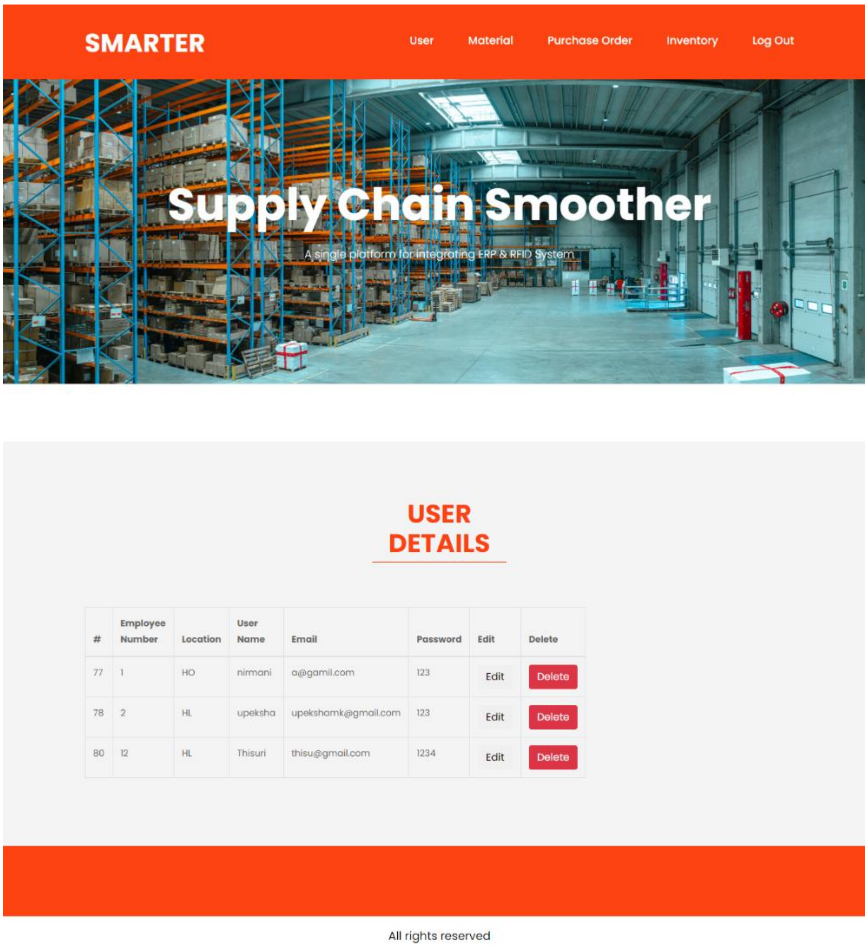

Figure 86: Display user details- Software

H.1.2 Material Log

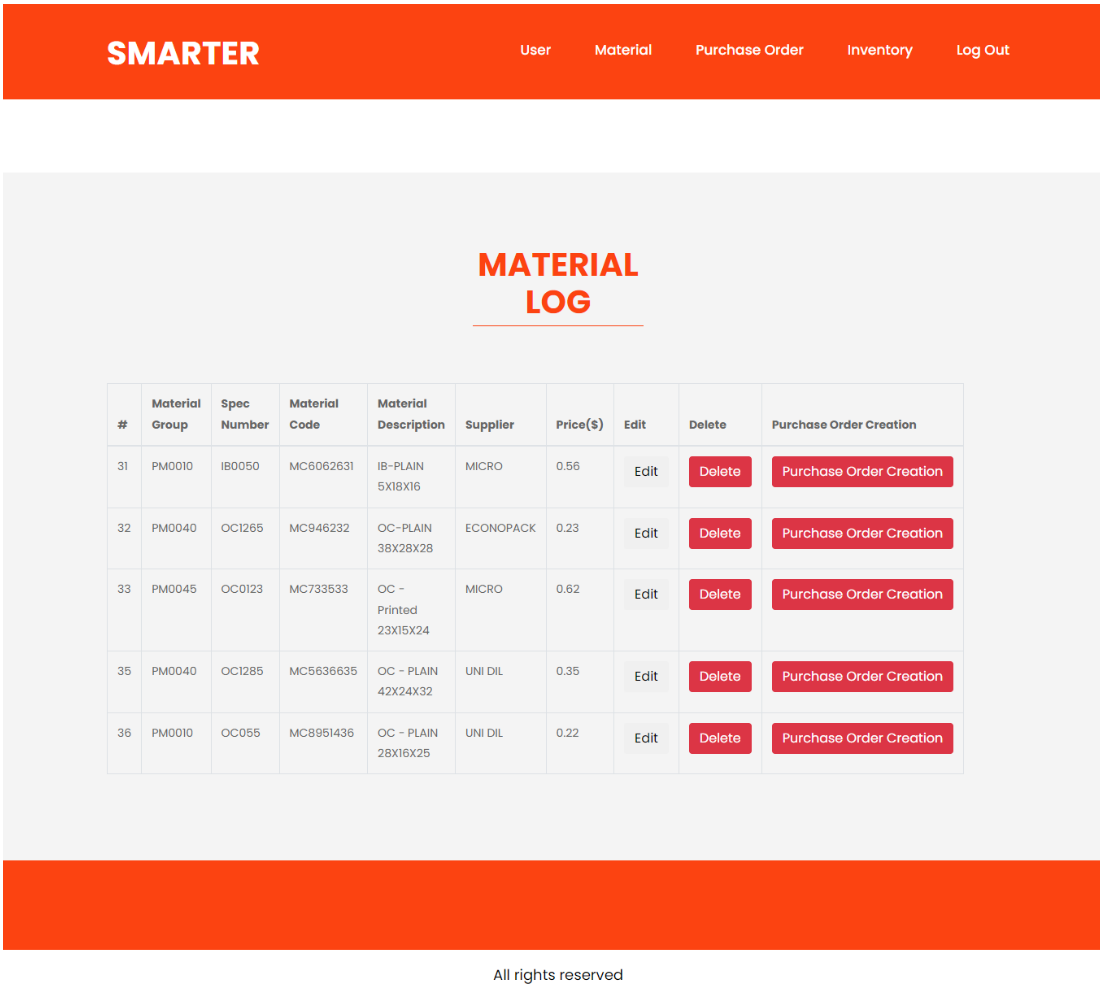

Figure 87: Display packing material- Software

H.1.3 Purchase Order Log

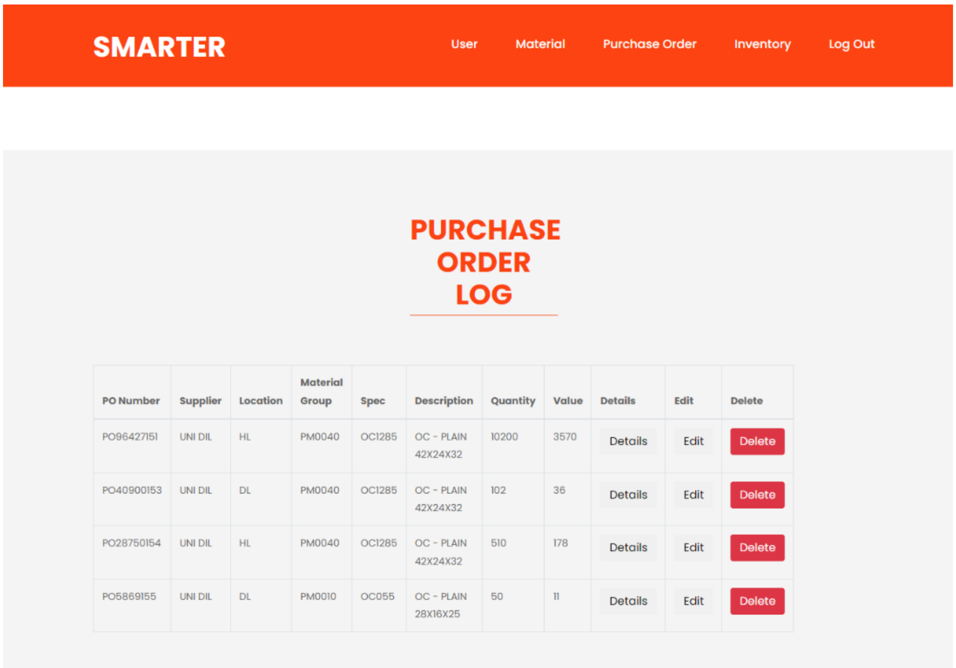

Figure 88: Display purchase order details- Software

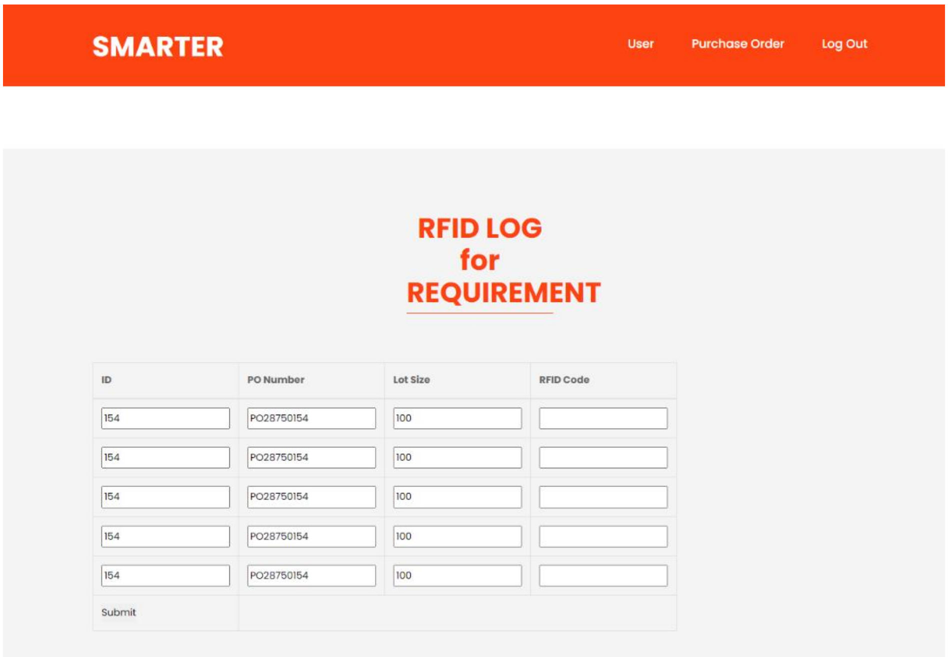

Figure 89: Add RFID code for lots of purchase orders- Software

H.1.3.1 GRN Function

Figure 90: GRN – Input (Station 1)- Arduino IDE

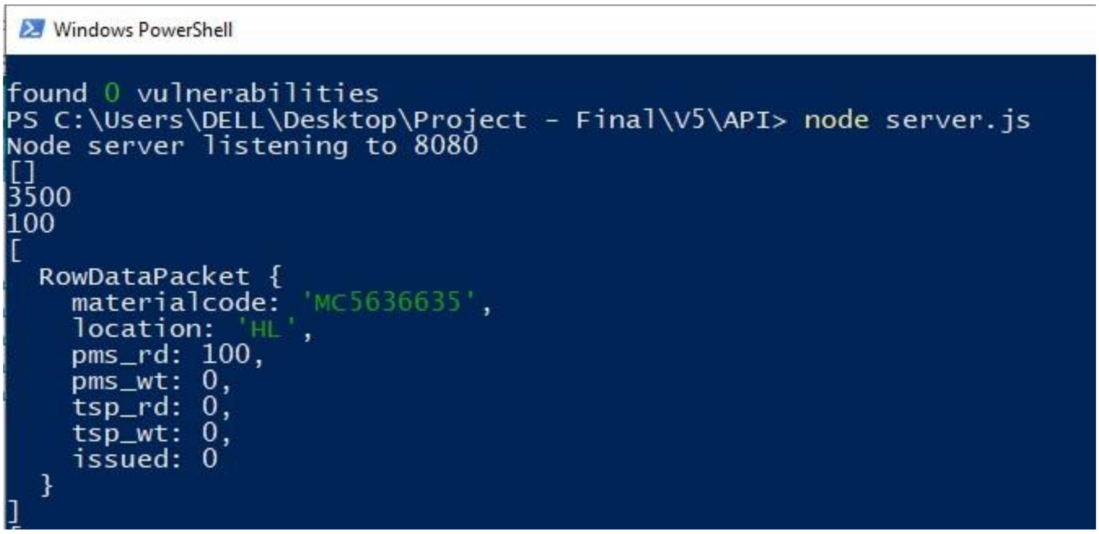

Figure 91: GRN – Input (Station 1)- Windows PowerShell

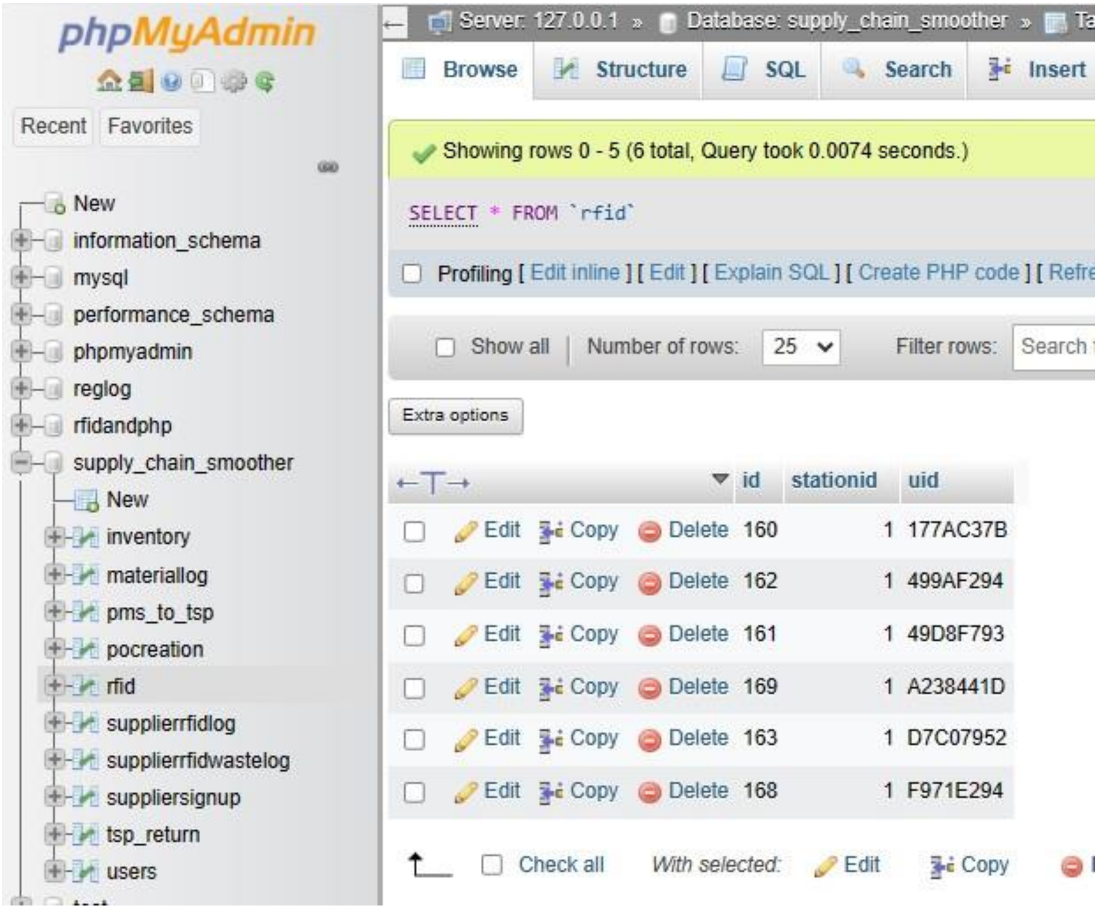

Figure 92: Input (Station 1)- phpMyAdmin(rfid table)

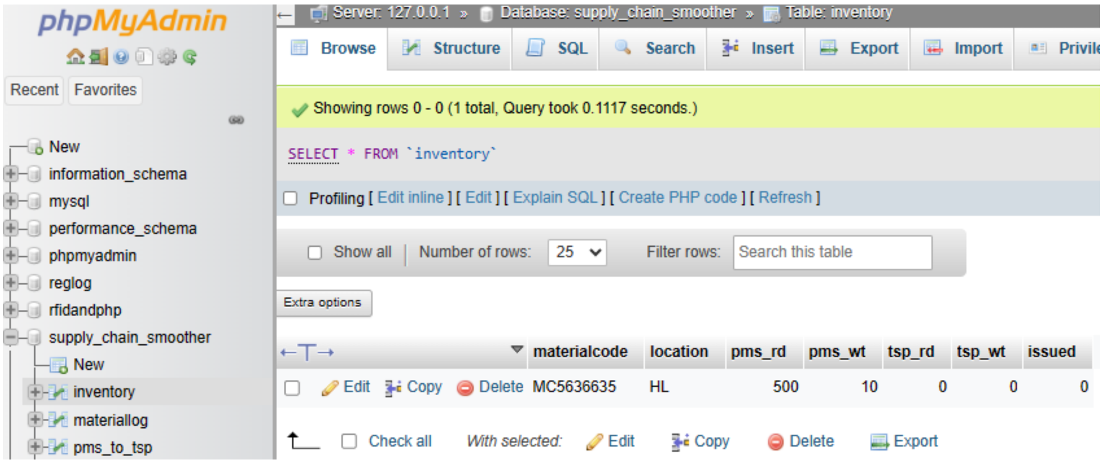

Figure 93: Input (Station 1)- phpMyAdmin(inventory table)

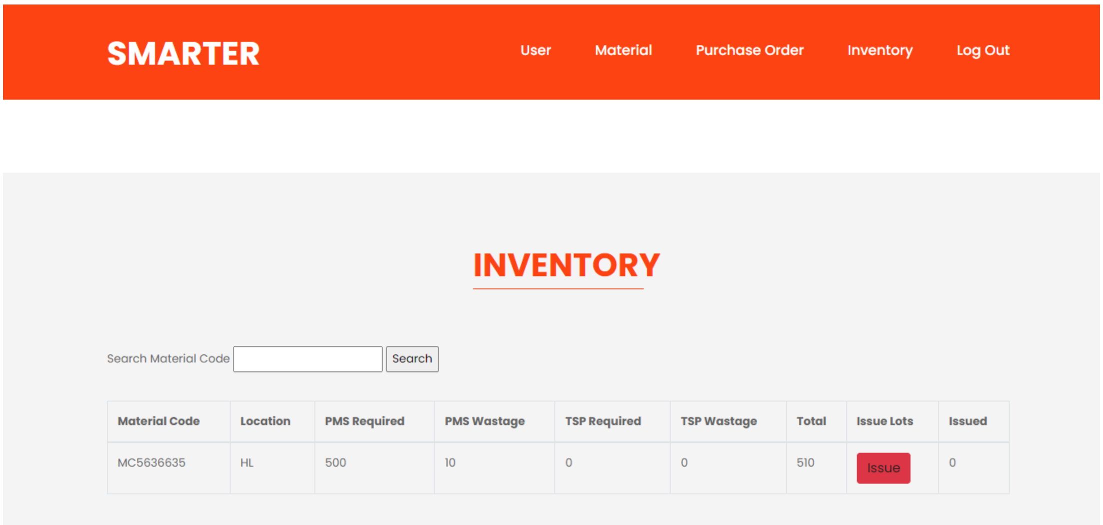

Figure 94: GRN – Input (Station 1)- Software

H.1.4 Inventory Log

H.1.4.1 Transfer Materials from PMS to TSP Function

Figure 95: Transfer materials from PMS to TSP – Input (Station 2) - Arduino IDE

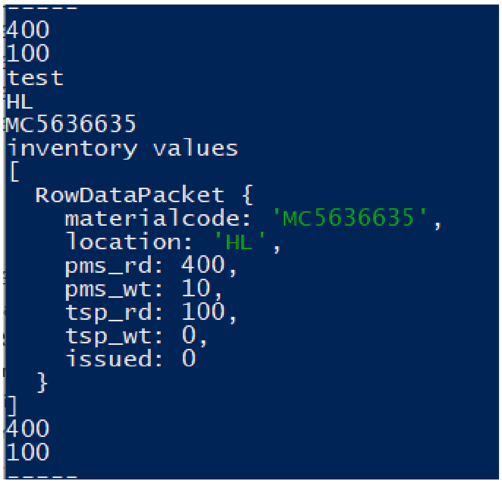

Figure 96: Transfer materials from PMS to TSP – Input (Station 2) - Windows PowerShell

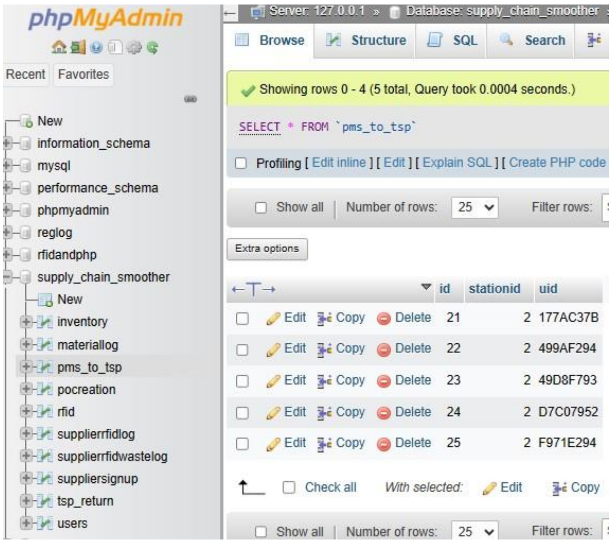

Figure 97: Transfer materials from PMS to TSP – Input (Station 2) – phpMyAdmin (pms_to_tsp table)

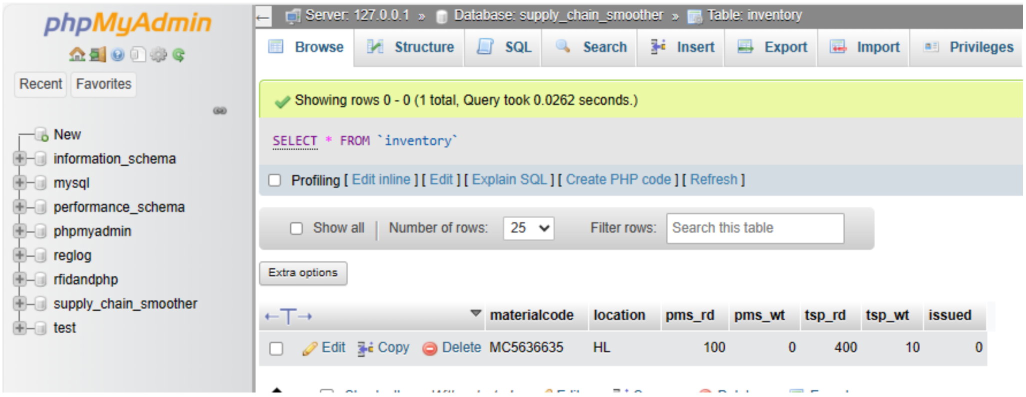

Figure 98: Transfer materials from PMS to TSP – Input (Station 2) – phpMyAdmin (inventory table)

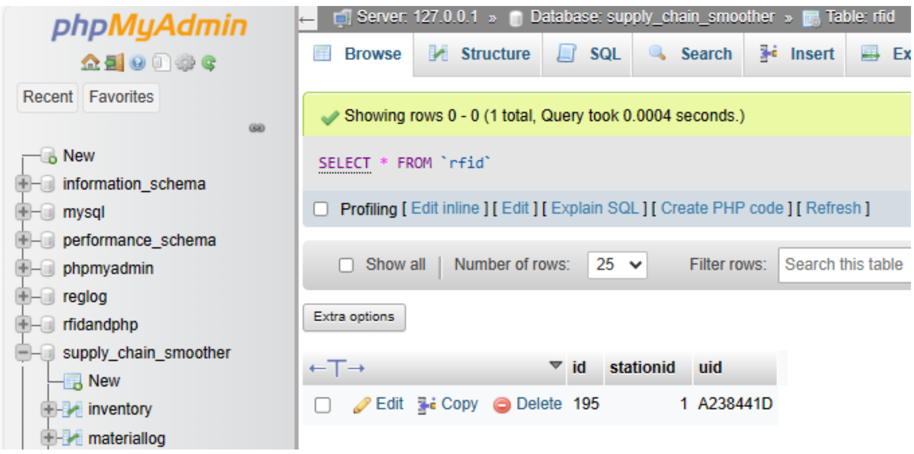

Figure 99: Transfer materials from PMS to TSP – Input (Station 2) – phpMyAdmin (rfid table)

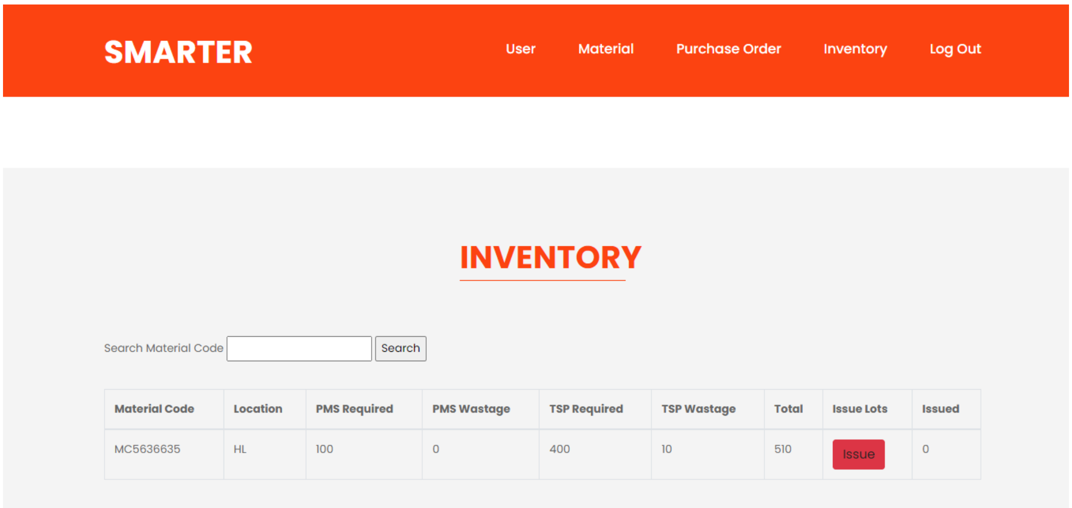

Figure 100: Transfer materials from PMS to TSP – Input (Station 2) – Software

H.1.4.2 Material Issue for Order Function

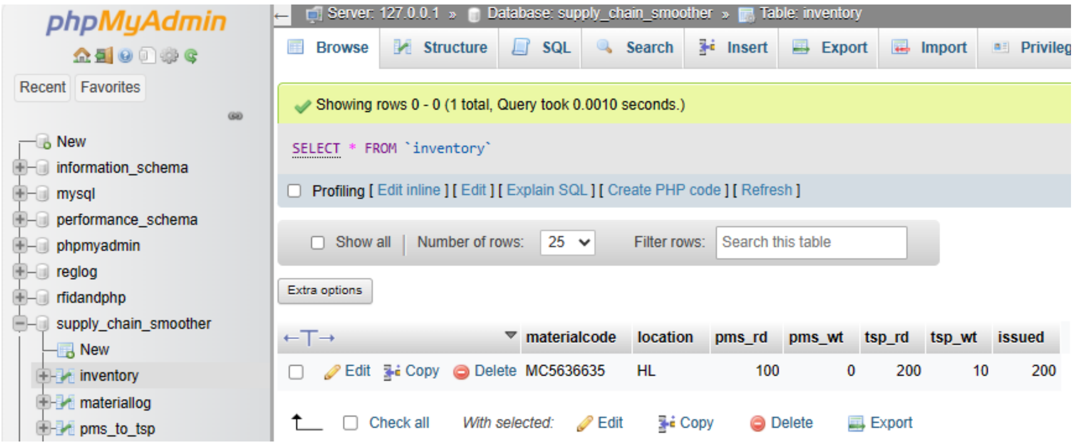

Figure 101: Materials issue for the order- phpMyAdmin (inventory table)

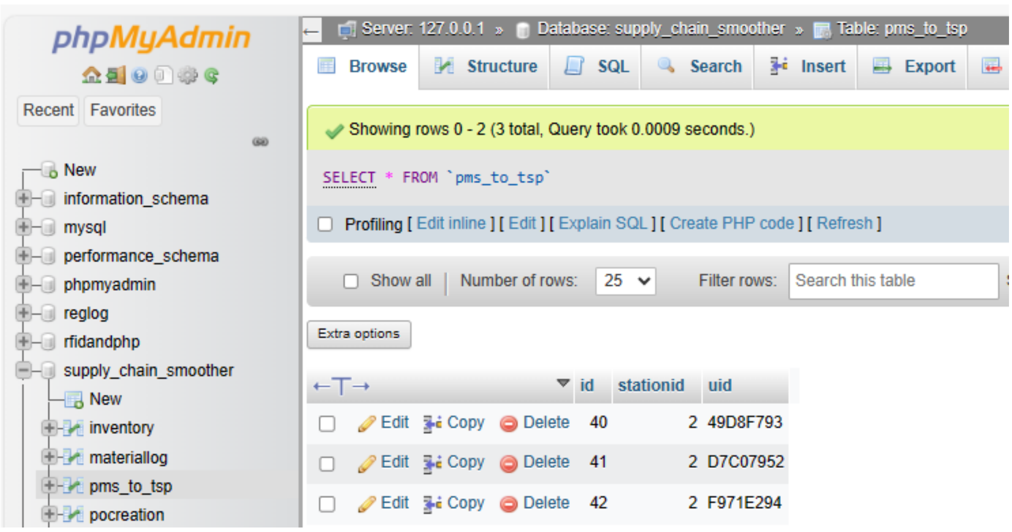

Figure 102: Materials issue for the order- phpMyAdmin (pms_to_tsp table)

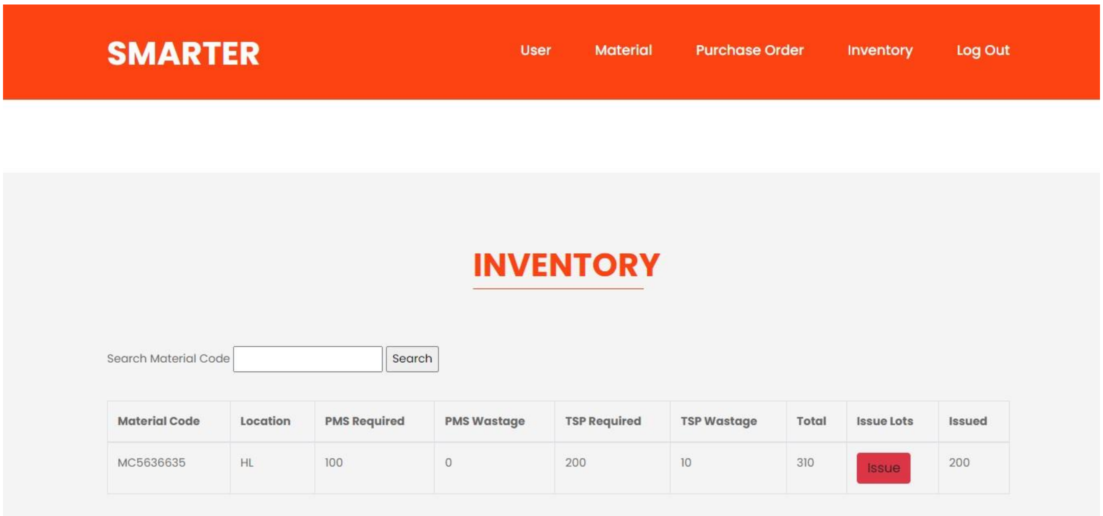

Figure 103: Materials issue for the order- Software (inventory UI)

H.1.4.3 Return Materials from TSP to PMS Function

Figure 104: Return materials from TSP to PMS – Input (Station 3) - Arduino IDE

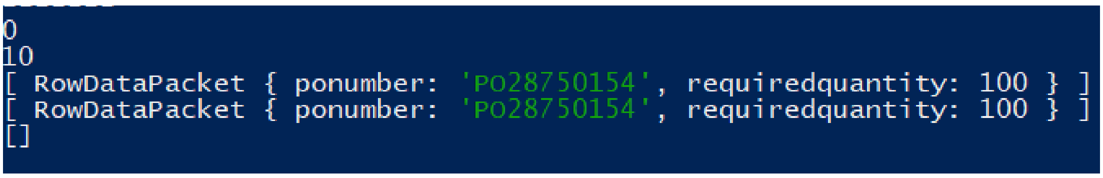

Figure 105: Return materials from TSP to PMS – Input (Station 3) - Windows PowerShell

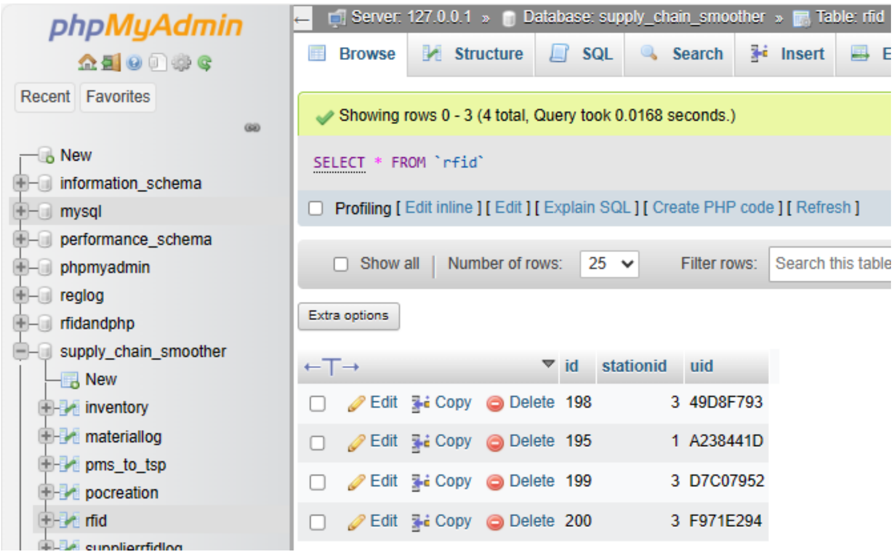

Figure 106: Return materials from TSP to PMS – Input (Station 3) - phpMyAdmin (rfid table)

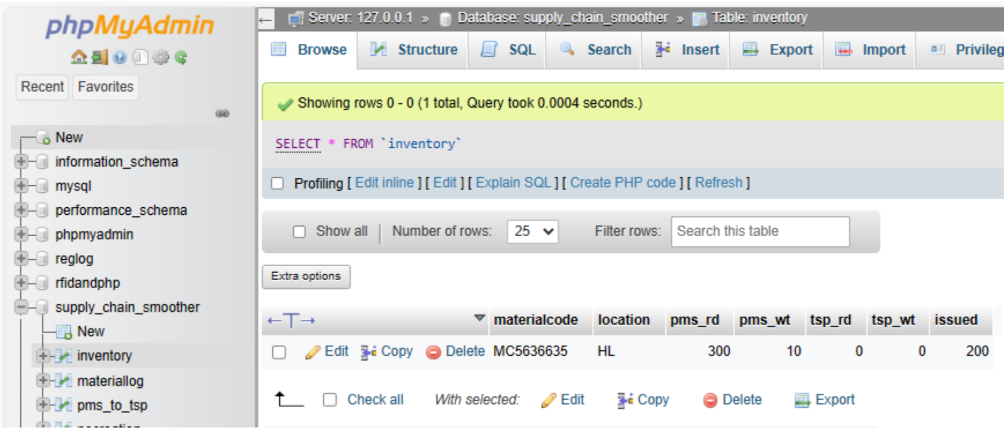

Figure 107: Return materials from TSP to PMS – Input (Station 3) - phpMyAdmin (inventory table)

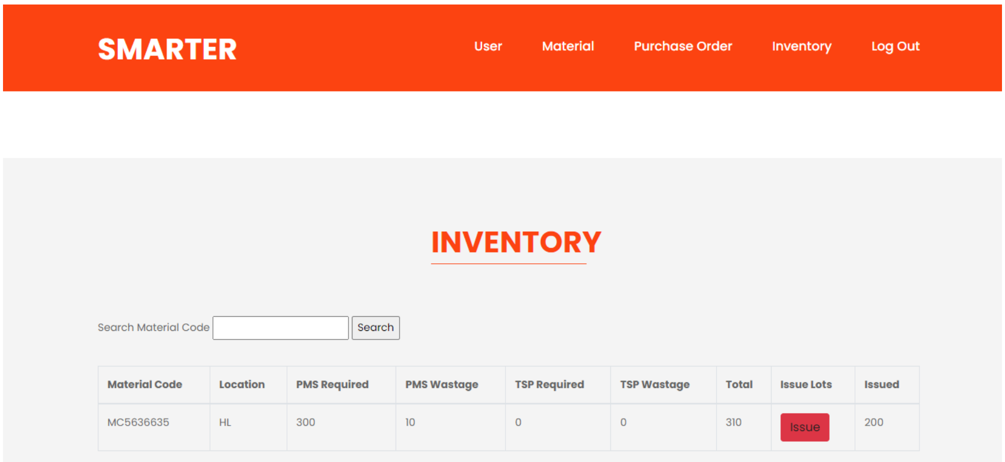

Figure 108: Return materials from TSP to PMS – Input (Station 3) - Software

Appendix I: Semi-Structured Interview Questionnaire

Quality: Inventory Discrepancy
1. How has the integration of ERP and RFID systems affected the frequency of inventory discrepancies?
2. What improvements have you observed in reconciling recorded and physical inventory?
Quality: Purchase Order Accuracy
3. How has the new system impacted the accuracy of purchase orders?
4. Have you noticed any changes in the percentage of discrepancies between actual requirements and purchase orders since implementation?
Delivery: GRN Cycle Time
5. What changes have you observed in the GRN cycle time since adopting the ERP and RFID systems?
6. How do you measure and manage the GRN cycle time with the new system?
Delivery: Emergency Purchase Rate Due to Inventory Figures
7. How has the ERP and RFID system affected the rate of emergency purchases due to inventory inaccuracies?
8. What improvements have been made in handling emergency purchases?
Inventory: Inventory Adjustment Rate (Quantity)
9. How has the integration of the ERP and RFID systems influenced the frequency and rate of inventory adjustments?
10. What improvements have you seen in aligning system inventory figures with physical stock?
Cost Saving: Inventory Discrepancy Value
11. How has the cost associated with inventory discrepancies changed since implementing the ERP and RFID systems?
12. What measures have you taken to reduce the financial impact of these discrepancies?
Cost Saving: Demurrage Cost Due to Emergency Purchases
13. What impact has the new system had on demurrage costs associated with emergency purchases?
14. How have you managed and reduced these costs with the ERP and RFID systems in place?

I.1.1 Responder 1: Procurement Manager 1

Quality: Inventory Discrepancy

1. The integration has drastically reduced inventory discrepancies. The RFID system provides real-time data, which ensures that recorded inventory matches physical inventory almost perfectly.
2. We no longer need to perform manual reconciliations frequently. The automated data capturing has improved accuracy and made the process almost seamless.

Quality: Purchase Order Accuracy

3. Purchase order accuracy has significantly improved. The system's real-time updates ensure that the actual requirements are always reflected accurately in the purchase orders.
4. Yes, the discrepancies have dropped from about 7% to almost negligible levels, around 0.04%. This has greatly optimized our procurement process.

Delivery: GRN Cycle Time

5. The GRN cycle time has been reduced from 4 minutes to about 0.15 minutes, which is a substantial improvement.
6. We measure GRN cycle time using system logs that capture the time from goods receipt to entry into the system. Management is automated and requires minimal manual intervention.

Delivery: Emergency Purchase Rate Due to Inventory Figures

7. The rate of emergency purchases has been eliminated. Accurate inventory figures prevent unexpected shortages.
8. With the accurate inventory data, emergency purchases are almost non-existent. When they do occur, they are handled swiftly due to better planning.

Inventory: Inventory Adjustment Rate (Quantity)

9. Inventory adjustments have decreased dramatically, from 10% to virtually 0%. This has made inventory management more efficient.
10. Inventory adjustments have decreased dramatically, from 10% to virtually 0%. This has made inventory management more efficient.

Cost Saving: Inventory Discrepancy Value

11. The cost associated with inventory discrepancies has dropped to zero, saving the company significant amounts annually.
12. Implementing the ERP and RFID systems was the primary measure. Additionally, ongoing training and process improvements ensure continued accuracy.

Cost Saving: Demurrage Cost Due to Emergency Purchases

13. Demurrage costs have been eliminated, as there are no emergency purchases due to inventory inaccuracies.
14. By maintaining accurate inventory records, the need for emergency purchases is eliminated, thus preventing demurrage costs

I.1.2 Responder 2: Procurement Manager 2

Quality: Inventory Discrepancy

1. It has nearly eliminated inventory discrepancies. The automation and real-time updates provided by the RFID system are crucial.
2. Reconciliation has become almost redundant. The system ensures both recorded and physical inventories are always aligned.

Quality: Purchase Order Accuracy

3. There has been a notable improvement in the accuracy of purchase orders. The system minimizes human errors in order placement.
4. Absolutely. Discrepancies have reduced from 7% to practically zero, enhancing our procurement efficiency.

Delivery: GRN Cycle Time

5. The cycle time has reduced significantly, from 4 minutes to about 9 seconds, streamlining our operations.
6. We use system-generated reports to track the GRN cycle time and address any issues promptly, though issues are rare.

Delivery: Emergency Purchase Rate Due to Inventory Figures

7. Emergency purchases due to inventory inaccuracies have been eliminated, leading to better resource planning.
8. With accurate inventory data, emergency purchases are minimal and managed effectively through better planning.

Inventory: Inventory Adjustment Rate (Quantity)

9. The frequency of inventory adjustments has dropped to almost zero, reflecting the system's accuracy.
10. The system's real-time updates ensure that physical stock always matches system inventory, reducing discrepancies.

Cost Saving: Inventory Discrepancy Value

11. The cost has been reduced to zero, which is a significant financial benefit for the company.
12. We rely on the ERP and RFID systems for accurate data, supplemented by staff training and process optimization.

Cost Saving: Demurrage Cost Due to Emergency Purchases

13. Demurrage costs have been cut to zero, thanks to the system's accurate inventory management.
14. Accurate inventory records prevent the need for emergency purchases, thereby avoiding demurrage costs.

I.1.3 Responder 3: IT Manager

Quality: Inventory Discrepancy

1. The integration has drastically minimized inventory discrepancies by ensuring real-time tracking and updates.
2. The system's real-time data capture has made reconciling recorded and physical inventory almost instantaneous and error-free.

Quality: Purchase Order Accuracy

3. The accuracy of purchase orders has improved significantly, with the system reducing manual errors.
4. Yes, discrepancies have decreased from 7% to almost zero, greatly enhancing procurement accuracy.

Delivery: GRN Cycle Time

5. The cycle time has been reduced from 4 minutes to mere seconds, which is a substantial improvement.
6. The system logs and tracks all GRN entries, allowing us to measure and manage cycle time effectively with minimal intervention.

Delivery: Emergency Purchase Rate Due to Inventory Figures

7. Emergency purchases due to inventory inaccuracies have been nearly eradicated, leading to more efficient resource utilization.
8. The accurate data from the system has minimized the need for emergency purchases, making handling them much more manageable.

Inventory: Inventory Adjustment Rate (Quantity)

9. The need for inventory adjustments has decreased significantly, reflecting the system's enhanced accuracy.
10. Real-time tracking and automatic updates have ensured perfect alignment between system inventory figures and physical stock.

Cost Saving: Inventory Discrepancy Value

11. The costs have dropped to zero, which is a significant saving for the company.
12. The ERP and RFID systems, along with regular audits and staff training, ensure continued accuracy and minimal financial impact.

Cost Saving: Demurrage Cost Due to Emergency Purchases

13. Demurrage costs have been eliminated, thanks to accurate inventory data preventing emergency purchases.
14. By maintaining precise inventory records, we have avoided emergency purchases and their associated costs

I.1.4 Responder 4: Warehouse Manager 1

Quality: Inventory Discrepancy

1. The integration has virtually eliminated inventory discrepancies by providing real-time and accurate tracking.
2. Reconciliation has become effortless and almost unnecessary due to the system's precise tracking.

Quality: Purchase Order Accuracy

3. The system has significantly improved purchase order accuracy, minimizing manual errors.
4. Yes, discrepancies have reduced drastically, from 7% to nearly zero, optimizing our procurement process.

Delivery: GRN Cycle Time

5. The cycle time has been reduced to mere seconds from several minutes, enhancing efficiency.
6. We use system logs to track and manage GRN cycle time, ensuring it remains minimal.

Delivery: Emergency Purchase Rate Due to Inventory Figures

7. The rate has been reduced to zero, thanks to accurate inventory figures.
8. Accurate data ensures that emergency purchases are rare, and when necessary, they are handled swiftly.

Inventory: Inventory Adjustment Rate (Quantity)

9. The need for inventory adjustments has been nearly eliminated, reflecting the system's accuracy.
10. The system ensures real-time alignment of physical stock and system inventory, minimizing discrepancies.

Cost Saving: Inventory Discrepancy Value

11. The cost has been reduced to zero, providing substantial savings.
12. The ERP and RFID systems, along with regular audits and process improvements, ensure minimal financial impact.

Cost Saving: Demurrage Cost Due to Emergency Purchases

13. Demurrage costs have been eliminated, thanks to accurate inventory data.
14. By maintaining precise inventory records, emergency purchases are avoided, thus eliminating demurrage costs.

I.1.5 Responder 5: Warehouse Manager 2

Quality: Inventory Discrepancy

1. The integration has almost eradicated inventory discrepancies, ensuring accurate and real-time tracking.
2. Reconciliation is now almost automatic, with minimal need for manual intervention.

Quality: Purchase Order Accuracy

3. Purchase order accuracy has improved significantly, reducing errors and discrepancies.
4. Yes, discrepancies have reduced from 7% to almost zero, optimizing the procurement process.

Delivery: GRN Cycle Time

5. The GRN cycle time has been reduced from several minutes to just a few seconds, greatly improving efficiency.
6. We use system logs to monitor and manage the GRN cycle time, ensuring it remains efficient.

Delivery: Emergency Purchase Rate Due to Inventory Figures

7. Emergency purchases due to inventory inaccuracies have been eliminated, leading to more effective resource planning.
8. With accurate inventory data, emergency purchases are rare and handled efficiently when they do occur.

Inventory: Inventory Adjustment Rate (Quantity)

9. The frequency of inventory adjustments has decreased significantly, indicating the system's accuracy.
10. The system's real-time tracking ensures that physical stock always matches system inventory, reducing the need for adjustments.

Cost Saving: Inventory Discrepancy Value

11. The costs have dropped to zero, providing significant savings.
12. The ERP and RFID systems, combined with regular audits and staff training, ensure minimal financial impact.

Cost Saving: Demurrage Cost Due to Emergency Purchases

13. Demurrage costs have been eliminated, thanks to accurate inventory data preventing emergency purchases.
14. By maintaining precise inventory records, we have avoided emergency purchases and their associated costs.

End of the Thesis.