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Which IoT technologies have the potential to be adapted to address issues with efficiency in order-picking warehouse operations?

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Signed by Student: Maria Sabatini Date: 24/04/2020

Abstract

The optimisation of warehouses, a critical business need, is often met by the applications of automation. The Internet of Things (IoT) can provide exceptional human and technological advancements. Successful warehouse optimisation is when IoT is used to aid the automation of tasks, providing a faster and more efficient solution for employees.

The order picking process involves receiving a customer's order, establishing the items to be picked and travelling to find the items in different locations in the warehouse. This task is a time and cost-intensive process carried out by warehouse employees known as order-pickers. When this process is entirely manual, it fails to meet the ever-changing customer demand, compared to the growing potential of having automated picking solutions by using and adapting on current IoT technologies. Researchers have previously explored the various opportunities IoT technologies and associated Warehouse Management Systems (WMS) can provide for optimising internal warehousing processes and the importance of providing employees with the required technologies to reduce order-picking time by reducing the travelling distance and the time taken searching for items to fulfil orders.

This project aims to investigate which IoT technologies currently exist in warehouses and how they can be adapted to propose a solution which will automate and improve the order picking process. The basis of this investigation will focus on using a WMS which integrates IoT technology which will optimise order picking through automating inventory locating, standard routing policies to find the optimal picking route and providing a warehouse simulation model for a hand-held device tool which is used by warehouse employees aiming to enhance the speed of the picking process, and provide the most efficient picking route to complete an order.

Acknowledgements

Firstly, I would like to thank my supervisor for all of his support during and throughout the project. Despite unprecedented circumstances which arose halfway through the project, I would like to thank him for his support and feedback throughout my honours year.

I would furthermore like to take this opportunity to thank the participants of the observation testing, survey and interviews which aided with the evaluation of my project.

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1. Introduction

This report presents an investigation into order-picking operations and how IoT has been used – and can be adapted to improve the order picking process which currently exists. The order picking operation is the most labour intensive and is a significant contributor affecting a warehouses performance. Due to this, warehouses seek technological solutions to automate the picking cycle. The desire for automated picking lists which uses the warehouse's inventory location to pick items from an order has recently gained attention as it derives from traditional picking models. The objectives and research listed in this report will present how the development of a warehouse tool using IoT technology can further automate the picking process and improve warehouse performance.

1.1 Project Background

Warehouses have transformed into smart centres, with IoT (internet of things) technologies optimising and improving warehouse operations. The internet is now not only used to connect people, (Gubbi, *et al.*, 2013) states that "it connects physical objects to create what we can now define as the smart environment.

The order picking process is a distribution warehouse operation that is very labour intensive and requires an abundance of time to ensure that the order picked meets the customers' expectations. Previous literature surrounding the investigation of order picking operations by (Ten Hompel & Schmidt, 2007), states that order picking involves picking one or more items from an allocated storage location and processing the fulfilled order for shipment to a customer. This process involves a significant amount of labour and accounts for one of the highest expenses in a warehouse. However, using an automated system which used IoT technologies for picking operations can present annual savings in picking and replenishment costs, "estimating between 20 and 40%" (Tompkins, 2010).

Automation has been a thriving topic throughout the years, especially with wearable and handheld technologies, enhancing the efficiency of picking operations. In a recent study (Lehmacher, 2017)) the author supports the use of handheld picking devices as the *thinking* is done by the system using AI – its knowledge expands as the system is used. The potential opportunities to adapt to handheld devices are endless; they optimise many picking processes through a single process. These processes include inventory tracking and locating, routing strategies for efficient picking and stock level reports. The most common revolution is the integration of picking lists: "once an item is picked, the screen of the handheld shows the next items to pick" (Battini *et al.*, 2015). Automation has increased workers productivity as the main priority is ensuring they pick rapidly and are efficient and accurate.

Warehouses that adopt modern approaches to technical advancements for picking operations develop an environment adaptable to change and performs to customers' expectations. Fully automating picking tasks is a costly investment and is not typically implemented in small to medium scale businesses. Order picking systems are usually partly optimised; however, (Grosse, *et al.*,2014) argues that manual order picking systems are still dominating. Presenting a solution in the warehousing industry which adopts IoT technology and revolutionises the current picking process, it will reduce the order picking time as "if products are staged for quick retrieval, customers will receive good service at a low cost" (Bartholdi, & Hackman, 2014). The issue surrounding order picking has previously been defined as "*the walking salesman"* problem (Ratliff & Rosenthal, 1983) this is due to manual order picking being unsuitable for today's increasing market demands.

Introducing Warehouse Management systems (WMS) with integrated IoT technology to automate the time-consuming manual processes using wearable gadgets will tackle the travelling and order picking problem which exists in this field of study. It is not enough in today's fast-changing economy to have warehouses that rely on manual labour and basic routing strategies. An investigation in warehouse inventory management by (Roodbergen, *et al.*, 2001) presented the fact that warehouse layouts are becoming more sophisticated and storing more inventory than ever before. Therefore, there is a requirement for IoT technologies to be further investigated to determine the best solution to tackle the issues surrounding order picking operations in warehouses.

1.2 Project Overview

This section of the report will detail the project outline; a description of the conclusions aimed to be drawn from answering the proposed research question. The project aims will be identified, and the primary and secondary objectives that are required for the investigations that will be conducted in the literature and technology review.

1.2.1 Project Outline

Order picking has received growing attention as the tasks involved in order picking need to be accurate to ensure customer satisfaction; this is essential due to constant increase in customer demand and the need to meet every customer's expectation. Improving the current order picking process using by automating picking tasks will reduce the order picking time. IoT technologies are appearing in businesses at a rapid rate, exploring the benefit of these technologies along with improving upon standard routing policies, will justify the requirement for a picking system. The research question for this project is:

Which IoT technologies have the potential to be adapted to address issues with efficiency in order-picking warehouse operations?

1.2.2 Project Aims and Objectives

The main goal of this project is to investigate how IoT technologies which already exist, can be adopted to improve the efficiency of picking operations in warehouses. In doing so, a picking tool will be developed, which tackles the existing order picking problems. In order to develop this warehousing tool, both primary and secondary objectives will be listed as these objectives are required for the success of the project.

1.2.3 Objectives to be examined in the literature and technology review:

Examine the order-picking process

An investigation on the current order picking process, factors which affect the order-picking time and how IoT technologies can improve operational efficiency, will allow conclusions to be drawn on how the overall picking process can be improved. Current and previous literature will be examined, to determine how efficient a new IoT development will be for tackling these problems.

Investigate Warehouse Management Systems (WMS) and IoT integration

An investigation on the current types of WMS systems which exist and how they will benefit from improvement by automating standard routing and warehouse storage policies. Further analysis on WMS and the capabilities for integrating IoT technologies to automate picking tasks, will conclude how current WMS can be used to adopt an IoT technology to automate picking operations.

An investigation into IoT technologies for picking operations

Investigate the current IoT technologies and WMS which are used for operational management. Through examining various views supported by current and previous literature, a conclusion can be drawn for the technologies and supported platforms which will be used for the development of the order picking system.

1.2.4 Primary research phase objectives

Develop the order-picking system

The system will be developed to meet the project research question, and thus the main requirements of the system will derive from the knowledge gained through the literature review to ensure that the system solves the discussed problems. From the elicited requirements, the system design stage will outline the component breakdown for the implementation of the required functionality.

Develop a Test Plan

The test plan for the picking system will use the knowledge gained in the literature and technology review to test how efficient the system was at aiding the user to pick an order. Participants feedback conclude if they found the system easy to use compared to using other picking methods.

Obtain Test Subjects

The purpose of using test participants is to evaluate if the order picking system is more efficient than other picking methods. Participants will involve order pickers and other users that carry out interactive testing. A permission document will be required for participants to consent to the testing process.

Conduct User Testing

Observation testing in a warehouse will be carried out to gain insight into the order picking process and order picking time. Order pickers will carry out a survey to determine if IoT technology is suitable to replace paper-based operations. Test participants will test the order picking system in an environment replicating a warehouse setting. Test participants will then be used to carry out testing of the RFID system and provide their feedback in a one-to-one interview.

Results of analysis and Evaluation

The results gathered from the final testing stage will be evaluated and discussed. Results will be gathered through user evaluations and surveys. Also, the time taken for participants to pick items using the order picking tool will be recorded and compared to manual order picking, this will draw a conclusion which will answer the research question.

1.2.5 Hypothesis

To ensure that the hypothesis can be evaluated, the testing of the project will involve the comparison of using the IoT device with manual order picking to determine which solution improves the overall order picking time. The aim is to reduce the travelling time by providing optimal routes, storage policies, batching items, and locating inventory in real-time. Therefore, The proposed hypothesis for the project will be:

The use of an IoT enabled hand-held picking device reduced the order picking time compared to other methods of order picking such as manual order picking, as it automates labour-intensive processes for the order picker, allowing orders to be fulfilled faster and more accurately.

From evaluating the hypothesis and analysing the results gathered from testing using participants, reviewing the survey and interview results will determine which method the participants preferred.

2. Literature and technology review

This section of the report will outline the secondary objectives of the project. Through examining the existing research that has been conducted by others in the field, conclusions will be drawn to decide on how useful the development of an order picking tool which adopts IoT Technologies will be for improving upon existing research.

The following secondary objectives that will be researched are as follows:

1. Examine the order-picking process
2. Investigate Warehouse Management Systems (WMS) and IoT integration
3. An investigation into IoT technologies for picking operations

2.1 Examine the order-picking process

It will be essential to investigate this problem to discover how picking tasks are currently operating and the types of methods currently used. A further investigation into route planning for picking operations will be examined to what extent these methods can help streamline WMS operations to improve inventory layout for more efficient order picking.

2.1.1 Factors affecting order-picking time

Distribution Warehouses have been exploring ways to use IoT technologies to help automate their picking processes over the years. Studies have shown that order picking operations are the most labour intensive and expensive warehouse operation, accounting for up to "55% of total operating expenses" (de Koster, *et al.*, 2007). There is a requirement for more efficient systems which prioritise improving the tasks of the picker instead of replacing them with fully automated systems. In order to achieve this (Bukchin, *et al.*, 2012) mentions that the factors which can determine the efficiency of order picking systems are "batching, picking sequence, storage policy, zoning, layout design, picking equipment and picking information strategies". The study focuses on how a combination of these factors, when utilized simultaneously, can reduce the overall picking time. Another study conducted by (Bartholdi & Hackman, 2011) shows in the below figure (Figure1) that travelling and searching for items is the most expensive and time-consuming activity of the order picking cycle accounting for a total of 70% of the order-picking time. The study also examines how using a Warehouse Management System (WMS) and integrating other computer systems into the WMS architecture, allows a significant reduction in the order-picking time.

Activity	% Order-picking time
Traveling	55%
Searching	15%
Extracting	10%
Paperwork and other activities	20%

Figure 1: Factors affecting order-picking time

When a warehouse focuses on improving its inventory management, a reduction in the order-picking time and travelling activities are improved. The *travelling salesman problem* (TSP) (Daniels, *et al.*, 1998) relates directly to how time-consuming searching for products in a warehouse can be with inefficient storage planning. The theory of the travelling salesman is presented by (de Koster, *et al.*, 2007) and explains that an order picker should know the details of every order and the amount and quantity of an item(s) to be picked and the distance between items to calculate the total travel distance, ensuring it is as optimal as possible. Therefore, inventory of similar types should be placed in the same aisle, usually grouped by weight. (Chiun-Ming Liu, 2004) mentions the importance of this as it will prevent pickers "backtracking through isles" which will reduce the order picking time and distance travelled.

Another factor influencing the order picking time is the different types of picking strategies, most commonly batch order picking which (Parikh & Meller, 2008) defines as having an assigned location in the warehouse for a collection of terms to be grouped for faster picking and fulfilment of an order. A study conducted by (Petersen & Aase, 2004) showed that order batching combined with other policies such as order picking policies, routing and storage type, can reduce the order picking time by around 20 %. However, this study only assumes that the orders will be picked *manually* in the warehouse when IoT technologies could further improve the study. A semi-automated picking system which uses order batching is explored by (Armstrong, *et al.*, 1979). The study uses a mixed-integer formulation to optimise the batching of many orders using conveyor systems along with isles; the main objective was to reduce the order picking time by reducing the required amount of travelling between isles. From the examined studies, there is a clear indication that the development of an order picking device which adopts IoT technologies will allow a reduction in order picking time.

2.2 Investigate Warehouse Management Systems (WMS) and IoT integration

Warehouse management systems (WMS) and their role in improving the efficiency of order picking has been investigated extensively in literature. The primary goal of WMS is to monitor and control the flow of inventory in a warehouse by having the WMS interact with other associated systems such as a technical control system which uses RFID and sensors (Faber, *et al.*, 2002). An investigation conducted by (Subramanya, *et al.* 2012) showed that implementing a WMS improved picking operation as it reduced the picking time by 49 minutes, resulting in a 77.78% overall process improvement compared to manual order picking. Using a WMS will, therefore, provide real-time inventory information and the most optimal picking route to reduce the order-picking time.

There are many different types of WMS, each varying with different optimization levels and requirements based on a business's operation. Partial-automated warehouses which use IoT technologies will require a WMS which integrates Enterprise Resource Planning (ERP) to support technical control systems (Richards, 2018). The most popular WMS solutions which integrate ERP systems provided by IBM (Sterling WMS), Oracle WMC, SAS (JIS) and many others. There is a standard framework which exists in modern WMS which compromises of the Basic Management System, Location management subsystem and the operational management implementation subsystem (Hui Tan, 2008), however, the most common framework involves RFID integration which influences all of the WMS layers, adding additional tracking, monitoring and reporting of inventory.

WMS incorporates an extensive range of features which automate manual picking activities. The optimization of standard routing heuristics is required for semi-automated systems. In a study by (Moeller, 2011), batch order picking – as discussed in the previous section, is optimized using a WMS which generates a "line sequence optimisation" which determines the most optimal picking route by assigning routes to a specific batch storage location, the results from the study show a batch picking improvement of 7.4%. Using WMS software can, therefore, reduce the order travelling time by developing picking techniques. Additional features such as the automation of manual picklists is a core function of a WMS, as shown in **Appendix A**, different picklists generated from an experiment conducted by (Molnár, 2005) shows the WMS database operation calculating the required number of runs for the order..

2.2.1 data management and handling

WMS requires integrated data collection methods – this can result in many WMS being data-intensive as large quantities of data is produced. WMS which embed IoT technology use automated data acquirement to cope with the scalability of IoT data; the data is stored and managed using a cloud or big data service (Tracey & Sreenan, 2013). Different IoT applications require different analytic systems for evaluating data in order to determine the scalability required for handling extreme data volume. Real-time analytics is the collection of data for IoT devices such as sensors; analytical techniques are essential for managing ever-changing data such as real-time clustering for relational databases (Marjani *et al.*, 2017).

Reviewing the IoT data storage framework for cloud computing, cloud services manage a variety of data types which is collected from IoT devices such as RFID readers and stored in relational databases for handling the structured data (Lihong Jiang *et al.*, 2014). Database storage "represents a more stable, more easily scaled, and more easily queried storage option" (Charles Bell, 2016). This statement is backed up by a study conducted by (Rautmare, *et al.*,2016) which compared MySQL with MongoDB – a big data service, the study concluded that MongoDB had a better response time; however, MySQL was more stable during the experiments. Therefore, cloud-based services provide a comprehensive structure for managing IoT data, particularly with RFID sensor data growing in popularity- requiring a scalable system.

2.3 An investigation into IoT technologies for picking operations

The project background chapter briefly described the growing influence IoT technology has within warehouses and the many different forms of IoT technology which is used for picking operations. In order to determine the technology to adopt, an investigation into existing technologies and the comparisons are drawn, allows evaluation into the technical requirements for implementing an IoT system.

2.3.1 IoT technologies and its uses in e-commerce

The Internet of things (IoT) is the bridge between physical objects and information networks which enables these ‘smart objects’ to become part of a business process allowing services of these processes to interact through the internet (Haller, *et al.*, 2008). IoT has surfaced in recent years, playing a significant role in the automation of commercial businesses that are technologically advancing to meet customer demand. By 2020, IoT for business will outnumber IoT for human communication at a ratio 30:1(Pengfei Guo, 2017), this involvement of IoT will take forms in many ways in daily business processes. Major e-commerce companies such as Amazon have invested in the future of IoT to automate their warehousing processes, such as implementing a fully automated robotic to pick orders known as Kivia shown in the below figure.

Figure 2: Kivia Robotic for Amazon

Amazon acquired Kivia robotics and renamed it in 2014 to Amazon Robotics (Ma & Koenig, 2017). The automated guided vehicle (AVG) uses a series of algorithms known as multi-agent pathfinding (MAPF) which drives the robots in dedicated pathways through the warehouse using pathfinding algorithms to find the most effective route (Liu, *et al.*, 2019). These AGV’s use cameras to scan and identify barcodes under product racks paired with other IoT technologies to “fulfil warehouse orders four times faster than previous systems” (Chui, *et al.*, 2016). The technologies the AVG adopts has some advantages such as the sensory floors the robots travel along at a speed of up to 5km/h -which is human walking pace (D'Andrea, 2012). Barcode scanning has its advantages as it allows verification of a physical object using a single unique code (Liang,*et al.*, 2015), but compared with Radio Frequency Identification (RFID) tagging, it is not as effective.

RFID is a technology which can be adapted to improve order picking as it is a “contact-free recording and transmission of data which uses electromagnetic waves to transmit information between a tag applied to goods and a scanner” (Hompel & Schmidt, 2007). RFID implementation in the distribution process is a growing requirement, (Shi, Zhang & Qu, 2010) presents a case study on GPS positioning for delivery trucks where delivered items are tagged with RFID and using GPS (Global Position System) on the delivery trucks along with other sensors that measure food quality and report back data. Combining IoT technologies can, therefore, help tackle inefficiencies in current business operations, particularly for warehousing and distribution services.

2.3.2 Handheld picking devices and RFID

As stated in the project background, IoT technologies for the optimisation of picking operations can work with different types of picking systems. The most common order picking devices used in warehouses are handheld barcode scanners, RFID hand-held scanners, voice-to-pick and pick-by-light (Battini, *et al.*, 2015)**.** Handheld picking devices are the most common type of system used for picking orders, but there has recently been an IoT solution which has adopted speech technology to improve the efficiency of picking operations in a warehouse known as voice-directed picking as shown in figure 3.

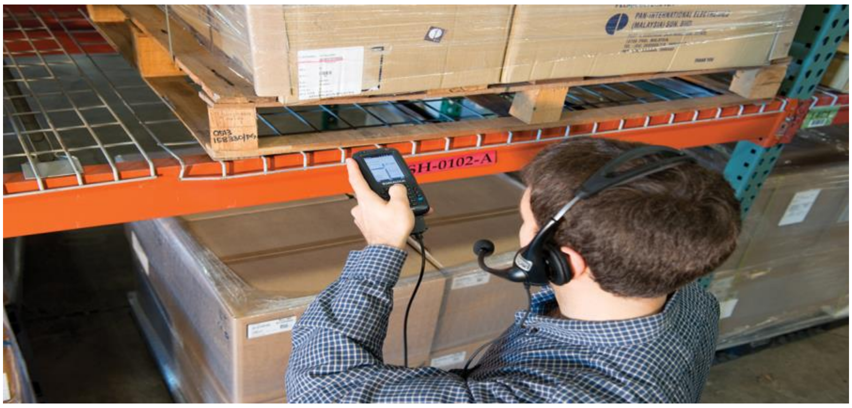


Figure 3: voice-directed order picking

State-of-the-art "voice-directed warehouse order selection is more accurate and more productive than both handheld scanning"(Miller, 2004). The technology presents a modern *Alexa* voice solution, it "leaves the workers hands and eyes free to move" (Connolly, 2008), equipping warehouse pickers with battery-operated microphone, headset and voice-directed picking tasks. However, in comparison to RFID scanners, voice-directed equipment is expensive, and the picking environment is often noisy which can interfere with the system (Vivaldini, *et al.*, 2016). It is clear why warehouses have continued to adopt RFID technologies, significant software suppliers such as IBM (WebSphere RFID), BEA Systems, CISCO and Siemens are continually improving ways to integrate RFID technologies into Warehouse Management Systems (WMS). There has already been significant growth in RFID integration with WMS as a real-time business tool. Due to its advanced capabilities compared to the traditional barcode, one significant advantage is the ability of batch scanning – allowing a group of items to be scanned instantly (Hui Tan, 2008).

The advancement in RFID technology, especially RFID-based inventory location tracking is "concrete and immediately measurable" (Lee & Lee, 2015). Therefore, the potentials of RFID are endless as they can be linked to the WMS and provide management with insights for inventory tracking throughout the warehouse (Holler, 2014). When implementing RFID technologies, it is essential to understand the various types of RFID technologies which exist and their supported platforms. A passive RFID tag is a tag usually attached to items and is scanned by picking devices, these tags have an "indefinite operational life and are small enough to fit into an adhesive label"(Want, 2006). RFID tags sustain environmental factors better than barcodes which can be prone to damage, causing them to become unreadable.

2.3.3 technical requirements for implementing an RFID WMS

A Raspberry Pi is a small computer that goes beyond the traditional capabilities of standard computers. The GPIO (general purpose input and output) pins allow the raspberry pi to communicate and control other hardware components (Mirjana, *et al.*, 2014). Using the Raspberry Pi and an RFID module and additional hardware components such as an LCD screen to output commands replicates a handheld picking device. It is a cost-efficient solution compared to using handheld RFID readers as they are expensive to obtain.

Furthermore, to store the data generated from the RFID implementation, the WMS will take form as a MySQL relational database as it proved previously by supporting literature to be the most stable database to host and support PHP along with a web-server for fetching and displaying data on a web interface for order pickers.

Therefore, uncovering researching from the literature review, a greater understanding of the requirements and methods for development has been gained. Conclusions which are drawn from the literature and technological review highlight how current order picking operations require significant improvement. In essence, this will be achieved through the development of an RFID order picking system, integrating cloud-based WMS technology, to reduce the order picking time and improve the efficiency of picking operations.

3. Execution methods

From carrying out the primary research methods stated for the project, there were various approaches taken to executing the required modelling, design and development considerations for the project. The main phases of execution involved requirement gathering techniques and system modelling. The primary research phase involved investigating and undertaking the required tasks to design, develop, implement and test the development of the product based on the conclusions drawn from the literature review. This section will explain the adopted execution methods.

The aim of this project is to develop an IoT enabled handheld picking device that will reduce the order picking time in warehouse environments. Through evaluating the product, the research question will be answered to determine to what extent system improves the efficiency of picking operations. Therefore, the appropriate methodology is a develop and test approach. (Mills, 1998) claims that quality can be measured by outlining a design approach before implementing technical requirements. Therefore, the findings gathered from the literature review and conclusions drawn on the approaches used by the author will be taken into consideration for the execution methods using the appropriate modelling techniques.

3.1 Requirement gathering techniques

The first stage of requirement gathering was to determine the requirements of system. Requirement gathering was achieved by evaluating different case studies which were identified by various authors in the technology and literature review. The conclusions compared the different types of IoT technologies which are currently used for order picking and highlighted the potential of RFID technologies and WMS.

To ensure that the findings were met, functional and non-functional requirements were elicited using various techniques. There are many requirement gathering techniques- varying depending on the nature of the project, and they can be categorised as – "traditional, contextual, collaborative and cognitive" (Tiwari & Rathore, 2017). Therefore, requirement gathering should involve more than one technique and span a range of categories to capture the scope of the system requirements fully. Due to the nature of the project- data gathering from existing systems and modelling techniques were used to fully understand the desired functionality of the system to meet the hypothesis.

3.1.2 Data gathering from existing RFID order picking systems

Data gathering from exiting systems conveyed the current issues with order picking IoT systems as discovered from the case study conducted by (Shi *et al.*, 2010) in the literature review.

A technique which was utilized to gather data from existing systems was conducting a thorough system analysis where the functional requirements of the system were tested against the hypothesis. The purpose of evaluating and comparing systems is mentioned by (Tiwari & Rathore, 2017) as being essential as "it is used when we gather data for a system to replace an existing one". This technique successfully highlighted the requirements for the system as it provides a small to medium amount of readily available data which is useful for eliciting requirements. Therefore, allowing justification for the need to implement a new system which will solve the issues identified in section 2.1.This technique feeds into knowledge management, which played a vital role throughout the project lifecycle and the data-gathering stage of requirement elicitation. (Mertins, *et al.*, 2003) describes the correlation between user requirements and data analysis, and how knowledge can be managed and controlled as a structure becomes defined. Implementing the correct methods were critical tasks for this stage.

3.1.3 Modelling requirements

Modelling requirements, is a collaborative data-gathering technique which requires developing visual models to encapsulate the requirements. Modelling has many approaches, but the primary purpose is to help visualise the process or sequence of the system. (de la Vara, *et al.*, 2008) highlights the importance of Business Process Modelling for information systems as a process model should describe the main activities. Thus, various modelling techniques were used to represent the requirements and allow external users to understand the system at a low level.

The discovered requirements identified from this stage fed into the design and implementation phases of the project. The system design was identified through system analysis carried out in the data-gathering stage but will be further detailed in section 3. An extensive overview of the requirement analysis is detailed in section 4, which presents the findings from this section.

3.2 Requirements

A data-gathering session was conducted to identify the functional and non-functional requirements of the system. The research question was examined to identify the main areas of the system to solve the order picking problem.

3.2.1 Identified Functional Requirements

The identified functional requirements are as follows:

Requirement ID	Functional Requirement
FR001	Reading RFID tags for order items
FR002	Writing data to RFID tags for items
FR003	Storing data for the RFID tags
FR004	Provide a visual interface for order picker to follow commands
FR005	Provide a visual interface to view items and location
FR006	The system should allow new item entries to be made and be allocated an RFID tag

Table 1: Functional Requirements

These functional requirements represent the scope of the system and reflect the hypothesis for the project. Functional requirements determine what the system must do, starting with necessary components and objectives of the system (Escalona *et al.*, 2011).

Reviewing the primary research objective

The first three identified functional requirements capture the reading, writing and storing functionality of the RFID order picking system. The primary research objectives highlighted that the system should be able to write data to the RFID tags, Read data to improve picking accuracy and store item data using the appropriate method.

Another requirement for the primary objective previously discussed was to ensure that the system solved the problems with improving the efficiency of order picking as literature had concluded. Functional requirements 4,5 and 6 highlighted the conclusions drawn from evaluating the technical requirements for developing an order picking system as concluded by (Lee & Lee, 2015).

3.2.2 Identified Non-functional requirements

The non-functional requirements were identified when the requirements were modelled and investigating the current technologies used for order picking operations in warehouses.

The non-functional requirements:

Requirement ID	Non-Functional Requirement
NFR001	Read an unlimited amount of tags into the system
NFR002	RFID reader should be able to scan items within a 2cm range

Table 2: Non-Functional Requirement

Non-functional requirements are essential to determining beyond the main functionality of the system; it provides a scope that handles system boundaries. In a study by (Kassab, *et al.* 2007) the authors use an NFR framework to determine detailed scope measurements known as soft goals. Identifying goals beyond the system leads to a more comprehensive system.

3.3 Methodology

To successfully carry out a development and test project, an agile methodology was adopted as it supported the complexity of the system development and allowed the project to be completed in the restricted timescale. (Kumar & Bhatia, 2012) highlight the several benefits of using an agile methodology for the software development process as requirements and change management is the most crucial feature of agile development; this was apparent for implementing the system features.

Furthermore, another method used for agile development was using an iterative delivery. The project required several development iterations where each iteration delivered a functional prototype. An iterative lifecycle "constructs a partial implementation of a total system, slowly adding increased functionality"(Alshamrani, *et al.*, 2015). In comparison to other lifecycles such as the waterfall model, requirements can be added throughout development. The waterfall model is inflexible as testing is carried out on the final system which hinders flexibility to revisit previous stages (Hossain, *et al.*, 2009). This statement supports the use of an agile framework for the project compared to the traditional waterfall model; agile development ensured that prototypes are released bug-free, with more complex phases but within a shorter release time.

3.3.1 Iterative product breakdown structure

The agile development stages can be simplified into the stages shown in **Figure 4**. Four iterations were used for building initial prototypes of the system before the final prototype was deployed. Therefore, when the prototype was tested, the iteration was evaluated to ensure that additional requirements were incorporated. This development method highlights the benefits using incremental approaches to meet the user quality expectations of the system.

Figure 4: Incremental delivery

Figure 6 shows the final iterations, which were used for the development of the order picking system. The implementation section discusses the breakdown of the iterations in further detail. This breakdown allowed an evaluation to be carried out before implementing the iterations to ensure that the requirements were met and reflected the hypothesis.

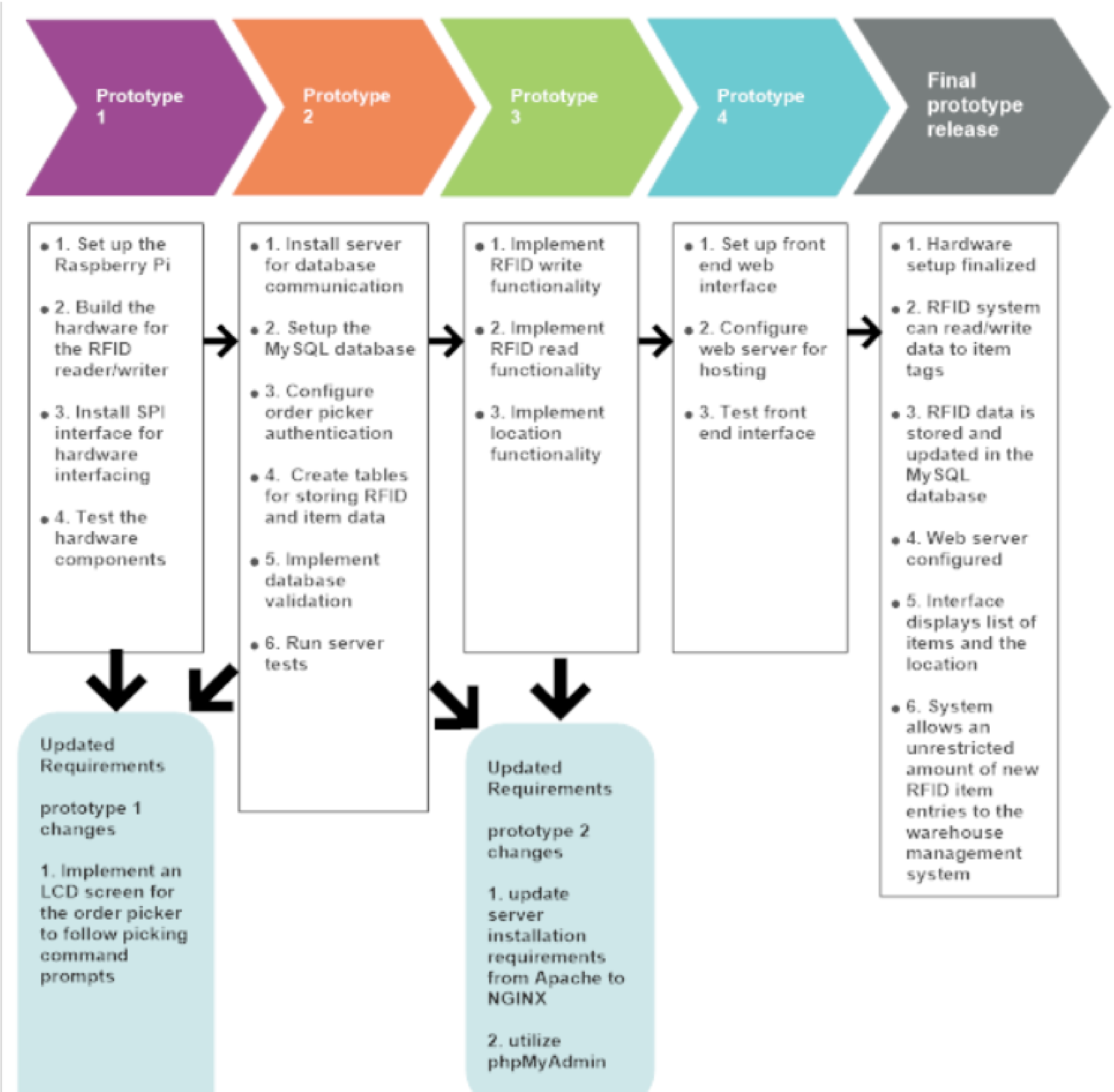


Figure 5: Increments for Order Picking system

3.4 Project timescale

To instigate the deployment of the functionality, 4 iterations were required for the project, a project timescale was created (**Figure 7**) which shows the start date, end date and total duration required for the design, implementation, testing and updates for each iteration. The project spanned 24 weeks of the academic year, where 16 weeks of the project was allocated for development. Iteration 2 and 3 was allocated extra time for the implementation stage as they were more complex. The testing was allocated 4-6 days to ensure that any updates or changes were accounted for to improve the quality of the iteration.

TASK NAME	START DATE	END DATE	DURATION	PERCENT COMPLETE
Iteration 1				
Design	11/5	11/8	4	100%
Implementation	11/9	11/20	12	100%
Test	11/21	11/25	5	100%
Update	11/26	11/28	3	100%
Iteration 2				
Design	12/1	12/8	8	100%
Implementation	1/9	1/22	14	100%
Test	12/23	12/28	6	100%
Update	12/29	12/31	3	100%
Iteration 3				
Design	1/1	1/7	7	100%
Implementation	1/9	1/24	16	100%
Test	1/22	1/26	5	100%
Update	1/27	1/31	5	100%
Iteration 4				
Design	2/1	2/9	9	100%
Implementation	2/10	2/20	11	100%
Test	2/20	2/23	4	100%
Update	2/23	2/26	4	100%

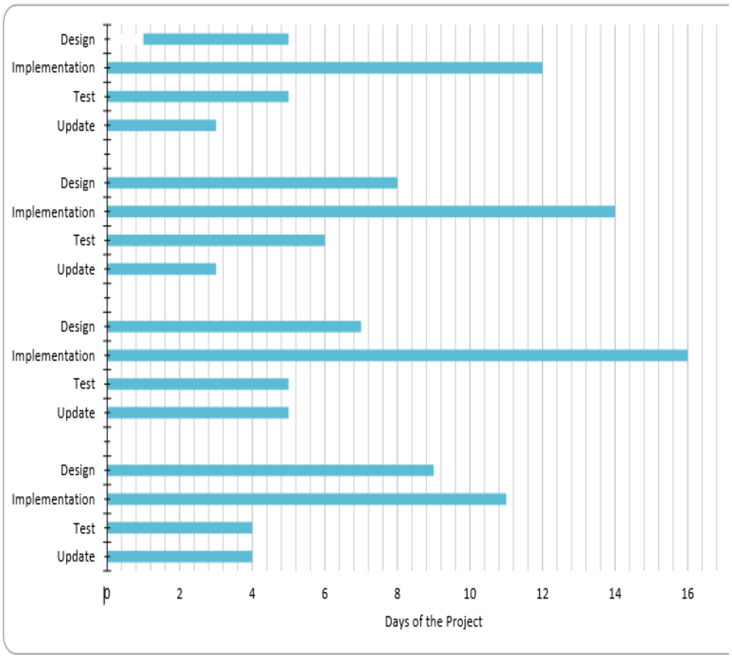


Figure 6: Project Timescale

3.5 Conclusion

The execution methods involved selecting the appropriate methods which were adopted before the main features of the order picking system were implemented. It identified the most suitable requirement gathering techniques from evaluating the conclusions drawn from the literature review. The project methodology, which was used for the execution of the project, was analysed and compared with other methodologies to highlight the benefits of using an iterative agile lifecycle. Therefore, from the execution section, the project design stage was carried out to define and reflect the justified design methods and to meet the project timescale set for the project.

4. Design overview

This section provides an overview of the design approach for the order picking system before the implementation section details the iterations. From the execution methods discussed previously, the results from the requirement gathering process will be detailed using system modelling.

4.1 Hardware Implementation

When setting up and installing the discussed hardware requirements for the prototype design, the first design consideration was mapping the architecture to visualise the setup **(Figure 8).**

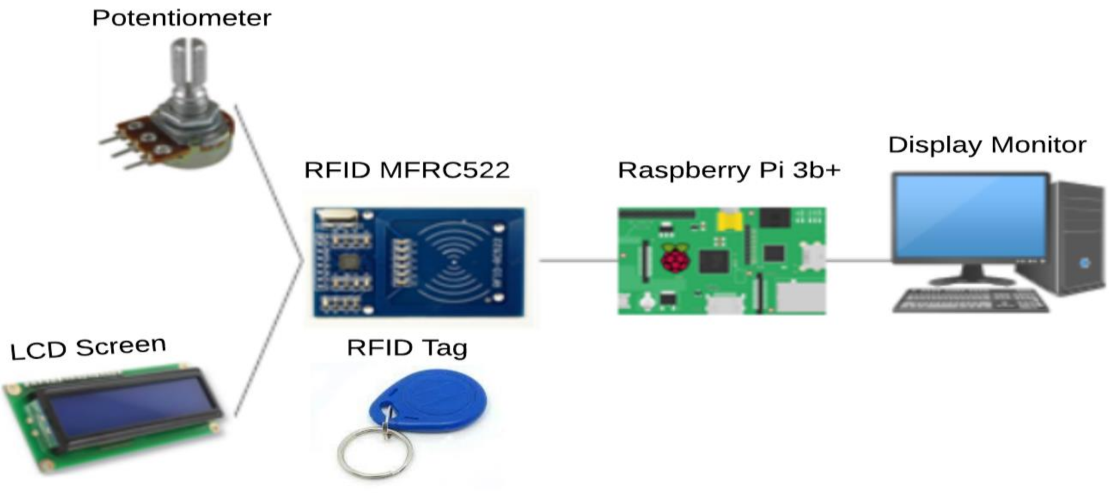


Figure 7: Hardware Architecture

From designing the prototype, the identified hardware represents the components of a production system, replicating the components of an RFID scanner. The literature and technology review section 2.3 *Investigation into IoT technologies for picking operations* concluded that the Raspberry Pi was a suitable platform to integrate the WMS and handheld device functionality – incorporating components which resemble a real RFID scanner. The handheld device functionality incorporated the components used in **Table 3.**

Component	**Description**
Potentiometer	A variable resistor used to control the LCD screen brightness and contrast levels
LCD Screen (Liquid Crystal Display)	The LCD screen is 16x2 size (16 characters in 2 lines). Module programmed to display text output to the order picker to aid with picking tasks.
RFID MFRC522	13.56MHz module used to read and write data to RFID tags. The primary component used to replicate an RFID scanner functionality
RFID Tags	Passive tags (power supplied by RFID MFRC522 reader) which are attached to items; each item is uniquely identified.

Raspberry Pi 3b+	Small computer which has GPIO (General Purpose Input/Output) pins to install the hardware components. Used to replicate a handheld RFID device and run the WMS.
Display Monitor	Used to remotely access the Raspberry Pi and display Raspberry Pi system.

Table 3: Hardware Descriptions

4.2 Modelling requirements

The requirements elicited for the system can be represented using use case modelling to show how actors interact with the system (Fernandez & Hawkins, 1997). Figure () is a use-case model which represents the main actors (users, hardware, database) which are involved in the activities which represent the functional requirements. Use cases can model specific stages of a complex requirement to allow a better understanding **(Appendix E).**

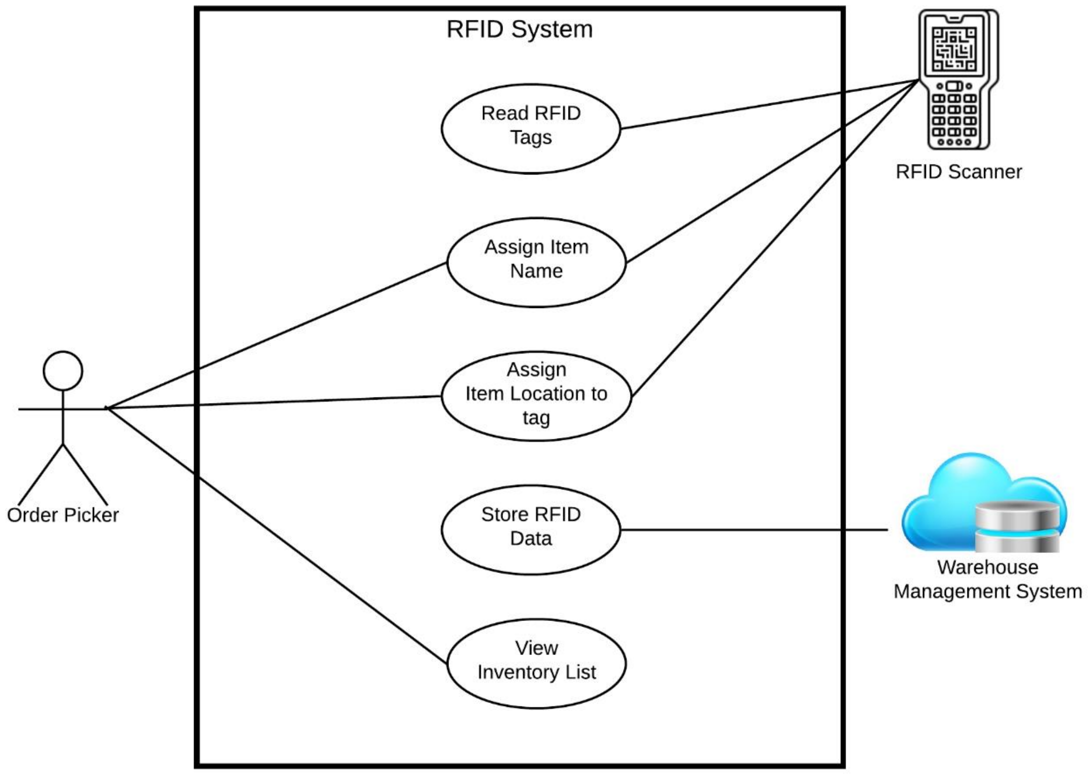


Figure 8 : Use Case Diagram

4.3 Modelling Processes

A Business Process Model (BMP) was used to recognise the main activities which occur between the different levels of the RFID order picking system. Using BPM allows re-engineering of processes whenever there is a change that influences the business environment (Ebrahimi, 2018). The main activities have been modelled to show all levels of the system interaction **(Figure 9)**. Furthermore, to gain further insight into the specific order picking process, a UML diagram was developed which displays the interaction between the WMS, the order picker and the Warehouse **(Appendix F).**

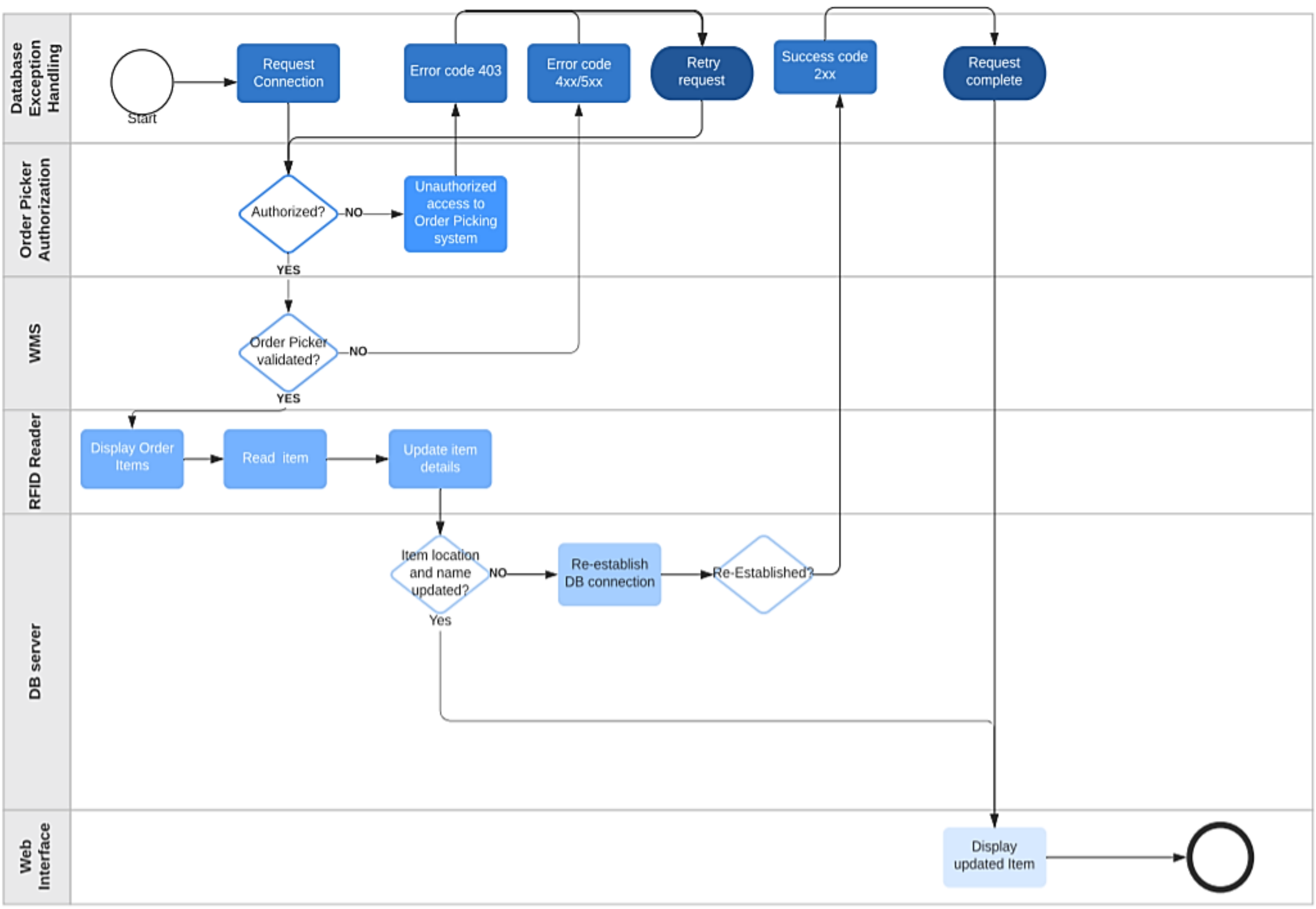


Figure 9: BPM

4.4 Order Database and Class Diagrams

The class diagram in **Figure 10** shows the two tables which will be implemented using MySQL and will act as the WMS. The items table will be required to store RFID tag information for each item. Each item will be assigned a unique id. Furthermore, the location and created fields will represent the desired functionality of the system as the location will faster a more accurate picking. The Created field log the time that the item was entered into the WMS.

The list table will store a complete list of Log-in times, similar to the Created field. Having the Log_In time of each item will improve the availability of data in the WMS as this is a requirement highlighted in the literature review.

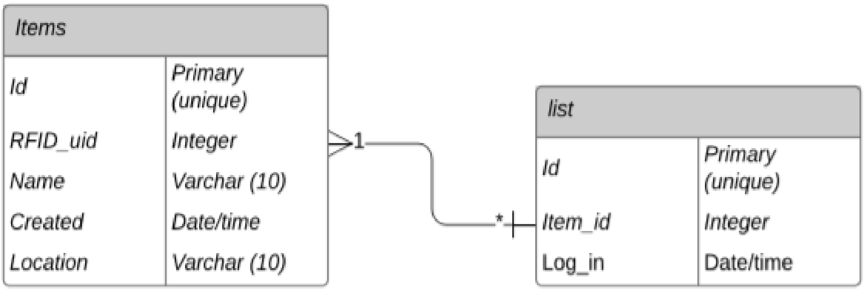


Figure 10: Database Class Diagram

4.5 User interface design

From the findings from the initial wireframe designs which were developed to reflect the design requirements of the system (Figure 11). The first wireframe shows the URL of the webpage where the pages are hosted through a private network as in a warehouse. The interface has minimal interference and page 2 shows the RFID inventory data which is updated in real-time.

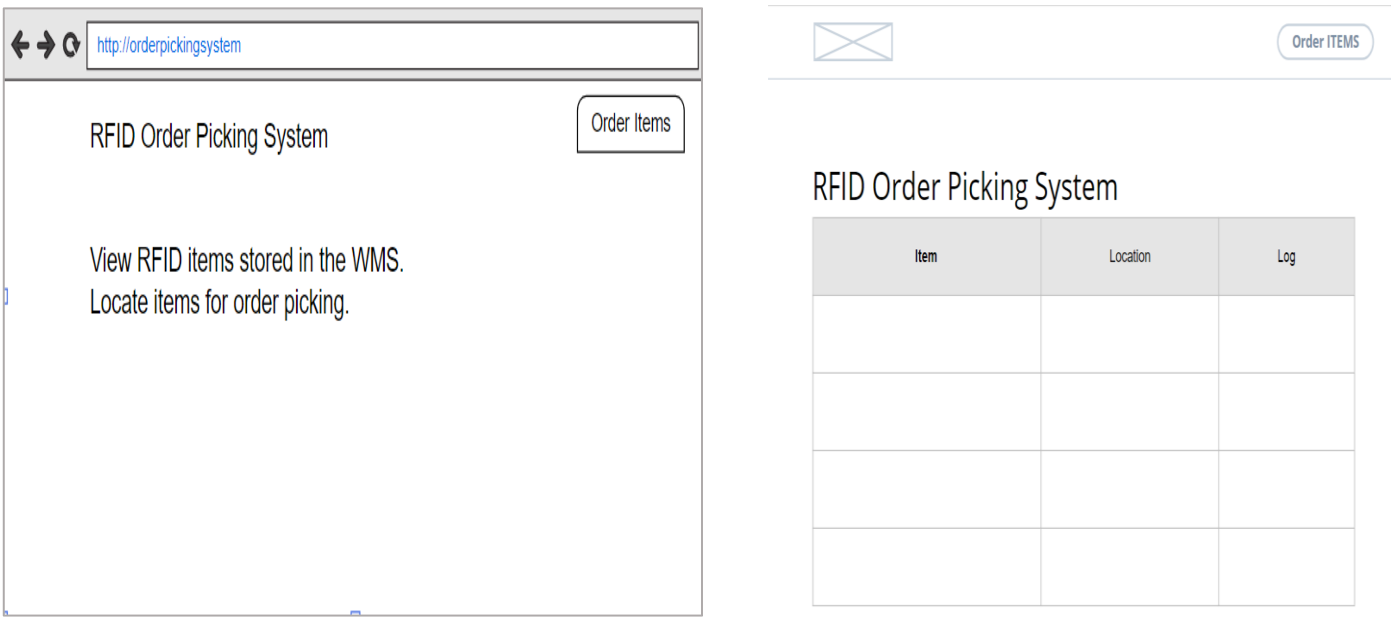


Figure 11: Wireframe Interface Design

The final user interface design designed for the RFID Order Picking System is shown in Figure 12. The user interface is user-friendly and reflects the versatile technical abilities of the order picker. The interface is used to display inventory information.

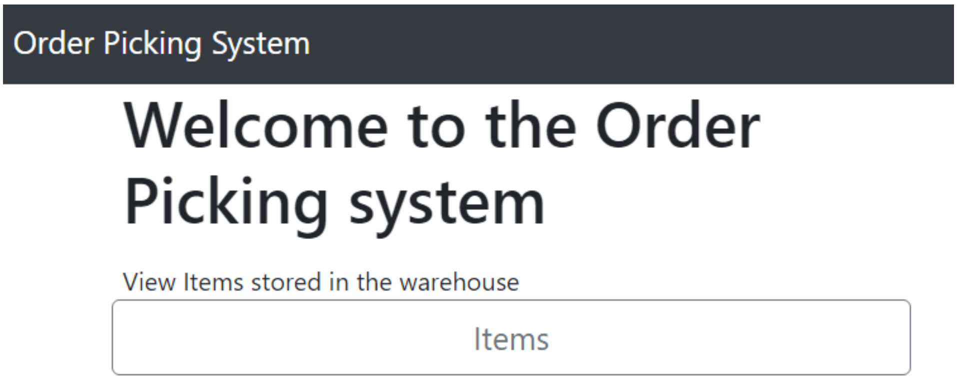


Figure 12: Final Interface Design

5. Implementation

The execution section discussed and justified the methods required to implement the development platform, programming language, hardware components and database required for developing and hosting the WMS. This section will detail the implementation methods used for implementing the RFID RF522 module for the raspberry pi, the development of the database and web interface based on the design considerations and methods from the previous section. The breakdown of the product will reflect the agile, iterative lifecycle, breaking down the development into a block of parts, or an assembly of executable components which completes the systems overall build (Panunzio & Vardanega, 2014).

5.1 Iteration 1: hardware and SPI implementation

This iteration involved implementing the architecture design, as shown previously in the design overview. The RFID order picking system consisted of 4 components, the RFID reader/writer, LCD screen, potentiometer and the RFID tags. The SPI (Serial Peripheral Interface) was implemented in this iteration to allow the hardware components to communicate with the Raspberry pi executing the writing and reading functionality, in order to solve the problems identified in the conclusions drawn from the literature review.

Raspberry pi model 3b+

The conclusions drawn in the literature review justified the use of a Raspberry Pi to replicate a WMS and incorporate components which would emulate an RFID handheld picking device. The official Raspberry Pi specification is presented in Appendix H. For the project, the raspberry pi model 3b+ was the most suitable as it is a cost-effective solution compared to other systems such as voice-directed equipment (Azanha *et al.*, 2016).

RFID MFRC RC522 reader/writer and smart tags

The RFID reader and writer sensor module were used for implementing the order picking system as identified from the literature review, RFID technology was the most suitable IoT technology to adopt to solve the order picking problems in warehouses. The RFID RC522 was a suitable alternative to purchasing top-end RFID scanners; it has a lower voltage, is cost-efficient and provided a 2-3cm read range – meeting the scope of the system.

The RFID RC522 module was implemented by importing the RPI.GPIO as GPIO (General-purpose input/output) which allocated the correct voltage and connections for the Raspberry pi pin configuration (Figure 13). The mfrc522 object was used to import the required library for the RFID reader; the library was cloned using a pre-built library recommended for the mfrc522 module (github.com, 2020).

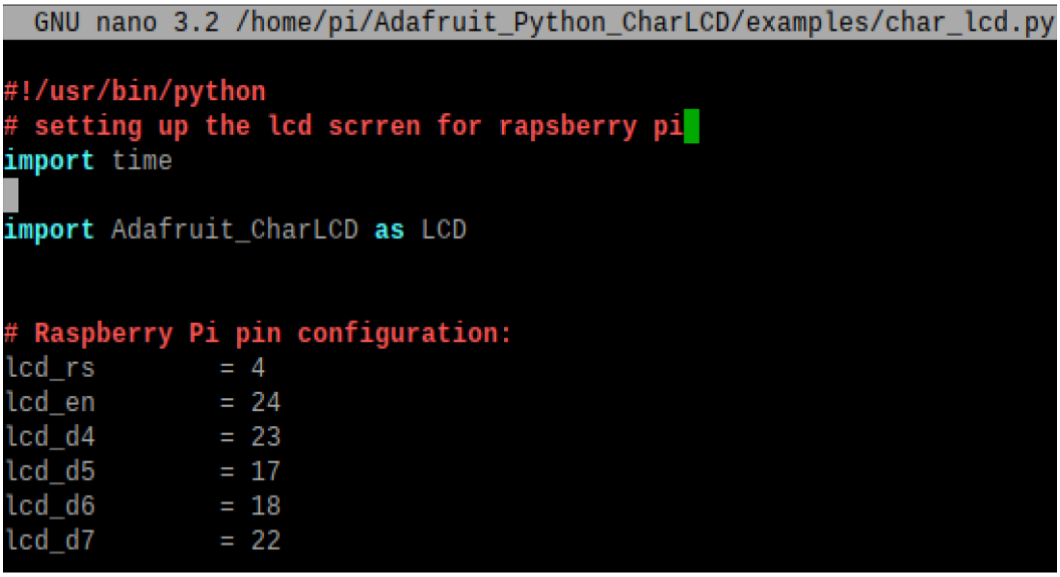
```
#!/usr/bin/env python

import RPi.GPIO as GPIO
from mfrc522 import SimpleMFRC522
```

Figure 13: Import mfrc522 module

Setting up and testing the Liquid crystal display (LCD)

Primary design consideration and a functional requirement was to implement an LCD screen to allow the order picker to read a tag or write data to a tag into the system. Setting up the LCD required using a potentiometer which is a variable resistor that handles the screen brightness levels. The screen size is 16x2 and connects as a 16-pin soldered header into the breadboard. **Figure 14** shows how the LCD screen was implemented using the python programming language and creating a file to store the data required to connect the LCD to the Raspberry pi.



```
  GNU nano 3.2 /home/pi/Adafruit_Python_CharLCD/examples/char_lcd.py

#!/usr/bin/python
# setting up the lcd scrren for rapsberry pi
import time

import Adafruit_CharLCD as LCD


# Raspberry Pi pin configuration:
lcd_rs        = 4
lcd_en        = 24
lcd_d4        = 23
lcd_d5        = 17
lcd_d6        = 18
lcd_d7        = 22
```

Figure 14: LCD set-up

Enabling the SPI Interface

Once the hardware was set up and implemented the next stage of the iteration was to install the required SPI libraries to enable communication with the RFID component.

Spidev: used to communicate with the RFID readers interface

Testing the RFID RFC522 Module

As an iterative lifecycle was adopted, testing was conducted to test the hardware interaction with the Implemented RFID module, a python file was run, a tag was scanned and the RFID ID was displayed **(Figure 15).** Python 3 was updated from the default python 2 as it was beneficial for the nature of the project. Python 2 has a less extensive library and lacks good modelling practice compared to Python 3. Updated input() and print() statements are available in python 3 (Summerfield, 2009). The author justifies the benefits of migrating to python 3 for development projects.

Figure 15: Testing RFID module

5.2 Iteration 2: Storing data in MySQL database

This iteration details the implementation of the data storage method used to handle the data written to RFD tags. This iteration meets the requirements which were gathered from the conclusions drawn from the literature and technology review in section *2.2.2 management and handling techniques for IoT data*.

Implementing the MySQL database and WMS

There are many options which were considered for storing RFID tag data. As discussed in the execution, Due to the project requiring a web interface to display order and item information for the order picker to view items and their location, a database was considered over other data storage techniques. From the conclusions drawn from the literature review, MySQL was the suitable option for the order picking system as the database incorporates a server, storage configuration and phpMyAdmin for database management. (Schwartz, *et al.*, 2012) describes these layers as “the sever-level and the storage-engine level”. The implementation techniques for these levels of the order picking system is detailed further in this iteration.

The server-level involved installing the MySQL-server to host the database that will be created as shown by the order database tables class diagram in the Design section **(Figure 16).**

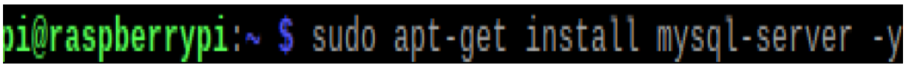


Figure 16: Install MySQL server

The database was created and named **orderpickingdb**. It was accessed on the MySQL interface on the Raspberry pi; this is where SQL queries were executed to manipulate, update and create tables **(Figure 17).**

```
pi@raspberrypi:~ $ sudo mysql -u root -p
Enter password:
Welcome to the MariaDB monitor.  Commands end with ; or \g.
Your MariaDB connection id is 114
Server version: 10.3.22-MariaDB-0+deb10u1 Raspbian 10

Copyright (c) 2000, 2018, Oracle, MariaDB Corporation Ab and others.

Type 'help;' or '\h' for help. Type '\c' to clear the current input statement.

MariaDB [(none)]> use orderpickingdb
Reading table information for completion of table and column names
You can turn off this feature to get a quicker startup with -A

Database changed
MariaDB [orderpickingdb]>
```

Figure 17: MySQL Database access

2 tables were created which incorporated the design from the previous section. The tables are used to store an items name, location and log time **(Appendix J).**

One of the primary objectives of this iteration was to implement order picker authorization to restrict access to the database (WMS). **Figure 18** highlights the server level in more detail. The host, user, and password set for the database during setup is required for making the server-level connection. Authorization level secures access to data (Xiaosheng Yu, *et al.*, 2010) .

```
db = mysql.connector.connect(
  host="localhost",
  user="picker",
  passwd="pi",
  database="orderpickingdb"
```

Figure 18: Connecting and setup up authorization for MySQL

5.3 Iteration 3: reading, writing and assigning location values to items

The literature and technology review section 1.1 *Examine the order-picking process* drew conclusions which shaped the requirements for the reading and writing of RFID tags. The system allows the order picker to streamline warehousing operations, with the aim to reduce labour and operating expenses (de Koster *et al.*, 2007). Writing data to tags is an additional feature which allows the order picker to ensure accuracy when reading items using the RFIS system. They can assign and read RFID data quicker than other IoT systems.

Recording items for order picking: writing

The implementation of the write functionality utilized the LCD screen and displayed a welcome message to the order picker to write RFID data to an item. Thus, this relates to the order picker reading items to update or assign a new to the WMS. This operation will improve the integrity of warehouse management tasks.

Figure 19 uses print statements to display messages to the order picker. The order picker scans an item to register the RFID tag.

```
print ("Welcome to the Order Picking system")
print ("Scan your item now")

try:
  while True:
    lcd.clear()
    lcd.message('Place tag to\nregister item')
    id, text = reader.read()
```

Figure 19: Welcome screen

The literature which was uncovered from evaluating current picking devices in section 2.3.2 handheld picking devices and RFID, highlighted the main features of RFID scanners and the User Interface requirements for picking operations. (Simon, *et al.*, 2014). They highlight the benefits of RFID based interface components such as the LCD screen which was implemented for the order picking system.

The order picker will then be instructed by the LCD screen to insert the name for the item. The sql_insert statement then uses the new_name object to insert the value into the order picking database. **Appendix I** shows the python code for the INSERT SQL statement which starts the process for writing and storing data to the tag. The output of the above statement will prompt the order picker to scan the RFID tag (Figure 20).

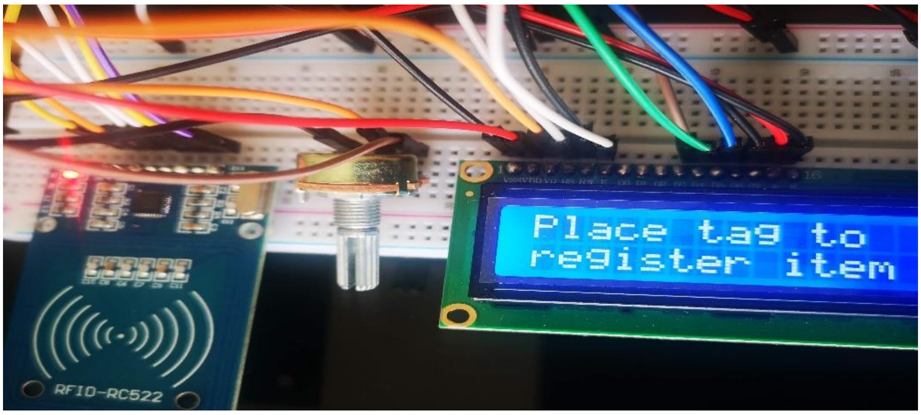


Figure 20: LCD Output

An if statement is used to Overwrite the item of the item already exists, the picker is instructed to answer Y (yes) or N (no). If the order picker answers Y, the item is overwritten. Then, a sql_insert statement is used to update the items tables, and the field name will be updated with the new item name. A WHERE statement is used to assign the new item an RFID_uid (RFID unique id). (Figure 21)

```
if cursor.rowcount >= 1:
  lcd.clear()
  lcd.message("Overwrite\nexisting item?")
  overwrite = input("Overwite (Y/N)? ")
  if overwrite[0] == 'Y' or overwrite[0] == 'y':
    lcd.clear()
    lcd.message("Overwriting Item.")
    time.sleep(1)
    sql_insert = "UPDATE items SET name = %s WHERE rfid_uid=%s"
  else:
    continue;
```

Figure 21: Overwrite Item

Recording item location

The technologies used to implement the location functionality was a python script which allocated items to a location in the warehouse. The previous section demonstrated how items were added to the WMS system (orderpickingdb). **Figure 22** prompts the order picker to scan the item to assign a location. The id is fetched for the existing item with the functionality implemented to overwrite the location if the item exists.

```
try:
  while True:
    lcd.clear()
    lcd.message('Place tag to\nregister location')
    id, text = reader.read()
    cursor.execute("SELECT id FROM items WHERE rfid_uid="+str(id))
    cursor.fetchone()

    if cursor.rowcount >= 1:
      lcd.clear()
      lcd.message("Overwrite\nexisting location?")
      overwrite = input("Overwite (Y/N)? ")
      if overwrite[0] == 'Y' or overwrite[0] == 'y':
        lcd.clear()
        lcd.message("Overwriting location.")
        time.sleep(1)
        sql_insert = "UPDATE items SET location = %s WHERE rfid_uid=%s"
      else:
        continue;
    else:
      sql_insert = "INSERT INTO items (location, rfid_uid) VALUES (%s, %s)"
    lcd.clear()
    lcd.message('Enter new location')
```

Figure 22: Location Feature

Once the item has been allocated a location, the sql_insert statement is used to insert the item location into the items table, matching the RFID_uid with the assigned location id.

The location is entered based on the available spaces in the warehouse and the storage policy. The item will be allocated a position which corresponds to the Bay (A, B,), the left side (A1, B1) or the right (A2, B2), then the row (1,2,3) with rows descending from lightest to heaviest and then the position on the row (A, B, C…).

Figure 23 demonstrates a warehouse layout implementing the storage policy.

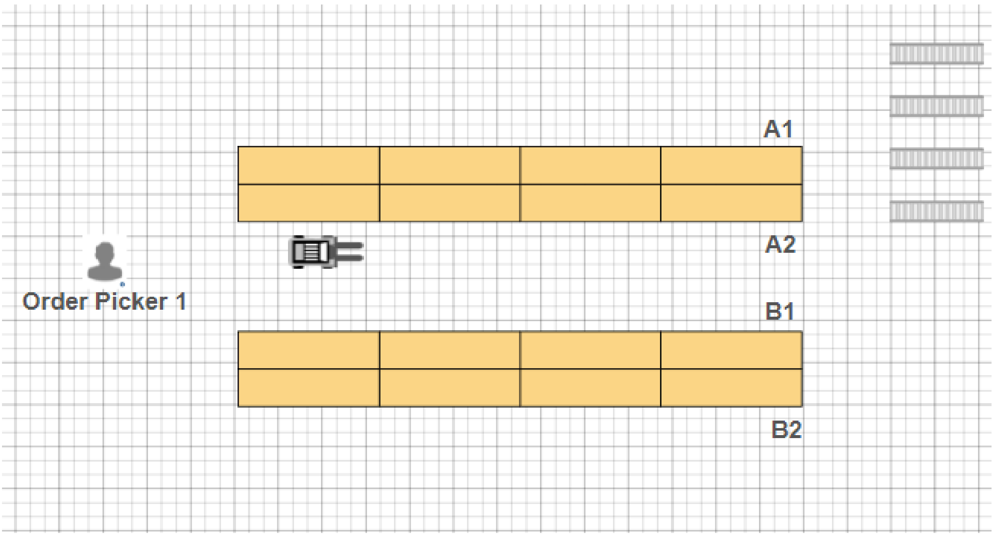


Figure 23: Warehouse Layout

To further demonstrate the implementation of the location functionality and the location algorithm for storing items uniquely, **Figure 24** details the rows and positions of Bay A and Bay B. This solves the issues which were identified in the study from the literature review by (Bartholdi & Hackman, 2011).

Moreover, extracting was another identified issue. The location feature assigns items in an order which is most natural for the order picker, such as having each row decrease in item weight to ensure the safety of the order picker during extracting. A study of the human factors highlights the urgency of minimizing the risk of injury and maximising occupational safety (Grosse, *et al.*, 2017).

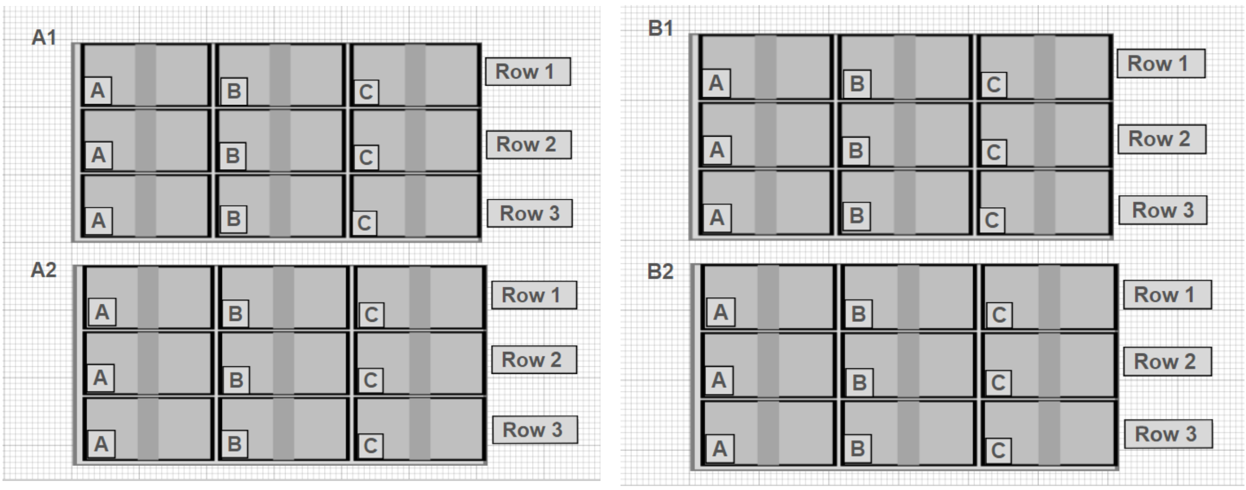


Figure 24: Warehouse storage policy

Reading item information for order picking

A requirement of the RFID order picking system is to read and display item data to improve picking accuracy. As the conclusions which were drawn from the literature and technology *review 2.3.2 handheld picking devices and RFID*, the order picking system should display replicate similar functionalities as an RFID scanner. The item is read by the RFID reader to ensure that the correct item has been picked.

Storing and updating data in the WMS

Items were logged in to the system to represent a full inventory list (Appendix M). The design overview of the database system helped model the conclusions drawn from the literature review Section 2.2 *Investigate WMS and IoT integration*. The system incorporated real-time data processing techniques to cope with the scalability of IoT data , using data clustering techniques to join similar RFID data in the relational database as (Marjani *et al.*, 2017) states that this technique is essential for managing ever-changing data.

5.4 Iteration 4: implementation of the server and front-end interface to view inventory

This iteration satisfied the requirements which were generated from the conclusions drawn from the literature and technology review *2.3 handheld picking devices and RFID*.. As the Pi, represents the WMS and the handheld picking device, an interface is required to display the inventory data using a server to host a PHP webpage.

Setting up the front-end web interface

Iteration 4 is the technical implementation of the interface. As the database is hosted using phpMyAdmin, a web server which supported PHP for displaying the information stored in the database was required.

Apache and Nginx are the most popular open-source web servers that handle HTTP traffic, but both differ in performance due to their differences in handling data requests. Nginx has a low resource requirement and less consumption due to its architecture (Soni, 2016). Therefore, Nginx provided the lowest memory and CPU usage for the Raspberry Pi, which has limited capabilities for high-performance data processing compared to Apache.

Configuring and using NGINX as a front-end webserver to host the order picking website

The final stage of the server-level installation was to test that the server has been configured for PHP. **Appendix L** shows the installation commands which were used to install and test the Nginx server, the hostname of the pi was then displayed to check the version of PHP installed. **Figure 25** shows that the server was successfully installed and was linked to the WMS.

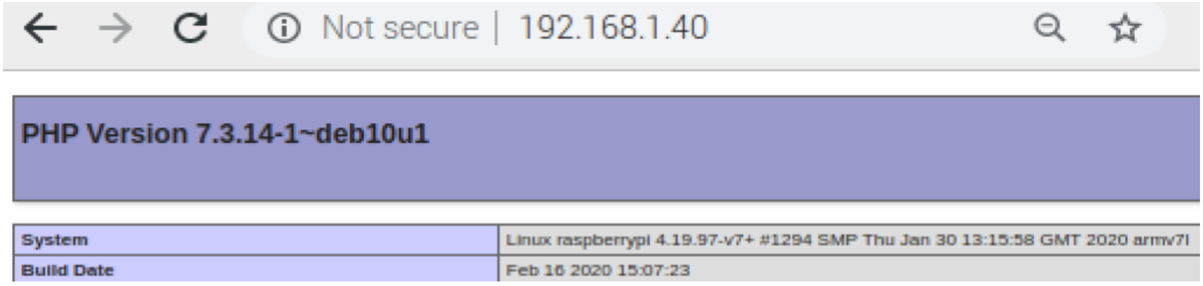


Figure 25: Testing PHP

Building the order picking web interface

Once Nginx was installed and tested to work with PHP, the front end was developed using 4 PHP scripts which required several programming languages such as HTML (hypertext mark-up language), CSS (cascading style sheets) and PHP. The frontend was developed in accordance to the wireframes in the design overview section.

Figure 26 displays the main page of the order picking system where a link to the items stored in the warehouse is visible to the order picker.

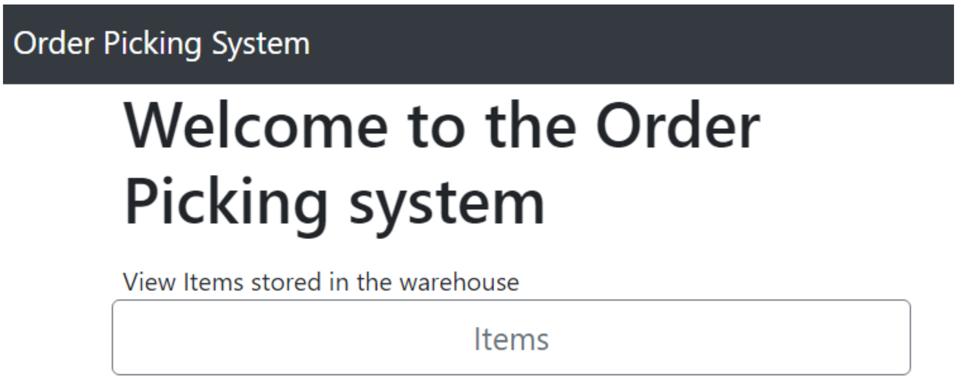


Figure 26: Final Wireframe

The order items page was created to view the available items in the warehouse, the RFID UID, location and the log time. The order picker will have an automatically updated inventory management list each time an item is added, overwritten or removed **(Figure 27).**

Order Items

ID	Name	RFID UID	Location	Log Time
1	Turtle Beach Gaming Headset	591997944397	B12B	2020-03-13 13:32:04
2	Samsung Smart TV 32"	314661192079	A12A	2020-03-13 13:59:27
3	logitech G502 Gaming mouse	857429401596	B12C	2020-03-13 14:22:46
4	HP Monitor 27"	650130251614	A11B	2020-04-05 14:00:50
5	ASUS VivoBook Laptop	933752649976	B21A	2020-04-05 18:27:08
6	Panasonic TX-24G302B 24 inch TV	39659487763	A12B	2020-04-06 13:24:48

Figure 27: Items Page

6. Evaluation and Discussion

This section will detail the evaluation of the RFID order picking system, which was designed using the stated execution methods and techniques drawn from the literature and technology review. The hypothesis will be evaluated along with the methods used to meet the research question and aim of the project.

The evaluation derives of observing current picking operations in a small warehouse, where paper-based picking operations are used to pick customer reservations. Observation testing is a testing method which was demonstrated by (Battini, *et al.*, 2015) in a case study which evaluated and compared different paperless picking systems, gathering test results through directly witnessing the operation of the different order picking systems. To gather the order pickers feedback on the potential adoption of the RFID system, a survey was completed by 5 order pickers from the observation testing.

Furthermore, a user-oriented evaluation using empirical methods will involve a group of six participants using the system to carry out picking operations and comparing their experience with paper-based methods. An interview will be conducted to gather feedback from the participants, with questions surrounding their feedback on specific features of the system. Therefore, from carrying out the evaluation methods, a critical analysis of the results can conclude the main topics identified in the literature and technology review and answer the hypothesis in two parts:

1. *Using an IoT enabled handheld picking device compared to other order picking methods will improve the efficiency of picking operations*
2. *Items were picked accurately and faster than other order picking methods*

Answering the hypothesis in two parts will allow a more significant evaluation and critical discussion to determine to what extent the hypothesis is met.

6.1 Observation Testing

An evaluation on paper-based order picking was carried out in a small warehouse which holds an extensive range of items along two isles in a warehouse, two pallet racks, two shelves on each pallet and one pallet rack having a double-sided storage area **(Figure 28).** 5 order pickers were used for the observation and an ethical approval form was signed online by the participants before the evaluation **(Appendix P).**

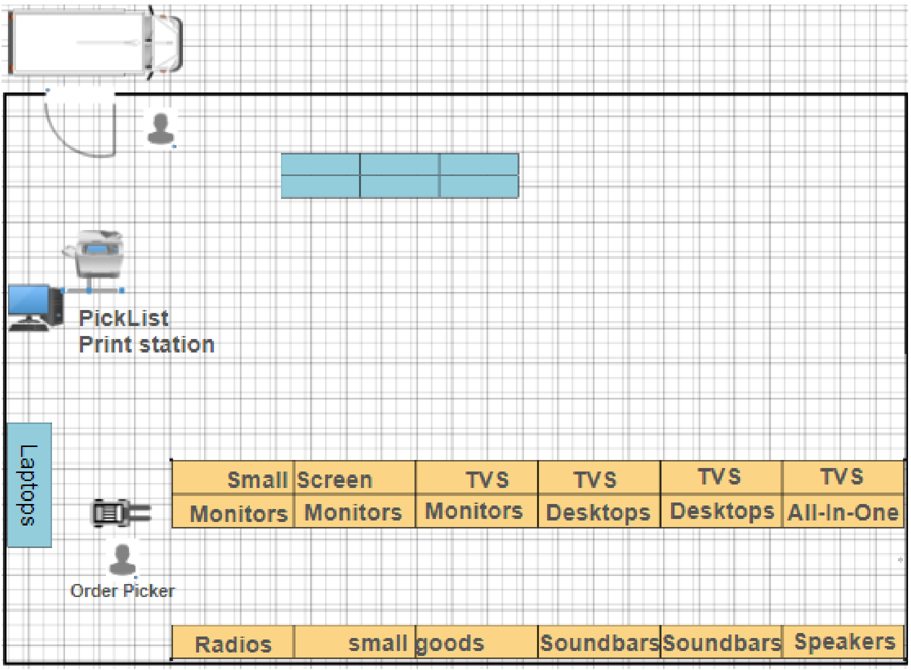


Figure 28: Observation Warehouse

Picking tasks are carried out in the small warehouse in the retail tech store using a paper-based picklist for customer reservations. The reservation list is shown in **Appendix O**. The picklist displays the items (model and unique identification SKU), the quantity to be picked and the price. During the observation test, the behaviours and interferences which occurred were analysed.

The picking strategy used to fulfil the reservation highlighted the issues identified in 2.1 *examine the order picking process*, where concussions were drawn from the study by (Bartholdi & Hackman, 2014), travelling and searching for items were the main factors affecting order picking time **(Figure 29).** Despite (Chiun-Ming Liu, 2004) highlighting that items which are grouped by product type and weight will prevent backtracking through isles, the main issue which arose was the time taken to locate items and planning an optimal picking route.

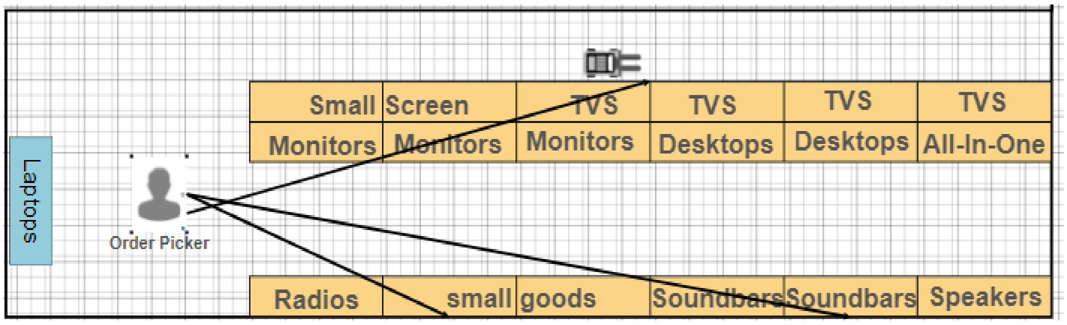


Figure 29: Picking Route

6.2 Results from observation testing

In order to determine the total pick time, which was taken to fulfil the reservation, the travelling time, searching time, and the extracting time was calculated, as shown in **Table 4**. The results from the observation testing concluded that searching time was the highest overall for all items. This was due to the order picker searching for the item amongst items of the same type. This would have been improved having numbered locations and being provided with the location of the item, concluding the study by (Bartholdi & Hackman, 2014) where travelling and searching for items accounted for 70% of the total order picking time.

Paper-based order picking results
Reservation 1

Picking strategy analysis: reservation 1 had 3 items to pick to fulfill the order. The reservation list was printed from the centralized reservation database and the order picker travelled, searched and extracted the items in the order listed on the reservation.

The order of the pick was : 1. Soundbar 2,. 2x HDMI cables 3., LG OLED TV

Item	Traveling time (s)	Searching time (s)	Extracting Time (s)	Total Pick Time (m)
LG Soundbar	20	120	58	3.3
2X HDMI Cable	10	55	10	1.25
LG OLED TV	38	132	300	7.83
			Total Pick time :	12.38 minutes

Table 4: Observation Picking Results

6.3 Warehouse order picker survey

The survey was created online using survey development software. Thus, the survey could be sent to the order pickers through email, and the results were evaluated based on the user's feedback. The purpose of the survey was to propose a solution to the participants to improve current paper-based picking methods. A brochure was created outlining the background of the system and the RFID order picking system functionality **(Appendix N)**.

Due to project limitations, the RFID order picking system could not be used within the warehouse to directly compare the picking methods. However, during the observation, five order pickers signed an approval form with their details highlighting that they give their permission for an observation test to be carried out, that they were briefed on the project objectives and that they would complete a survey sent through email.

6.4 Results from the survey

The survey consisted of eight questions which were specific to underpinning the current problems which occur using paper-based order picking, how the RFID order picking system would improve their picking efficiency and system improvements. Therefore, using the report generated from the online survey, the results can be evaluated against the hypothesis and conclusions drawn from the literature and technology review.

Using IoT for picking operations

In Question 1. 5 out of 5 of the users agreed that the RFID system would be the preferred choice to improve their picking operations.

Therefore, the results from this question conclude that integrating IoT technology into the warehouse would improve the efficiency of their picking operations.100% of participants responded Yes which further concluded section 3.1 of the literature and technology review where (Lee & Lee, 2015) conveyed that RFID systems in warehouses will immediately benefit order picking processes as it is a concrete solution.

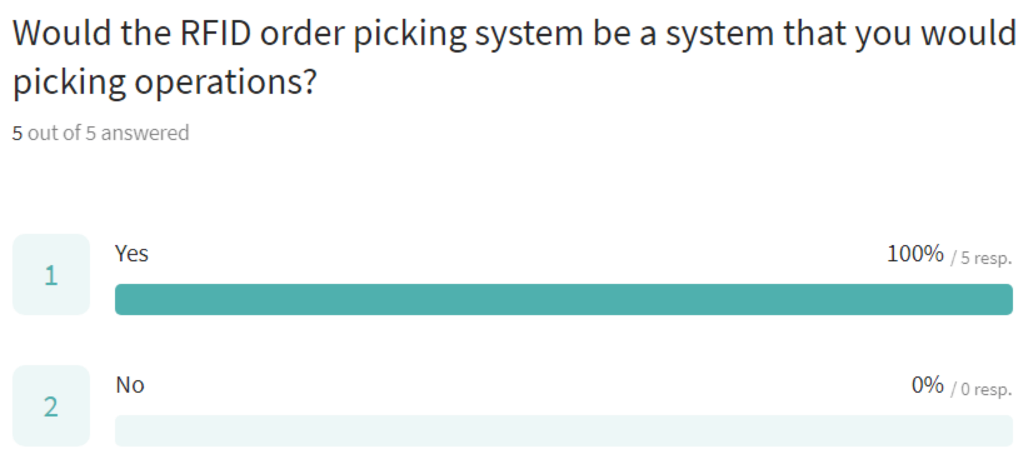


Figure 30: Question 1

Improving the current order picking process

Question 2 used an open-ended question style which allowed the user to express their opinion about how the system would improve their tasks. (Anderson, *et al.*, 2013) suggest that using open-ended questions allows the user to respond unrestricted with the freedom to express their answer in their own way.

The results emphasised the benefit of having the location feature. 3 of 5 users answers mentioned that providing the location of the item would increase optimal picking, accuracy, improve searching and locating items quicker.

How do you think the system would improve your day-to-day picking tasks?

5 out of 5 answered

"It would improve the current inventory system as it provides item location. This would allow me to plan my picking route through the warehouse. Picking items would be easier as i would be able to access items easier based on the item weight. Also, the reading, writing and updating data would improve the accuracy of item information"

"Aid in reducing time it takes to find and pick items"

"Make it a lot easier to locate the product and save time"

"Streamline the picking operations, alongside safety measurements taken into account with the weight:height ratio."

"Would improve overall accuracy of picking, products that have similar model numbers, colour variations etc would be less prone to error. It would also save a huge amount of time in manually locating and searching for products."

Figure 31: Question 2

Route planning

Question 3 asked the users whether they struggle planning a route to pick items. 5 out of 5 of the users responded yes- they struggle to plan a picking route; therefore, 100% of the users agree that automating picklists using the RFID system will improve the efficiency of the order picking operations meeting the conclusions drawn in section 2.1 of the literature review.

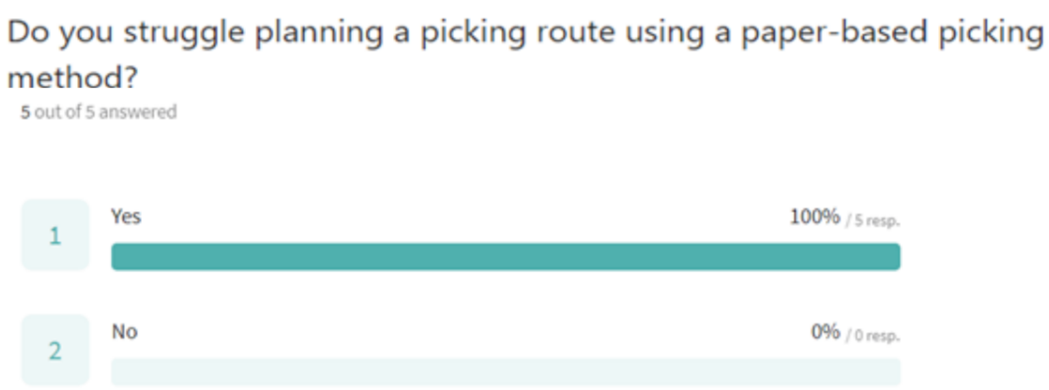


Figure 32: Question 3

Locating items

The location feature was implemented to meet part 2 of the hypothesis- to improve the accuracy and speed of order picking. this question asked the user whether they preferred having the location of items provided rather than manually searching. The results show that 5 out of 5 of the users responding Yes, therefore a 100% result highlighting the benefit of having the location feature.

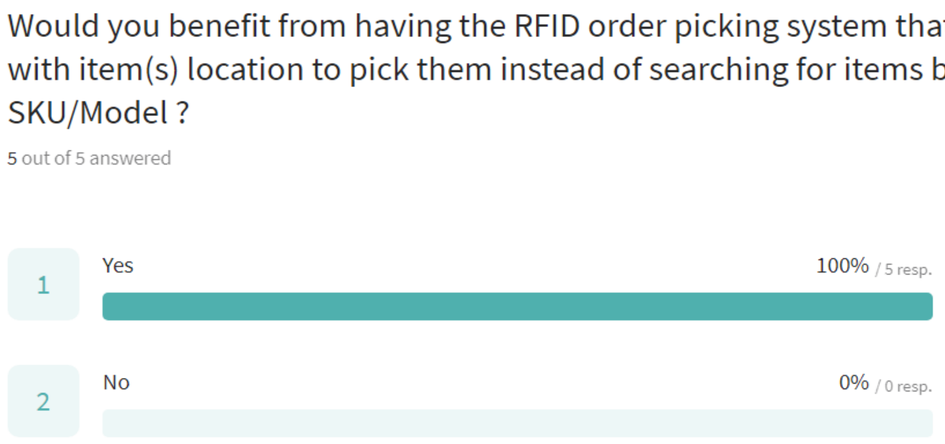


Figure 33: Question 4

Storage allocation

The fifth question focused on the issues surrounding storage allocation in warehouses for optimal picking as this was an issue which was to be addressed from the conclusions drawn from the literature review. (Bukchin *et al.*, 2012) concluded that storage policy is a factor which can determine the efficiency of order picking systems. The results reflected the research, as 5 out of 5 of the users would prefer allocating items in the warehouse by weight, with the heaviest items at more manageable picking height.

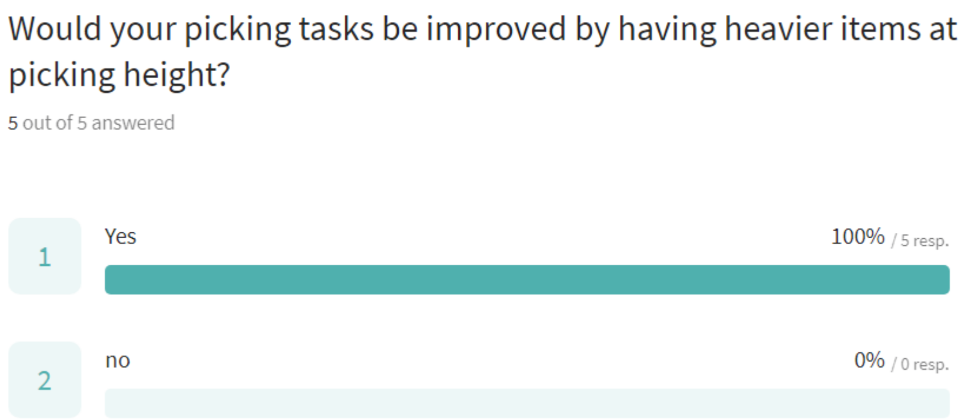


Figure 34: Question 5

System usability

This question asked the participants if the system appears easy to use. The results of the question differed compared to the others as 4 out of 5 users answered yes. Therefore, uncovering the research in the literature review section 2.3, RFID technology has only recently emerged in warehouses, as the participants haven't been introduced beyond paper-based systems, the technology would appear complex. However, section 2.1 of the literature review highlighted that once a technology is adopted, operational improvements are immediate and will aid the order picker.

Figure 35: Question 6

System improvements

An open-ended question was asked to gain insight into how the system could be improved. The results of the question indicated that 4 out of 5 of the participants would prefer additional features; the feedback mainly consisted of areas of future work considered for the project. However, as mentioned by two users, including the weight listed on the automated picklist and a stock replenishment feature would further streamline the operation.

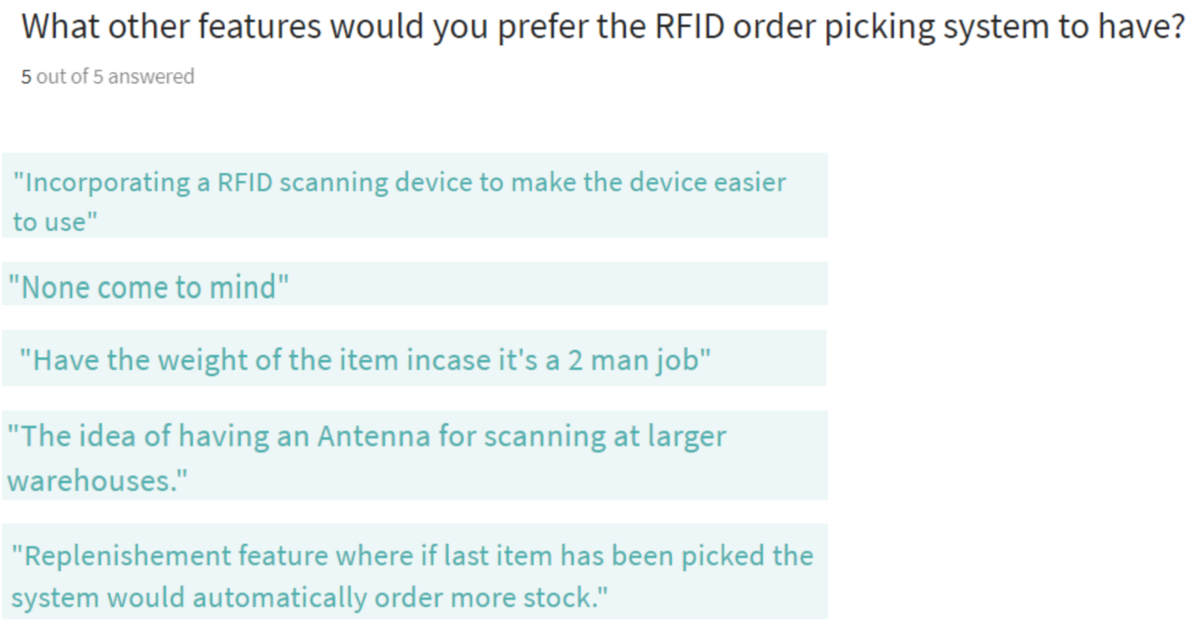


Figure 36: Question 7

6.5 Interactive testing

Six participants were gathered to test the RFID prototype by carrying out tasks which met the main functionality of the system in a warehouse setup **(Appendix T).**They compared their experience with paper-based operations where they carried out manual tasks. The participants were then interviewed on a one-to-one basis to provide their feedback on their experience. This method of interviewing is known as a structured interview where a few short questions were asked to each participant (Cassell, 2015). The questions were created to reflect the conclusions drawn in the literature review and aimed to answer the hypothesis. **Table 5** shows the questions which were curated to identify the sections of related literature and answer the hypothesis.

An ethical approval form was signed online by the participants before the evaluation **(Appendix Q)**

INTERVIEW QUESTION	RELATED LITERTURE AND TECHNICAL REVIEW SECTION	LITERATURE AND CONCLUSIONS
1. Were you familiar with the capabilities of RFiD technology before using the system? If so, where and what type of RFiD technology are you familiar with ?	2.1 Examine the order picking process	
2. From using the system and your understanding of what order picking operations involve, how did the system improve your picking experience?	2.1 Examine the order picking process Hypothesis (1) Hypothesis (2)	(Bukchin, Khmelnitsky, *et al.*, 2012) "batching, picking sequence, storage policy, zoning, layout design, picking equipment and picking information strategies".
3. Based on the automated pick list you were provided with to pick items, compared to manual order picking, was it easier to pick items with the location and details provided for items? If so, how?	2.1 Examine the order picking process 2.2 Investigate Warehouse Management Systems (WMS) and IoT integration Hypothesis (1)	(Bartholdi & Hackman, 2011) • improving the tasks of the picker • travelling and searching 70% of the order-picking time • Warehouse Management System (WMS) integration (Petersen & Aase, 2004) order batching + other policies = reduce picking time by around 20%.
8. what aspect of the location feature do you think could be improved for the system? Explain why?	2.3 An investigation into IoT technologies for picking operations Hypothesis (1)	(Lee & Lee, 2015) inventory location tracking measurability and availability
4. From the warehouse layout you picked from, how did the inventory layout improve your picking efficiency ? Did the system prevent you moving between shelves to find items?	2.1 Examine the order picking process 2.2 Investigate Warehouse Management Systems (WMS) and IoT integration Hypothesis (1)	(de Koster, Le-Duc *et al.*, 2007) quantity of an item(s) and the distance between items (Chiun-Ming Liu, 2004) reduce the order picking time and distance travelled
5. Did you find it easy to read and write data to the RFID tags ? If not, what could be improved ?	2.2 Investigate Warehouse Management Systems (WMS) and IoT integration 2.3 An investigation into IoT technologies for picking operations Hypothesis (1) Hypothesis (2)	(Lihong Jiang *et al.*, 2014). RFID readers integrating relational databases for handling structured data
7. Did the interface display information quickly from when you assigned data to the RFID tags?	2.2 Investigate Warehouse Management Systems (WMS) and IoT integration Hypothesis (1) Hypothesis (2)	(Rautmare & Bhalerao, 2016) MySQL was more stable during the experiments. (A, N. Subramanya & M. Rangaswamy, 2012) WMS reduced the picking time by 49 minutes- 77.78% improvement

Table 5: Interview Questions

6.6 Interview Results

The results of the interview are presented in **Table 6**. As the purpose of the interview was to gather feedback based on the user's experience from using the system, each response is shown with the corresponding question number.

INTERVIEW QUESTION	INTERVIEW RESULTS					
1.	**Yes, I was familiar with RFID, but I did not know it had so much to offer for the context it is being used for.**	No, I was unsure about what RFID technology was.	Yes, I use RFID scanners in work to check stock levels – the additional features in this systems goes beyond	No, I only knew that RFID technology was used for tags in cards for hotel keys, transport etc. – things that require scanning	No, I did not know about RFID technology at all	Yes I work in the airport, and RFID technology is used for passport scanning and many other things
2.	**I was able to pick items based on the item category – having the items assigned to individual bays with numbered positions reduced the time taken to pick items compared to manual picking**	I was able to plan my picking strategy – I chose items from the same shelf first	I thought it allowed safer order picking, having heavier items at the bottom made sense for the picking plan I used to pick quickly	I picked faster using the RFID order picking system; I like that the system has the details of the items	I was able to pick items – if it was in a real warehouse I would have planned to pick heavier items with a forklift or similar	I was able to plan a picking sequence, for example, I picked all items in bay A (A!, A2) first then bay B (B1, B2)
3.	**Yes, the location feature improved the picking time**	Yes, I spent less time searching for items	Yes, the location feature is something I wish the RFID scanners in my work had – so I can find items quicker in the warehouse	Yes, I noticed that when I picked manually, I spent too much time matching the item model to the picklist	Yes, I think the location of the item and the read functionality improved picking accuracy	Yes, I picked all items correctly compared to manually picking items – I could use the RFID reader to check the item for me
4.	It could be improved by automatically assigning a location rather than typing it	I wouldn't change anything about it	I think the warehouse layout should be shown to decide where to put the item	Adding an automatic location identification to scan in lots of items at the same time	Showing the route to pick the items	Nothing
5.	Yes I wasn't moving constantly between the shelves	Yes, compared to picking manually the location feature improved my searching task	Yes, the layout was easy to use, I used the RFID scanner to read the item	Yes, the layout was a great consideration – especially for tech items – the layout by weight helped	Yes, the logic was clear when I picked items. I didn't have to search for ages	Yes, I picked quicker than the manual system. I could find all the items easily
6.	**Yes I found it easy as the LCD screen guided me**	Yes it was a simple task	Yes, it was easy to use – the functionality was similar to the RFID scanners I use in work	Quite, however, it would have been better to have tags integrated on to the products	Yes, I found it easy – I like how the system displayed command prompts	No, I would have preferred a larger LCD screen
7.	**Yes, I saw the interface updated instantly**	When I made an error assigning the product name, it was easy to update – it displayed instantly when I changed it	Yes, I saw all the items I scanned into the system	Yes, it was a rapid response for all items logged in to the system.	Yes, the picklist was very easy to use and loaded items quickly	Yes, I like that the system updates the result instantly

Table 6: Interview Results

The answers gathered from Question 1, where 2.1 *Examine the order picking process* allowed the answers to be evaluated against the research surrounding issues in picking operations. It was apparent that only 3 of 5 of the interviewees knew about RFID technology. 2 of the interviewees had little knowledge about warehouse logistics and IoT technology. Therefore, as identified in section 2.1 of the literature review, RFID technology is widely adopted beyond logistics and is progressively being introduced in warehouses.

Question 2 supported the requirement for automating picking tasks. From the results of the question, all interviewees agreed that from using the system, picking tasks were improved –

highlighting the factors involved to determine the efficiency of order picking systems, presented in the study by (Bukchin *et al.*, 2012). The results concluded that the system imporved operational planning- they were able to pick quicker.

Question 3 and 4 focused on the location feature of the system, and how the system could be improved. From the results, all of the interviewees agreed that the location feature allowed them to pick quicker than paper-based operations. One user further highlighted that the read and write functionality improved picking accuracy.

Furthermore, The results from Question 5 concluded that all of the interviewees agreed that the inventory layout reduced the searching time for items, preventing backtracking through isles as presented in the related literature by (Chiun-Ming Liu, 2004).

Finally, The results from Question 6 and Question 7 justified the implementation of the LCD screen. 4 out of 6 of the interviewees agreed in Question 6 that the LCD screen was a useful addition as it replicated a real picking system. Furthermore, the feedback from Question 7 concluded that 6 out of 6 of the interviewees agreed that the WMS updated instantly, providing real-time data viewing which met the conclusion drawn by (Rautmare & Bhalerao, 2016) conveying the stable performance of MySQL.

6.7 Evaluation conclusion

The methods which were used to evaluate the system allowed conclusions to be drawn on the efficiency of RFID for picking operations. Observation testing, surveys, interactive testing and an interview allowed valuable feedback to be gained to answer the hypothesis. The results gathered from the observation testing proved that manual paper-based order picking operations lack operational efficiency for ever-changing organizational demands. Furthermore, the survey completed by order pickers provided insightful feedback on their thoughts about how an RFID based order picking system would streamline warehouse operations. The results overall concluded that adopting RFID technology and using location-based data for items; storage location polices and item reading functionality was essential ,therefore justifying the overall hypothesis.

Conducting interactive testing of system allowed the behaviours of the system to be evaluated first-hand. To gather the participant's feedback, the interview used open-ended questions to explore the participant's thoughts of the system and how it could be improved. Using participants with varying technical knowledge challenged the hypothesis, the results overall concluded that the RFID picking system enhanced and improved the speed of picking and accuracy measures and therefore met various conclusions which were identified from the literature review.

In conclusion, the quantitative and qualitative results obtained through the evaluation methods allowed the research question to be answered and the overall hypothesis with justified conclusions. Thus, examining IoT technologies has proved that adopting RFID to replicate a handheld picking device which incorporates the functionality of WMS, aids the order picker to achieve optimal performance.

7. Conclusions and Further Work

This section will present a discussion on the conclusions which have been drawn from the project. The discussion will highlight the main findings from the literature and technological review in relation to what extent to meet the hypothesis and research question. Furthermore, in order to review the project entirely, the project limitations which were discovered will be discussed as well as presenting areas for future work.

7.2 Discussion of results

The aim for carrying out the evaluation of the RFID order picking system was to determine what features of RFID technology improved the issues surrounding order picking. The literature review presented conclusions which justified the development methods for the system. The first investigation in the literature review highlighted issues with order picking. From the evaluation it was clear that the system improved the research conducted by (Battini, *et al.*, 2015), where various picking methods were compared against paperless picking operations. Furthermore, batching and combined policies significantly reducing order picking time. Thus, the system adopted locating and storage policies which met the conclusions drawn from the literature. The second investigation encapsulated the requirement for WMS for handling RFID data. From the research conducted, ,knowledge was gained surrounding the various storage and retrieval options for RFID data. It was concluded that relational databases handled structed automatic data better than other methods. The final investigation which was conducted highlighted the current uses of IoT in warehouses and detailed with further justification and comparison that RFID technology would solve the order picking problems through the automation of picking tasks.

The evaluation of the system using surveys and interviews as well as carrying out observation testing provided feedback which allowed the hypothesis to be answered. The feedback was overall positive with the survey having all of participants of whom were order pickers, agree that they would prefer the RFID system for picking operations compared to paper-based picking. Furthermore, from carrying out the observation testing and witnessing the picking operations directly, it was clear that operational efficiency was improved. The results of the picking test run carried out by the order picker highlighted lack of picking accuracy which influenced the high ‘searching’ times. The survey highlighted that 5 of 5 of the participants would prefer real-time inventory tacking, with improved storage polices for easier ‘extracting’ of items.

The interactive testing allowed a further evaluation to be made on answering the hypothesis. The results gathered from the interview allowed detailed feedback to be provided which reflected the users experience from using the system. The main topics which were discussed with the participants surrounded the areas of research from the literature review. The feedback primarily conveyed that the location feature improved searching for items, as all users agreed. Section 2.1 Examine the order picking process allowed the issues identified with order picking to be solved – all feedback from the participants concluded that the system solved one or more of the identified order picking issues.

7.3 Project limitations and future work

The RFID order picking system produced results which have justified the decisions for the execution and implementation techniques and supported the hypothesis of the project. Due to the nature of the project and the vast implementation stages for the iterations of the system development, some factors presented project limitations on the identified primary research objectives. The project had a 16-week execution timescale for the development of the prototype, which is a small timescale compared to the deployment of a real RFID handheld picking device. Thus, the limitations reflected the evaluation of the system; however, these limitations present an opportunity for future work.

The evaluation stage of the project presented limitations for determining how effective the RFID order picking system is compared to other picking methods. Due to unprecedented circumstances, carrying out further observation testing of the RFID order picking system and comparing to the results gathered from the warehouse's existing system was hindered. Comparing the system would have allowed further insight, however, using several evaluation methods allowed the hypothesis and research question to be met.

There are future considerations which will improve the capabilities of the proposed system. The implementations of additional components such as including using an antenna or GPS position in the warehouse will extend the range of passive tag reading. Furthermore, as only passive tags were used for the project, future consideration will involve implementing Active and Semi-Passive RFID tags. The comparison of the tags is presented in by (Khan, *et al.*, 2009) in Figure 38, where active and semi-passive RFID tags have a higher scan rate and lifetime which would be suitable for warehouses.

Characteristics	Passive RFID	Active RFID	Semi-Passive RFID
Frequency (UHF)	860MHz -960 MHz	868/915MHz and 2.4 GHz	868/915MHz and 2.4 GHz
Internal Power	No	Yes	Yes
Bit Rate (Kbps)	246	20/40/250	16
Memory (KB)	128	128	4
Multi –Tag Collection	3 sec. to identify 20 tags	1000 tag / sec at 100 mph	7 tags / sec at 3 mph
Read Range	1-30 ft.	1-300 ft.	Up to 15 ft.
Cost	INR 10-150	INR.1250-2500	INR 500-2000
Life Time	3-10 years	½ -5 years	½ -5 years

Figure 37: RFID Tag Types

7.4 Conclusion

This project focused on the problem of how to improve the efficiency of order picking operations in warehouses through the adoption of an IoT technology. In order to achieve the research question, IoT technologies were compared and examined to justify the adoption of RFID as the primary technology to automate picking operations. To answer the hypothesis, an RFID order picking system was proposed in this paper, which achieved the real-time visualisation of inventory, locating and storing items using optimal storage assignment policies. Furthermore, a WMS was developed to handle RFID inventory data. This project demonstrated that RFID technology improved the efficiency of order pickers, without needing to replace them with fully automated systems. The purpose of semi-automated solutions is to prioritize the skills of the worker and furthermore, improve WMS by optimizing warehouse storage, improving inventory and picking accuracy whilst reducing labour.

Through the research conducted in the literature and technological review which consisted of examining current order picking processes, factors which affect order picking time, WMS and IoT integration and investigating IoT for picking operations, conclusions were drawn on each of these areas which improved the author's knowledge for conducting the activities in this project. Moreover, the Execution Methods allowed a detailed requirement elicitation to be carried out which identified the system requirements, the identified agile methodology which allowed an iterative adoption which reflected the project timescale.

The design stage involved carrying out a hardware implementation design, system modelling and database diagramming, which thoroughly detailed the functionality and requirements of the system. Therefore, through Business Process Modelling, UML sequence diagrams, Interface wireframing, class diagrams and use class modelling, the system design was thoroughly explored and allowed the author to carry out the implementation of the system. The implementation stage met the objectives stated in the iterative breakdown diagram.

The conclusions which were drawn from the evaluation stage was critical for answering the research question meeting the aims of the hypothesis. Overall, the developed RFID order picking system improves existing systems and paperless picking methods as it enhances the efficiency of order picking operations based on the requirements defined throughout the project. From the evaluation methods, the feedback which was gathered determined that the location feature, reading and writing functionality, WMS integration and automatic data generation were critical factors which concluded that adopting IoT technology to replicate a handheld picking device improves the efficiency of order picking operations- improving the speed and accuracy of order picking.

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9. Appendices

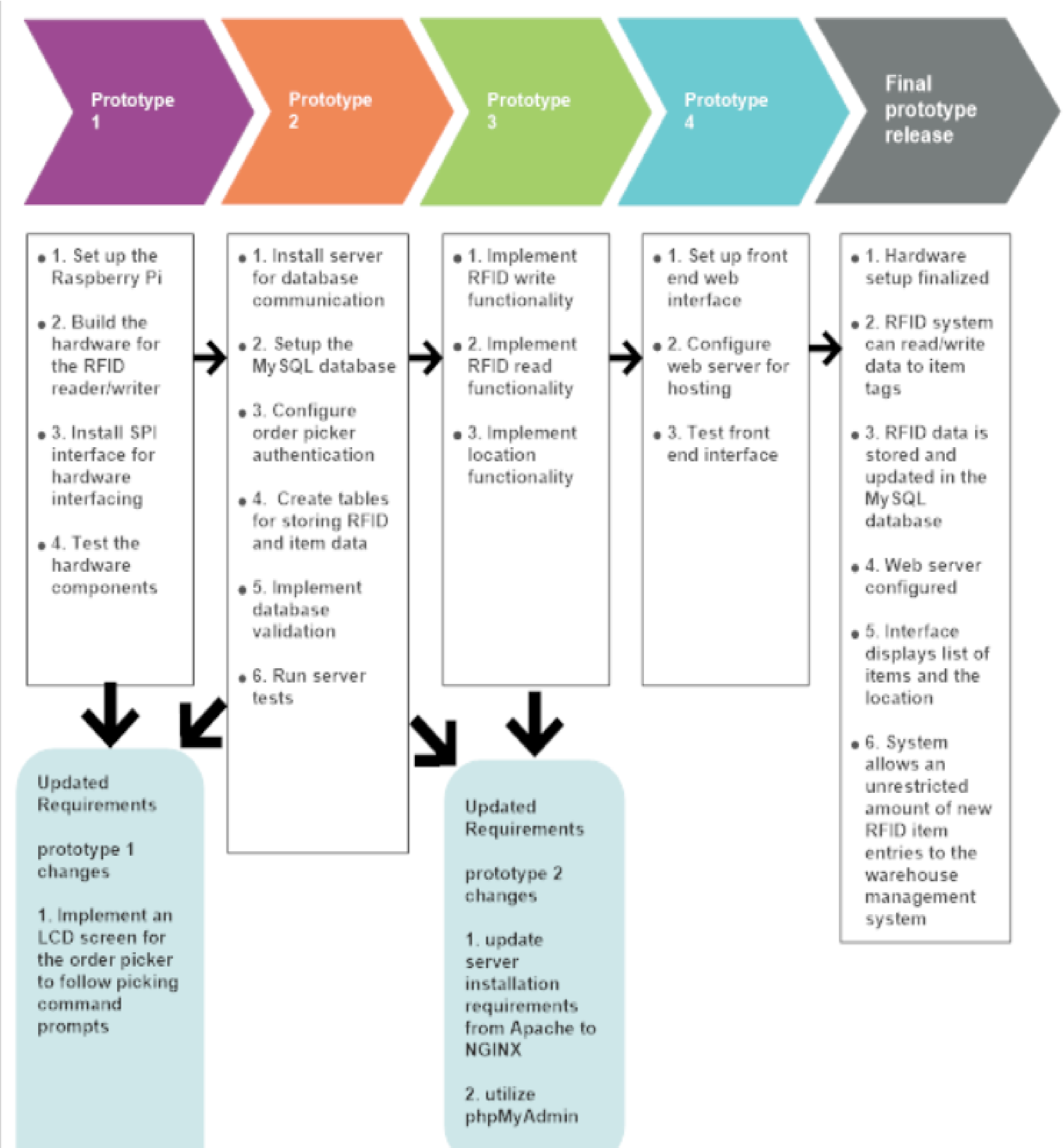
Appendix A: Results of the experiment phase

Results of Experiment in ED

Number of runs in ED: 10

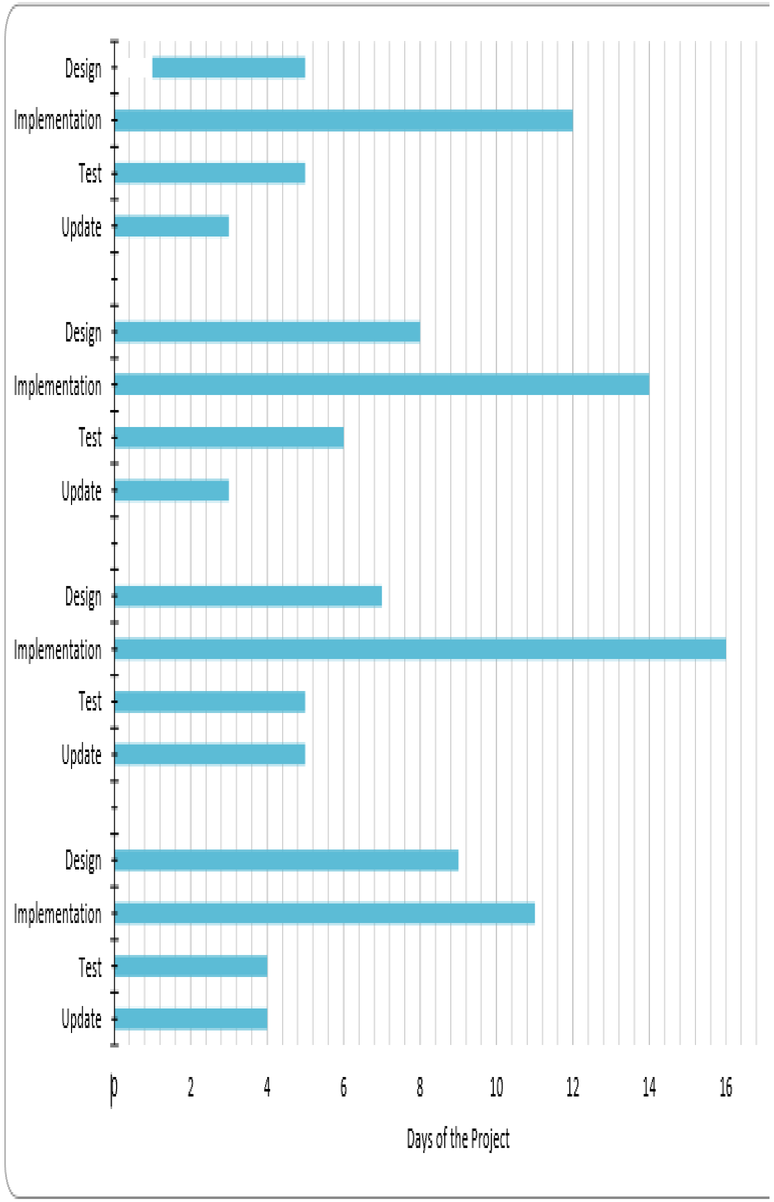
	7	8	9	10	Mean/Avg.	Std.Deviatior
PickList1	1019	1015	1034	1017	1017	7
PickList2	420	416	421	422	420	2
PickList3	974	959	986	967	972	9
PickList4	964	975	971	962	965	5
PickList5	570	573	575	577	574	3

Appendix B: Iteration Breakdown Diagram

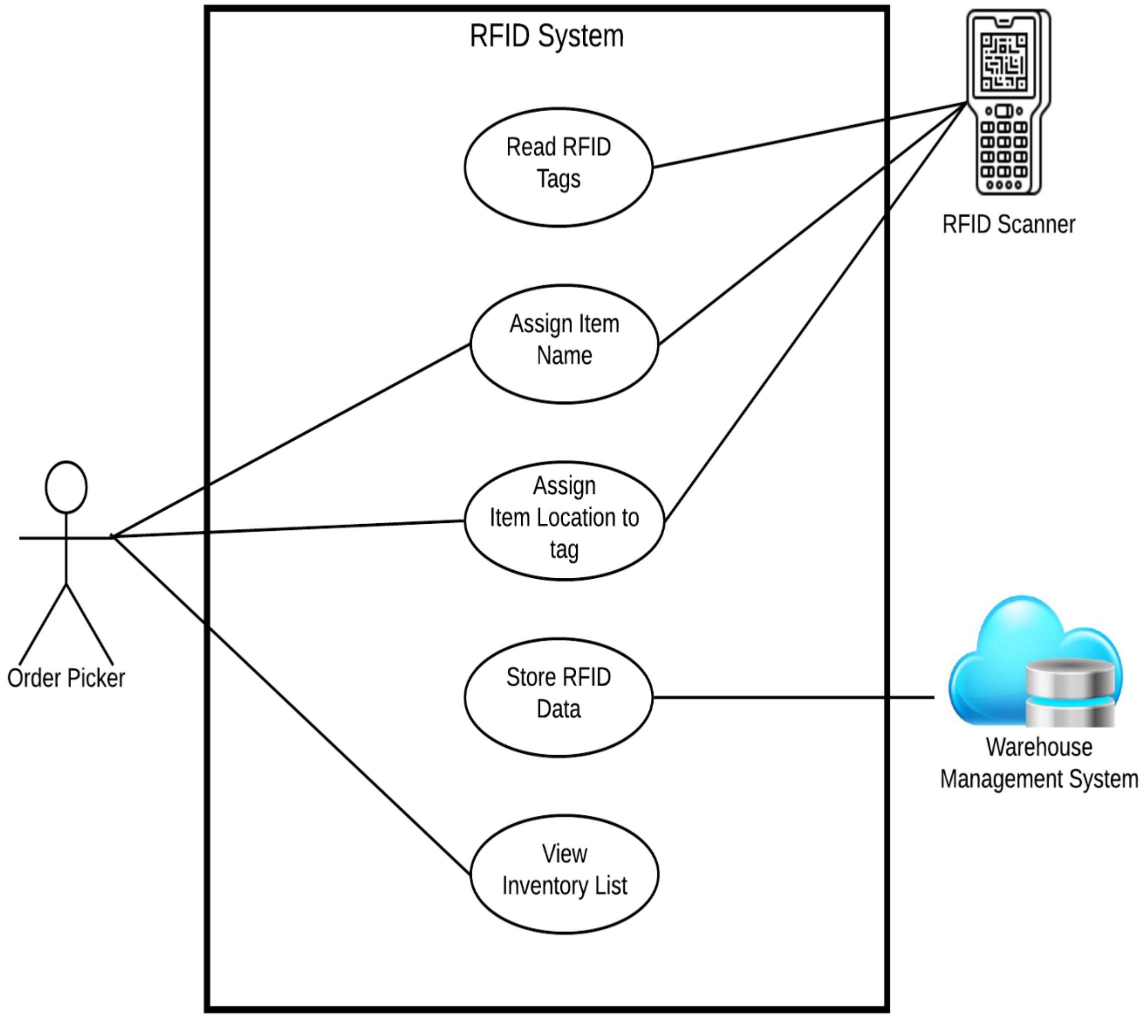


Appendix C: Project Timescale

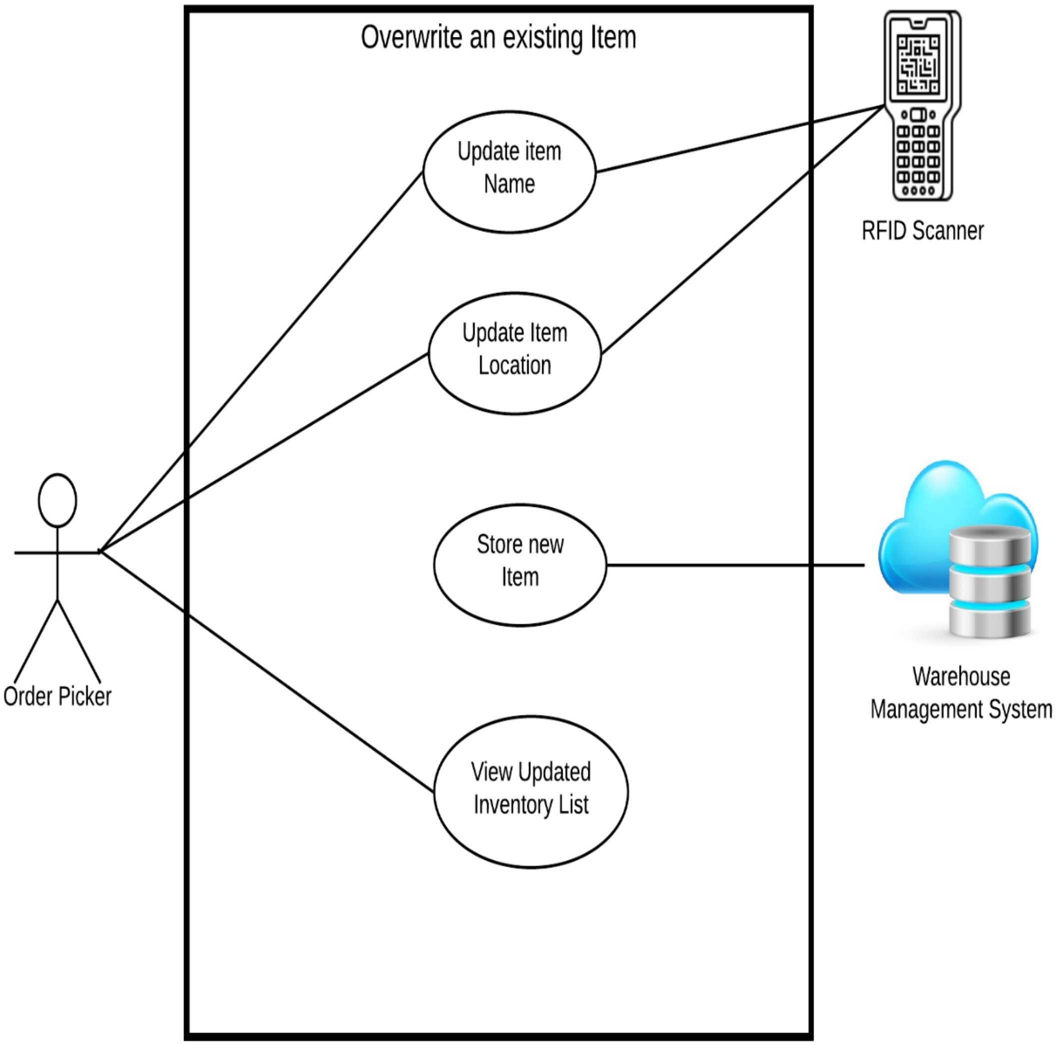
TASK NAME	START DATE	END DATE	DURATION	PERCENT COMPLETE
Iteration 1				
Design	11/5	11/8	4	100%
Implementation	11/9	11/20	12	100%
Test	11/21	11/25	5	100%
Update	11/26	11/28	3	100%
Iteration 2				
Design	12/1	12/8	8	100%
Implementation	1/9	1/22	14	100%
Test	12/23	12/28	6	100%
Update	12/29	12/31	3	100%
Iteration 3				
Design	1/1	1/7	7	100%
Implementation	1/9	1/24	16	100%
Test	1/22	1/26	5	100%
Update	1/27	1/31	5	100%
Iteration 4				
Design	2/1	2/9	9	100%
Implementation	2/10	2/20	11	100%
Test	2/20	2/23	4	100%
Update	2/23	2/26	4	100%



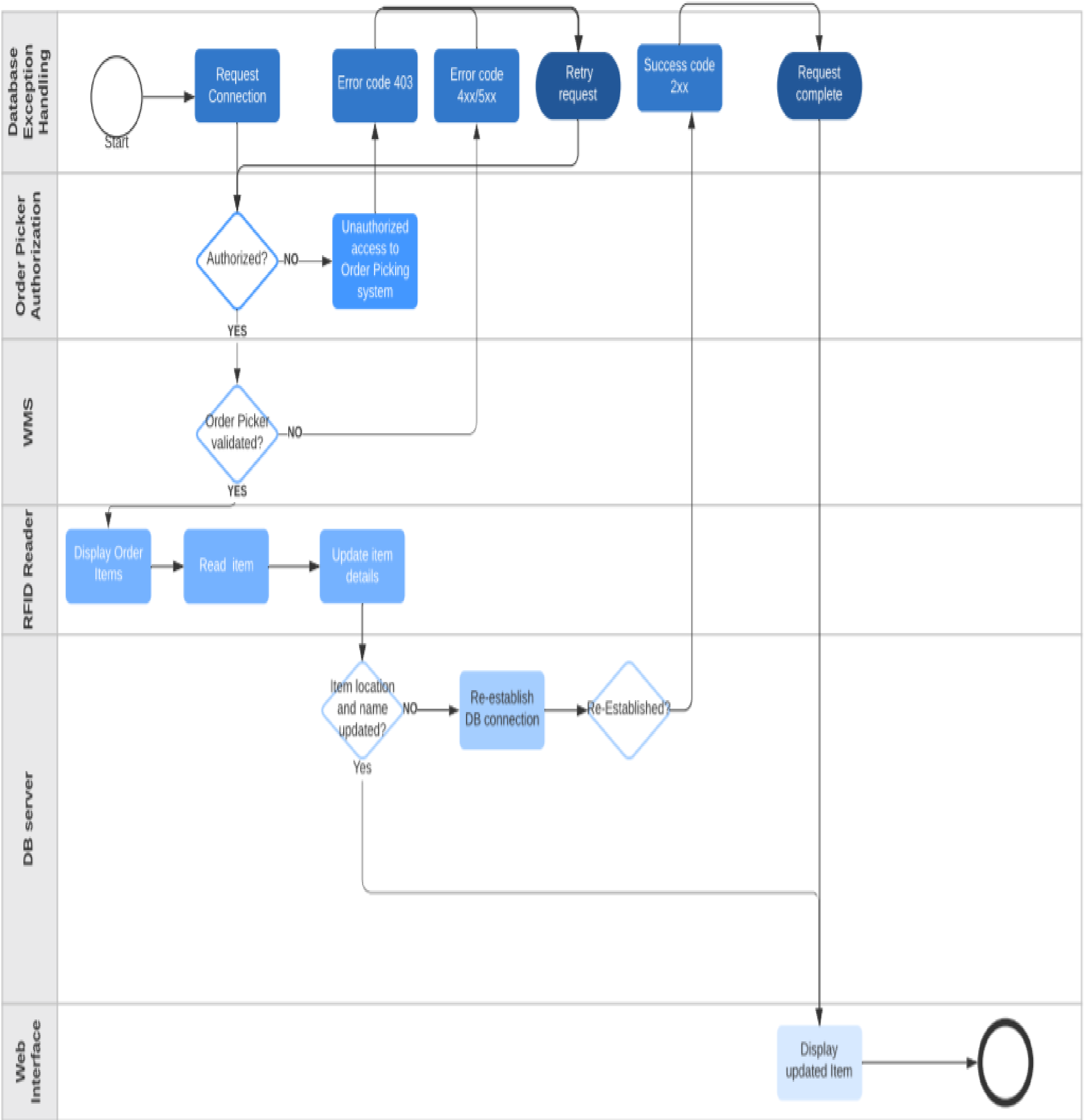
Appendix D: System Use Case Diagram



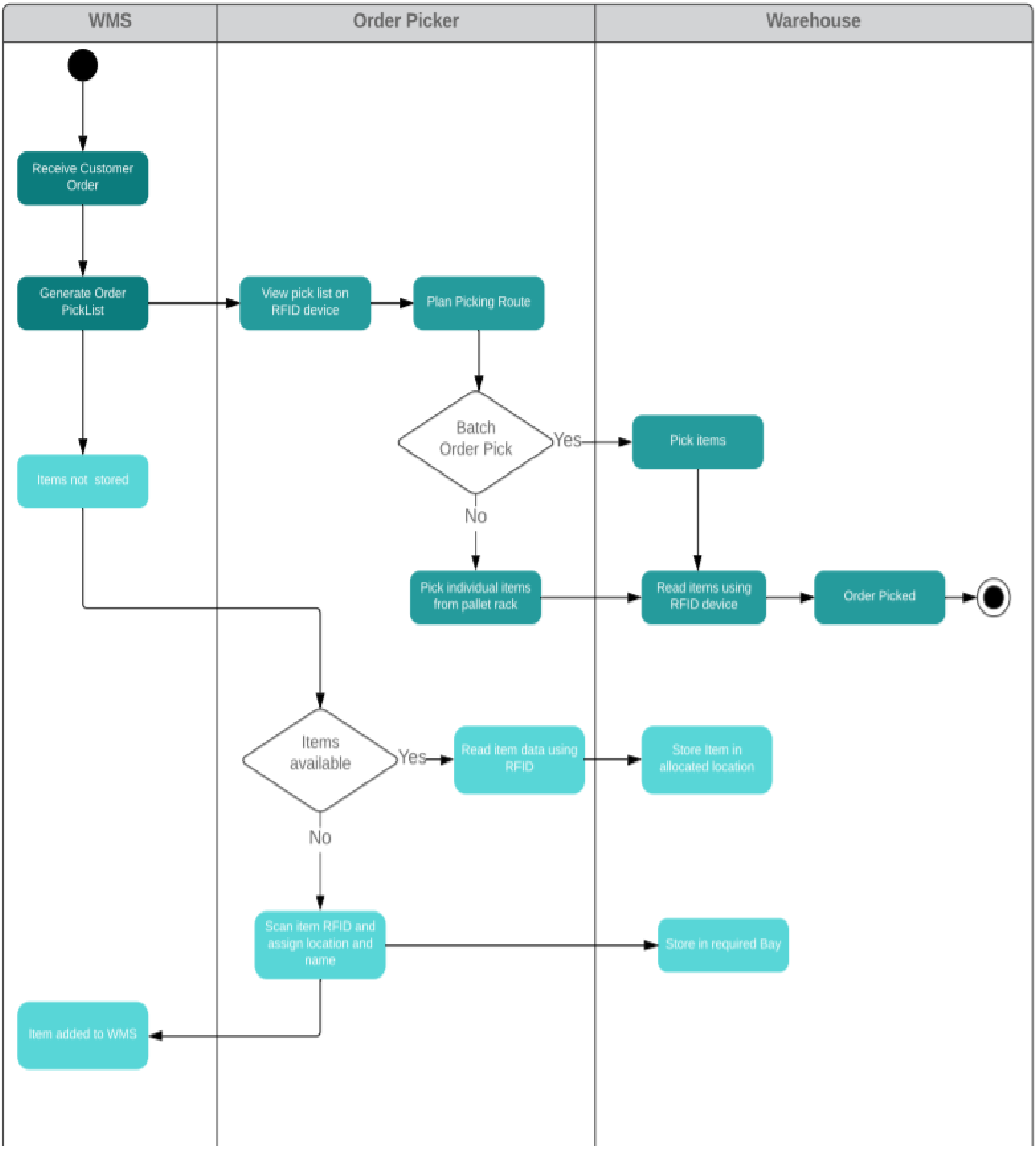
Appendix E: Use Case Diagram (Overwrite item)



Appendix F: Business Process Model system Interactions



Appendix G: UML Diagram



Appendix H : Raspberry Pi Specifications

Specifications

Processor: Broadcom BCM2837B0, Cortex-A53 64-bit SoC @ 1.4GHz

Memory: 1GB LPDDR2 SDRAM

Connectivity:
- 2.4GHz and 5GHz IEEE 802.11.b/g/n/ac wireless LAN, Bluetooth 4.2, BLE
- Gigabit Ethernet over USB 2.0 (maximum throughput 300Mbps)
- 4 × USB 2.0 ports

Access: Extended 40-pin GPIO header

Video & sound:
- 1 × full size HDMI
- MIPI DSI display port
- MIPI CSI camera port
- 4 pole stereo output and composite video port

Multimedia: H.264, MPEG-4 decode (1080p30); H.264 encode (1080p30); OpenGL ES 1.1, 2.0 graphics

SD card support: Micro SD format for loading operating system and data storage

Input power:
- 5V/2.5A DC via micro USB connector
- 5V DC via GPIO header
- Power over Ethernet (PoE)–enabled (requires separate PoE HAT)

Environment: Operating temperature, 0–50°C

Compliance: For a full list of local and regional product approvals, please visit www.raspberrypi.org/products/raspberry-pi-3-model-b+

Production lifetime: The Raspberry Pi 3 Model B+ will remain in production until at least January 2023.

Appendix I : Writing Data to an RFID tag

```
import time
import RPi.GPIO as GPIO
from mfrc522 import SimpleMFRC522
import mysql.connector
import Adafruit_CharLCD as LCD

db = mysql.connector.connect(
  host="localhost",
  user="picker",
  passwd="pi",
  database="orderpickingdb"
)

cursor = db.cursor()
reader = SimpleMFRC522()

lcd = LCD.Adafruit_CharLCD(4, 24, 23, 17, 18, 22, 16, 2, 4);# Capture SIGINT for cleanup when the script is aborted
def end_read(signal,frame):
    global continue_reading
    print ("Ctrl+C captured, ending read.")
    continue_reading = False
    GPIO.cleanup()


print ("Welcome to the Order Picking system")
print ("Scan your item now")

try:
  while True:
    lcd.clear()
    lcd.message('Place tag to\nregister item')
    id, text = reader.read()
    cursor.execute("SELECT id FROM items WHERE rfid_uid="+str(id))
    cursor.fetchone()

    if cursor.rowcount >= 1:
      lcd.clear()
      lcd.message("Overwrite\nexisting item?")
      overwrite = input("Overwite (Y/N)? ")
      if overwrite[0] == 'Y' or overwrite[0] == 'y':
        lcd.clear()
        lcd.message("Overwriting Item.")
        time.sleep(1)
        sql_insert = "UPDATE items SET name = %s WHERE rfid_uid=%s"
      else:
        continue;
    else:
      sql_insert = "INSERT INTO items (name, rfid_uid) VALUES (%s, %s)"
    lcd.clear()
    lcd.message('Enter new Item')
    new_name = input("Name: ")

    cursor.execute(sql_insert, (new_name, id))

    db.commit()

    lcd.clear()
    lcd.message("Item " + new_name + "\nSaved")
    time.sleep(2)

finally:
  GPIO.cleanup()
```

Appendix J : Database Tables

Iteration 1

Name	Type	Collation	Attributes	Null	Default	Comments	Extra
id	int(10)		UNSIGNED	No	*None*		AUTO_INCREMENT
rfid_uid	varchar(255)	utf8mb4_general_ci		No	*None*		
name	varchar(255)	utf8mb4_general_ci		No	*None*		
created	timestamp			No	current_timestamp()		
location	varchar(5)	utf8mb4_general_ci		Yes	*NULL*		

	#	Name	Type	Collation	Attributes	Null	Default	Comments	Extra
	1	id	int(10)		UNSIGNED	No	*None*		AUTO_INCREMENT
	2	item_id	int(10)		UNSIGNED	No	*None*		
	3	log_in	timestamp			No	current_timestamp()		

Appendix I : SQL_INSERT statement

```
  sql_insert = "INSERT INTO items (name, rfid_uid) VALUES (%s, %s)"
lcd.clear()
lcd.message('Enter new Item')
new_name = input("Name: ")

cursor.execute(sql_insert, (new_name, id))
```

Appendix J: CHECK_PICKLIST prompt

```
pi@raspberrypi:~/orderpickingdb $ python3 check_picklist.py
Welcome to the Order Picking system
Scan your item now
```

Appendix K : Viewing Database entries on pi for list and items table

```
atabase changed
ariaDB [orderpickingdb]> SELECT * FROM ITEMS;
RROR 1146 (42S02): Table 'orderpickingdb.ITEMS' doesn't exist
ariaDB [orderpickingdb]> SELECT * FROM items;
----+--------------+-----------------------------+------------------+
---------+
 id | rfid_uid     | name                        | created          |
location |
----+--------------+-----------------------------+------------------+
---------+
  1 | 591997944397 | Turtle Beach Gaming Headset | 2020-03-13 13:32:04 |
B12B     |
  2 | 314661192079 | Samsung Smart TV 32"        | 2020-03-13 13:59:27 |
A12A     |
  3 | 857429401596 | logitech G502 Gaming mouse  | 2020-03-13 14:22:46 |
B12C     |
  4 | 650130251614 | HP Monitor 27"              | 2020-04-05 14:00:50 |
A11B     |
```

```
MariaDB [orderpickingdb]> SELECT * FROM list;
+-----+---------+---------------------+
| id  | item_id | log_in              |
+-----+---------+---------------------+
|   1 |       1 | 2020-04-05 13:04:42 |
|   2 |       1 | 2020-04-05 13:04:44 |
|   3 |       1 | 2020-04-05 13:04:46 |
|   4 |       1 | 2020-04-05 13:04:49 |
|   5 |       1 | 2020-04-05 13:04:51 |
|   6 |       1 | 2020-04-05 13:04:53 |
|   7 |       1 | 2020-04-05 13:04:55 |
|   8 |       1 | 2020-04-05 13:04:57 |
|   9 |       1 | 2020-04-05 13:05:00 |
|  10 |       1 | 2020-04-05 13:05:02 |
|  11 |       1 | 2020-04-05 13:05:07 |
|  12 |       1 | 2020-04-05 13:05:09 |
```

Appendix L : Installing NGINX

```
pi@raspberrypi:~ $ sudo apt-get install nginx
Reading package lists... Done
Building dependency tree
Reading state information... Done
nginx is already the newest version (1.14.2-2+deb10u1).
The following packages were automatically installed and are no longer required:
  apache2-data apache2-utils
Use 'sudo apt autoremove' to remove them.
0 upgraded, 0 newly installed, 0 to remove and 0 not upgraded.
```

```
pi@raspberrypi:~ $ hostname -I
192.168.1.40 fdaa:bbcc:ddee:0:d13:579e:dbe0:f827
```

Appendix M : Full Inventory Database list of items

Options

←T→	id	rfid_uid	name	created	location ▲ 1
Edit Copy Delete	10	316991717992	Dell Monitor 24"	2020-04-13 10:47:36	A11A
Edit Copy Delete	4	650130251614	HP Monitor 27"	2020-04-05 14:00:50	A11B
Edit Copy Delete	2	314661192079	Samsung Smart TV 32"	2020-03-13 13:59:27	A12A
Edit Copy Delete	6	39659487763	Panasonic TX-24G302B 24 inch TV	2020-04-06 13:24:48	A12B
Edit Copy Delete	8	1001715516148	Sonos smart speaker (Black)	2020-04-13 10:44:24	A22A
Edit Copy Delete	13	934284154151	Samsung Q6 soundbar	2020-04-13 15:10:40	A23A
Edit Copy Delete	9	248827396435	LG SK4D soundbar	2020-04-13 10:46:28	A23B
Edit Copy Delete	7	719651889134	Razor gaming keyboard (LED)	2020-04-13 10:37:32	B12A
Edit Copy Delete	1	591997944397	Turtle Beach Gaming Headset	2020-03-13 13:32:04	B12B
Edit Copy Delete	3	857429401596	logitech G502 Gaming mouse	2020-03-13 14:22:46	B12C
Edit Copy Delete	5	933752649976	ASUS VivoBook Laptop	2020-04-05 18:27:08	B21A
Edit Copy Delete	11	445023798466	Dell Inspiron Laptop	2020-04-13 10:51:17	B22A
Edit Copy Delete	12	353565874737	HP Pavillion Laptop	2020-04-13 10:52:39	B23A

Appendix N : Brochure (Observation Testing)

RFID Order Picking system

This brochure has been created to introduce an RFID order picking system which has been developed with the order picker in mind to help improve the efficiency of order picking operations in warehouses which use paper-based picklists to fulfil orders.

The Internet of Things (IoT)

IoT is a collection of computing devices which use Unique Identifiers (UIDs) to transfer data over a network without requiring a human or computer to do work. RFID is an example of adopting IoT as RFID is an automated technology requiring minimal interaction as objects are identified through radio waves.

RFID (Radio Frequency Identification)

RFID is a technology that is used for order picking, commonly used as picking devices in warehouses. They use smart labels/smart tags, which are placed on items and store item information. RFID enabled devices are more efficient compared to barcode scanners and other picking technologies. Furthermore, they allow asset tracking, where items in a warehouse can be located using the device and additional software. They can also interact with a warehouses WMS (warehouse management system) where inventory information is managed.

Purpose

The purpose of this RFID order picking system is to communicate a new way and improved way of order picking to warehouse employees and managers who are considering or want to implement a smarter solution to improve their picking operations.

"order picking is an important aspect within any warehouse; it forms as much as 55% of operation costs."

-www.adaptalift.com

RFID: HOW DOES IT WORKS?

RFID Order Picking System

The RFID Device

The RFID order picking device assigns each item in the warehouse a unique RFID to the item, replacing traditional SKUs used for barcodes attached to products. RFID technology is faster and

Items in the warehouse are automatically uploaded to the WMS database with the log time the item was assigned to the database to track new inventory and each time the item is scanned to be picked or logged in to the system.

How the System Works

Replace paper-based order picking with the RFID Order picking system. This system will allow improved inventory management from scanning items and assigning the relevant item information, viewing a complete list of order items for picking and assigning location information for each item.

Complete your picking journey with ease- know where items are located in the warehouse and choose the most efficient picking strategy to reduce the time taken Travelling, Searching, Picking and extracting. Items are assigned on shelves based on weight – heavier items are more accessible to pick- reducing labor intensive work.

Order Items

ID	Name	RFID UID	Location	Log Time
1	Turtle Beach Gaming Headset	[illegible]	[illegible]	[illegible]
2	Samsung Smart TV 32"	[illegible]	[illegible]	[illegible]
3	Logitech G502 Gaming mouse	[illegible]	[illegible]	[illegible]
4	HP Monitor 27"	[illegible]	[illegible]	[illegible]
5	ASUS Vivobook Laptop	[illegible]	[illegible]	[illegible]
6	Panasonic [illegible] 24 inch TV	[illegible]	[illegible]	[illegible]

"RFID Improves receiving efficiency and accuracy as well as picking and ordering accuracy."-
www.barcoding.com

Expand your inventory

The RFID system allows an unlimited amount of items to be scanned and stored in the WMS database.

For larger warehouses, antennas can be added across the warehouse to expand the signal range. For a warehouse with multiple order pickers, more RFID scanners can be added to the system. Each RFID scanner will have an authorized log in for added security, protecting vital inventory information and orders.

Appendix O: Reservation picklist

Reservation 1			
Product	SKU	quantity	Price
LG OLED55C9MLB 55" Smart 4K Ultra HD HDR OLED TV with Google Assistant	671081	1	1299
LG SK8 2.1 Wireless Soundbar with Dolby Atmos	233487	1	129.99
SANDSTROM Gold Series S1HD315 Premium High Speed HDMI Cable with Ethernet	128479	2	39.99

Appendix P: Ethical Approval for observation testing and survey

Permission For Observation Testing and Survey

ETHICAL APPROVAL

The purpose of this document is to obtain permission to carry out an observation test and survey which will investigate current picking operations used for picking customer reservations. The feedback gathered from the observation will aid the evaluation for an Undergraduate Honours project. the project aims to determine:

Which IoT technologies have the potential to be adapted to address issues with efficiency in order-picking warehouse operations?

Permission is granted for the following order pickers:

John Jamieson

Graeme Barr

Ross Boyd

Costas Shakas

Jamie Rankin

Permission is granted by:

Michael Nuttall (store manager)

To allow the observation test to be carried out at Currys PC world by **the stated order pickers**. Furthermore, the order pickers grant their permission to have **shared via email** a project outline, brochure and a survey link

Observation Requirements: *I, the author, will ensure that the observation test is carried out outwith business hours to reduce distruption. Furthermore, I will ensure that the survey is emailed to the participants with only the stated content:*

A link to the online survey
A brochure outlining the project
A project overview of the project objectives

APPROVAL OUTLINE: *I, the order participant, hereby authorize to participate in an observation test and carry out a survey which I will receive by email.*

SIGNATURES

John Jameson	Graeme Barr	Costas Shakas
Jamie Rankin	Ross Boyd	Michael Nuttall

Project Organizer Signature: Maria Sabatini

Appendix Q: Ethical Approval for Interactive testing and Interview

Permission For Interactive Testing and Interview

ETHICAL APPROVAL

The purpose of this document is to obtain permission to carry out an **interactive test** and **interview**, which will investigate current picking operations. The feedback gathered from the interview will aid the evaluation for an Undergraduate Honours project. the project aims to determine:

Which IoT technologies have the potential to be adapted to address issues with efficiency in order-picking warehouse operations?

Permission required for the following participants:

Jean-Mike Bonjotin

Abbie Madigan

Brendan Barclay

Karen Konkon

Fabio Jackson

Amara Sewrage

Author statement: *I, the author, will ensure that the interactive test is carried out in a safe environment which replicates as closely as possible, a warehouse layout. I will ensure that the participants only carry out tasks which are discussed with the participants during the verbal briefing of the project outline. I will ensure that the participants fully understand the nature and purpose of the project*

APPROVAL OUTLINE: *I, the order participant, hereby authorize to participate in an interactive test and participate in a one-to-one interview to provide my feedback.*

SIGNATURES

Jean-Mike Bonjotin	Brendan Barclay	Fabio Jackson
Abbie Madigan	Karen Konkon	Amara Sewrage

Project Organizer Signature: Maria Sabatini

Appendix R : Interview Questions and related literature

INTERVIEW QUESTION	RELATED LITERTURE AND TECHNICAL REVIEW SECTION	LITERATURE AND CONCLUSIONS
1. Were you familiar with the capabilities of RFiD technology before using the system? If so, where and what type of RFiD technology are you familiar with ?	2.1 Examine the order picking process	
2. From using the system and your understanding of what order picking operations involve, how did the system improve your picking experience?	2.1 Examine the order picking process Hypothesis (1) Hypothesis (2)	(Bukchin, Khmelnitsky, *et al.*, 2012) "batching, picking sequence, storage policy, zoning, layout design, picking equipment and picking information strategies".
3. Based on the automated pick list you were provided with to pick items, compared to manual order picking, was it easier to pick items with the location and details provided for items? If so, how?	2.1 Examine the order picking process 2.2 Investigate Warehouse Management Systems (WMS) and IoT integration Hypothesis (1)	(Bartholdi & Hackman, 2011) • improving the tasks of the picker • travelling and searching 70% of the order-picking time • Warehouse Management System (WMS) integration (Petersen & Aase, 2004) order batching + other policies = reduce picking time by around 20%.
8. what aspect of the location feature do you think could be improved for the system? Explain why?	2.3 An investigation into IoT technologies for picking operations Hypothesis (1)	(Lee & Lee, 2015) inventory location tracking measurability and availability
4. From the warehouse layout you picked from, how did the inventory layout improve your picking efficiency ? Did the system prevent you moving between shelves to find items?	2.1 Examine the order picking process 2.2 Investigate Warehouse Management Systems (WMS) and IoT integration Hypothesis (1)	(de Koster, Le-Duc *et al.*, 2007) quantity of an item(s) and the distance between items (Chiun-Ming Liu, 2004) reduce the order picking time and distance travelled
5. Did you find it easy to read and write data to the RFID tags ? If not, what could be improved ?	2.2 Investigate Warehouse Management Systems (WMS) and IoT integration 2.3 An investigation into IoT technologies for picking operations Hypothesis (1) Hypothesis (2)	(Lihong Jiang *et al.*, 2014). RFID readers integrating relational databases for handling structured data
7. Did the interface display information quickly from when you assigned data to the RFID tags?	2.2 Investigate Warehouse Management Systems (WMS) and IoT integration Hypothesis (1) Hypothesis (2)	(Rautmare & Bhalerao, 2016) MySQL was more stable during the experiments. (A, N. Subramanya & M. Rangaswamy, 2012) WMS reduced the picking time by 49 minutes- 77.78% improvement

Appendix S : Interview Results

INTERVIEW QUESTION	INTERVIEW RESULTS					
1.	**Yes, I was familiar with RFID, but I did not know it had so much to offer for the context it is being used for.**	No, I was unsure about what RFID technology was.	Yes, I use RFID scanners in work to check stock levels – the additional features in this systems goes beyond	No, I only knew that RFID technology was used for tags in cards for hotel keys, transport etc. – things that require scanning	No, I did not know about RFID technology at all	Yes I work in the airport, and RFID technology is used for passport scanning and many other things
2.	**I was able to pick items based on the item category – having the items assigned to individual bays with numbered positions reduced the time taken to pick items compared to manual picking**	I was able to plan my picking strategy – I chose items from the same shelf first	I thought it allowed safer order picking, having heavier items at the bottom made sense for the picking plan I used to pick quickly	I picked faster using the RFID order picking system; I like that the system has the details of the items	I was able to pick items – if it was in a real warehouse I would have planned to pick heavier items with a forklift or similar	I was able to plan a picking sequence, for example, I picked all items in bay A (A!, A2) first then bay B (B1, B2)
3.	**Yes, the location feature improved the picking time**	Yes, I spent less time searching for items	Yes, the location feature is something I wish the RFID scanners in my work had – so I can find items quicker in the warehouse	Yes, I noticed that when I picked manually, I spent too much time matching the item model to the picklist	Yes, I think the location of the item and the read functionality improved picking accuracy	Yes, I picked all items correctly compared to manually picking items – I could use the RFID reader to check the item for me
4.	It could be improved by automatically assigning a location rather than typing it	I wouldn't change anything about it	I think the warehouse layout should be shown to decide where to put the item	Adding an automatic location identification to scan in lots of items at the same time	Showing the route to pick the items	Nothing
5.	Yes I wasn't moving constantly between the shelves	Yes, compared to picking manually the location feature improved my searching task	Yes, the layout was easy to use, I used the RFID scanner to read the item	Yes, the layout was a great consideration – especially for tech items – the layout by weight helped	Yes, the logic was clear when I picked items. I didn't have to search for ages	Yes, I picked quicker than the manual system. I could find all the items easily
6.	**Yes I found it easy as the LCD screen guided me**	Yes it was a simple task	Yes, it was easy to use – the functionality was similar to the RFID scanners I use in work	Quite, however, it would have been better to have tags integrated on to the products	Yes, I found it easy – I like how the system displayed command prompts	No, I would have preferred a larger LCD screen

Appendix T : Interactive Testing warehouse layout setup