UNIVERSITY OF PORTSMOUTH

Integration and Optimisation of an RFID-Enabled Inventory Management System of a Future Generation Warehousing System

by

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Abstract

It is widely accepted that future generation warehouses require a real-time visibility and accuracy of inventory data in order to maintain efficient and effective warehousing operations, optimal SKU levels, and up-to-date inventory management and control of incoming and outgoing goods that often occur today at increasingly centralised distribution centres. This phenomenon is partially due to a sharp rise of online shopping activities in many countries where customers now prefer to purchase goods online and demand a fast delivery of ordered products to be dispatched directly at their door steps. Thus, there is a strong desire from supply chain and logistics sectors to seek even more efficient and cost-effective methods for sorting, storing, picking and dispatching goods at increasingly centralised distribution centres in which automation and integration of warehousing systems is inevitable. As part of a research programme for future generation warehouses, this thesis presents an investigation into some design theories and an integrated optimisation methodology for a future generation warehousing system in which an RFID-based inventory management system has the capability of interacting with a proposed RFID-enabled automated storage and retrieval mechanism without any human intervention. An efficient item selection algorithm based on pre-defined rules was developed and implemented within an RFID-based inventory management system, which also allows a manipulation of RFID-tracked items to seek an optimal solution by assigning a priority to one of selected items to travel in an order (if applicable) with both minimal travel time and waiting time to a specified collection point; this maximises efficiency in material-handling and minimises operational costs. A pilot test was established and carried out based on the proposed RFID-enabled inventory management system for examining the feasibility and applicability of its embedded RFID-enabled item-selection optimisation algorithm. Experimental results demonstrate that the developed methodology can be useful for determining an optimal solution (or route) for the RFID-enabled pusher to push a selected RFID-tagged item located randomly from a storage rack to an output conveyor system in a sequence that allows all the selected items traveling to a specified collection point with a minimal waiting time for packing. In theory, such a system can also be expanded by incorporating other pre-defined selection parameters as requested by users. Moreover, a multi-objective model using the multi-criterion fuzzy programming approach was developed and used for obtaining a trade-off decision based on conflicting objectives: minimisation of the total cost, maximisation of capacity utilisation, maximisation of service level and minimisation of travel distance within the proposed warehousing system. The developed model also supports design decisions in determining an optimum number of storage racks and collection points that need be established for the proposed warehouse. To reveal the alternative Pareto-optimal solutions, a decision-making algorithm namely TOPSIS was also employed to select the best Pareto-optimal solution obtained using the multi-criterion fuzzy programming approach. Case-studies were also conducted to demonstrate the feasibility and applicability of the developed multi-objective model and optimisation methods. The study concluded that the research work provided a useful basis by developing a framework as part of contributions in design theories and optimisation approaches for integration of future generation RFID-based warehousing systems and a practical means of exploring the further work in this field.

Keywords: Warehouses, Inventory, RFID, Automation, Integration, Optimisation, Supply chains.

Declaration

This is to certify that I am responsible for the work submitted in this thesis, that the original work is my own except as specified in acknowledgments or in footnotes, and that neither the thesis nor the original work contained therein has been submitted to this or any other institution for a higher degree.

Author's signature ……………………………………………………………………

Date ………………………

Publications

Journal

- A. Mohammed, Q. Wang, S. Alyahya, N.Bennett “Design an optimisation of an RFID-enabled warehousing system under uncertainties: a multi-criterion fuzzy programming approach”, The International Journal of advanced manufacturing technology, 91(5), pp.1661-1670, 2016.
- S.Alyahya, Q.Wang, N.Bennett, “Application and integration of an RFID-enabled warehousing management system - A feasibility study”, Journal of Industrial Information Integration, Vol. 4, pp. 15-25, 2016.

Conference

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- S. Alyahya, Q. Wang, “An RFID-embedded mechanism of automated storage and retrieval racks”, International Conference on Electrical, Electronic and Computer Engineering Technologies (ICEEECET 2016), pp.62-77, Shanghai, China, April 2016.
- Q. Wang, S. Alyahya, N. Bennett and H. Dhakal, “An RFID-enabled automated warehousing system”, 2015 International Conference on Robotics, Mechanics and Mechatronics (ICRMM 2015), Singapore, March 2015; International Journal of Martials, Mechanics and Manufacturing (IJMMM), Vol. 3, pp. 287-293, 2015.
- S. Alyahya, Q. Wang, G. Yang, “Mathematical modelling of a U-shaped assembly cell using flexible workers”, Academic Journal of Art and Sciences’ *(IJAS) Conference*, Academic Journal of Science, Vol.1, No.2, pp.21-26, Boston, USA, May 2012.

Research Seminar

- S. Alyahya, “Application and integration of an RFID-enabled warehousing management system– a feasibility study”, University of Portsmouth, UK, 9th December 2015.

Abbreviations

IT: Information Technology.

RFID: Radio Frequency Identification.

TX: Transmitter Antenna.

RX: Receiver Antenna.

NFC: Near Field Communication.

FFC: Far Field Communication.

EMF: Electro-Magnetic Fields.

UID: Unique Identification.

PWM: Pulse Width Modulation.

HF: High Frequency.

LF: Low Frequency.

UHF: Ultra High Frequency.

EPC: Electronic Product Code.

RTD: Row Tag Database.

SKUs: Stock Keeping Units.

Auto-ID: Automatic Identification.

WMS: Warehouse Management System.

DWMS: Digitalised Warehouse Management System.

RMS: Resource Management System.

ECA: Event-Condition-Action.

RICMS: RFID-based Inventory Control and Management System.

PLM: Product Life Cycle Management.

ERP: Enterprise Resource Planning.

AIM: Application Implementation Methodology.

WSN: Wireless Sensor Network.

LabVIEW: Laboratory Virtual Instrumentation Engineering Workbench.

LAN: Local Area Network.

WLAN: Wireless Local Area Network.

PLC: Programmable Logic Controller.

AS/RS: Automated Storage and Retrieval System.

AS/RR: Automated Storage and Retrieval Rack.

ACO: Ant Colony Optimisation.

VNS: Variable Neighbourhood Search.

BOSC: Build-to-Order Supply Chain.

B2B: Business-to-Business.

RPC: Returnable Produce Container.

AGV: Automated Guided Vehicle.

EOQ: Economic Order Quantity.

ICs: Integrated Circuits.

PET: Polyethylene Therephtalate.

RC: Reader Coordinator

DC: Data Collector.

IDE: Integrated Development Environment.

LLRP: Low Level Reader Protocol.

MVS: Microsoft Visual Studio.

ORM: Object Relational Mapping.

API: Application Programming Interface.

ODBC: Open Database Connectivity.

GUIDE: Graphical User Interface Development Environment.

GUI: Graphical User Interface.

DMS: Database Management System.

Table of Contents

List of Figures

List of Tables

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Chapter 1 Introduction

1.1 Research background

The traditional concept of automated warehousing systems often refers to applications of automatic storage and retrieval modules, lifting equipment, robots, AGVs (automated guided vehicles), conveyor systems and so on for stacking, picking and transporting incoming and outgoing goods of a distribution centre. These facilities are used to overcome some disadvantages of manually operated warehouses which often lead to a high frequency of human errors, a consistent increase of labour costs and poor efficiency of material-handling operations. In recent years, it has been seen an exponentially rising number of customers who like ordering products online and expect a fast delivery of ordered products to be dispatched directly to their door steps. Because of this new type of online shopping habits, many traditional stores (or warehouses) are no longer suitable for satisfying such demands of online shoppers who require the service as described above. A study through a literature review shows that future generation warehouses may be designed and implemented as more centralised distribution centres that partly replace conventional stores or warehouses of manufacturers, suppliers and retailers in supply chain and logistics sectors (Wang et al., 2010). This requires a novel design of a more efficient and cost-effective mechanism of automated storage and retrieval systems as a key element of distribution centres for sorting, storing, picking and dispatching goods. Implementation and integration of fast-growing IT technologies have demonstrated great improvement opportunities of a warehouse in terms of a tighter inventory control, a shorter response time and a greater variety of SKUs (stock keeping units). These capabilities can be enhanced by using smart-labels such as radio frequency identification (RFID) tags, automatic identification (Auto-ID) sensors, wireless communication networks and indoor warehouse management systems (iWMS).

In the past decade, applications of RFID-related techniques or systems have increasingly been becoming popular particularly in logistics and supply chain sectors. A latest literature review provided a summary in benefits, challenges and future trends in RFID applications (Ming et al., 2013). Further, Sahin et al. (2007) presented a literature review by examining the impact of inaccurate data records on inventory management and suggested the potential of the RFID-technology to tackle this issue.

Wang et al (2010, 2015) investigated the trend of future generation automated warehousing systems and proposed a framework of an RFID-enabled automated warehousing system aiming to maximise utilisation of warehouse capacity and efficiency of warehouse material-handling operations. Wang et al. (2010) introduced an RFID-based warehouse management system (WMS) in which events were managed and controlled under so-called event-condition-action (ECA) rules. Chow et al. (2006) proposed an RFID-based resource management system (RFID-RMS) in which a pure-integral-linear programming model using the branch-bound algorithm for determining an optimal travel distance of a material-handling forklift in a warehouse. Liu et al. (2006) carried out some experiments on an RFID-based resource management system and results showed an improved utilisation of rack space and a reduction in operational errors. Poon et al. (2009) developed an RFID-based logistics resource management system which shares data with a warehouse database that manages order-picking operations. Ting et al. (2012) applied an RFID-based inventory control and management system (RICMS) into a manufacturing enterprise providing the integrity of records in transaction and location of goods. Ross et al. (2009) examined an RFID-based decision maker using a simulation model incorporating major operations (receiving, storing, picking and shipping), which occur in a typical warehouse. The decision maker can be useful for evaluating operations of a distribution centre and examining alternative RFID implementation strategies. Xu et al. (2013) introduced an optimisation method for implementing an RFID-enabled warehouse management at varying SKU levels.

Integration of RFID-based systems is an important task for future generation automated warehousing systems. Liu et al. (2009) conducted a case study by integrating an RFID system into an enterprise resource planning (ERP) system focusing on two modules: an electronic receiving module and an inventory transaction module. Wang et al. (2014) discussed a number of key challenges in integration of wireless sensor networks (WSN) with RFID systems providing an infrastructure for data acquisition, distribution and processing in a manufacturing environment. Zhou et al. (2008) proposed an adaptive protocol for an RFID-WSN which integrates the RFID-based warehouse management system for tracking goods. Jehng et al. (2008) integrated the RFID system into an automatic conveyor system in which material flow was monitored and traced in a real time manner as each product was attached with an RFID tag. Zhai et al. (2016) presented a real-time locating system (RTLS) based on Internet of Things (IoT) seeking more accurate positions in interested sites and scalable system topology with a flexible system capacity. In summary, it has been widely accepted that applications of RFID techniques can facilitate automation of storage and retrieval operations of a warehouse. Compared to a conventional warehouse using the barcode approach, implementation of RFID systems has demonstrated a significant improvement in warehouse data handling efficiency and space utilisation (Liu et al. 2009). Within an RFID-based automated storage and retrieval mechanism, each item in a tote (or a tote containing identical items) is attached with an RFID tag so that these items can be traced, sorted and inventoried in a real-time manner under an integrated RFID-inventory management system. Ideally, this system can also interact with the control system of the automated storage and retrieval mechanism. By implementing the RFID-enabled mechanism of the proposed warehousing system, each item can also be stored and dispatched in a storage rack (S/R) at any random location wherever a place is available for incoming or outgoing goods.

In other relevant developments, the multi-objective optimisation approach can be useful for obtaining a trade-off solution among conflicting objectives in logistics and supply chain management relating to such as facility location-allocation and costs (Gen and Cheng, 1997; Deb, 2001). Messac (2015) defined the multi-objective optimisation as "*a methodical approach to solving problems involving several competing design objectives simultaneously".* The fundamental principle of this is that a compromised solution can always be achievable to prioritised objectives, accordingly. Ma et al. (2015) formulated an automated warehouse as a constrained multi-objective model aimed at minimising the scheduling quality effect and the travel distance. Huang et al. (2015) proposed a nonlinear mixed integer program under probabilistic constraints for site selection and space determination of a warehouse by minimising the total cost in inbound and outbound transportation and the total cost in warehouse operation in a two-stage network. Lerher et al. (2013) investigated the design in optimisation of an automated storage and retrieval system aiming to minimise the initial investment and annual operating cost of the system. A genetic algorithm was used for the optimisation process of decision variables. Furthermore, Lerher et al. (2013) proposed a mono-objective optimisation approach for seeking the cost-effective design of an automated warehouse. In brief, the literature review indicated that there were very limited studies according to previous publications in optimising the design of RFID-based automated warehousing system using the multi-objective method.

This thesis presents a study on design theories and an integrated optimisation methodology as part of the on-going research work for future generation automated warehousing systems (Wang et al., 2010). The study provides a framework in development of an integrated optimisation algorithm that is embedded into an RFID-based inventory management system. Such a system has a capability to seek an optimal solution to select an in-store item with an assigned priority in an order to be pushed on and transported through an automated conveyor system to a specified collection point within the proposed RFID-based automated warehousing system, which has the potential capability of interacting directly with the RFID-based inventory management system. Furthermore, this thesis also presents a study using the multi-objective method as an aid for optimising the design of the proposed RFID-enabled automated warehousing system. The aims and objectives of this research work are outlined below.

1.2 Research aim and objectives

The PhD research work was aimed at investigating the latest developments of RFID-based inventory management and systems integration for future generation automated warehousing systems at increasingly centralised distribution centres due to the trend of online shopping activities. Based on these, the research work was aimed at developing an RFID-based efficient item-selection algorithm that can be embedded and integrated into an RFID-based management system for a proposed RFID-enabled automated storage and retrieval mechanism. This includes an establishment of a pilot test to examine the feasibility and applicability of the developed methodology for the system integration of hardware and software. A multi-objective optimisation model using the multi-criterion fuzzy programming approach was also developed as an aid of decision making to maximise the warehouse capacity utilisation and service level of satisfying all demands of dispatching products from the warehouse, minimise the travel distance of products from a storage rack to a collection point and the total cost required for implementing RFIDs into the proposed automated warehousing system. The developed model also supports design decisions in determining an optimum number of storage racks and collection points that need be established for the proposed warehouse. The detailed objectives of this research work are as follow:

- To carry out an industrial survey relating to the issues of RFID-based management systems for future generation automated warehouses.
- To develop a framework in design theories and/or a methodology for an RFID-based inventory management system that can be integrated into the control system of a proposed future generation RFDI-enabled automated warehousing system (Wang et al., 2010).
- To create an optimisation algorithm embedded into the RFID-based inventory management system to determine and generate a shortest travel time of selected items in a pick-up sequence (if applicable) and route for material-handling equipment.
- To identify and propose a cost-effective infrastructure of the RFID-enabled communication system for the proposed automated storage and retrieval racks (AS/RR).
- To develop an integrated program containing a scheduling a job priority algorithm for the RFID-based inventory management system.
- To develop GUI using MATLAB allowing a visualization in changing locations of any possibly selected item in the warehousing system in order to determine the optimal selection of the specified/ordered item.
- To develop an optimisation mathematical model using the multi-objective approach for 1) obtaining a trade-off solution among four conflicting objectives; 2) supporting design decisions with the optimum number of racks and collection points that should be established.
- To set up and execute a pilot test for examining the feasibility and applicability of the RFID-based inventory management system for the proposed AS/RR mechanism using the developed methodology and the integration approach.
- To carry out a cost analysis on existing inventory tracking systems using barcode and RFID, respectively.

1.3 Thesis organisation

Research background

This chapter presents a research background and addresses the research problems which motivated this research work. The aim and objectives are included.

Industrial survey

Collected information through an industrial survey.

Literature review

This chapter provides a relevant literature review related to this work. It includes a study in conventional and modern automated warehousing system operations.

Key components of the RIFD system

Database, RFID (Tags, reader, antenna), Connectivity of RFID system, Cables of the RFID systems, RFID Controllers and RFID Software.

Mechanism of the proposed RFID-based AS/RS

This chapter describes Mechanism of the proposed RFID-based automated warehouse system and its measurement.

Programme integration approach

This chapter describe the RFID-enabled warehouse management system and programme integration approach. It also includes the RFID-related components.

Pilot study

This chapter shows the experimental results through a pilot test using the developed optimisation algorithm and integration approaches based on the proposed RFID-based inventory management system.

The multi-objective optimisation

This chapter presents a study in developing a multi-objective optimisation model which was used for obtaining a trade-off decision for the proposed RFID-enabled warehousing system design towards four conflicted objectives.

Cost analysis

A real case study in a financial analysis of the library at the University of Portsmouth.

Conclusion and future work

The final chapter gives a summary of the research work and recommendations of future work and enhancement.

Chapter 2 Industrial survey and empirical analysis

A survey was carried out to a designated group of members by answering some questions relating to the issues of RFID-based management systems for future generation automated warehouses based on their own experience or knowledge in this field. The aim of the survey was to reveal the current state of warehouses in various forms, operations of distribution centre (DC) and management and future improvements by implementing latest developments of IT techniques and so on. The online questionnaire sheet in details can be found in Appendix A). These warehouses/distribution centres are conventional in which material movement is manually performed or relies on equipment operated by human operators. Manual material handling equipment are mostly operated within these warehouses. The size of warehouses varies which are between 25,000 and 50,000 square feet. A questionnaire was developed and sent via email to UK and oversees companies. Table 1 shows a total of 33 qualified responses which were received from managers in the relevance to their company's warehouse management system operations. The design of questionnaires was aimed at identifying warehouses' current system operations, these include the warehouse management system (WMS), information stored within the WMS, operators' productivity and performance, type of warehouse, real time inventory, human errors, e-commerce services, cost reductions and rated responses for future generation automated warehouse system.

Table 1: Qualified responses received from companies.

Valid		Missing		Total	
Number of respondents	Percentage	N	Percentage	N	Percentage
30	90.9%	3	9.1%	33	100.0%

The statistical package for the social sciences (SPSS), which is a computer program for statistical analysis, was used to run factor analysis and correlation analysis in this study (see Appendix A). The data of the survey in descriptive statistics were collected through a developed questionnaire sheet that is explained further in the following subsections.

2.1 Applications of database

The result of the survey shows more than 60% of respondents used the structural database, while approximately 18% of others used the unstructured database in the form of flat file. Microsoft is a leading provider of structural database software, almost 30% of respondents used Microsoft SQL database and Microsoft access almost 15%. In addition, approximately 20% of respondents used oracle database and almost 18% of respondents used MySQL database. The remaining respondents used the unstructured database management software. Based on the survey, it clearly shows that almost 80% of the respondents used computer database for their organisation~~,~~ in customer data and inventory tracking information for goods.

The top two primary reasons of using database were the storage of information of customers' details (27%) and product details (26%). Others include storage of information of supplier details (approximately 21%) and sales data (approximately 18%). The survey shows that 50% of the respondents have their database linked with enterprise resource planning (ERP). 44% of the respondents utilised MRP (material requirement planning), data are extracted on a periodic basis from MRP systems. Data from these systems can be cleaned, validated, formatted, analysed and linked with data from many other sources. The survey also shows that 60%of the respondents used a cloud database. In addition, slightly more than 50% of the respondents used customer relationship management (CRM) and approximately the same amount used application programming interface (API).

2.2 Warehouse operations

79% of respondents indicated the presence of a warehouse in their organisation. In terms of the preference for operators' performance measurements, 30% of respondents indicated that three main factors had an equal response: operator accuracy, operator speed and operator efficiency; 50% of the respondents used key performance indicators (KPIs) to measure performance within the warehouse. As shown in Figure 1, although 60% are aware of automated warehousing systems, only 21% of the respondents had fully automated warehousing systems, a third of the respondents had semi-automated warehousing system, and the rest of the respondents manually operated warehouses.

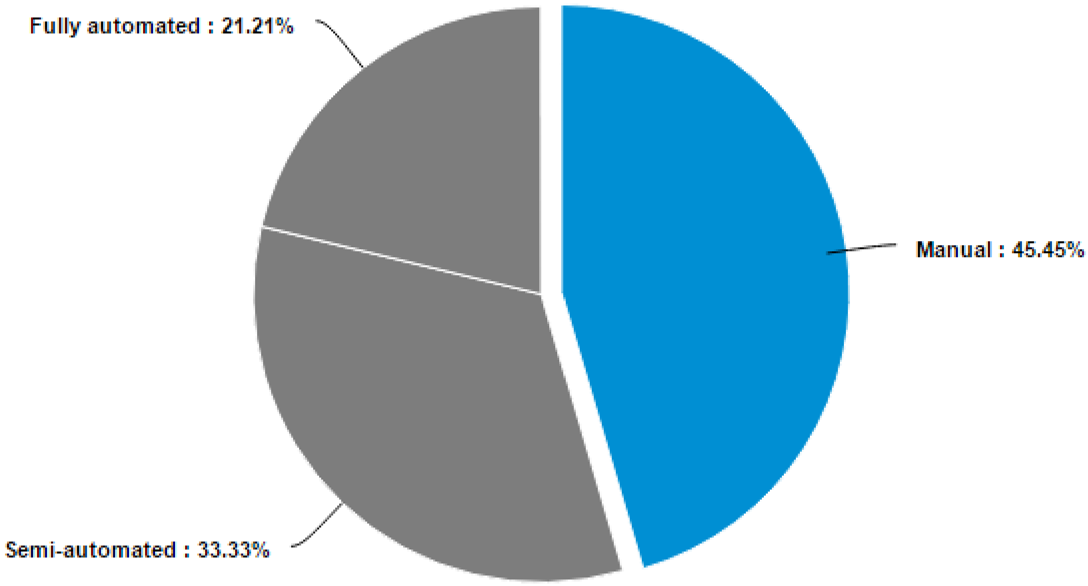

Figure 1: Share of manual, semi-automated and fully automated warehousing systems.

2.3 Inventory management

The survey found that nearly 63% of the respondents used the real-time inventory. As shown in Figure 2, 50% indicated that respondents used barcodes. 41% had voice picking and the remaining 9% relied on other technology in the warehouse. Predominantly, it was found that 70% of the respondents were aware of radio frequency identification (RFID). In contrast, only 44% knew of an RFID-based warehouse management system. Through the survey, accuracy, efficiency, operator speed and stock loss were rated equally important. Interestingly, the survey also revealed the estimated percentage in human errors to pick up 100 items in a manual warehouse was 34%.

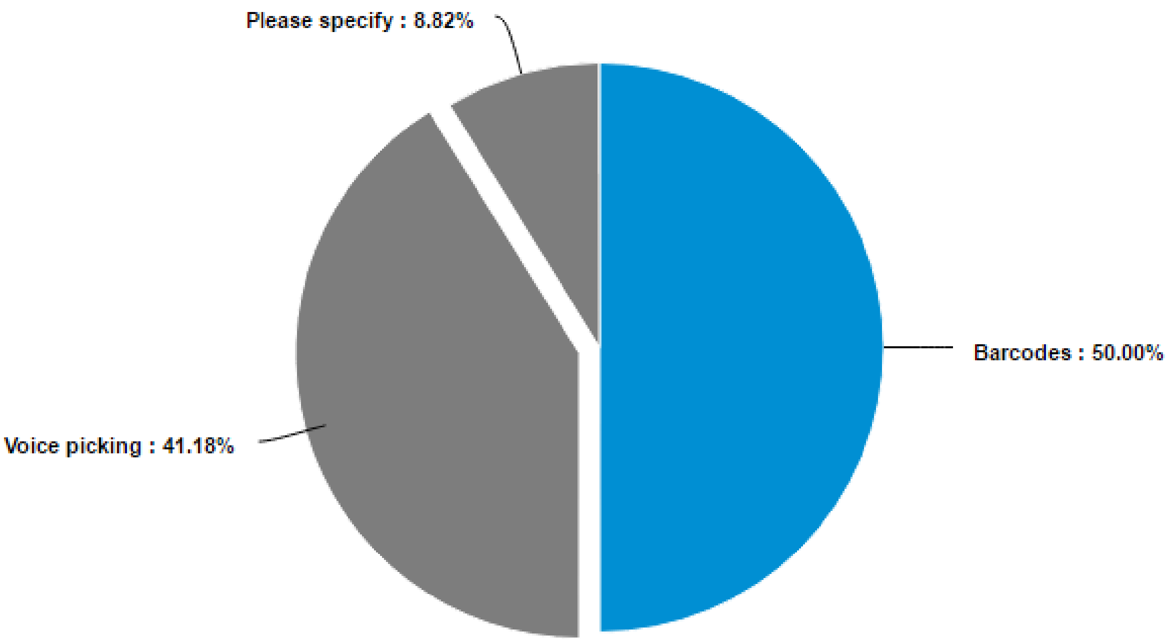

Figure 2: Barcodes, voice picking or other technologies within the warehouse.

2.4 E-commerce services

According to the survey, 44% of the respondents used e-commerce services. In terms of cost reduction to incentivise the use of e-commerce, 47% of the respondents indicated this was the case.

2.5 Delivery

According to the survey, three main types of delivery scored quite high. The next day delivery is most commonly used with a score of 40%. The same day delivery was the second most popular option at 31%, followed by three days' delivery at 22%. Additionally, 60% of the respondents indicated that their customers require flexibility for deliveries, although around 88% of the respondents considered the speed of delivery as an important factor. Furthermore, it was found that about 59% of the respondents had reserve and collect service.

Figure 3 illustrates the response rate of future generation automated warehouse system by the respondents through the survey. It indicates that almost 79% of the respondents scored high for the desire of future generation automated warehouse systems as it can create a more efficient use of storage space, operate instantly and reduce errors of manpower.

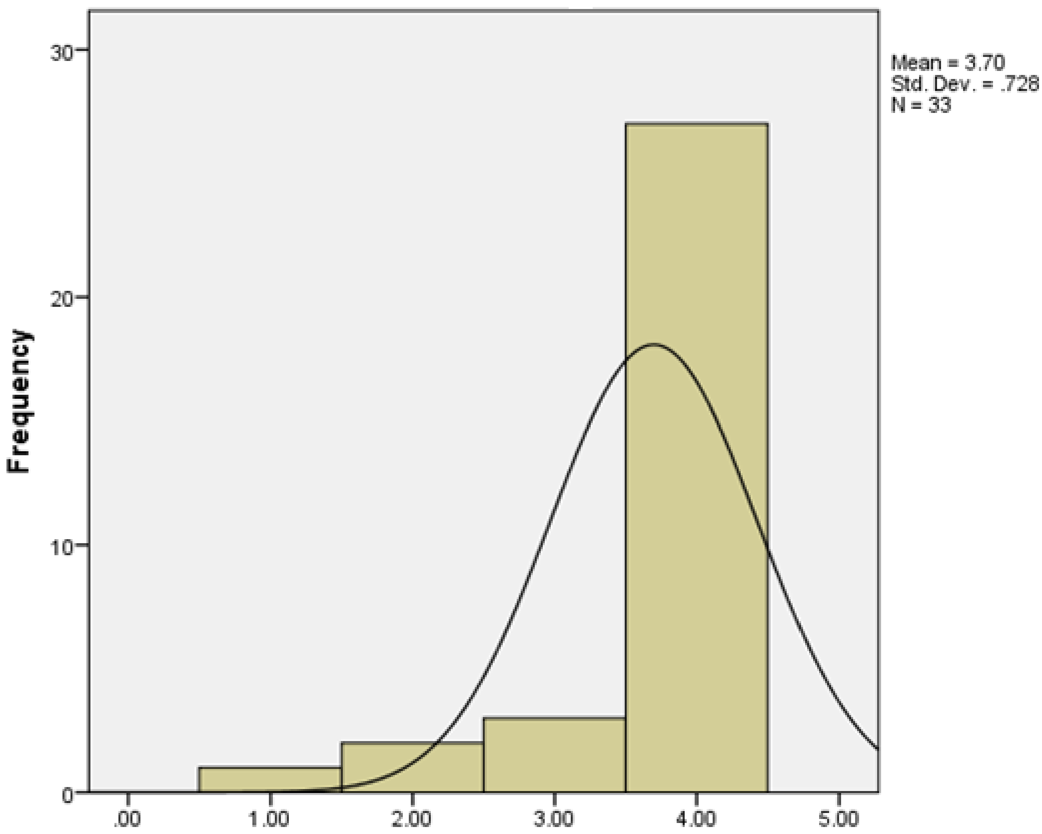

Figure 3: Response rate of future generation automated warehouse system.

Summary

A survey was conducted as part of this research work aimed to identify the current state of warehouse operations, the type of application database used, integration with other software (i.e., ERP, MRP…..), API usability, performance of warehouses used type of warehouse used, real time inventory, e-commerce services and type of delivery.

Chapter 3 Literature review

Warehouses primarily serve as storage points in a supply chain network between origins of raw materials and destinations for consumption of final products (Wang et al., 2011). Figure 4 illustrates a typical warehouse in operations, functional areas and product flows (Tompkins et al., 2003). Warehousing operations can be divided further into the following functions (de Koster, 2007; Lambert, 1998):

- **Receiving**: This consists of unloading the products from transportation vehicles to receiving docks, inspection of products for decencies or missing products, and updating warehouse inventory records to react changes.
- **Transfer or put away**: which includes operations in moving products from receiving docks to assigned storage locations, shipping docks or other areas in the warehouse, and moving products between these areas,
- **Order picking**: which consists of collecting required quantities of specified products from storage locations to satisfy customer orders,
- **Shipping**: which includes operations in loading products onto transportation vehicles, inspection of products to be shipped, and updating warehouse inventory records, sorting and packing products.

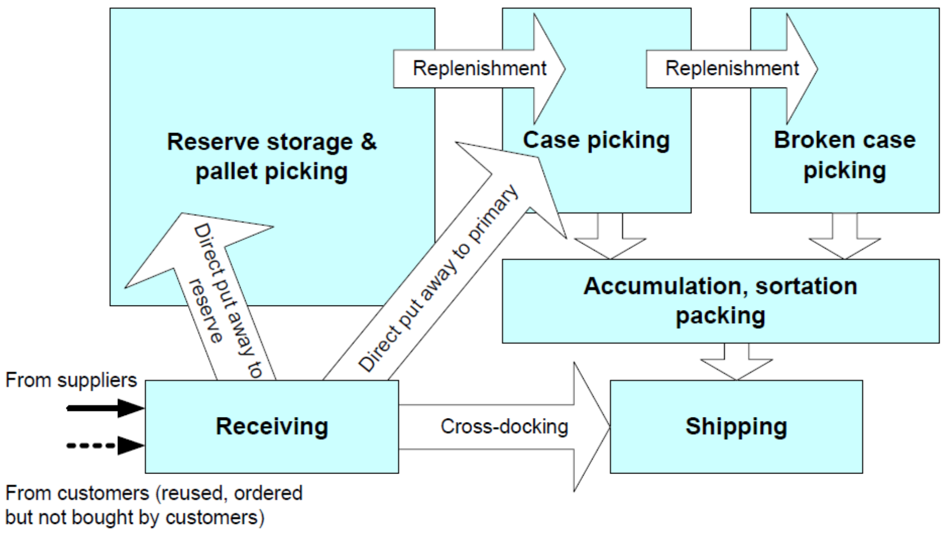

Figure 4: Typical warehouse functions (Tompkins et al., 2003).

These operations may be performed under a warehouse management system (WMS) which controls the storage and movement of materials and processes the transactions within a warehouse. The successful warehouse resources management is one of the most vital factors in terms of handling warehouse operations effectively and efficiently leading to satisfaction of demands of suppliers and customers (Poon et al., 2008). Inventory management is a key in logistics and supply chain management because inventory decisions are often a starting point for other business and operation activities. In addition, different organizations of warehouses may have different inventory management objectives (Marphy & Wood, 2011).

3.1 Inventory management systems

3.1.1 MRP/ERP

In other aspects, to develop cost-effective and efficient operations in manufacturing, reduction of costs and optimisation of operations is one area that needs to be addressed. A large part of this task relies on how manufacturing companies plan their operations, control inventory and organise logistics. Material requirements planning (MRP) is a time phased priority-planning technique that calculates material requirements and schedules supplies to meet demands across all products and parts in one or more plants (Hamid et al., 1991). MRP determines the quantity and timing in acquisition and demand of dependent items that needs to satisfy master schedule requirements. One of its main objectives is to keep the due date that equal to the need date aiming to eliminate material shortages and excess stocks. The MRP system breaks a component into parts or subassemblies, and generates plans for those parts to arrive into stocks when needed (Ghobbar et al., 2004). In the past decades, information technology has played a major role in designing and implementing MRP systems as it provides a platform for information integration from manufacturing needs that link with customer demand and existing inventory levels. MRP techniques are developed and used for bills of material (BOM) and net material requirement plans for future production. MRP are computer-based planning and scheduling systems designed to improve and enhance the management control of manufacturing. Extension of MRP systems may have capability to capture other manufacturing related requirements.

Several studies explored the effectiveness of using MRP in manufacturing sectors. Landvater et al. (1985) carried out a survey of 1800 companies and the result showed that 60% of these companies used MRP/MRPII. Advantages reported by the companies are: (1) reduction in inventory levels, (2) improvement of consumer services, (3) increase in productivity and (4) reduction in raw material costs. other management oriented inventory control techniques such as Just-In-Time (JIT) and Enterprise resource planning (ERP) also plays an important role (Lwiki et al., 2013), although small and medium enterprises and some larger companies still rely on past data and experience to determine amount of materials to purchase. ERP is an information system that supports company management integration and or an interaction among a group of cooperating enterprises ERP may also be as marital planning system or more commonly known as manufacturing resource planning. In the past decades, ERP has been widely used for managing the following business activities:

- Financials.
- Order processing, logistics.
- Sales, marketing, customer relationship management.
- Manufacturing processes & quality control.
- Service management.
- Budgeting & general forecasting.
- Human resources.
- Payroll.

In supply chain sectors, most ERP systems are used to collect, manage, store, and covert data from different business units across the organisation. Yüksel et al. (2011) introduced middleware software (ERP/MRP) for business models using RFID technology in a supply chain management. Liu et al. (2009) combined an RFID technology with an enterprise resource planning (ERP) system for resolving various wafer receiving and inventory transaction problems.

3.1.2 Warehouse management systems (WMS)

WMS is an inventory tracking software-based system in which it processes the incoming/outgoing transactions, including shipping, receiving, stock allocation, order picking and fulfilment. A WMS monitors the warehouse progress of items as follows:

- Inventory location assignments.
- Order picking & fulfilment management.
- Warehouse capacity management.

- Capability for data management.
- Cross docking management.
- Put-away and picking optimisation.
- Labour utilisation.

3.1.3 Lean management

Lean management is a concept that was first applied in the Toyota motor corporation in the 1950 (Hines et al., 2004). It was originally developed and applied by the Japanese due to the lack of natural resources and intense domestic competition in automobile industry in Japan. This method also made it possible for Toyota and other firms to achieve high levels of quality and productivity in manufacturing (Cusumano, 1994). Lean manufacturing helps in enhancing production processes and boosting up the employees' job satisfaction (Singh et al., 2010c). Gupta et al. (2013) argued that the traditional methods in dealing with manufacturing activities rely on a good management of inventory of the system, whereas lean manufacturing, however, considers the inventory as a waste in production and lean manufacturing focuses on the elimination of wastes in production, i.e., the waste of overproduction, the waste of waiting for parts to arrive, the waste of conveyance, the waste in processing, the waste of inventory, the waste of motion and the waste of rework (Ballé et al., 2005). Figure 5 illustrates the seven wastes identified in Lean Manufacturing.

By implementing lean manufacturing properly, it may increase efficiency in production outputs and operators and decrease in process inventory (or work in progress) levels of ongoing and finished goods (Seth et al., 2015). Ultimately, lean manufacturing system aims at eliminating all wastes if possible within the entire organisation. Dennis (2007) stated that the main goal of a lean manufacturing system is to produce products of higher quality at the lowest possible cost in the least time. Chen et al. (2013) applied lean production and radio frequency identification (RFID) technologies to improve the efficiency and effectiveness of supply chain management.

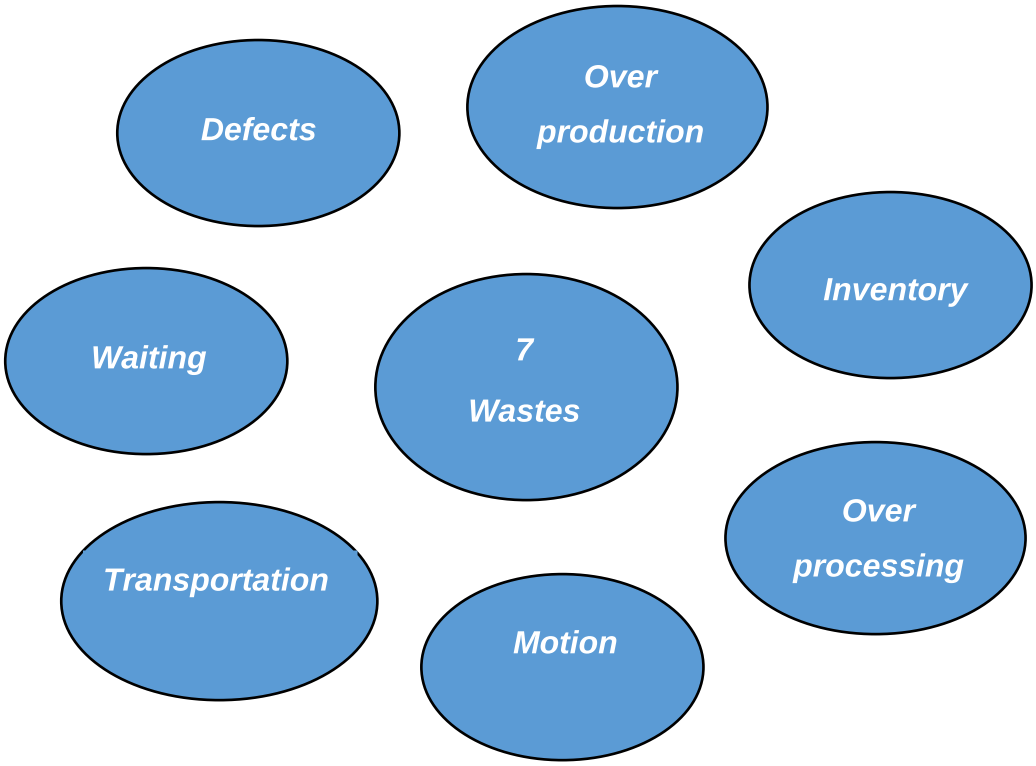

Figure 5: Seven wastes in lean manufacturing.

3.2 Manual warehouse

In manually operating warehouses, operators travel to a pick location, pick goods, and move these goods to the delivery point. Operators may also engage with forklift and conveyors that transport these goods in certain locations in the warehouse. This type of manual warehouse may lead to (Wang et al., 2010):

- Material handling inefficiency.
- Poor space utilisation.
- Slow process for stacking and dispatching.
- Low variety and high level of SKUs.
- Frequent human errors.
- Costs of labours Training.
- Accidents.
- Outdated inventory data.
- Poor inventory visibility.

Thus, many companies intend to replace traditional warehouse with automation.

3.3 Automated warehouses

Modern warehousing systems can be classified as mechanized (conventional) or automated. A combination of labour and handling equipment is utilised in mechanized warehousing systems to facilitate receiving, processing, and/or shipping operations. Generally, labour constitutes a high percentage of the overall costs in mechanized systems. Automated systems on the contrary, attempt to minimise the labour element as much as possible by flaking capital investment in equipment. An automated system operates faster and more accurate than a mechanized system. During the last two decades, researchers have developed a number of solution procedures in warehouse design and operation (Ashayeri et al., 1985).

Conventional automated warehouses use extensive conveyors, sortation equipment, automated storage and retrieval systems (AS/RS), and other material handling solutions. Qiu et al. (2013) proposed the concept of a supply hub addressing the construction of warehouses for manufacturing enterprises located within an industrial park. The research focused on evaluating the value of freight consolidation using the SHIP (Supply Hub in Industrial Park) approach. The warehouse is used as a switching facility rather than as a long-term storage house. Attention is paid to higher inventory turnover, lower operating cost, and shorter cycle time. Simulation methods are also widely used for automated warehouse design for seeking maximum space utilisation and increasing material flow to achieve a higher productivity and cost reduction that fits into the objectives of the effective supply chains. Advantages and disadvantages using automated systems, however, can be held against each other. Grant et al. (2006) listed some of the advantages and disadvantages as follows:

Advantages

- Cost reduction in labour.
- Increase of output rate.
- Reliability and time of service will be improved.
- The amount of material handling will be reduced.
- Increased accuracy level.
- Increased availability.
- Better working/ergonomics condition.

Disadvantages

- Initial capital cost might be high.
- Risk of downtime and unreliability of equipment.
- Software related problems.
- Lack of flexibility to respond to changing environments.
- Problems with the capacity.
- Maintenance interruptions and the related costs.
- User interface and training.
- Work acceptance.
- Obsolescence.

Automated warehouses are suitable for both boxed and palletised goods stored on shelves or racks. The automated storage and retrieval racks (AS/RR) are designed for undertaking a high volume of loads being moved into and out of storage racks. The load handling area is situated at one end of the shelves or racks and conveyor systems are installed to mechanise the movement of items from one place to another. The inventory of warehouse is controlled by the warehouse management system (i.e, WMS), which records information of all the in-store goods. The benefits of these are (Lerher et al., 2010):

- Automation of the product entry and exit operations.
- Saving space and time devoted to storage tasks.
- Elimination of manual handling errors.
- Ease of inventory data management, updating and control.
- Retrieval equipment guided by management software, which coordinates all warehouse movement operations.
- Reduction of damage and loss of goods.
- Decrease of the number of warehouse workers.

3.4 Internet of things (IoT)

Advances in enterprise information management, system control, inventory management, machines-to machines (M2M) communication, human-to-machines interaction and item tracking are shifting to a new paradigm of Internet of Things (IoT) for future industrial enterprise information systems (Zuehlke, 2010; Niu et al., 2013). Internet of Things (IoT) is defined as the ability of various things to be connected to each other through the Internet (Evangelatos et al., 2012). The goal of the Internet of Things is to enable things to be connected anytime, anyplace, with anything and anyone ideally using any path/network and any service (Vermesan et al., 2013). Examples include personnel positioning (Werb, et al., 1998), tool management, material and product tracking (Won et al., 2009; Cao et al., 2013; Zou et al., 2014), process control (Ma et al., 2011), assembly (Rakotondrabe et al., 2011) and mobile robot localisation (Song et al., 2012; Squire et al., 2014). The operating distance can be on a large scale, for example, a warehouse, or on a small scale, for example, a machine area, with required localisation accuracy from a few meters to centimetres. Consequently, a reliable and scalable real-time locating system (RTLS) becomes essential to enable enterprise location intelligence. In the Internet of Things (IoT) paradigm, many of the objects in the warehouse can be on the network in one form or another. Radio frequency identification (RFID) and sensor network technologies will rise to meet this new challenge, in which information and communication systems are invisibly embedded in the industry environment. This results in the generation of enormous amounts of data which must to be stored, processed and presented in a seamless, efficient, and easily interpretable form.

Internet of Things has some exceptional advantages as a new technology, to achieve the objects of the intelligent identification and management, improve resource utilisation and efficiency. Internet of Things can use RFID technology to achieve the exchange and sharing of information is an important means to break through the bottleneck of the times the items transparent tube through the open computer network (Yanhui, 2013).

Cloud-based inventory systems can track items in real-time by scanning them in and out of stock locations. Products usually have either an RFID tag or barcode label so they can be scanned and identified by the system. Currently, this is how inventory management systems can give an organization visibility into their inventory levels, expiration dates, item location, forecast demand, etc. Within the IoT, the ability to track and communicate with RFID-tagged products can be greatly increased and will be able to communicate the information with an inventory system. In this case, RFID tags will be built into objects, which will then be able to send information about the status of this object. Such an ability to track, and monitor inventory can be improved through integration of IoT. Within the IoT, it will eliminate human-to-human or human to machine interaction. Nevertheless, RFID is currently a better system for the inventory management system, this is due to the higher cost of the IoT which is still under development, more research is still required to make the IoT a reality.

3.4.1Technology Readiness Levels

TRLs are a systematic metric/measurement system that supports assessments of the maturity of a technology and the consistent comparison in maturity between different types of technology. As stated previously, academic interests in RFID technology have been growing in recent years particularly in supply chain management and logistics functions of retail sectors. McGuinness (2008) examined the readiness of the high-technology manufacturing industry to adopt and use RFID technology in its products and processes through a case study analysis of the Irish medical devices sector. Ly (2006) presented a readiness assessment method for the maturity of RFID technology in order to implement an automated checkout system at a supermarket. The readiness assessment results indicated that the levels 1, 2, 3 and 4 reached the maturity of the RFID technology. For the levels 5 and 6, the technology was still in yellow state because the current RFID tags do not transmit well on certain products such as liquids or metals. This limits the overall benefit of RFID until the problem is solved. In addition, the automated checkout system prototype neither demonstrated nor was completely tested in level 7 and 8. Finally, the level 9 was not achieved because the system failed to perform operations. Ebrahimi et al. (2015) conducted a study aimed at comparing the readiness of Shiraz University of medical sciences hospitals for implementation of RFID system. The study showed that the readiness level of the hospitals was moderate and the total readiness of hospital was higher than other hospitals. Despite the general acceptance of the superior benefits that RFID technology offers over competing auto-identification technologies, the level of adoption of RFID technology within manufacturing sectors remains small. Nevertheless, there appears to be a trend amongst many organisations that it may only be a matter of time before adoption of this technology becomes widespread (McGuinness, 2008).

3.5 RFID technology and applications

It is difficult to trace the history of RFID technology back to a well-defined starting point; Figure 6 illustrates the evolution of RFID technology from 1940 to 2000. The important decade for RFID technologies was in 1990s when the United States developed a regionally compatible electronic toll collection system using a signal tag and signal billing account vehicle to access the highways and bridges of several toll authorities (Landt, 2001). RFID is a term used to describe a system that transfers the identity information of an object or person wirelessly using radio waves. RFID is an automatic identification method in which an FRID system can store and remotely retrieve data using chips called RFID tags and RFID readers. A typical RFID system uses passive RFID tags to hold information, much like barcodes, but these tags can contain other more useful user-define information. These types of RFID tags are read by antennas that power RFID tags by interrogating them with a radio signal. There are also long-range RFID systems that use active and semi-active battery-powered RIFD tags rather than using interrogating radio frequencies. RFID tags are often used to identify pallets and large packages in logistic and supply chain sectors. Implementation of RFID systems has also become popular in healthcare settings as it allows nurses access medication cabinets, track medication inventory, equipment and staff, and patients within a RFID system. In supermarkets or big stores, implementation of an RFID-system can track and trace the stock from a supplier to a customers' shopping trolley (Brown, 2007).

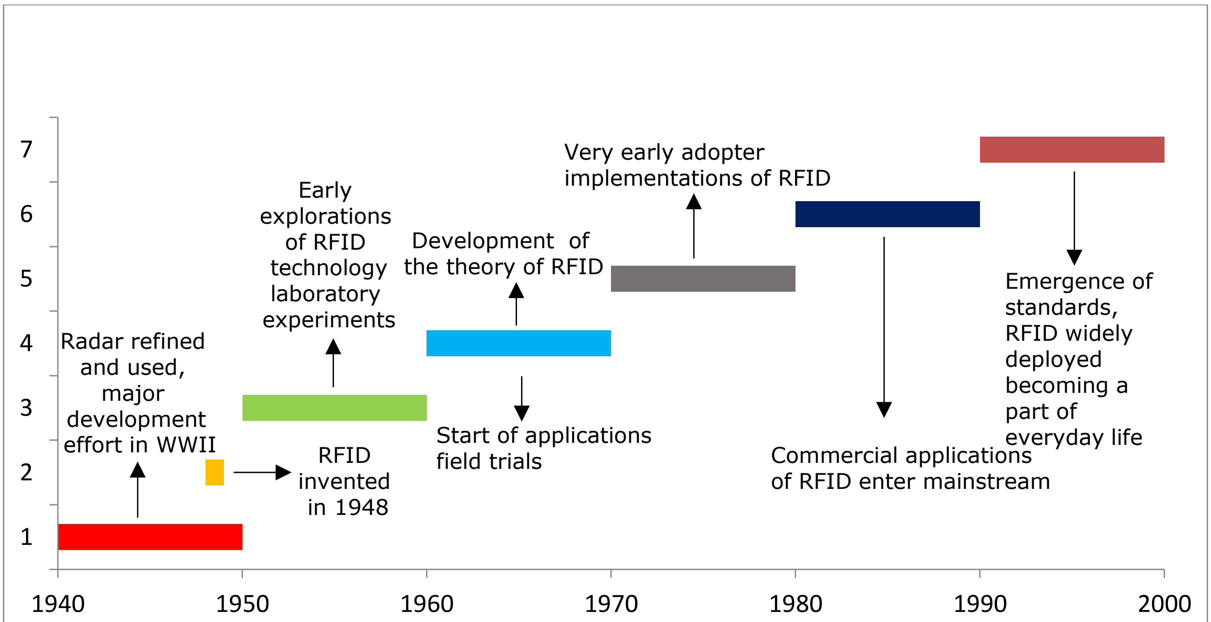

Figure 6: Evolution of RFID technology (author's compilation).

RFID offers a number of advanced properties in terms of its ease of communication and real-time information (Saygin et al., 2007). Leung et al. (2007) summarised the benefits of using the RFID technology. Roberti (2003) showed a study that out-of-stock items with RFID were replenished three times faster than items using the standard barcode technology. Sounderpandian et al. (2007) presented a study in costs of implementing RFID technologies in a supply chain. Due to recent developments in data processing and microelectronics, RFID components are becoming smaller, much less expensive and more effective. The RFID applications also includes sectors of retail, textile, healthcare, automotive and luxury goods. For instance, in the competitive textile and fashion industries, RFID is an effective means by which it provides a quick response to customers in identifying counterfeits and genuine products. In pharmaceutical industry, RFID are used for tracing the whole life cycle system in raw material supplies, production, transportation and storage. Figure 7 shows the report in penetration of active RFID into different application sectors over the next ten years (2009–2019).

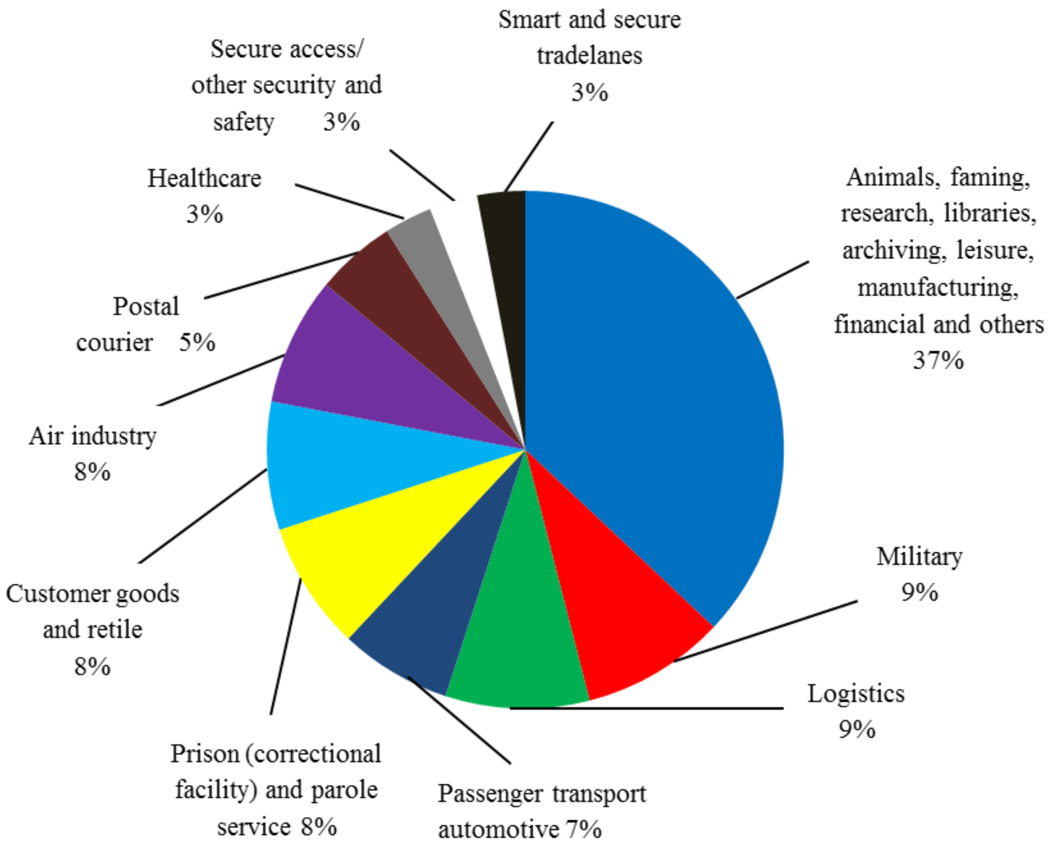

Figure 7: RFID applications into different sectors (Harrop et al., 2010).

The latest development of RFID techniques has gained even greater attention in logistics and supply chain sectors where the implementation of a RFID-integrated information management system is becoming increasingly desirable (Bagchi et al., 2007). Ne´meth et al. (2006) examined the challenges and possibilities applying RFID systems into supply chains. Compared to the barcode approach, the implementation of RFID systems has demonstrated a significant improvement in supply chain management through the reduction of inventory losses and efficiency of inventory processes. Chen et al. (2010) proposed RFID-based enterprise application integration (EAI) approach for the real-time management of dynamic manufacturing processes. A prototype system was developed to demonstrate the applicability of the proposed method in a shop floor environment. Brusey et al. (2009) focused on the issue of correctly identifying, tracking and dealing with aggregated objects in customised production using RFID. Chao et al. (2007) reviewed the trends on RFID technologies in supply chain management. Delaunay et al. (2007) presented a survey in the causes of inventory inaccuracies in supply chain management. Dolgui et al. (2008) also presented a literature review on RFID technology in supply chains outlining the advantages of RFID technologies in inventory management and analysing privacy and authentication properties of RFID technologies. Kärkkäinen (2003) discussed the possibility of RFID being implemented to improve supply chain efficiency for short shelf-life products. McFarlane et al. (2003) looked into certain obstacles faced by the processes of supply chain logistics in terms of transportation, shipping, receiving, and in-house operations to assess and analyse the potential benefits of this technology. Turcu et al. (2007) examined the potential benefits generated by integrating a RFID system with business-to-business (B2B) applications and subsequently proposed an integrated RFID-B2B system. The system offers multiple performance levels for varying systems or application needs, and it can be readily personalised to meet users' demands.

In manufacturing sectors, some companies used RFID technology to track components or parts at each stage of the manufacturing status of operations that take place during the production process. Data exchanged from this transaction can then be stored within the ERP system, which is made accessible to managers and decision-makers. There is vast literature on the use of RFID to better manage inventory and improve the operations in a supply chain. Lee et al. (2004) analysed the level of inventory visibility, accuracy and shelf replenishment policies of inventory operations.

Doerr et al. (2006) used the factorial structure for analysing the non-cost related benefits and the ROI (return on investment) in RFID implementation. In recent years, a great deal of demands have been arisen from logistics and supply chain companies for an improved inventory visibility by recognising the importance of the RFID-based management system that can be implemented into the automated warehouses.

3.5.1 RFID applications in warehousing systems

The growing trend for online shopping is likely to gain even greater prominence every day. More and more customers nowadays prefer to order their goods that can be found online and these customers also demand a faster delivery of ordered goods to be dispatched directly to their door steps. A number of studies through a literature review suggested that future generation warehouses may be designed and implemented as more centralised distribution centres that partly replace traditional supplier and retailer stores or shopping malls in the commercial street. As a result, these suppliers and retailers require more efficient distribution centres in which a novel design of automated storage and retrieval systems are increasingly desirable. Current automated warehouses are equipped with expensive equipment including palletising robots, carton flow order picking systems, automated guided vehicles (AGVs), rotary storage cabinets, and automated storage and retrieval systems (AS/RSs). These facilities can partially replace human workers for performing operations of picking and placing items and vertically improve space utilisation of a warehouse. Furthermore, implementation of IT capabilities has also demonstrated the potential for greater improvement opportunities in terms of tighter inventory control, shorter response time and greater variety of SKUs (stock keeping units). These IT capabilities can be implemented by using smart-labels such as barcodes, radio frequency identification (RFID) tags and automatic identification (Auto-ID) sensors, together with cable and/or wireless communication networks and integrated warehouse management systems (iWMS). A study by Wang et al. (2010) indicated that an RFID-enabled automatic warehousing system has several advantages over the conventional automatic warehouse as described above. In such a novel design of storage and retrieval mechanism, an item, which is attached with a RFID tag, can be traced, sorted and inventoried in a real-time control manner but also the item can be stacked on the storage racks randomly at wherever a place is available for incoming goods and distributed from anywhere throughout the system.

Unlike the barcode scanning method, radio frequency identification or RFID technology uses wireless non-contact radio wave communication mechanism to identify an object by transmitting a unique identity code that contains information of this item, each item is attached with a passive RFID tag (containing a silicon chip) and the captured data through the signal transmission between an RFID tag and a reader can be uploaded to a warehouse computer database to look up information relating to this item. Some RFID systems use active and semi-active tags which are powered with batteries to communicate with the reader. With this approach, the travel distance of the signal transmission between an active RFID and an RIFD reader can be much longer than passive RFID tags. It has also been seen as a trend that RFID systems may replace barcode systems in future. With RFID technologies, warehouse inventory can be tracked more accurately in a simple, timely and more efficient manner leading to a significant reduction of data processing time and labour cost, compared to the barcode method as each barcode has to be scanned individually, which is a labour intensive and time-consuming process. An RFID tag can also store much more user-predefined information than traditional barcodes. Figure 8 shows the advantages and disadvantages of using barcodes and RFID methods, respectively (McCathie, 2004). The cost of RFID tags is one of the main constraints for the full RFID implementation within supply chains (Chomka, 2003).

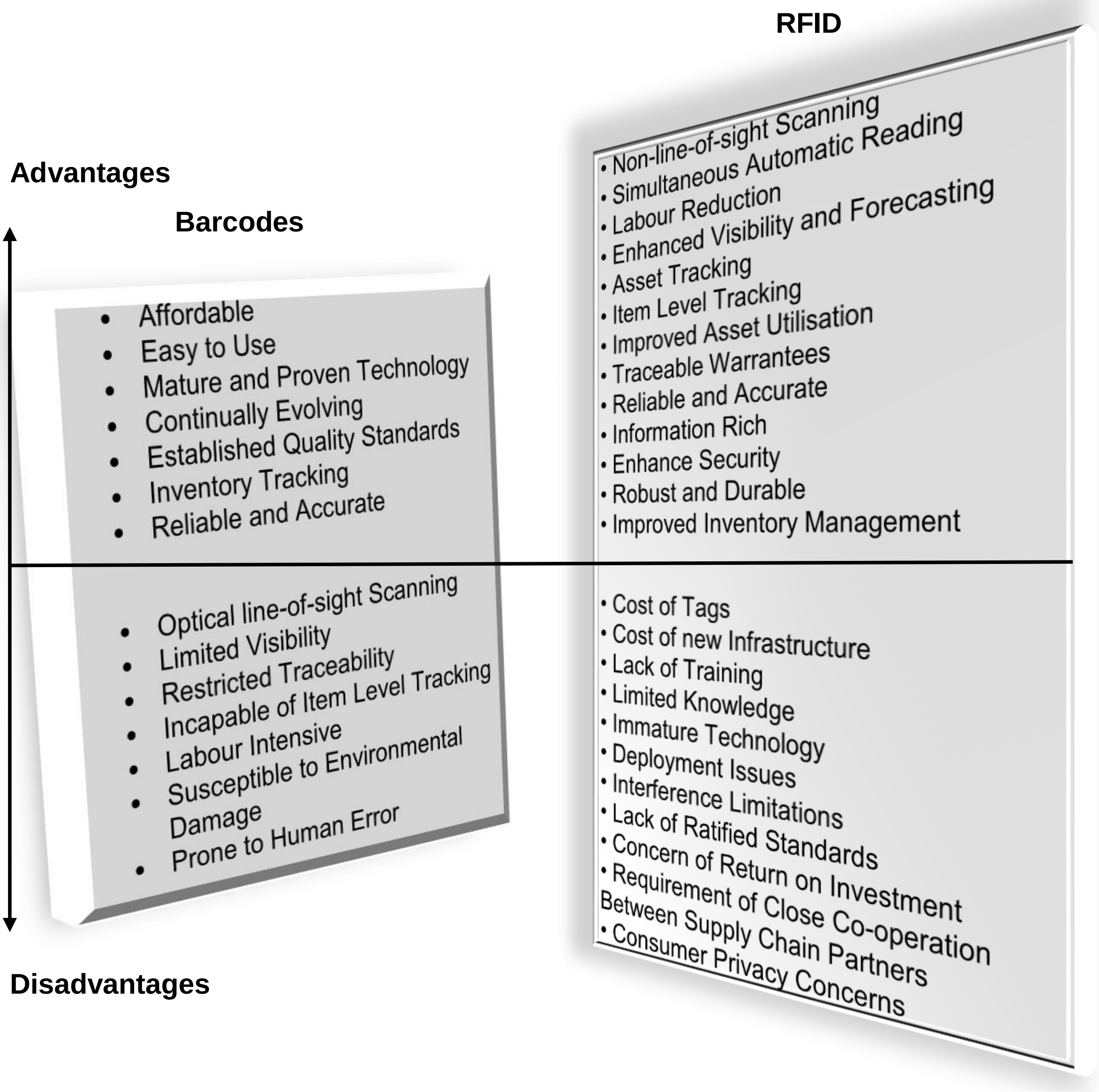

Figure 8: Barcodes vs RFID (McCathie, 2004).

The cost of RFID tags depends on their type. Reported by RFID Systems in the Manufacturing Supply Chain (2003), although there is a 5–35% decrease of labour costs using RFID tags, prices of active or semi-passive RFID tags (at least $1 per tag) are still a hindrance allowing the economic application; the applications were mainly suitable for high-value goods over long ranges. By comparison, barcodes are the least expensive way offering a simple method to capture the data. Barcode labels cost less than 2 cents per label while RFID tags are at least three times more expensive per tag (Williams et al. 2014). The precise cost of RFID tags varies depending on the underlying RFID technology and the number of items attached by RFID tags. Typically, passive RFID tags are between 7 and 20 cents. Table 2 shows a summary in performance measures between barcodes and RFID tags through a literature review.

Table 2: Summary of a comparison between barcodes and RFID tags (Source: Çakıcı et al., 2009 and Hedgepeth, 2009).

Criteria	**Barcodes**	**RFID**
Convenience	Require line of sight scan	Automatic scan without line of sight
Efficiency	Cannot support batch reading	Can read multiple tags at once
Accuracy	Susceptible to misreads and human error	Reduced human error and misreads improves data accuracy
Traceability	Limited traceability. Some harsh manufacturing processes (link baking) make barcode tacking impossible	Allows detailed tracking and tracing of process status, input/output, and the time that each processing step was performed.
Speed	Process information not in real-time	Real-time process information
Reliability	Barcodes are easily dirtied or scraped in harsh manufacturing environment	RFID tag can survive harsh environment such as high temperature
Automation	Need more human labour to collect and track process data limited process information	Replace or reduce human labour in data collection and tracking
Information	Limited process information	Vast amount of detailed process information
Storage (data)	Allows only centralized data storage	RFID tags carry large data capabilities

Table 3 shows various RFID applications in different sectors with expected outcomes based on a literature review.

Table 3: A number of case studies in RFID applications through a literature review.

Authors	Industry	Applications	Results
Lefebvre et al. 2006	Warehouse of a specific supply chain	Four inter-related firms from three echelons of the supply chain.	RFID technologies are useful to apply because it can improve the existing processes, provide a new business model and increase the communication between supply chain actors
Wamba et al. 2007	Mobile business to business e-commerce	Four different companies.	RFID-EPC network can enhance the operational processes such as shipping, receiving and put-away processes and business processes through automated activities.
Tzeng et al. 2008	Health care industry	Five hospitals in Taiwan	RFID employment can significantly change processes and human resources of the organisations, enhance customer satisfaction and improve efficiency and flexibility of process redesign. They note that re-engineering application optimises systems.
Wang et al. 2007	Construction supply chain environment	High-tech factory building in Taiwan	RFID technology can significantly improve supply chain control and construction project management by improving the efficiency of operations and also by providing a dynamic control.
Hou et al. 2006	Printing industry	Eight members of the Taiwanese printing industry.	Proposed different models with varying complexity and provide quantitative cost and benefit analyses of RFID technologies integration.
Ergen et al. 2007	Intelligent components in engineered-to-order (ETO) management	Three experiments in three types of components.	Demonstrated the technical feasibility of RFID technology in supply chains, and indicated that active UHF RFID technology can create intelligent components efficiently.
Huber et al. 2007	Retail supply chain	Nine Australian RFID vendors and associations	RFID can minimise losses in the supply chain and the visibility of stocks is the main shrinkage factor that RFID can improve
Baars et al. 2008	Retail supply chain	Three-level supply chain – Chinese manufacturers, a consolidator	Cooperation between the business intelligence and RFID technologies enhances supply chain operations, but a cost-benefit analysis should be realised

		and a GDC in Germany	
Bottani et al. 2008	Fast-moving consumer goods (FMCG) supply chain	Three-echelon supply chain which contains manufacturers, distributors and retailers of FMCG.	Both in the integrated and non-integrated scenarios, RFID technologies at pallet level can provide benefits for all echelons however manufacturers cannot obtain positive revenues because of the high cost of case level tagging.
Mourtzis et al. 2008	Automotive industry		RFID significantly reduces the order to delivery time so that customisation orders can be realised in spite of market variation.
Zhang et al. 2010	Automotive industry		Showed the benefits of RFID technology in the green supply chain (GSC) area
Kim et al. 2008	Retail supply chain	Numerous U.S. and Korean retailers,	Hardware and software applications influence RFID benefits in inventory management for U.S. retailers while, for Korean retailers, it can improve the efficiency of store operation and demand management.
Kim et al. 2010	Retail supply chain	278 adopting organisations	Showed the organisational needs, perceived factors and organisational readiness.
Poon et al. 2009	Warehouse		Three main objectives: simplifying RFID integration, improving the visibility of warehouse activities and the performance of the warehouse.
Pigni et al. 2008	Fashion industry		RFID technology integration improves the system business process and provides an inter-organisational information system that improves the efficiency and effectiveness of the entire supply chain

3.6 RFID-based automated warehouse systems

A modern warehouse combines the state-of-the-art mechanical hardware with information systems to achieve warehousing operations for a high variety of loads. The key part of automated warehouses is automated storage and retrieval systems (AS/RS) (Lerher et al., 2010). The AS/RS is a material handling mechanism which is a key element of automated warehouses or distribution centre. The basic components of AS/RS are storage racks (SR), automated storage and retrieval (S/R) machines, and accumulating conveyors. AS/RS offers the advantages of fewer material handlers, better material control and more efficient use of storage space. The disadvantage is that the cost to maintain such equipment is relatively high once it is installed. Figure 9 illustrates the overall design of an RFID-enabled automated warehouse model by Wang et al. (2010). It consists of an individual module in which all levels of output conveyors are interconnected to equal levels of a loop spiral conveyors to collection points. These conveyors, which also act as delivery paths as well as buffers, form the output zone of the warehousing system. The module is designed as standardised element for manufacturing and assembly, although each module can be of different sizes and arrays in a module can be configured easily in many different ways, i.e., capacity of warehouse is adjustable. In the warehouse, items are pre-loaded onto pallets named totes; totes need not be of identical sizes. Each item in a tote (or a tote containing identical items) is attached with an RFID tag and each item in a tote is thereafter tracked and manipulated by the developed RFID-inventory management system throughout the warehouse.

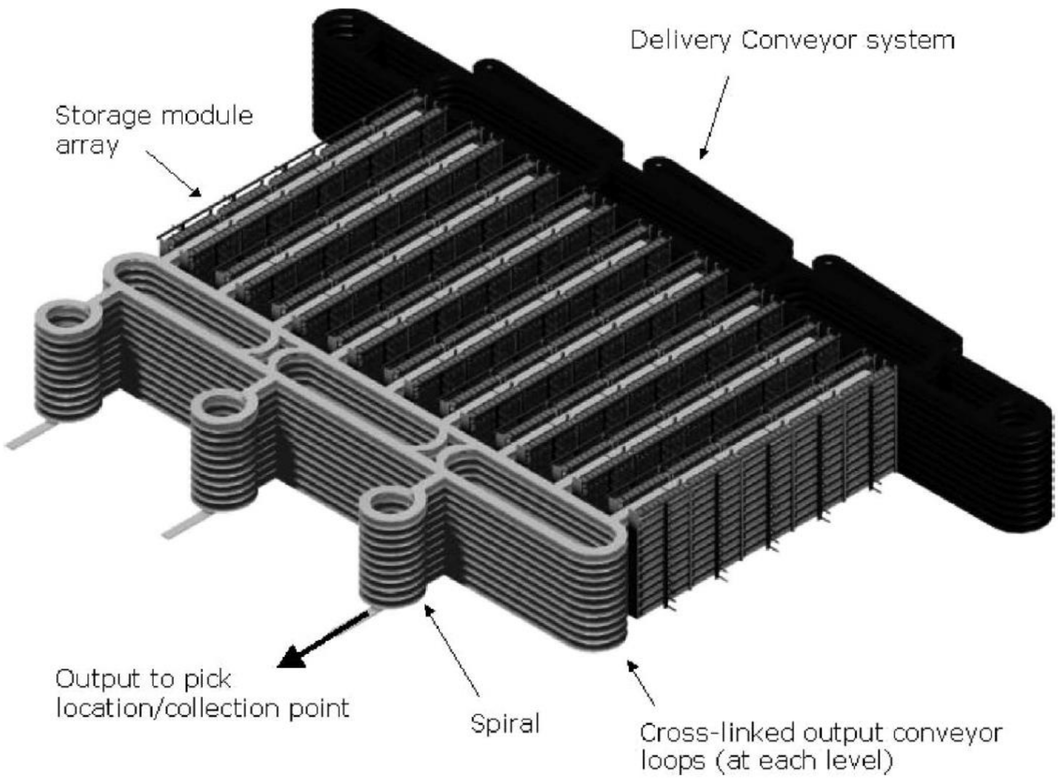

Figure 9: The overall layout of the 3D warehousing system (Wang et al., 2010).

As the travel time covers a substantial part of picking processes in warehouses, an appropriate optimisation in sequencing of picking lines within a batch is crucial to achieve high efficiency. Many researchers have focused on minimisation of travel time for an item travel to a collection point using various methodologies (Shaw, 2002). Lerher et al. (2006, 2010) presented an analytical travel time model for multi-aisle AS/RS considering parameters in acceleration, declaration, deceleration and maximum velocity. Yahong et al. (2003) introduced a new type of storage/retrieval (S/R) mechanism to handle loads and proposed a travel time model under the dwell point policy. The dwell point in an AS/RS is the position where the S/R machine resides when the system is idle. The dwell point is selected such that the expected travel time to the position of the first transaction after the idle period is minimised. An effective dwell point strategy may reduce the response times of the AS/RS, since the S/R machine typically performs a sequence of operations following an idle period (Vasili et al., 2006). Similarly, Hu et al. (2005) developed a new type of S/R mechanism and proposed a travel time model under the stay-dwell point policy, i.e. the platform remains where they are after completing a storage/retrieval operation. Liu et al. (2014) carried out a research on a travel time model of a new compact storage system which is an extension of conventional automated storage and retrieval system (AS/RS). Agarwal et al. (2015) proposed an analytical model for the computation of travel time for automated warehouses with the aisle transferring S/R machine. Lerher et al. (2015) developed an analytical travel time model for the computation of travel (cycle) time for shuttle-based storage and retrieval systems (SBS/RS). The proposed model incorporates the operating characteristics of the elevators lifting table and the shuttle carrier with parameters in acceleration and deceleration and the maximum velocity. The study conducted by Schenone at al. (2016) aimed at providing a new methodology suitable for computing the travel time for an AS/RS system based on the class-based storage assignment policy.

Early warehouses gave little consideration to space efficiency, order picking methods or material handling. Today, tighter inventory control, shorter response time and greater variety of SKUs (stock keeping units) are most important challenges for designing modern warehouses. Although these challenges can be prompted in part by adoption of a number of management philosophies such as just in time or 'lean' methods as the warehouse inventory policy, the latest advanced IT and communication technologies play a vital role in bringing effectiveness and efficiency to the warehousing system through speedy information processing and internal and external connectivity. However, the degree of usage of the latest IT tools such as Radio Frequency Identification (RFID) and communication systems depends on management policy, product type, market competition and customer expectation. Some leading e-commerce retailers have used automated storage systems to gain a greater efficiency in progressing their e-tail operations. As the materials handling revolution continues, there will be more techniques applied in design and operation of production and distribution systems. For instance, routing sequence of older picking can be programmed into the WMS (warehouse management system) (Moeller, 2011). Order picking can be defined as the activity order requested by a customer. Order picking can be performed in a variety of high-level approaches under an order picking system (OPS). In a manual operating warehouse, picking processes are seen as the most labour-intensive and costly activity and the cost of order picking is estimated to be as much as 55% of the total warehouse operating expense (De Koster et al., 2007). Poor performance in order picking can lead to unsatisfactory service level and high operational cost for warehouses. Figure 10 shows operating costs (e.g., shipping, picking, storage and receiving) in a typical warehouse (Tompkins et al., 2003). As shown in the Figure, the cost of order-picking operation dominates up 55% of the total operating cost. Given this economic importance, the decision supports for planning and controlling the order picking processes within a WMS is a central task.

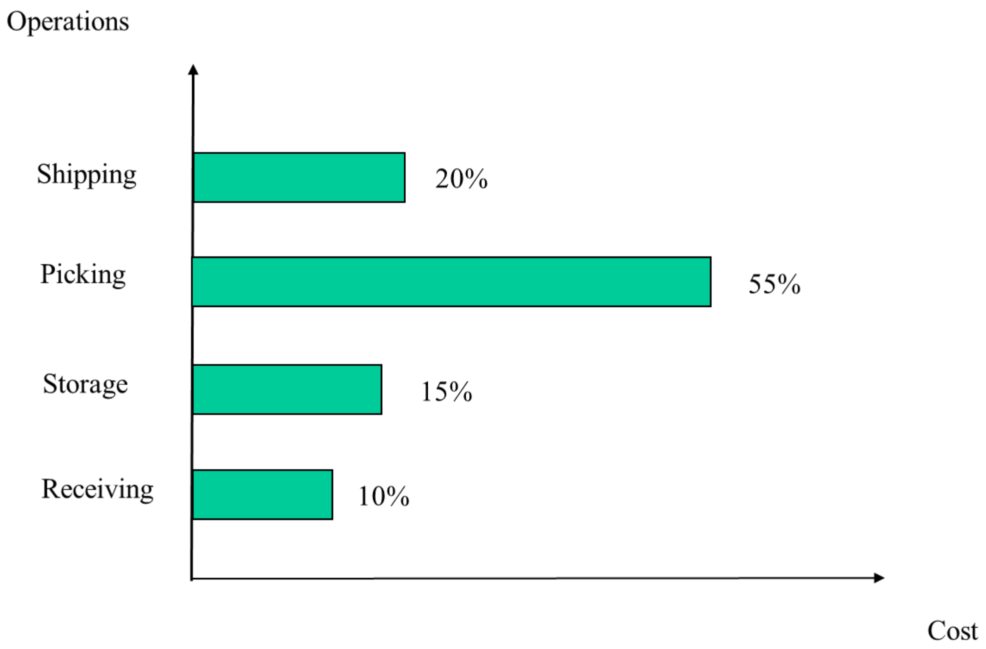

Figure 10: Operating costs in a typical warehouse (Tompkins et al., 2010).

Intelligent control software is required to realise the potential offered by the warehousing system design shown in Figure 9. Input variables in the control software can be classified into three categories, namely application parameters, hardware parameters and software parameters. Application parameters may include such as numbers of different SKUs handled by the system, the storage information of each SKU, the number of items per request, the number of requests per time unit, and the number of concurrent users etc. Hardware-related parameters may include factors such as the height and depth of each rack, the number of racks per aisle etc. Software parameters may cover scheduling and optimisation algorithms used for job priorities to assign or dispatch items to/from arrays of each individual storage modular element to minimise the travel time and minimise the operation cost as shown in Figure 6. In order to achieve this, a material-handling solution should be provided based on optimal algorithms in order to generate the shortest pick-up sequence and route for the material handling equipment.

Summary

This chapter presents a literature review study in which it examines developments of existing manual and automated warehouses, and warehouse inventory management systems and methods. The chapter also examines RFID and sensor network technologies including the background of the RFID and its application mainly for supply chain and logistics sectors and review the applications that have been established by researchers. Besides, the RFID- based warehousing system is illustrated as the basis of this research work. A comparison between barcodes and RFID methods was provided within this chapter. A number of case studies in RFID applications were included. The chapter illustrates a typical RFID-based automated warehousing system of which inventory of incoming and outgoing items in a warehouse is controlled under the warehouse inventory management. Travel time covers a substantial part of picking processes in warehouses in which the item can be dispatched to travel from the storage rack to the collection point. The relationship between the operation and cost in the warehouse was also explained. In conclusion, through a comprehensive literature review, there was no study which was found in reporting design theories and integration approaches for the RFID-based future generation automated warehousing systems. By leveraging the latest supply chain technology and the Internet of Things (IoT), a smart warehouse can now serve as a hub to boost efficiency and speed throughout the entire supply chain, internet-enabled devices and technology may profoundly change logistics management in the near future.

Chapter 4 The RFID-enabled inventory management system

Figure 11 shows the key components of the RFID-enabled inventory management system used for this study, which are described in details as follows:

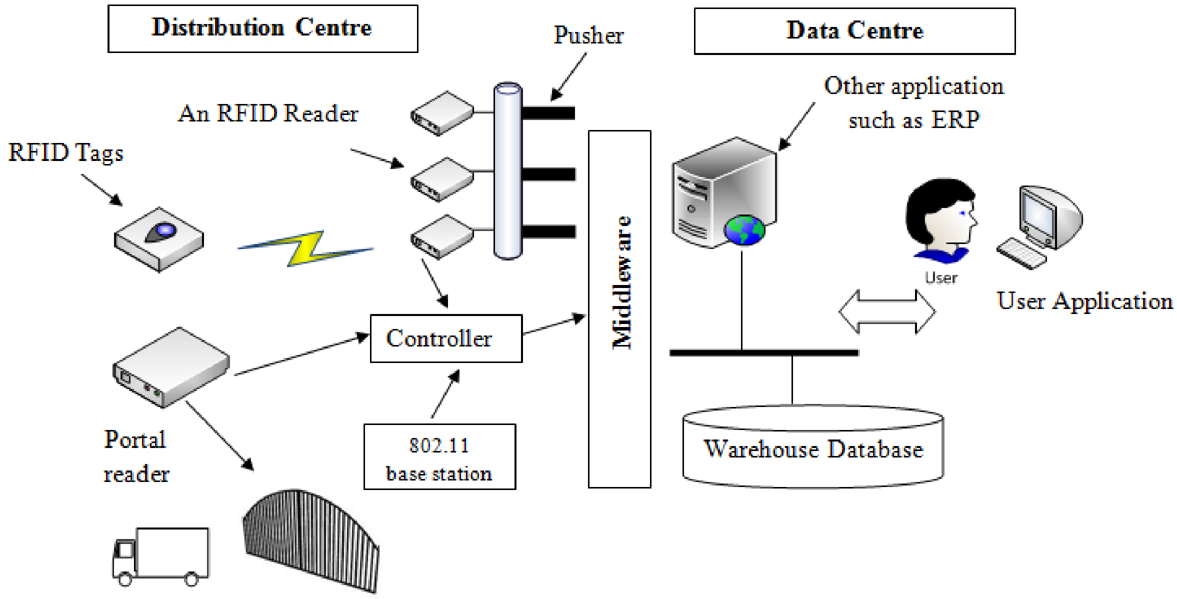

Figure 11: The key components of the RFID-enabled inventory management system.

4.1 RFID tags

RFID data are store in an RFID-based warehouse database as shown in Figure 9. The supporting software for the RFID-based database can be developed using Oracle, SQL Server, Postgres, or MySQL. Figure 12 shows the key components of a typical RFID chip. A typical RFID tag contains a small chip, also called an IC, and RFID tags can be attached to everything that needs to be tracked. The circuit connects with an antenna, which can be integrated with a vast array of labels, security tags, and apparel hang tags, and other kinds of industrial asset tags. The chip of each RFID tag contains a pre-programmed serial number or unique identifier (UID) assigned along with memory, which includes a unique tracking identifier that stores the product's unique electronic product code (EPC) and other data on memory contained in its chip, which enables it to be read and tracked using RFID technology (Brown, 2007).

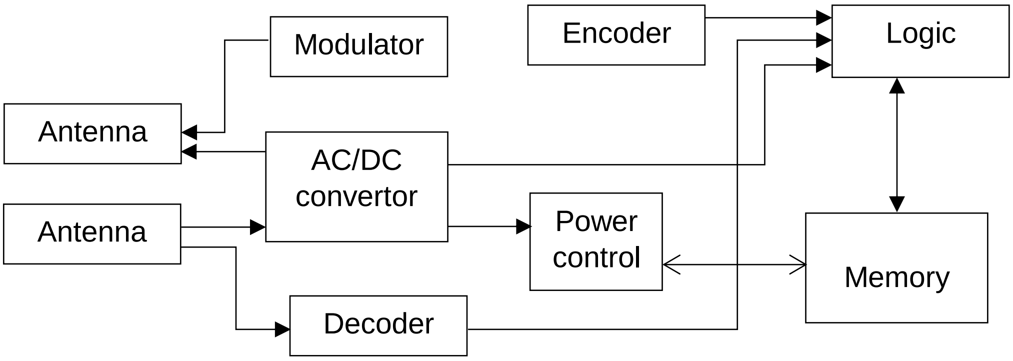

Figure 12: key components of a typical RFID chip.

As shown in Figure 13, different types of RFID tags are available in the market to suit usages of tagging not only products but also people (Gambon, 2009). For instance, some of the features of these RFID systems allow nurses to access medication cabinets, and to track medication inventory, equipment, and staff as well as patients by substituting wristbands and charts with a combined patient chart and medical bracelet with an implemented RFID system (Lingle, 2007; Park, 2014). Another application of RFID systems is in supermarkets and large stores, whereby miniscule RFID tags are assigned to every item on every shelf, so that the supermarket is able to track and trace stock from the factory from their distribution chains to customers' trolleys (Roberti, 2004).

Figure 13: A variety of RFID tags (Impinj Company).

There are several types of RFID tags depending on the purpose of their applications. The RFID tag can be adapted to suit various design requirements according to the types of items to which the tags will be attached (e.g., wrist belt, buttons, jewellery or even a tattoo). The amount of information each RFID tag can carry vary depending on the capacity of its computer chip memory. The type of data carried by each RFID tag also varies. Jian (2010) lists three types of RFID tags according to the specific requirements of application. These include passive RFID tag, active RFID tag, and semi-active RFID tag. RFID tags are designed with multiple antennas, making them more reliable than RFID tags with only one RFID antenna as those RFID tags that have a single antenna can be affected by “dead zones”, where parts of the RFID tag may remain unresponsive to incoming signals resulting in the RFID tag not acquiring sufficient energy for powering its internal chip and inlay therefore preventing communication with the reader (Kodaka et al., 2009; Taguchi & Mizuno, 2006). RFID tags with dual antennas can bypass this obstacle, increasing their readability, provided it matches the chip design (Lee & Yu, 2015).

4.1.1 Passive RFID tags

Passive RFID tags do not have access to their own source of power; instead, these RFID tags are entirely reliant on the RFID readers to activate them. When a passive RFID tag is triggered, it transmits the information that is stored in the RFID tag through its antenna to the RFID reader antenna (Hunt et al., 2007). The RFID reader analyses the information it receives and acts according to the requisition of the RFID system. Passive RFID tags are typically used cards to authenticate valid users (Jian, 2010). As passive RFID tags can connect with the RFID reader using both inductive and propagation coupling due to having an on-board RF transmitter. In addition, information cannot be transmitted without the RFID reader being in the same vicinity. Also, the communication is one-way only, in which an inquiry is made by the RFID reader first, followed by the response from the RFID tags.

The frequency for passive tags which commonly function well are 860–960 MHz in UHF (ultra-high frequency), 13.56 MHz in HF (high frequency) (Liu et al., 2014; Park & Yu, 2008), and 124–125 kHz and 135 kHz in LF (low frequency) band (Park & Yu, 2008; Yang, 2010). There are also different frequency bands that RFID can legally use depending on what country the RFID is being implemented in; it must therefore be legally compliant to the frequency regulations of the country in which it will operate (Brown, 2007; Yang, 2010). Moreover, it is often thought that RFID can provide constant and continuous location data (Ferguson, 2007).

4.1.2 Active RFID tags

An active RFID tag, unlike a passive tag, has its own battery power, allowing it to actively broadcast the data stored on it via an antenna, even without the presence of a RFID reader. An active RFID tag is often used for sensing pressure, humidity, temperature, etc. Typical applications for active RFIDs are wireless sensors. In comparison, semi-active RFID tags are also battery-powered; however, this type of RFID tag is able to turn itself off after being triggered by a given action from an RFID to transmit data to the RFID reader (Jian, 2010). Active RFID tags typically function in frequency range of 455 MHz, 2.45 GHz, or 5.8 GHz, and characteristically have a readable range of 20–100 metres. Frequently, these RFID tags are used to track larger, more valued assets, such as containers, vehicles or aircraft due to their effectiveness for tracking objects with a greater distance.

4.1.3 Semi-active/Semi-passive RFID tags

Semi-passive RFID tags have a battery, which can be used to increase transmission range; for this reason, they are also called battery-assisted tags. These RFID tags transmit by modulation of backscatter (as do passive tags), but they are still too high in cost for use with lower value items (Brown, 2007). Semi-active RFID tags, or semi-passive/battery-assisted RFID tags as they are also called, are now available and targeted for use in specific applications (Hunt et al., 2007). These types of RFID tags contain batteries used to support the RFID tag's sensors and embedded memories only. When communicating with a RFID reader, the same process used by passive RFID tags takes place, meaning that energy is generated from the reader antenna in addition to reflecting a signal back to the reader. As with passive RFID tags, this process always begins via the reader's enquiry, followed by the tag's response. With passive RFID tags, however, antennas must perform two separate tasks: gathering energy for the operation of the tag, and transmission of data. Thus, the antenna design has to be able to balance the performance between these different functions. Therefore, with battery-assisted RFID tags, which have their own battery for tag operation, the antenna is enabled to focus solely on data transmission. The result is that these RFID tags are readable at greater distances, even as far as 30 metres away, and perform better around liquids and metals compared to regular passive tags. In addition, time is not required for semi-active RFID tags to acquire energy for activating the tag chip, meaning that reading speed is also faster, making them more effective at tracking objects moving rapidly. Table 4 lists five common categories of RFID tags.

Table 4: Five common categories of RFID tags (Brown, 2007).

Class	Class Layer Name	Functionality
1	Identity Tags	Purely passive, identification tags
2	Higher Functionality Tags	Purely passive, identification + some additional functionality (e.g. read/write memory)
3	Semi-Passive Tags	Addition of on-board battery power
4	Active 'ad hoc' Tags	Communication with other active tags
5	Reader Tags	Able to provide power for and communicate with other tags i.e. can act as a reader, transmitting and receiving radio waves

4.1.4 Selection of RFID tags

In terms of selection of RFID tags, there are a number of considerations, which include:

- Frequency Range.
- Memory Size.
- Range Performance.
- Form Factor.
- Environmental Conditions.
- Standards Compliance.
- Read Compatibility.

The RFID tags have been designed to transfer data only if a reader is in range of the RFID tags, in order to conserve energy and battery life (Brown, 2007). Table 5 below shows the typical characteristics of RFID tags, examples include:

- Key-ring fob tags.
- Disk tags.
- Wrist band mounted tags.
- Self-adhesive label tags, 30mmx26mm, flat, mounted on plastic.
- Tamper-proof label tags.
- “Credit card” style tags.
- “Laundry” tags (temperature, chemical and heat resistant).
- Tags with a backing label for over-printing.

Table 5: Typical characteristics of RFID tags (Author's completion).

Category	Passive tags	Semi passive tags	Active tags
Power supply	External (from readers)	Internal battery	Internal battery
Read range	Up to 20 feet	Up to 100 feet	Up to 750 feet
Type of memory	Mostly read-only	Read-write	Read-write
Cost	$.20 to several dollars	$2 to $10	$20 or more
Life of tag	Up to 20 years	2 to 7 years	5 to 10 years

4.2 RFID antennas

Generally speaking, RFID readers produce electricity modulated to contain data and instructions, and feed it to an external antenna. The antenna converts the electricity to radio waves and broadcasts them. The RFID tag antenna receives the radio waves and converts them back to electricity used to power the embedded IC chip and to decode the data and instructions. The RFID tag feeds the electricity to its antenna to power the circuit and broadcast their coded response, on which the reader reads. Radio waves travel in a particular direction through space; it can be either horizontally or vertically polarised as illustrated in Figure 14.

4.2.1 Antenna characteristics

The antenna fundamental characteristics are:

- Impedance.
- Polarization.
- Gain and effective radiated power.
- Bandwidth.
- Appearance.

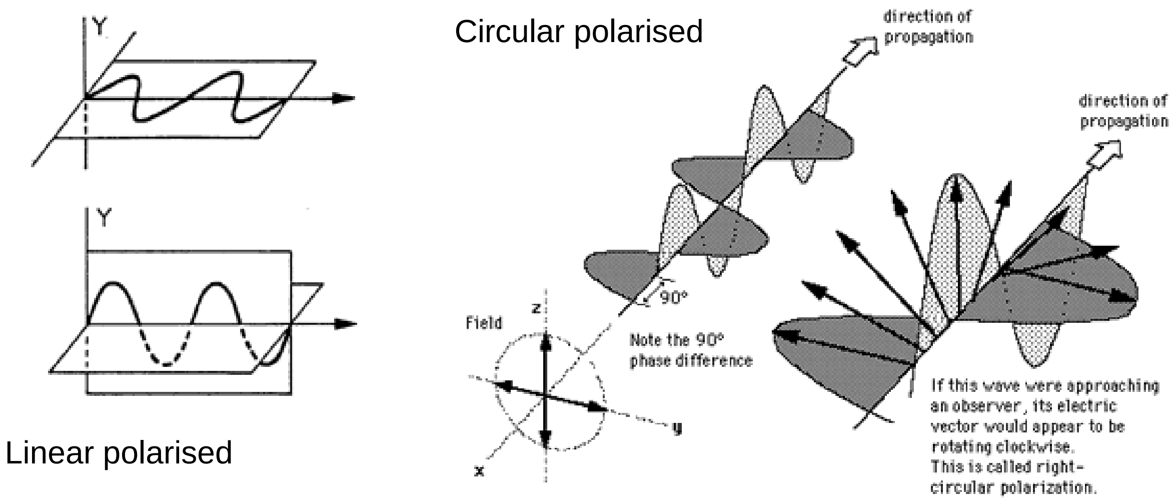

Figure 14: A typical wave pattern of linear-polarized and circular-polarised antennas (Brown, 2007).

The types of antenna required depend on environment and exact specifications (Jian, 2010). In most cases, antennas with linear polarity are the most common types of antenna in use, although there are also those with circular polarity (Deavours, 2009). An antenna that radiates electrical wavelengths with linear polarisation has a much longer range and higher power levels, which can then produce stronger signals more capable of penetrating various substances and materials (Deavours, 2009; Jian, 2010). However, these types of antennas are more sensitive to the orientation and direction of a tag's position and angle, making some RFID tags harder to read (Nikitin et al., 2008). In contrast, antennas radiating with circular polarisation do not face this obstacle in reading tags, although their range and signal strength is much weaker, relative to power usage. Figure 15 shows a typical antenna that is used in this research.

Figure 15: A typical antenna. (Impinj company).

4.3 RFID readers

The RFID reader is central to an RFID system, which has the capability of writing and reading data to RFID tags. It is also becoming more common for RFID readers to exchange information securely by using authentication to validate users via encryption.

Readers usually have three forms:

1. **Stationary readers:** These types of readers are usually mounted at gates of warehouses as shown in Figure 16.

Figure 16: A typical stationary reader (Impinj Company).

2. **Handheld readers**: These types of readers are convenient, as they can be used in a more flexible manner as shown in Figure 17.

Figure 17: A typical handheld reader (Bibllotheco Company).

3. **Mounted readers:** Mounted readers are in between the types mentioned above. They are usually mounted on a mobile device/system (Henrici, 2008).

Most passive RFID readers, which usually operate under a current of 100–300 mA, often have the external power due to a much greater quantity of energy consumption. With this method, an RFID reader is also called an interrogator. An RFID reader is a device that establishes a wireless connection with RFID tags to capture RFID data. RFID tags can be accessed by the RIFD reader for a range of tasks in such as filtering, writing/encoding RFID tags and simple or continuous inventory operations. An antenna is attached to the RFID reader in order to collect this data and perform these tasks and operations. After a connection is established, the data is streamed to a computer for processing. RFID readers can be set up in fixed locations, such as within a warehouse or store, and others may be integrated with portable devices, such as handheld scanners. In addition, other models can be embedded within electronic devices and even in vehicles (Brown, 2007). In a warehouse management, the system needs to identify which item arrives and when to ensure that all items are stored effectively in the warehouse. The database makes a record and stores the data for those items that have RFID tags attached to them, allowing those items to be identified and information data regarding the availability of items stored in the warehouse are ~~to be~~ known and updated.

4.3.1 RFID reader performance

There are a number of considerations when selecting an RFID reader; importance is its ability to fulfil the requirements of the system. The performance parameters include identification range, identification rate, read range, read rate, write range and write rate as explained in table 6 below.

Table 6: RFID reader performance parameters (Brown, 2007).

Performance parameters	**Description**
Identification Range	The distance at which tags can be identified
Identification Rate	The number of tags that can be identified within the coverage range
Read Range	The distance at which tags can be read
Read Rate	The maximum number of tags that can be read per second
Write Range	The distance at which tags can be loaded with information.
Write Rate	The maximum number of tags that can be loaded with information per second

The environment can have major impact on the performance of the RFID reader. For instance, items like metals and other non-penetrable items can affect the performance of an RFID reader. Other components of the RFID reader, such as I/O ports, can also affect the performance of the RFID reader. The types of RFID interfaces include RS-422, RS-232, RS-485, and Universal Serial Bus (USB) interfaces, which are all standard interface components for the majority of RFID readers (Jian, 2010; Xiaoyong et al., 2007). RFID readers become increasingly portable and mobile, enabling more convenience and flexibility when deploying RFID systems, and installations. Commercial devices might be designed with additional features and components, for example, input and output ports for annunciator, additional memory and sensors, which can help to maximise the effectiveness of the RFID reader (Brown, 2007).

4.4 Communication between RFID tags and RFID readers

One of the most important aspects of RFID systems, compared to barcode systems, is that the communication with the reader does not need a line of sight, or wiring. Rather, the communication between RFID tags and RFID readers is performed by electromagnetic means (Henrici, 2008). The radio frequencies used in RFID can be categorised into three types according to their usage: low frequency, high frequency, and ultra-high frequency. Frequency refers to the size of the radio waves used to communicate between RFID systems components. RFID systems operate in low frequency (LF), high frequency (HF), or ultra-high frequency (UHF) bands depending on trade-off cost effective solutions. In selecting the right operational frequency for an RFID system, the specifications of the system need to be assessed carefully as radio waves have different patterns of behaviour according to the various frequency bands. One example of this is the ability of radio waves at low frequencies to pass through most liquids including water, as well as most other materials and substances; these also operate well in the presence of various metals. At higher frequencies, the behaviour of radio waves is more like that of light, which tends to be more easily absorbed by various materials or reflect off other surfaces (Brown, 2007).

Retail inventory management is one of many applications for which UHF is used. In addition to pharmaceutical anti-counterfeiting systems, LF RFID tags are usually readable from a distance of 0.3 metres, whereas HF RFID tags are readable up to 1 metre. In contrast, high data transfer rates are achievable using UHF waves, although the rates of performance in environments containing liquids and metals are significantly reduced, and data transfer becomes practically ineffective (Hunt et al., 2007). Nonetheless, there was an ongoing development of passive RFID tags that work in UHF, which continues to gain interest (Ting et al., 2012). In terms of the motives for using UHF-RFID tags in supply chain management, as opposed to LF RFID tags or HF RFID tags, it simply comes down to cost effectiveness and the read-range of the RFID tags, with commercial vendors offering relatively simple and inexpensive RFID tags in the UHF band. UHF RFID is the most sensitive to radio wave interference compared to LF and HF RFID tags; however, many UHF products, such as RFID tags, antennas, and readers, are designed to perform even in more challenging environments (Impinj, 2015).

4.5 Electromagnetic field

There are two kinds of fields used for data transmission and powering the tags:

- RFID Near Field Communication (NFC).
- RFID Far Field Communication (FFC).

There are certain key criteria in which NFC and FFC differ. The range for RFID tag-reading with NFC reading RFID tags is no more than a metre away, while FFC is able to read RFID tags from distances of 10–12 metres away. Other differences include the way the data is stored and transferred. Identifying the differences in terms of functionality will help in selecting the correct capabilities and tolerances for meeting the required specifications (Nikitin & Rao, 2008). The type of antenna required for operations is also dependent on the distance involved in reading the RFID tags, which is called the read-range. There are “near-field” or short range antennas, for which the read-range is less than 30–35 cm, and “far-field” or long range types, which can have a read-range of several metres, or perhaps even twice or thrice that distance in optimum conditions. The maximal field strength allowed depends on national regulations. It is limited for electromagnetic compatibility (EMC), i.e., for avoiding disturbing other systems and to prevent harming the environment (Brown, 2007).

4.5.1 Near Field communication vs Far Field communication

RFID functions at different frequencies, including low, high and ultra-high frequencies. The implementation of the frequency is to determine the distance in which the RFID tags can be read, how many RFID tags can be read at a time, how fast these tags are read and how the performance will impact on its application environment (Chawla, 2007). Table 7 shows the individual performance between near-field communication and far-field communication in terms of capabilities, strength, weakness, and application suitability. Figure 18 shows different frequencies between the near-field communication and the far-field communication.

Table 7: Comparison in performance between NFC and FFC (Author’s completion).

Near Field Communication		Far Field Communication
Read range	Up to 1 meter	Up to 10- 12meters
Security	Data is stored in a tag itself	Data ID is stored and server is required
Range control	Fixed	Controllable
Transfer data	Low	Fast
Waiting time	More	Less
Design	Standardised	Tamper proof
Queue management	One by one reading from close distance	Automated reading from controlled distance
Reading	No multiple reading capabilities	Multiple reading capabilities
Cost	Cheaper	Moderate

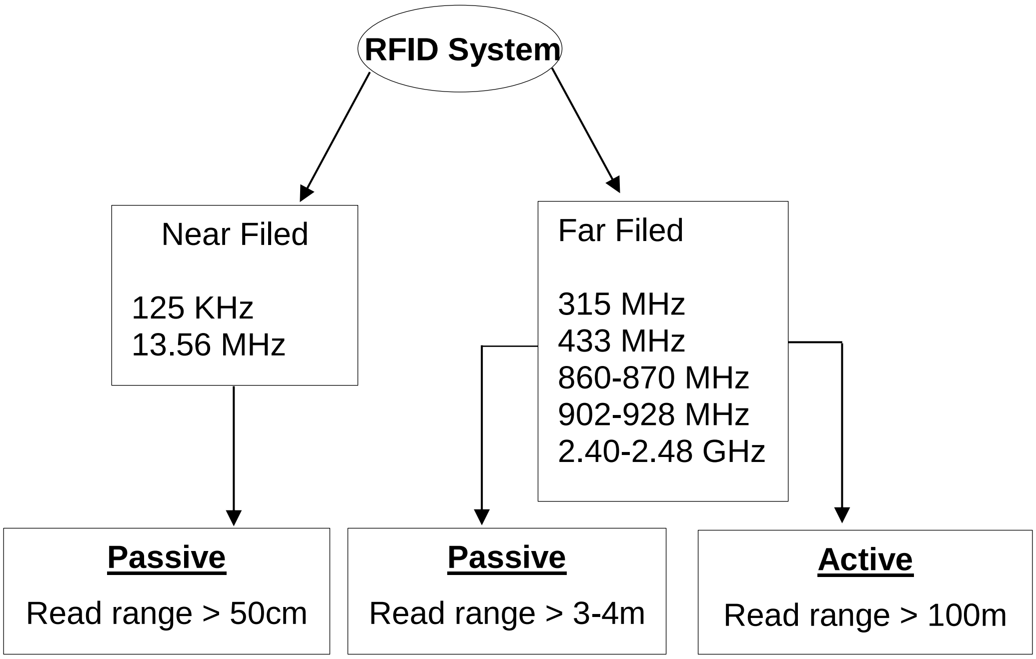

Figure 18: different frequencies between NFC and the FFC. (Author's completion).

4.6 RFID controllers

Controllers are devices that allow a group of RFID readers to communicate with a computer system, i.e., the data server. With the proliferation and increased complexity of RFID systems, it has become necessary to introduce a device that handles the communication between many RFID readers and a host computer, where the information gathered from the RFID system is stored. Reva Systems, a leader in the integration of RFID within current network infrastructure, designed an architecture that simplifies the network management of RFID readers with a product called Tag Acquisition Processor (TAP) (Brown, 2007). The aim of TAP is to move away from the reliance on middleware by having a controller that provides an efficient integration with enterprising applications.

4.7 RFID software

There are two categories of RFID software as follows:

1. RFID middleware.
2. Application software.

4.7.1 RFID middleware

RFID middleware handles data and communicates with RFID reader devices. Middleware, as the name suggests, provides a middle level event filter. For almost all RFID management events, repetitive read cycles are needed because of reading inaccuracies. High-volume raw data are processed by the middleware in detailed read cycles with results that contain disinteresting streams of data, which are useless to its end-users. Processing the data received from RFID reader devices provides the user applications with more clear and comprehensive results at the event level (Brown, 2007; Henrici, 2008). In addition, standard application level API is provided, with event level information being sent over a standardised interface via a service connecting it to higher level applications. The gathered information can also be stored by middleware, such as with a backend database that stores RFID tag information. The RFID middleware is logically positioned in the midway between the real business-end applications and the RFID hardware infrastructure. The middleware usually operates the RFID reader devices via the server that connects it to the RFID readers or to the RFID reader network. This allows direct communication and control between all devices, enabling event information to be prepared and processed, in a standardised format at the higher level, for its business-end applications. This standardisation is defined in EPC Application Level Events specification (ALE), which describes and sets out logical architecture and the implementation of RFID middleware. Numerous commercial RFID middleware products compatible with EPC ALE are available in the market (EPC Global, 2005). The RFID middleware is located between RFID hardware infrastructure and real business applications. Middleware normally works on the server that is connected to the RFID reader. The middleware communicates and manages the event data/information that is being created by an RFID device in a standardised format in order to match business applications at a higher level. It is suggested that middleware must work within the constraints of corporate standards and security policies, and interface with warehouse management system (WMS), however, each company has its own unique set of conditions and requirements. The main tasks of the RFID middleware include:

- Device management.
- Data collection and integration.
- Data structuring.
- Data filtering and routing.
- Line coordination and control.
- Visibility and reporting (both business information and device performance).
- Track and trace applications for recall and shipping (Park & Yu, 2008).

4.7.2 Application software and implementation for RFID systems

RFID systems require application software for RFID implementation. Brown (2007) stated that some companies used standard ERP applications from vendors such as SAP, JD Edwards, Oracle, PeepleSoft, or Microsoft to manage their supply chain activities. Also, other companies utilise manufacturing execution systems (MES), warehouse management system (WMS), supply chain management systems (SCMs), and finite forward scheduling (FFS) packages. The software needed for an RFID system to function effectively involves RFID reader control and application software, which is frequently referred to as middleware, which enable the RFID reader operation and data communication that is necessary for operating the RFID system if the application is a new system, then the RFID system can be embedded/integrated initially. On the other hand, if the RFID system is integrated with the existing system, it is very important to define and decide how to interface with it for integration. An RFID reader can read multiple RFID tags at the same time, this is called batch reading. The RFID system also needs an effective mechanism to deal with the enormous amounts of data being processed per second. All records of RFID tags are stored in the data server where the data volume, data capturing speed, and complexity of the data being captured by the RFID readers can make the process of the data for storage very challenging. The WMS also maintains instant inventory updates via the control unit that continuously transmit data over a LAN using middleware, which is the layer of software or programmed applications that translate commands and data between an RFID reader and the organisation's enterprise system. Databases are compiled in terms of identification and availability of each product and other data variables. Advantages of RFID include the ability to obtain more accurate product information and data transfer, enhance data security and control, and ensure adequate speeds of data-processing. Pallets and other equipment passing through doors and access ways can also be monitored using RFID providing sufficient coverage of the plant.

4.8 RFID cost elements

There are three cost categories (i) Hardware cost, (ii) Middleware cost, and (iii) Service cost. Hardware cost category covers the costs of tangible elements of the RFID system, such as RFID tags and RFID readers. Hardware cost is considered usually in the preliminary planning stages and it is important to note that economic models should also consider other cost categories. Justification of hardware costs is not sufficient for implementation decision, although hardware vendors may suggest otherwise. Service cost, such as business process redesign cost, and configuration cost, require an elaborate study on the firm and supply chain specific requirements. A whole range of cost elements may emerge depending on the context (Baysan et al., 2013).

Summary

In this section, key components of the RFID-enabled inventory management system are described in terms of functionality and implementation. This includes RFID database, RFID tags and an RFID reader, RFID antenna, bandwidth/connectivity of RFID system, connectors/cables of the RFID systems, RFID controllers and RFID software. To synchronize products and information flow, both RFID-based inventory management system and the warehousing control system need to be integrated in order to communicate effectively through a developed interface. The methodology for systems integration including hardware and software were identified and proposed as part of this research study.

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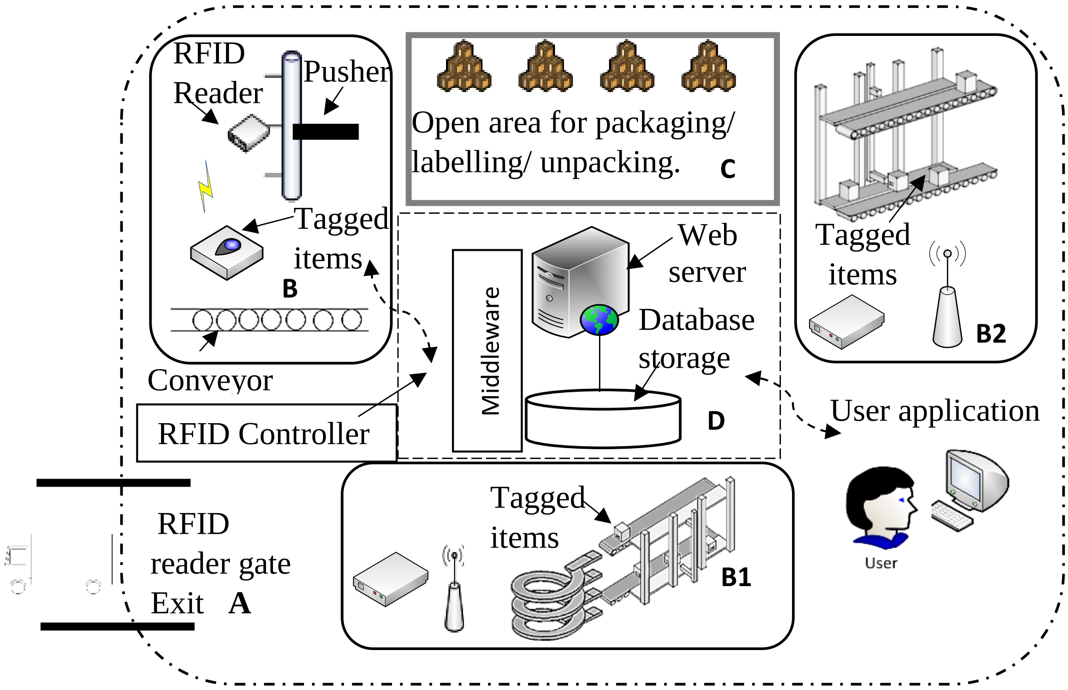
Chapter 5 The proposed RFID-based inventory management system and measurement

5.1 Mechanism of the proposed RFID-based automated warehouse system

Figure 19 illustrates the key components of the RFID-based management system for the proposed automated warehousing system. At the gate of the warehouse entrance/exit, it is equipped with an RFID reader (shown at A) which collects RFID information data of RFID-tagged goods for each incoming and outgoing lorry that passes through the gate. After the process of unloading and unpacking goods if applicable, each item will be contained in a tote entering into a storage conveyor, namely a storage rack (shown at B1). When a specific item is demanded, it can be transferred automatically from a storage rack onto an output conveyor (shown at B2) by a pusher device (shown at B). Each pusher also contains an RFID reader with its own antenna that receives wireless signals sent from RFID tags attached with RFID-tagged items in storage racks. Collection of inventory data by the RFID reader is updated instantly by a warehouse management system through a controller which transmits the collected data via a middleware (shown at D). The middleware is the software translation layer between an RFID reader and the warehouse management system. Database of the warehouse management system contains records, which include data in identification, availability and other use-defined information of each item stored in the warehouse. Once an in-store item is ordered, the RFID-based inventory management system has capability to carry out an automatic check on information data of the item in the warehouse database. Once the ordered item is identified by the RFID-based inventory management system, a pusher is activated by a PLC (programmable logic controller) to push the selected item in a tote onto an output conveyor. The item will then be transported by the output conveyor and it travels along an RFID-guided route to a specified destination (i.e., a collection point) for packaging (shown at C). The RFID-based warehouse inventory database will then be updated as soon as this ordered item is shifted out of the distribution centre in a lorry passing through the gate of the warehouse entrance/exit. The whole process is performed automatically without any human intervention apart from unpacking, labelling and packing operations in the warehouse.



A. Portal reader. B. Storage area. C. Open area for packaging/ labelling/ unpacking. D. Data Centre.

Figure 19: Key components of an RFID-based automated warehouse system.

5.2 The RFID-enabled automated storage and retrieval system (AS/RS)

Figure 20 illustrates an automated storage and retrieval rack (AS/RR) as one of the core components of the proposed RFID-based automated warehousing system. The module is designed as a standardised element for manufacturing and assembly, although each module can be of different sizes and arrays in a module that can be configured easily in many different ways, i.e., capacity of a warehouse are adjustable. The module is comprised of two types of powered conveyors aligned next to one another; these are input conveyors (storage racks) and output conveyors. The operation of both conveyor systems is controlled by a PLC that communicates with mounted sensors via a local area network (LAN). Within the RFID-inventory management system, a chosen SKU can be released by the mechanical system of AS/RR based on a number of assignments polices or rules. These include, for example, the rule of being nearest to a collection point and/or a pusher which is free or adjacent to the chosen SKU and so on, which are explained (in chapter 6 sections 6.4.1).

In the warehouse, once an item (or a tote that contains identical items) is attached with an RFID tag, it can be tracked and manipulated by the RFID-based inventory management system. An RFID tag has a unique identification and other user-defined information in association with a status of each item. It is composed of two main components which are an antenna and a computer chip. The computer chip stores data and the antenna allows data communication between an RFID tag and an RFID reader through a wireless signal transmission. A typical RFID reader is a microcontroller-based radio transceiver that powers an RFID tag using the time-varying electro-magnetic field (EMF) generated from an RFID antenna. Two types of RFID tags (active and passive RFID tags) can be used depending on a range in RFID reading performance at a location of an AS/RR. The RFID information data gathered by an RFID reader can be transferred to a host PC database for data processing and storage (as illustrated in Figure 19). By using RFID tags, a SKU can be distributed randomly at any location of an AS/RR wherever a place is available for incoming goods as illustrated in Figure 21. Thus, a SKU can also be dispatched randomly at varying locations for outgoing goods in the warehouse. This significantly facilities operations of storage, retrieval and replenishment, and improves capability, flexibility and responsiveness of the warehousing system to store and dispatch an item in/from an AS/RR.

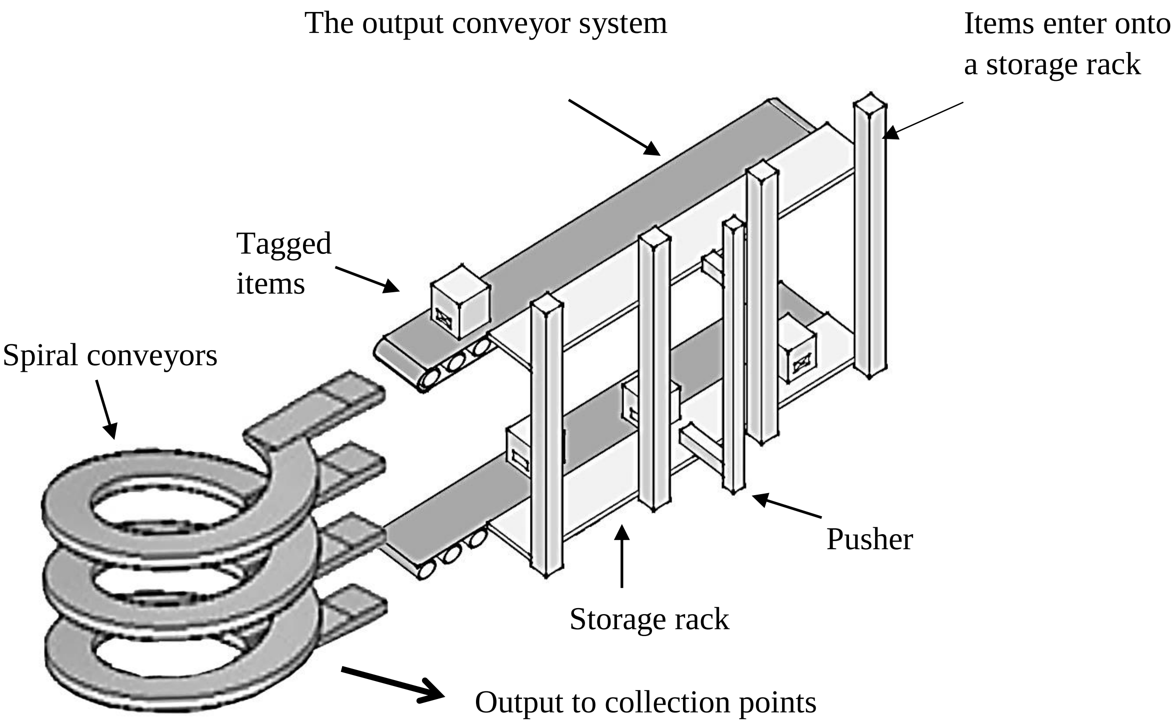


Figure 20: Structure of the automated storage and retrieval system.

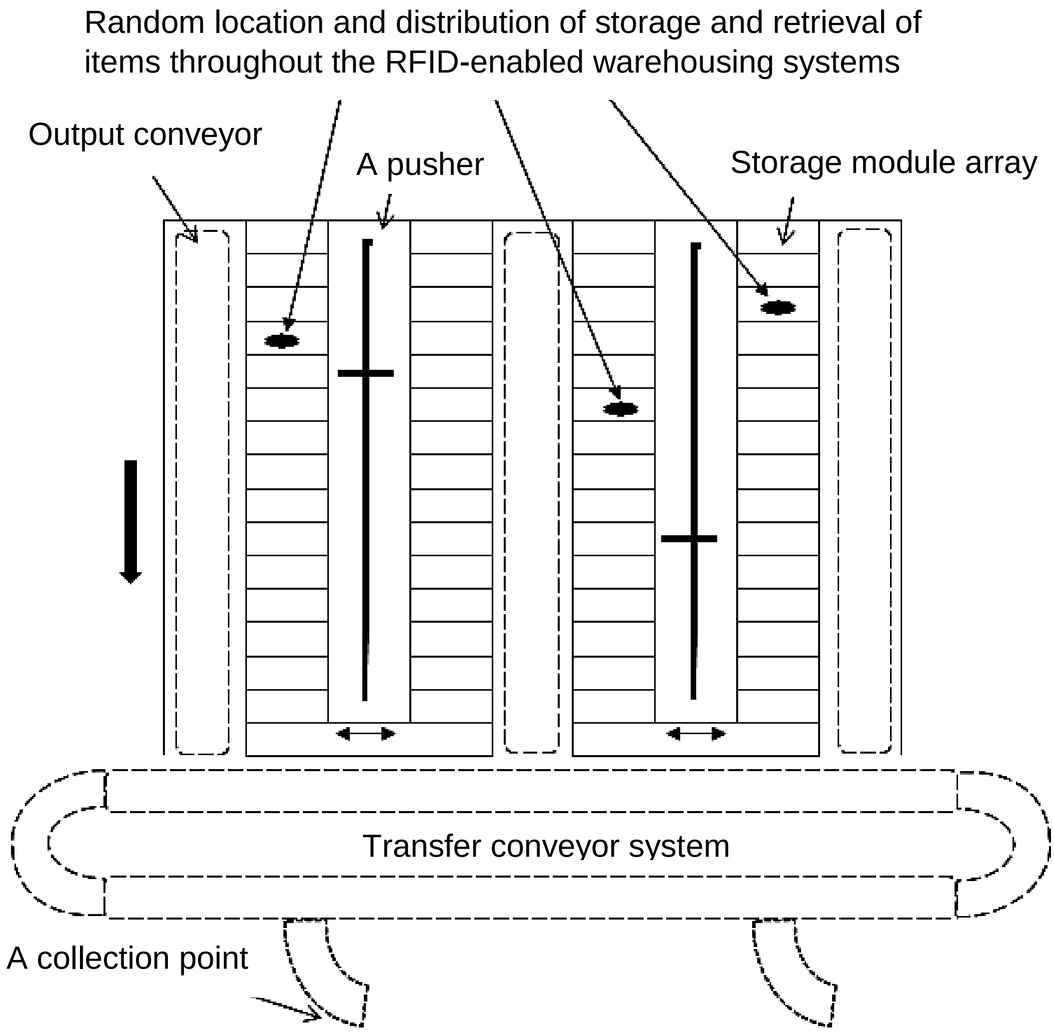


Figure 21: Random storage and retrieval locations of SKUs.

5.3 Measurement of the storage and retrieval mechanism

Figure 22 illustrates the key components and corresponding geometric parameters of the proposed storage and retrieval system (as illustrated in Figure 20): 1) output conveyor; 2) storage rack containing items; 3) height of a storage rack *H*; 4) length of a storage rack *L*; 5) depth of a storage rack *D*; 6) pusher; 7) length from an end of an output conveyor to an entrance of a spiral conveyor; 8) entrance to a spiral conveyor; 9) length of a single spiral conveyor; 10) a spiral conveyor; 11) length from an end of a spiral conveyor to a collection point. The aim of the following work is to determine a total travel time an item needs from the moment when a pusher device is activated to push a selected item in a tote onto an output conveyor to the moment this item travels down to a collection point. Figure 23 shows a two dimensional cross-section diagram based on Figure 22. The pusher can move simultaneously in both horizontal and vertical directions from one location (*i, j)* at where the pusher currently stays to another location (m_y, n_x) at where an identified item is selected to be pushed onto the output conveyor.

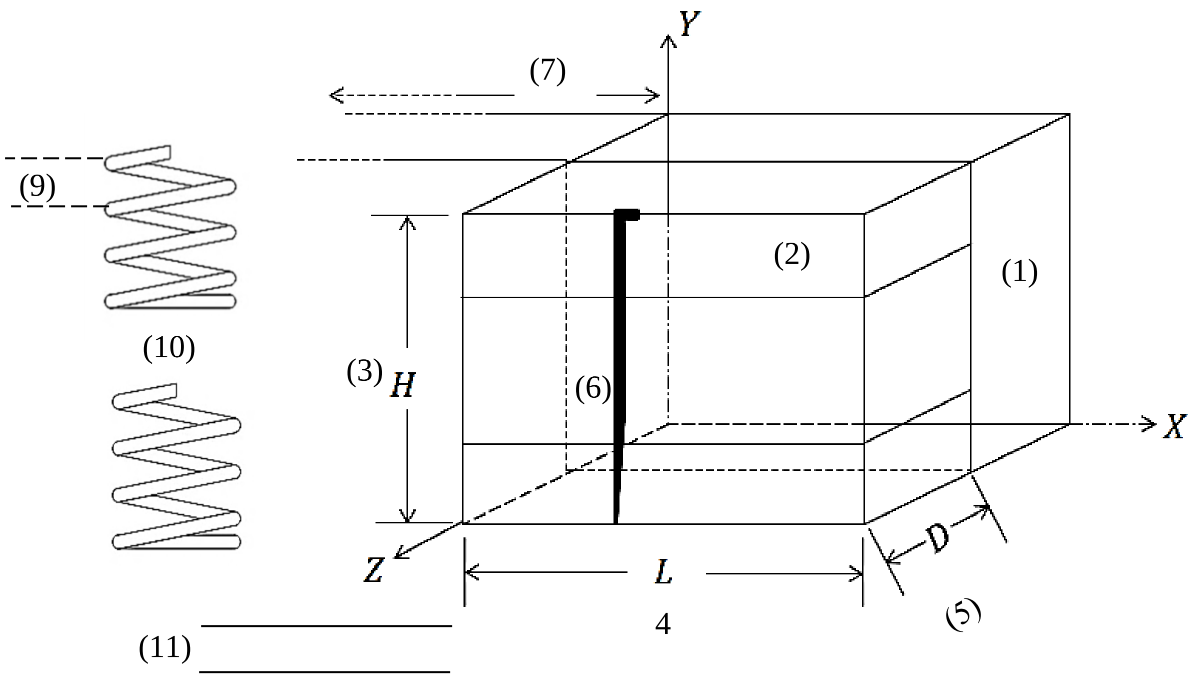


Figure 22: Geometric parameters corresponding to the key components of the storage and retrieval system.

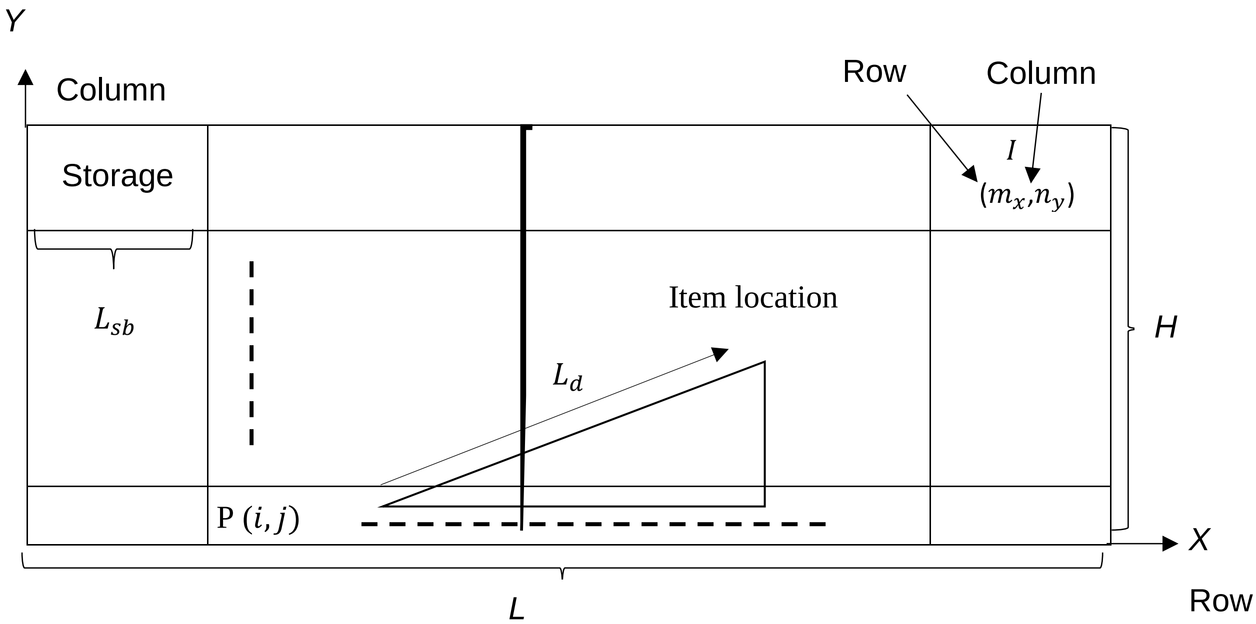


Figure 23: Geometric parameters in a storage rack.

5.4 Travel time

The following assumptions and notation are used when two cases of the velocity profiles for the pusher:

- *a*: acceleration/deceleration rate of the travelling S/R pusher.
- *v(t):* velocity of the travelling S/R pusher at time t.
- V_{max}*:* maximum velocity of the travelling S/R pusher.
- *d(t):* moving distance at t.
- *ta*: time necessary to reach the peak velocity.
- *T*: total travel time of the pusher.

There are two cases of velocity profiles that are used to compare the total travel time of the pusher. Case I where pusher has three different motion phases – acceleration, constant speed and deceleration. In case I, pusher first starts to accelerate to obtain the maximum speed V_{max} and then it travels with that maximum speed for certain time and then decelerate to reach the final destination as illustrated in Figure 24. Case II where pusher travels with a constant speed of V_{max} throughout whole journey. as illustrated in Figure 25, where the traveling S/R pusher V(t) is:

$$V(t) = \begin{Bmatrix} at & \text{t } \in \left[0, t_a\right] \\ v\max & \text{t } \in \left[t_a, T - t_a\right] \\ -a(t-T) & \text{t } \in \left[T - t_a, T\right] \end{Bmatrix} \tag{1}$$

Thus,

$$d(t) = \int_0^T v(t)d(t) = v_{\max} - \frac{v_{\max}^2}{a} \tag{2}$$

Equation 1 and 2 describe the velocity-time and distant-time relationship of the pusher when case I motion is applied on the pusher.

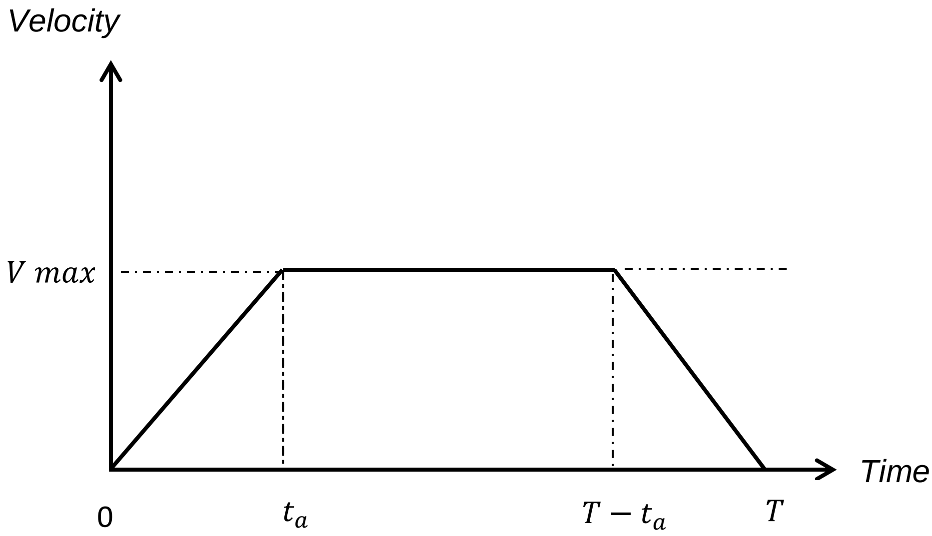


Figure 24: Velocity-time relationship of the travelling S/R pusher for the case I motion where acceleration, constant speed and deceleration is utilised.

- S/R pusher traveling for case II (Figure 25).

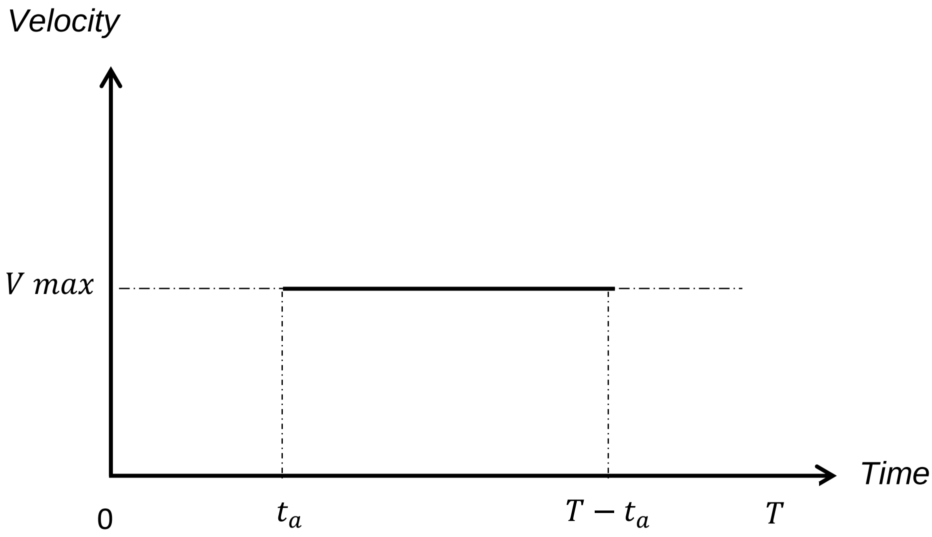


Figure 25: Velocity-time relationship of the S/R pusher travelling- case II.

The following assumptions are used in this case:

1. A pusher is located at the centre (i_c, j_c) of a storage rack; this is a default location of the pusher to be activated.
2. The pusher is capable of moving simultaneously in both vertical and horizontal directions at an estimated speed, this implies that the pusher can move along the linear route *Ld* to a specified location before pushing a selected item from

a storage rack onto and output conveyor.

3. Each item in a tote is pushed onto an output conveyor instantly without any delay.
4. The specification of the pusher (max. velocities in horizontal and vertical directions; and acceleration and deceleration rates) as well as the length (L) and height (H) of the SR are known.
5. The L and H of the SR are long enough for the S/R pusher to reach max. velocity from the default location.
6. A SKU can also be dispatched randomly at varying locations for outgoing goods in the AS/RR.

The following notations are used in this model.

- *I*: an item located at a row m_x and a column n_y i.e., (m_x, n_y) in an AS/RR.
- *P*: a pusher at a location (*i, j)*.
- *Lsb*: length of a tote in a storage room of an AS/RR.
- *Lsc*: length from a position of a selected item in a tote to be pushed onto an output conveyor to a position where this item in a tote travels at an end of an output conveyor.
- *Lss*: length of a single spiral conveyor.
- *Lsp*: length from an end of a spiral conveyor to a collection point.
- *Ld*: distance between a pusher and a selected item.
- *Vc*: speed of an output conveyor.
- *Vp*: speed of a moving pusher along L_d.
- *Vpp*: speed of a moving pusher to push an item onto an output conveyer.
- *Vs*: speed of a spiral conveyor.
- *ci:* chosen item, (where ci = 1, 2….., n).
- *Tm_ci*: time needed for a pusher to move to a selected (chosen) item *ci*.
- *Tp_ci*: time needed for a pusher to push a selected item *ci* onto an output conveyor. from an input conveyor (i.e., a storage rack).
- *Ts_ci*: travel time of a selected item *ci* in a tote along an output conveyor to a spiral conveyor.
- *Tsc_ci*: travel time for a selected item *ci* in a tote to move from the top level to the bottom level of a spiral conveyor.
- *Tse_ci*: travel time of a selected item *ci* from an end of a spiral convey to a collection point.

- *n:*number of chosen items.
- *Ttt_ci*: total travel time of each of selected items from the moment when the pusher is activated to push the selected item to the moment when the selected item arrives at a collection point.
- *Ttt:* least travel time of one of selected items from the moment when the pusher is activated to push the selected item to the moment when the selected item arrives at a collection point.

Illustrated in Figure 22, assuming an item is located at (m_x, n_y) and a pusher has a random location at (i, j) in a storage rack. Thus, a distance L_d between the activated pusher and the selected item is given by:

$$L_d = \sqrt{(m_x - i)^2 + (n_y - j)^2} \tag{3}$$

Therefore, the travel time T_m is given by:

$$T_m = \frac{L_d}{V_P} \tag{4}$$

Where, V_p is a speed of the moving-pusher along L_d. We define T_p is a travel time from the moment when the pusher starts to push a selected item to the moment that the selected item has been pushed onto an output conveyor, it is given by:

$$T_p = \frac{D}{V_{PP}} \tag{5}$$

Where, D is a depth of the storage rack at which the selected item is located. V_{pp} is a constant speed of the moving-pusher to push the selected item onto the output conveyer. Knowing L_{sc} refers to a distance from the centre of the tote at the end of the conveyor. L_{sb} is a length of a storage room containing each item in a tote, n_y refers to the number of columns in row m_x , V_c is the constant speed of the output conveyor. Thus, T_s is given below:

$$T_s = \frac{L_{sb} \times (n_y - 0.5) + L_{sc}}{V_C} \tag{6}$$

The item travels down through a powered spiral output conveyor from the top level to the bottom level towards a collection point where the item is collected for packing. Thus, T_{sc} is calculated by:

$$T_{sc} = \frac{m_x \times L_{ss}}{V_S} \quad (7)$$

Where, L_{ss} is the length of the single level spiral conveyor. m_x refers to the number of rows in column n_y. As T_{se} is a travel time that the item needs from the end of the spiral conveyor to a collection point. L_{SP} is a travel distance between the end of a spiral conveyor system and a collection point. Therefore, the travel time between the end of a spiral conveyor and a collection point is given by:

$$T_{se} = \frac{L_{SP}}{V_C} \quad (8)$$

Hence, the total travel time T_{tt_ci} for the selected item is obtained by:

$$T_{tt\_ci} = T_{m\_ci} + T_{s\_ci} + T_{sc\_ci} + T_{p\_ci} + T_{se\_ci} \quad (9)$$

T Where, ci= (1, 2, ……n). The selected item that needs a minimal travel time T_{tt} , which is identified by the RFID-inventory management system throughout the storage and retrieval system, can be obtained by

$$T_{tt} = \min\ (T_{tt1}, T_{tt2}, ..., T_{tt\_ci}) \quad (10)$$

The longest travel time T_{max} of the one of selected items to a collection point can be obtained by

$$T_{\max} = \max[T_{tt\_ci}\ , T_{tt\_ci+1}\ , ..., T_{tt\_ci+n}] \quad (11)$$

After an order for multiple items are made by a customer, the RFID-inventory management system needs to determine which item has a longest travel time and subsequently issue a priority to this item to be dispatched first. Figure 26 illustrate the multi-directional trajectory of a pusher which travels to a selected item. Assuming that an item has a random location (m_x, n_y) and a pusher is located at the centre (i_c, j_c). of a storage rack; this is a default location of the pusher to be activated. The pusher *P* can move simultaneously in both horizontal and vertical directions from the centre location (i_c, j_c) at where the pusher currently stays to a location (m_x, n_y) at where the selected item awaiting to be pushed onto the output conveyor by the pusher mounted in AS/RR. As stated previously, when an order for multiple items is executed, the pusher can only push one item at a time according to the estimated travel time determined by RFID-based inventory management system (illustrated in Figure 44, chapter 7).

Therefore, it is desired to determine an overall estimated waiting time for an order that contains multiple items from the moment when a pusher is activated to push the first selected item with a longest travel time to a specified collection point to the moment that the last selected item with the least travel time arrives at the same collection point. With this approach, it gives a minimum waiting time for all the items to meet at the specified point.

The following notations are used.

- *Pc*: a pusher at a centre location (i_c, j_c)
- V_1 : a constant speed of an output conveyor.
- V_2: a constant speed of a spiral conveyor.
- 1_B : identified items in each row at different columns of an AS/RR.
- 1_L : identified location of each of ordered items in each row at different columns of an AS/RR.
- T_{max}: longest travel time of the one of the selected items.

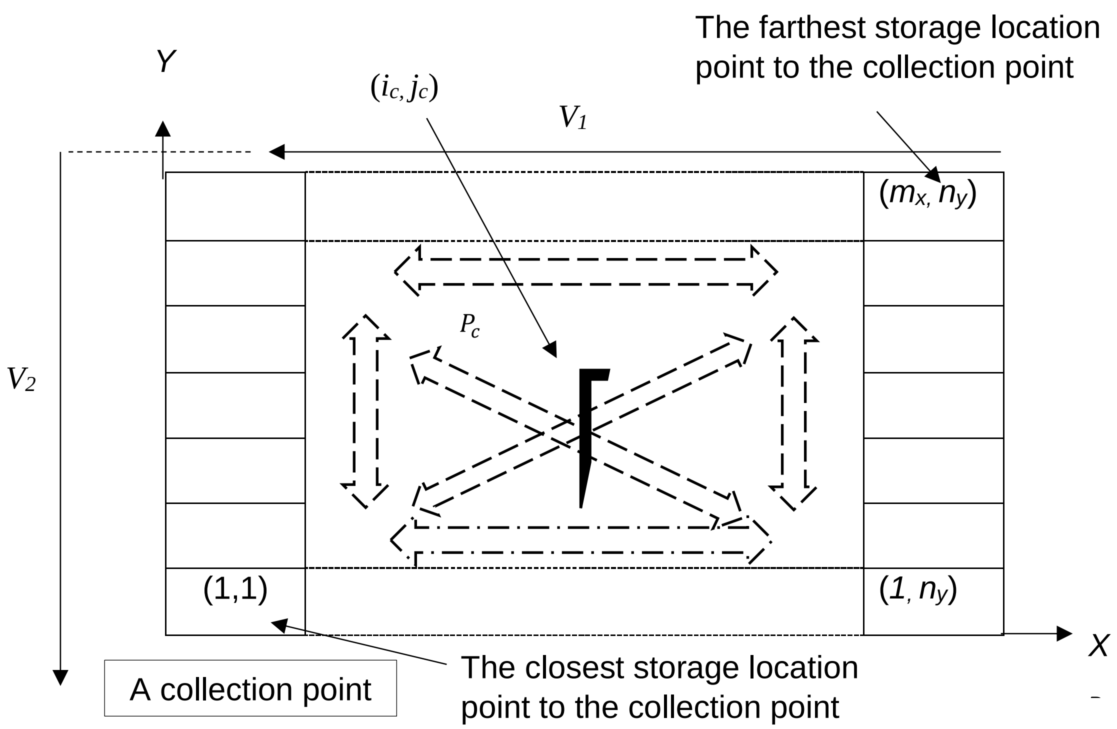


Figure 26: Multi-directional trajectory of a pusher which travels to selected items.

5.5 Indicator function

In mathematics, an indicator function is a function that defined by a set of x that indicates the membership of an element in a subset *B* of *x*, assuming that a value 1 for all elements of *B* and a value 0 for all elements of *X* not in *B*.

The indicator function of a subset *B* of a set *X* is a function defined as below

$$1_B(x) = \begin{cases} 1 & \text{if } x \in \mathrm{B} \\ 0 & \text{if } x \notin \mathrm{B} \end{cases} \tag{12}$$

Let *B* be the set of random locations (m_x, n_y) for each of items in AS/RR

$$1_B(m_x, n_y) = \begin{cases} 1 & \text{if } (m_x, n_y) \in \mathrm{B} \\ 0 & \text{if } (m_x, n_y) \notin \mathrm{B} \end{cases} \tag{13}$$

As an example, if $1_B(m_x, n_y) = 1$, it indicates that an ordered item is identified by the RFID-inventory management system, i.e., this ordered item is available at this particular location (m_x, n_y). If $1_B(m_x, n_y) = 0$, it indicates that an item is not ordered. Figure 27 illustrates this process. Assuming that there are multiple items ordered by a customer, the inventory management system will then search and identify a location of each ordered item in an AS/RR. The system will search and identify a location of each ordered item from location *(1,1)* to location ($1, n_y$) in a row across each storage rack of an AS/RR as shown in Figure 26. Figure 27(a) shows the process of searching and identifying locations that contain ordered items from left to right in row 1 of the storage rack. Figure 27(b) shows a number of identified locations containing ordered items in a storage rack by issuing a value 1 for each of the ordered items and a value 0 for a non-ordered item at a location (m_x, n_y). Figure 27(c) shows the final result of selected locations which contain ordered items in this storage rack.

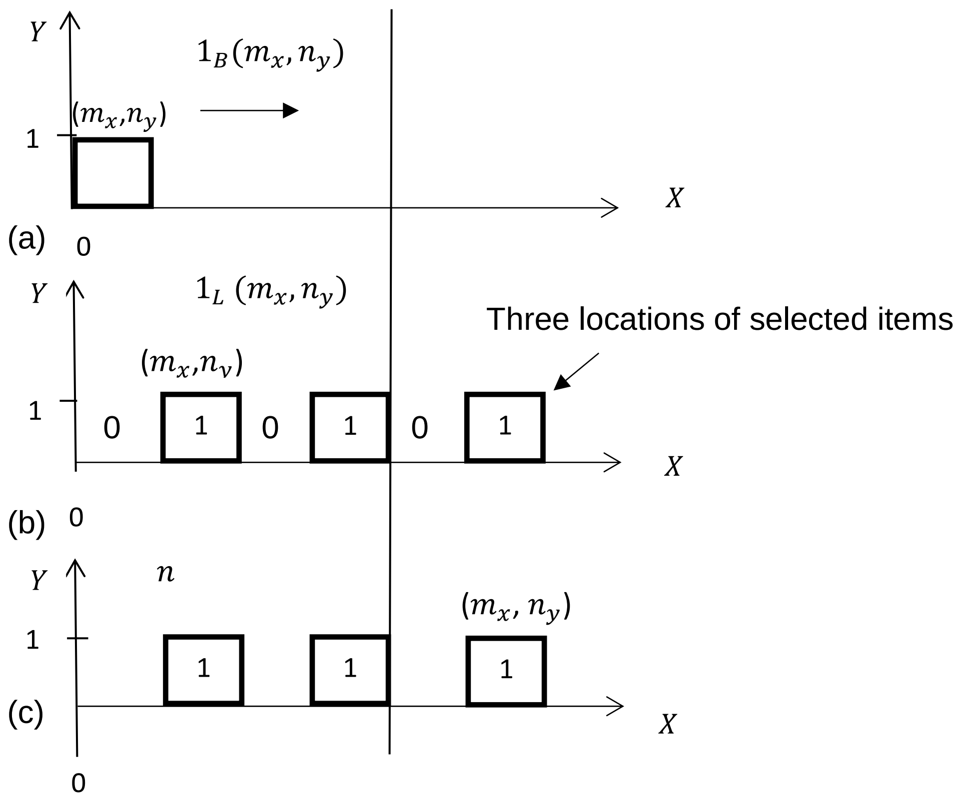


Figure 27: Mechanism of searching and selecting an ordered item in a storage rack.

Hence, a total number of ordered items *n* can be obtained by

$$n = 1_{B(m_x,\ n_y)} \times 1_{L(m_x,\ n_y)} \tag{14}$$

Figure 28 illustrates the routing algorithm for a pusher to be given the priority to travel to one of selected items. Let us define *Ttt* which refers to the total travel time needed for a selected item to travel from the moment a pusher is activated to push the ordered item to the moment this item arrives to a specified collection point. Assuming that a number of items *n* are ordered from the warehouse, these items are randomly placed at different location *ci* (where *ci*= 1, 2, …..n) in the AS/RR. The total travel time for each of selected items is denoted by *Ttt_ci*.The RFID-inventory management system calculates an estimated travel time *Ttt_ci* for each of the selected items to a specified collection point in order to determine the item with a longest travel time to be given a priority to be pushed onto the output conveyor by the pusher. The system will then repeat the same process by determining the second item with a longest travel time among the remaining items until the last item with a least travel time to be pushed onto the output conveyor. With this approach, the pusher can also travel through in an optimal route to ensure that all the selected items will arrive and meet at the specified collection point with a minimal waiting time for packers to receive these items.

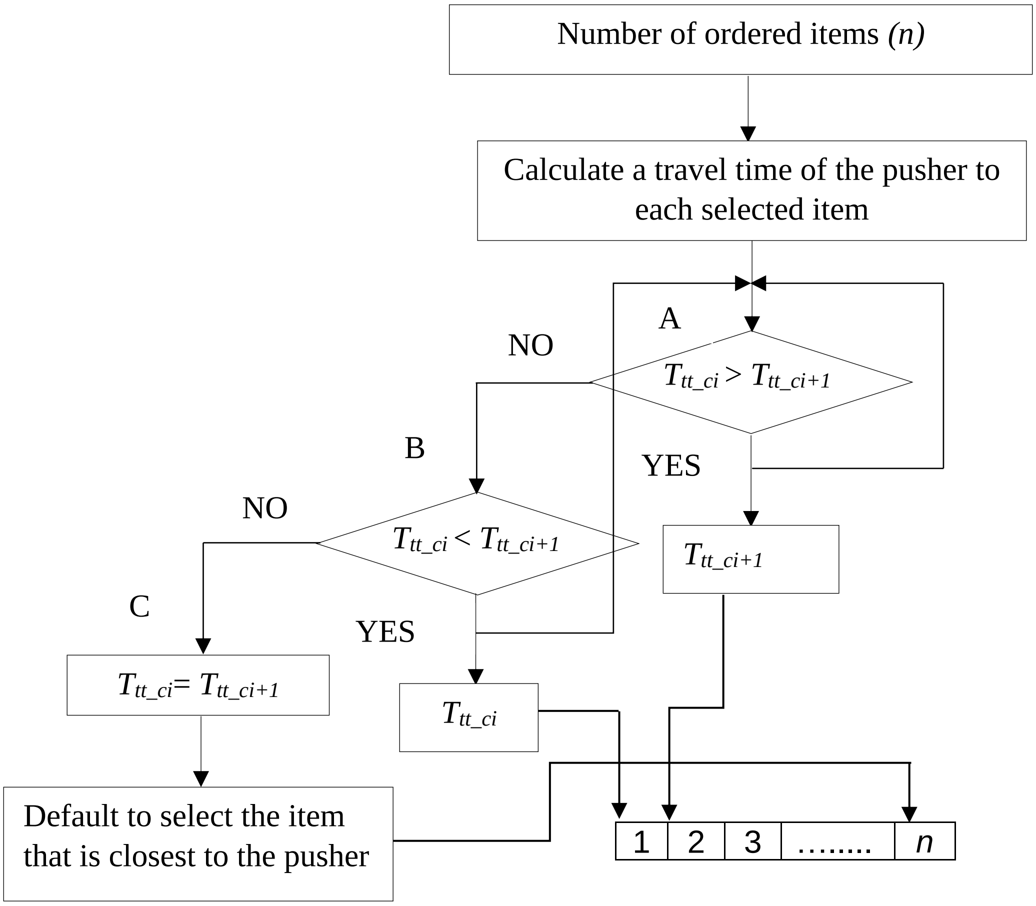


Figure 28: The routing algorithm for a pusher to travel to each of selected items.

Summary

This chapter describes the mechanism of the proposed RFID-based automated warehousing system and its key component of AS/RR; one of the core components of the proposed RFID-based automated warehousing system is the design of the automated storage and retrieval system AS/RS. The module was explained and illustrated in details for scheduling job priorities to selected items to be dispatched from the warehousing system travelling to a collection point. Thus, the aim of this work is to determine a total travel time an item needs from the moment when a pusher device is activated to push a selected item in a tote onto an output conveyor to the moment this item travels down to a collection point. Indicator function was identified to in order to search and select an ordered item in a storage rack. With the developed routing algorithm approach, it gives a minimum waiting time for all the items to meet at the specified point.

Chapter 6 Integration of the RFID-enabled warehouse management system

6.1 Key components used for integration of the RFID-enabled warehouse management system

Figure 29 shows the key components used for an experiment towards the integration of the RFID-enabled warehouse management system. A typical RFID reader was used and it is a microcontroller-based radio transceiver that powers RFID tags using the time-varying electro-magnetic fields (EMF) generated from an RFID antenna. Two types of RFID tags (active and passive RFID tags) can be used for this experiment depending on a range of RFID reading performance at a location of an AS/RR. An electromagnetic field's characteristics change depending on the distance from the antenna. This varying field is broken up into two parts: the near field communication (NFC) and the far field communication (FFC). An RFID tag is composed of two essential components: an antenna and a computer chip. The computer chip is used to store data while the antenna allows data communication between the tag and the RFID reader through a signal transmission. RFID tags have their unique identification (UID), which is used to uniquely identify an item each RFID tag is assigned to. The collected RFID tags can be read by the reader and sent back to the host PC for processing.

Arduino and Microsoft Visual Studio environment software are used to allow users to perform a group of coordinated functions, tasks, or activities.

MATLAB is a foundation for all other MathWorks products providing a high level of programming language and interactive technical computing environment and functions for algorithm development, data analysis and visualization. In this study MATLAB was used to demonstrate the data process output of ordering items using the developed algorithm.

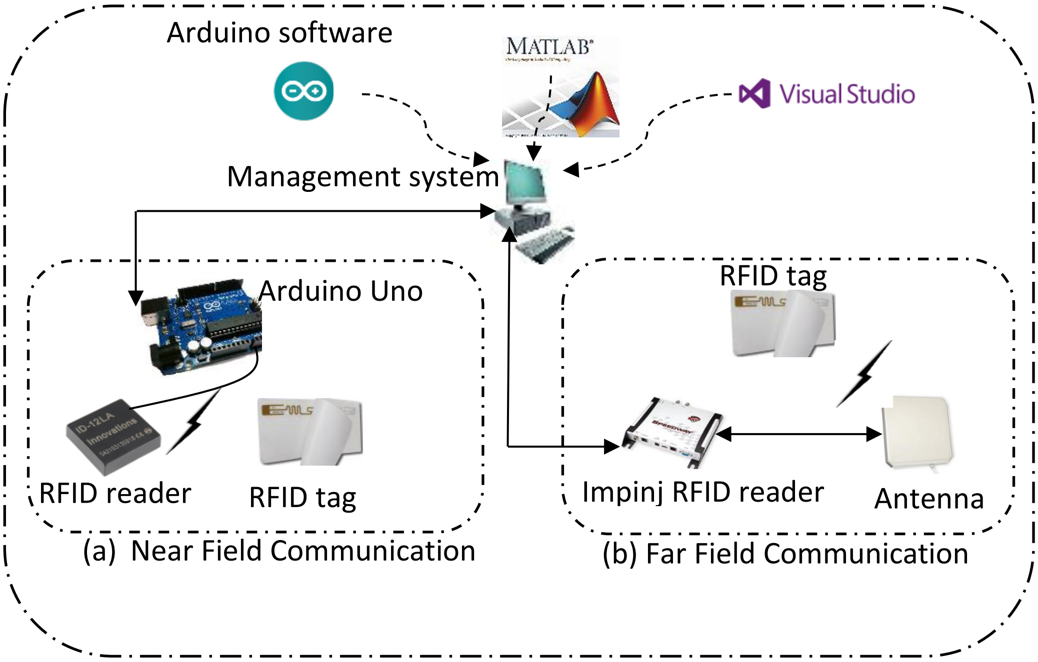


Figure 29: Key components used in this experiment.

6.2 RFID near-field communication

Near field communication (NFC) is a set of standards for smartphone and similar devices to establish radio communication with each other. Applications include contactless transactions, data exchange, and simplified setup of more complex communications such as Wi-Fi. Figure 30 shows Arduino which is an open-source platform and it can be used to develop stand-alone interactive objects or can be connected to software on a computer (e.g. Flash, Processing, MaxMSP). The Arduino has the ability to be installed to any type of operating system and it can be powered and programmed via the built in USB connection. Arduino UNO contains; 6 pins used for pulse width modulation (PWM) as outputs and 6 pins used as analogue input. Arduino UNO also includes a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button. Table 8 shows specifications of Arduino UNO.

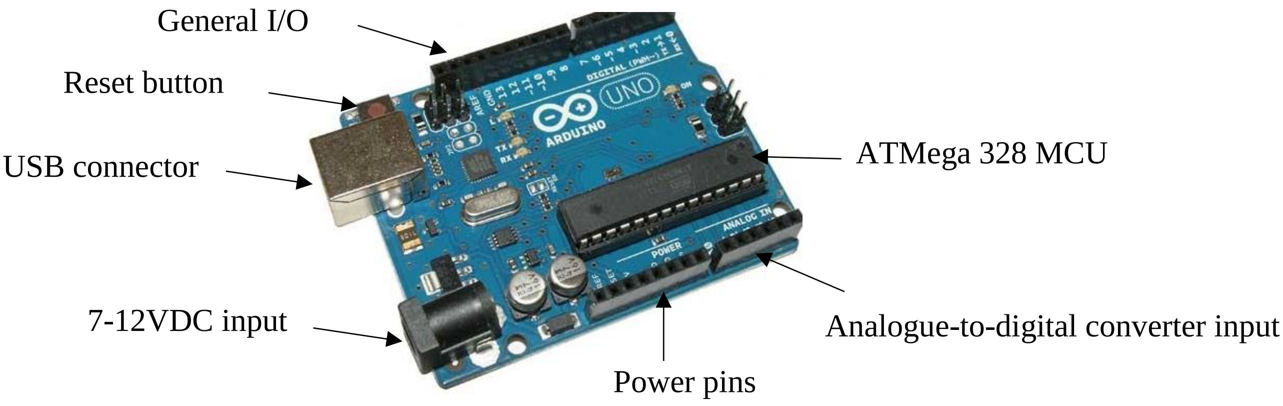


Figure 30: Arduino UNO (Arduino Company).

Table 8: Specifications of Arduino UNO.

Microcontroller	ATmega328
Operating Voltage	5V
Input Voltage (recommended)	7-12V
Input Voltage (limits)	6-20V
Digital I/O Pins	14 (of which 6 provide PWM output)
Analogue Input Pins	6
DC Current per I/O Pin	40 mA
DC Current for 3.3V Pin	50 mA
Flash Memory	32 KB (ATmega328) of which 0.5 KB used by boot loader
Clock Speed	16 MHz

6.2.1 Recognition between an RFID tag and an RFID reader

Figure 31 shows a flowchart of reading activities between an RFID tag and an RFID reader using the ID-12 reader model. Initially, the device will determine the input and output pins to be used in order to perform the task of reading an RFID tag, and then set up the serial connection to the RFID reader module. Once the Wi-Fi connection is established, the RFID reader waits to obtain the unit code, as it starts to read tags each UID tag will be transmitted to the server.

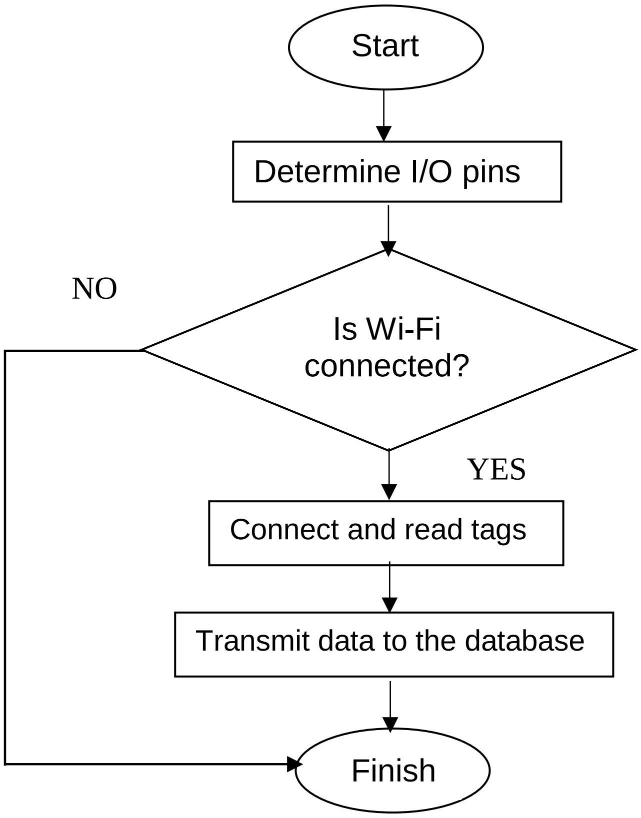


Figure 31: Reading activities between an RFID tag and an RFID reader.

The ID-12 reader module was used because it meets the requirement that includes the actual size of the RFID reader and internal antenna with a range of 12cm. It requires between 2.8-5 volt of power supply, a ground pin and a digital pin (on the Arduino) that will be utilised for serial connection. The data retrieved from RFID tag ID is programmed to transmit instantly to the server for fast response by RFID ID-12 reader, as storing data to the tag memory will lead to delay/bugs. The RFID (ID-12) reader is a low frequency (LF) RFID with 125 kHz frequency, it supports ASCII, Wiegand26 and Magnetic ABA track2 data formats. In this experiment, an RFID reader with ISO/IEC 18000 Part 3 Standards as shown in Figure 32.

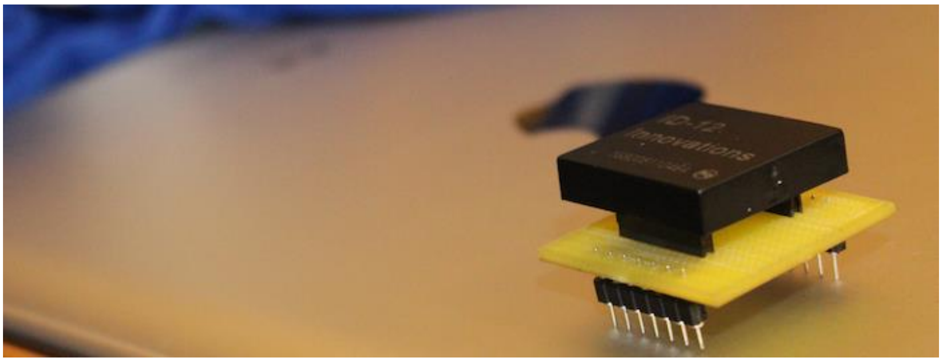


Figure 32: The RFID Reader (ID-12) (Author's completion).

6.3 RFID far-field communication

Figure 33 shows key components for a pilot test of the RFID inventory management system, which has a capability of interacting with the mechanical control system of the proposed RFID-embedded automated storage and retrieval rack (AS/RR). The system hardware includes a host computer, an ultra-high frequency (UHF) Impinj RFID reader, an Impinj far-field antenna, and a number of passive tags. The RFID reader is attached with the antenna in a range of 902~928 MHz (using the EPC global Gen2 ISO18000-6C standard) in a direction of 70° to capture data transmitted from the passive RFID tags and these gathered data are stored in a laptop for data processing (Liu et al., 2014). The RFID-based inventory management system was developed under the Imping Octane SDK, which is a package for configuring settings of the RFID reader using a Low Level Reader Protocol (LLRP). LLRP offers a high-level control in reader settings, tag query and tag-writing operations. The RFID reader API (application program interface) package provides a common programming interface to allow an interaction between the RFID hardware and the RFID application software hosted in an MVS (Microsoft Visual Studio) environment. The software also defines a high-level object-oriented interface that permits the communication with the RFID reader.

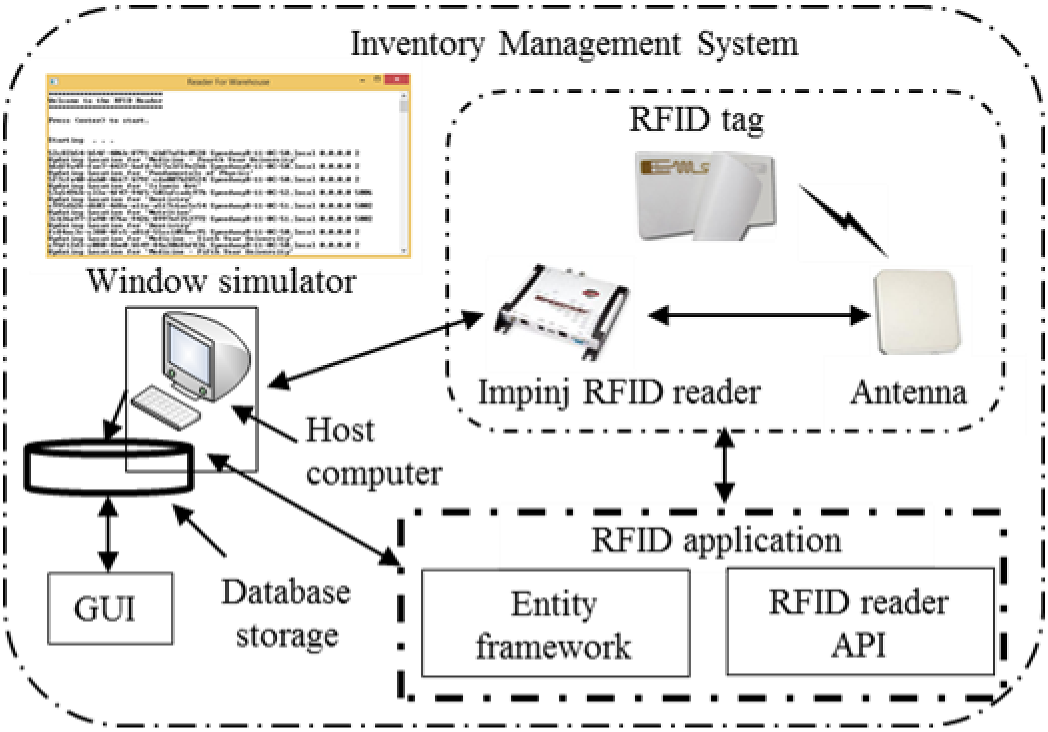


Figure 33: Key components of the RFID inventory management system for the pilot test.

The MVS supports a NuGet which is an open source package manager providing a number of application tools including the entity framework, which is an object relational mapping (ORM) mechanism. Within the ORM mechanism, it can create classes based on database tables in which each entity framework allows a web application to communicate with the database. The inventory management system contains a transaction database using the Microsoft SQL server. The database can automatically update an existing location of an RFID-tracked item at any time when a change of it takes place. As an example, when an RFID event (e.g. a reader reads an RFID tag) occurs, the database automatically updates the record of the collected information relating to this event. The inventory management system then runs the associated program using the selection algorithm to determine the updated location of an RFID-tracked item in the warehousing system and the location of this item can be displayed in the GUI (graphical user interface) (as shown in Figure 44 in chapter 7). The GUI was developed in MATLAB and it allows for visualizing changing locations of any possibly selected item in the warehousing system. MATLAB toolbox supports communications using the open database connectivity (ODBC) that can link with any compatible database such as Microsoft SQL. An ODBC is a middleware application program interface that allows an access of the management system database.

6.4 Database of the RFID inventory management system

The database of the inventory management system is the core of RFID systems. The database can be implemented using Microsoft SQL, Microsoft SQL, Sybase, Oracle, DB2, MySQL or MS-Access. In this study, the database of the RFID-inventory management system was created using Microsoft SQL. The database records contain data of each item attached with an RFID tag indicating the identification and availability of this item stored in the warehouse. Table 9 shows a list of records of searched items which contain RFID-inventory information within the SQL database.

Table 9: Part of information data within the SQL server.

Type of item	Item location	Expiry date	RFID Tag id	Label number
'Milk'	(40, 50)	'20160201'	'3008-33B2-DDD9-0140-0000-0001'	1111119
'Milk'	(50,30)	'20160222'	'3008-33B2-DDD9-0140-0000-0000'	1111118
'CD'	(90,60)	'00000000'	'3008-33B2-DDD9-0140-0000-0002'	1111120
'Mobile'	(80,20)	'00000000'	'3008-33B2-DDD9-0140-0000-0003'	1111121
'Bread'	(70,10)	'20160203'	'3008-33B2-DDD9-0140-0000-0004'	1111122

6.4.1 The data processing algorithm using MATLAB

As stated previously, the RFID-inventory management system has capability of performing an inventory searching process of ordered items by executing a set of pre-defined selection rules, which include an availibilty check of each of ordered items, locations of ordered items, expiry dates of each of ordered items if applicaple, a shortest path for the ordered item traveling to a specified collection point and other user-predefined selection criteria. Figure 34 illustrates the inventory selection process of ordered items to be dispatched by the warehouse. If an item is selected from a group of the same type of items stored in multiple locations in the warehouse, the RFID-inventory management system will issue a priority based on the pre-defined selection rules to be given to a selected item and initialise a demand to push the selected item onto the output convyeor (as illustrated in Figure 20 in chapter 5). To schedule a job priority for the selected item to be dispatched from the warehousing system, an algorithm was developed to seek an optimal solution for selecting an item which has a priority over other items of the same type. Table 10 shows part of the programming codes which demonstrate the data process of ordered items using the developed item selection algorithm (Other codes can be found in Appendix C).

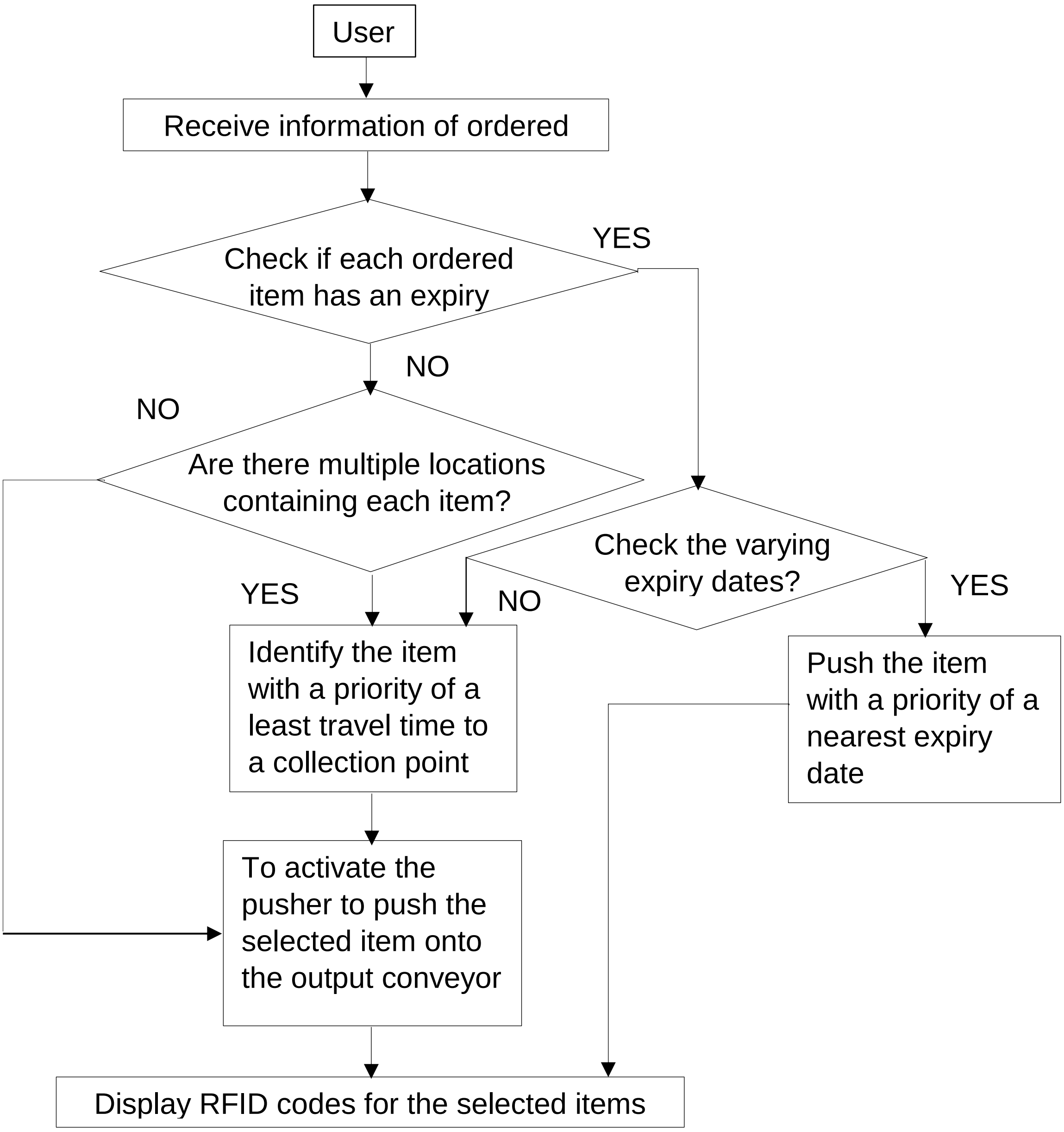


Figure 34: The RFID-data processing algorithm.

Table 10: Part of MATLAB programming codes for data processing.

```
================================================================
Data Processing
disp('Please Input The Name of Ordered Item!')
OrderedItem='Milk     '; % Change the name of ordered item.
Find and save the location information which contains the ordered item
No=0; % Starting number of ordered item
Location=[]; % For storing the location information of ordered item
Calculate the computation time
        Tm=sqrt((PP(1)*Hf-Location1(1)*Hf)^2+(PP(2)*L-Location1(2)*L)^2)/Vp;
        Tp=D/Vpp;
        Ts=((Location1(2)-0.5)*L+Lsc)/Vc;
        Ti=(rack-Location1(1))*Lss/Vs;
        Te=Lsp/Vc;
        Tt=Tm+Tp+Ts+Ti+Te;
```

6.5 Standardisation of RFID Technology

RFID standards are guidelines or specifications for all RFID products. Standards provide guidelines on how RFID systems work, what frequencies to operate at, how data ~~is~~ are transferred, and methods in communication between the RFID reader and the RFID tag. The UHF frequency band covers the range from 300 MHz to 3 GHz. Systems comply with the UHF Gen2 standard for RFID use the 860 to 960 MHz band. While there is some variance in frequency from region to region, UHF Gen2 RFID systems in most countries operate between 900 and 915 MHz. Passive UHF RFID is currently the only type of RFID to be regulated by a single global standard. This standard is called EPCglobal UHF Gen 2 V1, or just UHF Gen 2. UHF Gen 2 defines the communications protocol for a passive backscatter, reader-talks-first radio frequency identification (RFID) system operating in the 860 MHz - 960 MHz frequency range. EPCglobal certification testing includes conformance testing, which ensures that RFID products are compliant with the UHF Gen2 standard, and interoperability testing, which makes sure that all aspects of the tag reader interface are properly designed to interoperate seamlessly with other Gen 2 certified products. Table 11 shows the product code for RFID components that used in the research work.

Table 11: RFID components product code (Arduino Uno company, Impinj company).

Product type	Product Code
Fixed Readers-Impinj Speedway Revolution	IPJ-REV-R220-EU11M1

MTI Far Field Antenna	THI004
Label RFID Tags-Casey EPC Global Class 1 Gen 2 (ISO 18000-6C) Compliant	CON008
Arduino UNO	A000066 (TH); A000073 (SMD)
The ID-12 reader module	ID-12LA

Summary

The concept of integration enables RFID components to be embedded within the warehousing system's infrastructure. This includes an integration of hardware and software applications. This chapter describes the RFID-enabled inventory management system integration approach and the types of radio frequency fields that operate within RFID systems according to antenna signal. Under the integration of RFID-enabled warehousing management system, customers place their orders online through a web-based platform and the RFID-inventory management system can automatically check its database in terms of availability of these ordered items. Key components of the RFID system was identified and used for an experiment for integration of the RFID-enabled inventory management system. Based on this, a pilot test (described in the next chapter) of the RFID inventory management system was carried out and it demonstrates the capability of interacting with the mechanical control system. The RFID-data processing item selection algorithm was illustrated based on the inventory selection process of ordered items to be dispatched by the warehouse with respect to its criteria. The routing algorithm for a pusher to be given the priority to travel to one of selected items was also illustrated

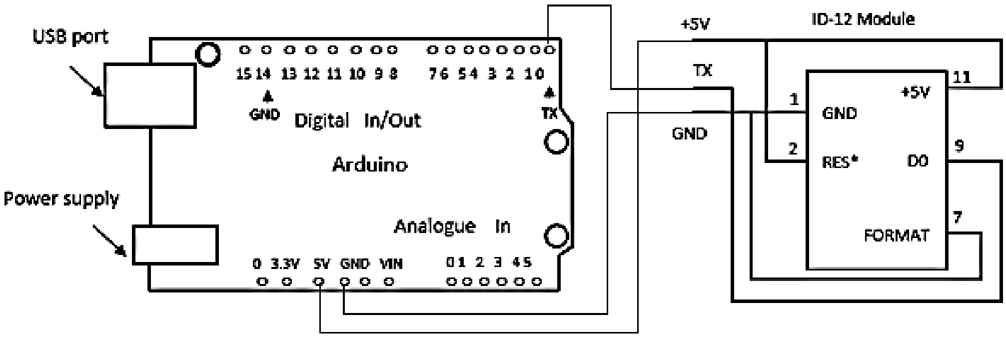
Chapter 7 A pilot study and experimental results

As discussed previously, one of the key elements of an RFID-enabled warehousing system is its data processing mechanism, namely the warehouse management system (WMS) that deals with in-store inventory data received by the RFID system. This chapter provides detailed experimental results based on a pilot test. In order to carry out a pilot test, a program, which is based on the developed mathematical model to determine the estimated travel time for items to be dispatched from an AS/RR to a specified collection point in order to determine the optimal solution (with the least travel time), was developed using MATLAB (shown in Figure 44). A prototype of the proposed RFID-based management system was built using two segments as follows.

a) Near field communication (NFC) using a microcontroller board on the Arduino ATmega328.
b) Far field communication (FFC) using the Impinj Speedway Gen2 RFID.

The ATmega328 microcontroller is the main system controller and the ATmega328 compiler is written using C++ language. The Arduino near field antenna is operated in 125 KHz-13.56 MHz RFID standards. The compiler is a platform for the computer program that converts source code (written in a computer language such as C++) to accomplish tasks. Figure 35 shows a prototype of the RFID-inventory management system which was built with its backbone using an Arduino interface which interacts with the RFID management system. The ID-12 module was used to perform the task of detecting and reading RFID tags and subsequently printing out RFID codes over a USB port terminal interface (COM4) as shown in Figure 36.

7.1 Hardware and software of the RFID inventory management system



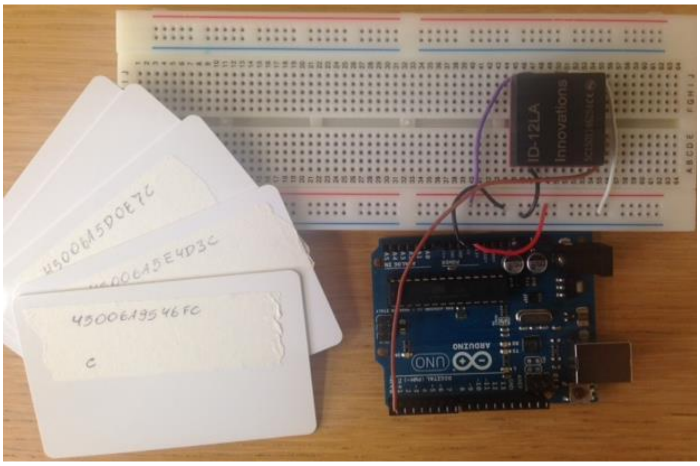


Figure 35: The prototype of the RFID-inventory management system using an Arduino interface (Author's completion).

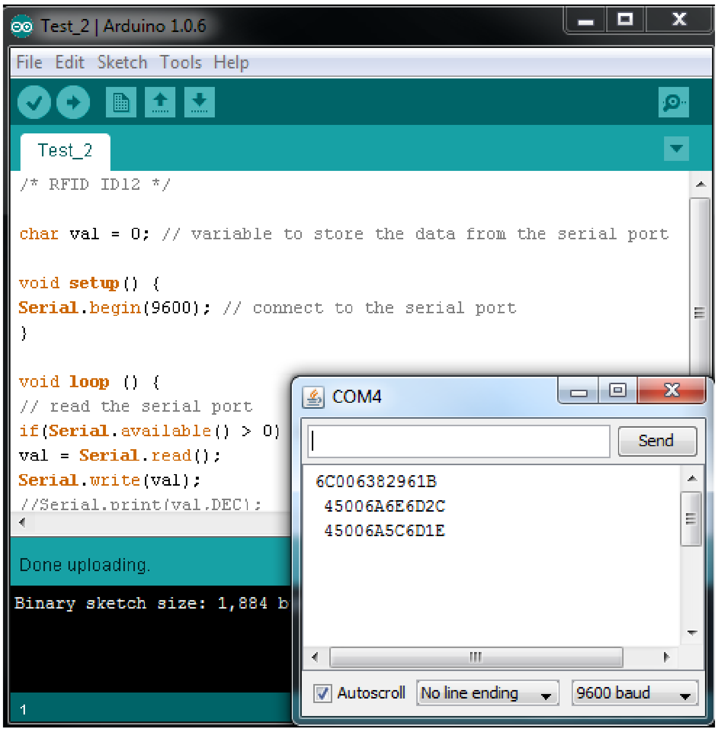


Figure 36: Screen shot of an example of RFID codes generated through the Arduino platform (Arduino open source software).

Figure 37 shows a screen shot of an example in the command window of information collected by reading RFID tags in a MATLAB environment based on the following rules:

(1) The location of an ordered item.

(2) The state of an ordered item.

(3) The identity of an ordered item at a particular location.

(4) The nearest object to the collection point.

The developed RFID-based management system can automatically detect and identify a number of locations of the ordered item by displaying objects in rows and columns on a storage rack. If there are several locations containing the same type of the ordered item, based on the developed item selection algorithm, the system will then issue a demand to dispatch the ordered item by assigning a priority to the selected item based on the closest expiry date if applicable and the nearest location of an item to a collection point.

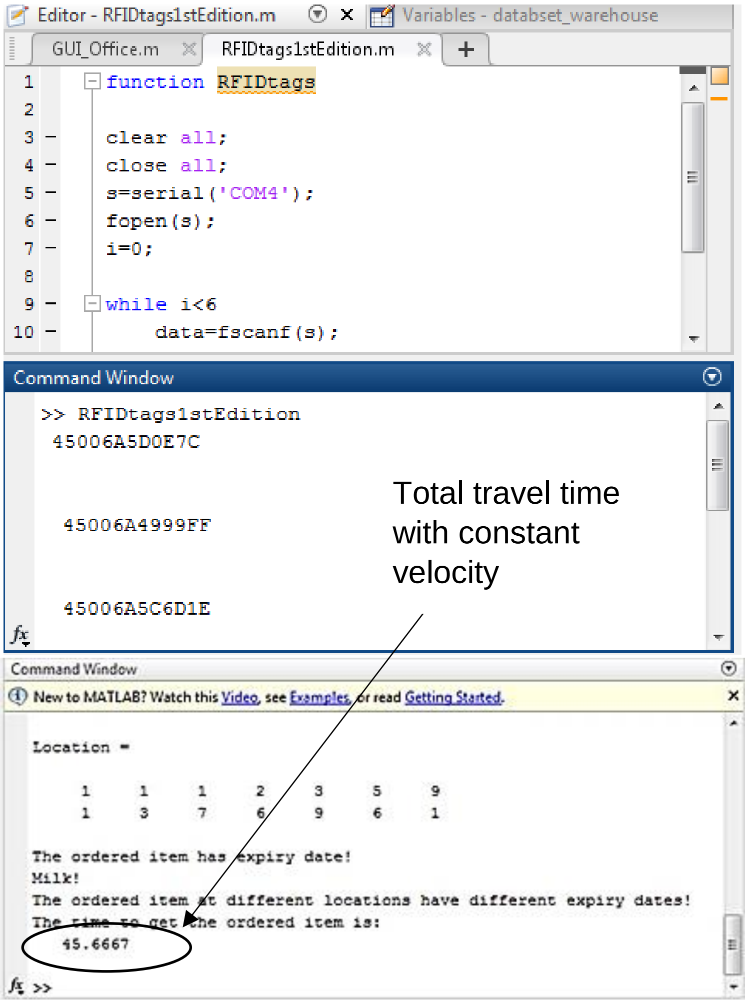


Figure 37: Screen shot of processed RFID data of an ordered item.

In order to determine the travel time of an ordered item as discussed previously in section 5.4 in chapter 5, two scenarios are considered, i.e., in case I with a constant velocity and case II with an acceleration and declaration. Figure 38 shows a comparison in the experimental result of the total travel time obtained with the constant velocity and acceleration/declaration, respectively. It indicates that the total travel time obtained with acceleration/declaration is slightly higher than that using the constant velocity without not much difference.

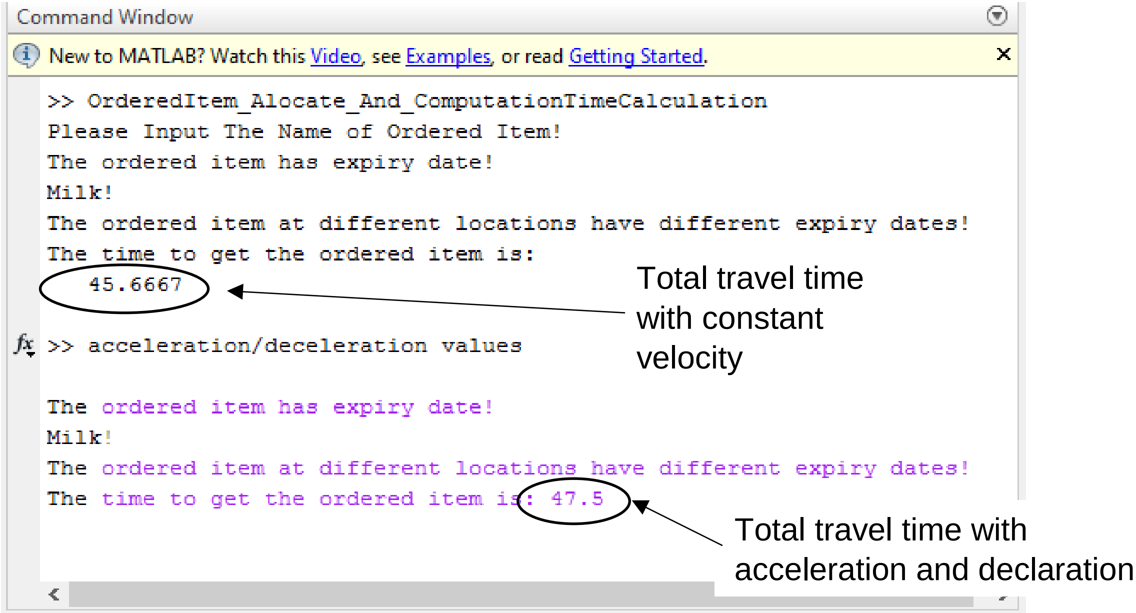


Figure 38: Screen shot of the constant velocity vs acceleration/deceleration.

Figure 39 shows the hardware used for constructing the RFID-based warehouse management system consisting of the following key elements:

1. An Impinj RFID reader product (Speedway R420). (Impinj company)
2. A UHFA Gen 2 RFID antenna.
3. Multiple UHF Gen 2 RFID tags.
4. Connect the reader to a PC (laptop) via Ethernet cable.

Figure 39: Testing of the RFID-based inventory management system.

7.2 Tests of RFID passive tags

An experiment was performed indoors in a room 7 m long and 5 m wide. A number of RFID passive tags were placed on the ground throughout the room. The distance between passive tags was 70-100 cm. Two pairs of far-field antenna were placed on a desk table, which are fixed to the holder at a distance from the ground of 1 m, with the tilt angle of 45 degrees toward the ground where RFID passive tags are. In order to configure the MultiReader software platform (Impinj multireader software-configure setting) as an example shown in Figure 40, the following steps were used Ensure the latest version of multi-reader is installed/used.

1. Click on 'Configure Settings'.
2. Select 'Modes, RF, Power' menu - ensure desired antenna is checked and that Rx Sensitivity Max is checked.
3. Select the 'Run Mode' menu
4. From the Run Mode drop-down box, select 'Margin Test'.
5. Ensure that the On Time is at least 10 seconds (10000 ms) for FCC reader hops ~ every 200ms across 50 frequencies/channels so in 10 seconds it will cover all available.

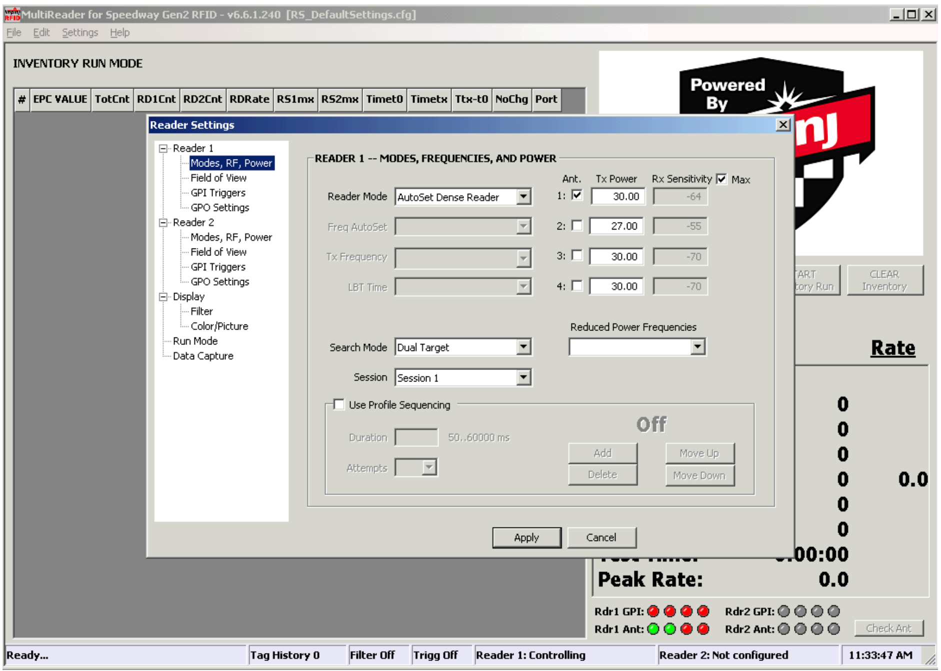


Figure 40: Screen shot of configure the MultiReader software platform (Impinj multireader software-configure setting).

6. Set the Start to desired value. Minimum power s +10dBm and max can be up to 32.5dBm, depending on the region, model and power source. The power can be set to increment in as little as 0.25dB steps (Shown in Figure 41).
7. Click 'Apply' - this will return you to the main screen.
8. Click 'Start Margin Test Run'.

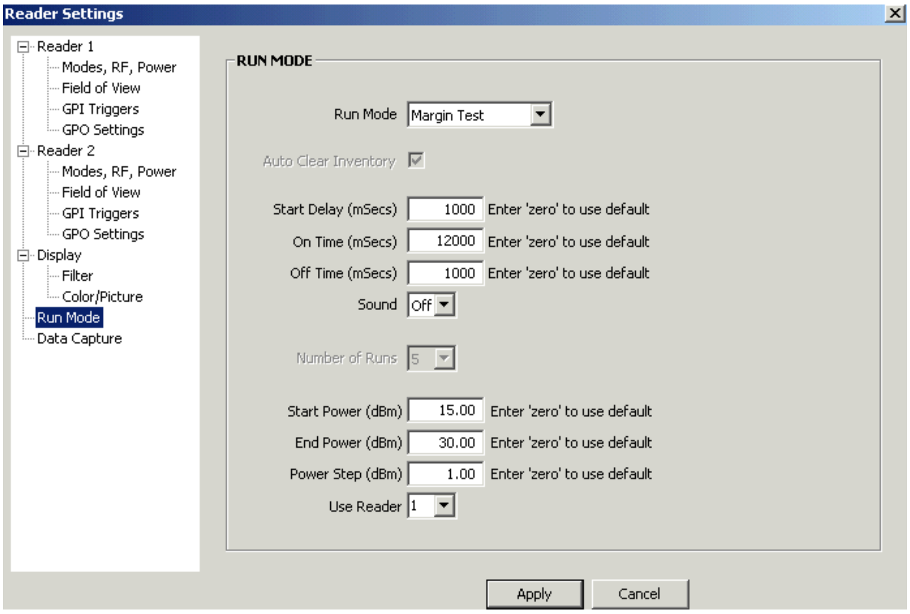


Figure 41: Setting is applied correctly for the MultiReader software platform (Impinj multireader software-configure setting).

The Impinj Speedway Gen2 RFID reader was used to perform the task of detecting and reading RFID tags. RFID codes can be displayed on the MultiReader window as shown in Figure 42 over an Ethernet port. This MultiReader software offers a platform which allows a user to configure the RFID reader’s operational settings and tests.

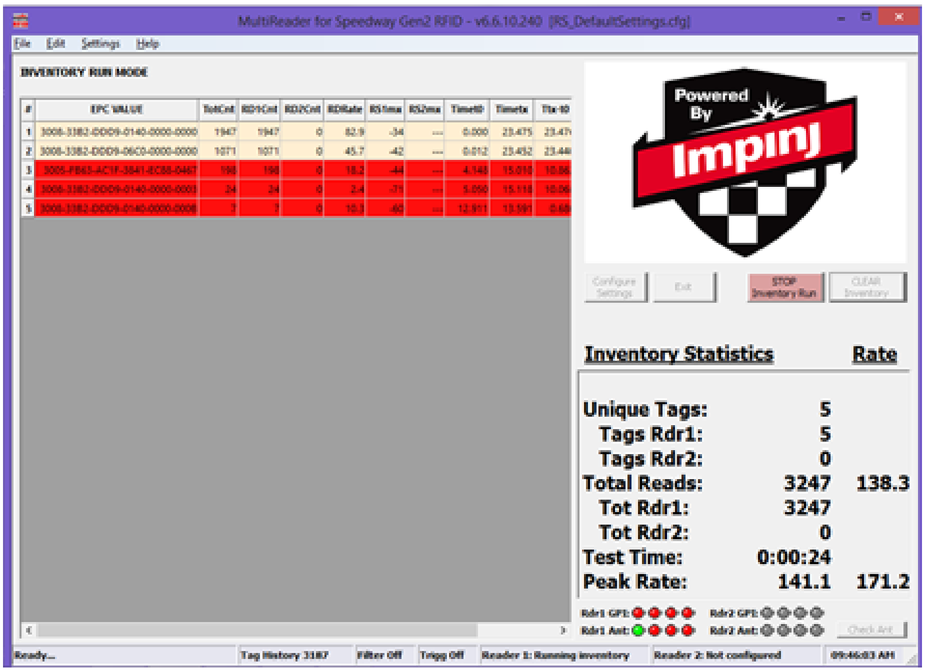


Figure 42: Screen shot of RFID codes generated through the MultiReader software platform (Impinj multireader software).

7.3 RFID tags read rang test

The primary consideration in selecting RFID tags is to find the optimal balance between size of the RFID tag and read range. The right read range is determined by the physical distance between the assets and the RFID reader. The read range for the selected RFID passive tags in this research is up to 9 m/30 ft. A test was carried out to see how the RFID passive tags operate regarding the response time rate and the ideal distance to place the RFID tag from the RFID antenna. Different read ranges were performed for the RFID tags from 1 m to 9 m in order to make a comparison over numbers of RFID tags used. The test showed that up to 4 m the read range gave approximately the same time rate per second. This was considered to be the ideal location to place an RFID tag. Nevertheless, in retailers, or any environment where many assets are close together, a long read range can cause signal interference, making it difficult to take inventory data on just one aisle or section. When assets are in close proximity, a shorter read range works better.

7.4 RFID application development

The first step is to download the Octane SDK from Impinj intended to create the RFID application using the programming language of C#/.NET under the Octane libraries. Once the basic windows presentation foundation (WPF) solution was built in Visual

Studio, the Octane Library was imported ready for usage. Table 12 shows part of the SDK programming code (C#) for processing RFID data in the MVS environment, which is the window simulator shown in Figure 43 (the whole SDK programming is shown in Appendix F).

Table 12: Part of the SDK programming codes for data processing of acquiring RFID tags.

```
==================================================================
When the user presses the button to start reading to get a new Rfid tag, it calls the
following function:
RfidTracker project: app\public\trackeditem.js getNewRfidTag()
This in turn calls app\public\services\repository.trackeditem.js getNextRfidTag()
RfidTrackerController.cs GetNextRfidTag()
This checks to see if we are using the simulation reader. If we are, we just return a
new fake tag id.
if (_repository.UseRfidSimulation)
{
  rfidNewTagResponseToReturn = new RfidNewTagResponse()
                { ReturnCode = 0,
                        RfidTagValue = Guid.NewGuid().ToString(),
                        ErrorMessage = string.Empty };
}

Otherwise we call into the actual RfidReader code. This is in the
RfidTracker.Communications project in the RfidController.cs file. GetNewTag()

Running the Rfid Reader Console
{
USE [RfidTrackerWarehouse]
-- Get the last 10 records from the tag event table
SELECT TOP 10 * FROM [dbo].[RfidTagEvent]     ORDER BY [DateAndTime] DESC
-- Get the last 10 records from the tracked item event table
SELECT TOP 10 * FROM [dbo].[TrackedItemEvent] ORDER BY [EventDate] DESC
-- Get the items that moved!
SELECT *
  FROM [dbo].[TrackedItem]
 WHERE [Id] IN (SELECT TOP 10 [TrackedItemId]
              FROM [dbo].[TrackedItemEvent]
                              ORDER BY [EventDate] DESC
}
```

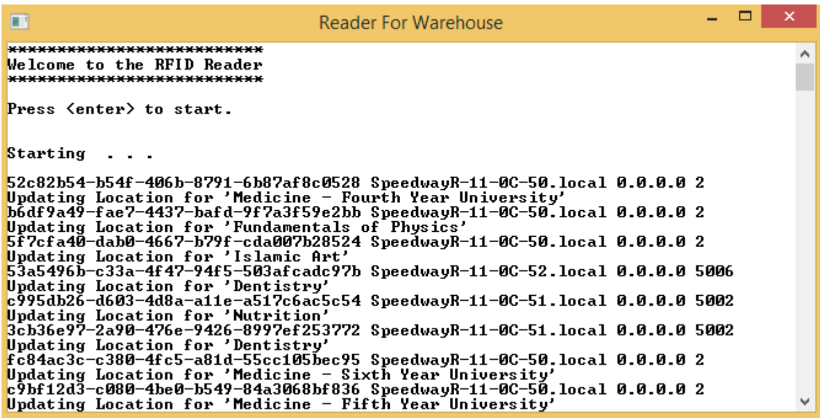


Figure 43: MVS window simulator.

The GUI allows a matrix manipulation of item locations and it can interface with other programs written in different languages such as C, C++, C#, Java etc. For instance, as shown in Figure 44, a user can search an ordered item in the GUI by clicking on the Search button and entering the item's name (e.g., ''Milk''). The GUI office will then indicate where the item is located in the map of storage racks. Once the item is identified, information of this item can also be found by clicking on the Display button with the displayed information including the identity of the ordered item, the state of the ordered item (e.g., milk expiry date), the location of the ordered item (rows and columns of storage racks), the number of the ordered items available and the nearest item of the same type to a collection point. (In appendix D, it shows the GUI programming codes).

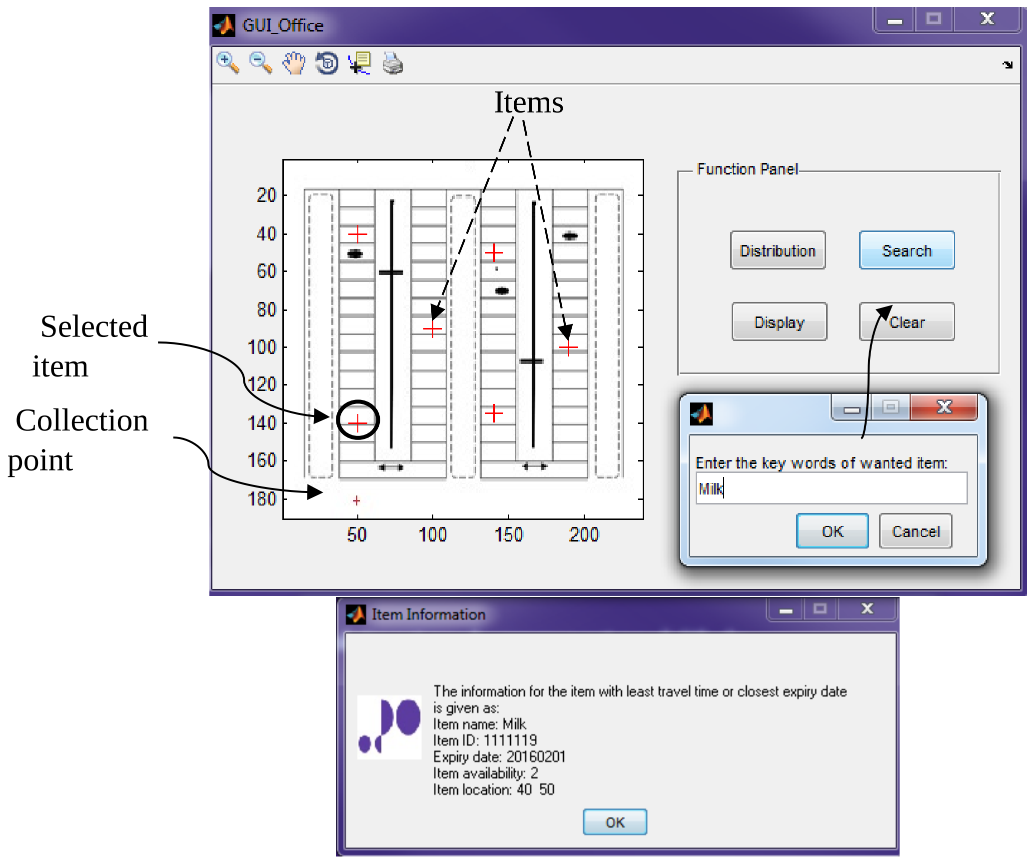


Figure 44: Display of an optimal location of one of a selected item in the GUI.

7.5 MATLAB simulation results

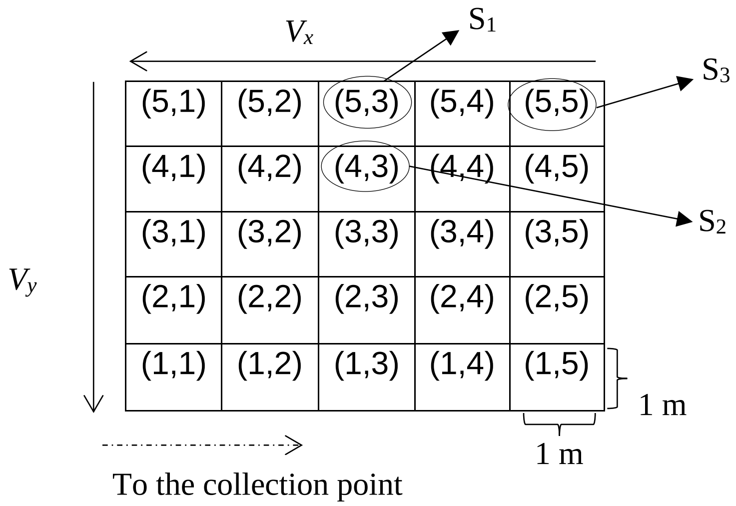
The travel speed V_x is 210mm/s and the same travel speed was assumed for V_y as shown in Table 13, which explains the determination of an item with a longest travel time in an AS/RR. Assuming there are three items which are located in storages namely S_1 (5, 3), S_2 (4, 3) and S_3 (5, 5), respectively. Let us V_x refer to a speed of an output conveyor and V_y refer to a speed of a spiral conveyor. As stated previously, a standby pusher has a default location at the centre (3, 3) of the AS/RR. Assuming each grid, which represents a standard storage space of the AS/RR, has coordinating dimensions in height and width of 1 x 1 meter.

To calculate the total travel time T_{tt_ci} for each selected item is obtained by:

$$T_{tt\_ci} = T_h + T_v = \frac{Number\ of\ Coloumns}{V_x} + \frac{Number\ of\ Rows}{V_y}$$

Where $T_h \; and \; T_v$ refer to the horizontal and vertical travel time of a selected item, respectively.

Table 13: Determination of an item with a longest travel time in an AS/RR to the collection point.



$$T_{tt\_ci}(S_1) = \frac{3 * 1000}{210} + \frac{5 * 1000}{210} = 38.09 \; sec$$

$$T_{tt\_ci}(S_2) = \frac{3 * 1000}{210} + \frac{4 * 1000}{210} = 33.32 \; sec$$

$$T_{tt\_ci}(S_3) = \frac{5 * 1000}{210} + \frac{5 * 1000}{210} = 47.6 \; sec$$

Based on these calculated results, the RFID-inventory management system can determine the optimal route for the pusher to travel to select an item in a sequence as shown in Figure 45.

Figure 45 shows the MATLAB simulation result which determines an item with a longest travel time from the selected items to be pushed in a sequence onto the output conveyor by a pusher from an AS/RR, i.e., the item with a longest travel time is given a priority to be pushed by the pusher to travel to a specified collection point until the last selected items with the least travel time arrives to the same destination. This allows a minimum waiting time for packers to receive all the selected items at the collection point. As shown in Table 13 as an example, the result indicates that the selected item at S_3 (5, 5) has a longest travel time of 47.6 seconds and this item should be given the highest priority to be pushed onto an output conveyor travelling to the specified collection point. The selected item at S_2 (4, 3), however, has a least travel time of 33.32 seconds and this item (i.e., the last remaining item shown in Figure 46) should be given the least priority to be pushed onto an output conveyor travelling to the specified collection point. The selected item at S_1 (5, 3) has a travel time of 38.09 seconds and therefore it should be the second item to be pushed onto an output conveyor towards the same destination. However, if there are two ordered items which have the same travel time, the RFID-based management system will be set as a default to select the ordered item that is close to the pusher. The result was generated by the RFID-inventory management system according to the pre-defined selection rules and the system subsequently issues a priority to be given to the selected item. The mechanical control system then initialise a demand to push the selected item onto an output conveyor and this item will be transported along the RFID-guided route to the collection point (Other result can be found in Appendix I).

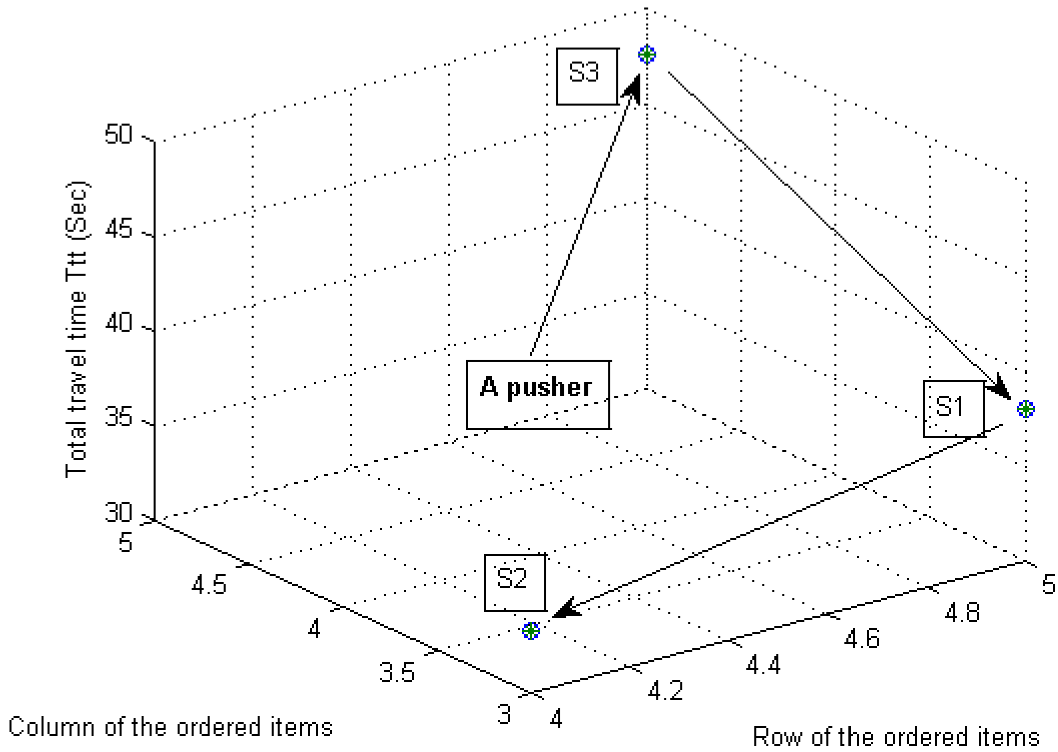


Figure 45: Determination of a longest travel time among ordered items.

Figure 46 shows the accumulating results of travel times for each selected item which travels through the five different sections along the RFID-guided route from the moment when the pusher is activated to the moment these selected items arrive at a collection point. It shows the travel time T_{ij} in minutes between the activated pusher *i* and the selected item *j*. T_{jk} refers to a travel time from the moment when the pusher *i* starts to push a selected item *j* to the moment that the selected item *j* is pushed onto an output conveyor *k*. T_{kl} refers to a travel time of a selected item *j* which travels at a constant speed along an output conveyor *k* to the entrance point of a spiral conveyor *l*. T_{lm} refers the travel time from the top level *l* to the bottom level *m* through a powered spiral output conveyor. Finally, T_{mn} refers to the travel time between the end of the spiral conveyor *m* and the collection point *n*. As shown Figure 46, item 3 has the longest travel time T_{ij} of 15.6 seconds, whereas item 2 has the least travel time of 3.23 seconds as the default location of the pusher is closer to item 2. All the selected items have the same travel time T_{jk} as the storage space for each item has a standard height and width of 1 x 1 meter. Either of items 2 or 3 has the same travel time T_{kl} of 12 seconds because these items are located at the same column in the AS/RR. Overall, item 3 has the longest accumulative travel time of 47.6 seconds and item 2 has the least travel time of 33.32 seconds. Thus, the developed programing model of the RFID-enabled inventory management system can generate the priority list of selected items to travel in a sequence from the first item with a longest travel time to the last item with a least travel time, accordingly.

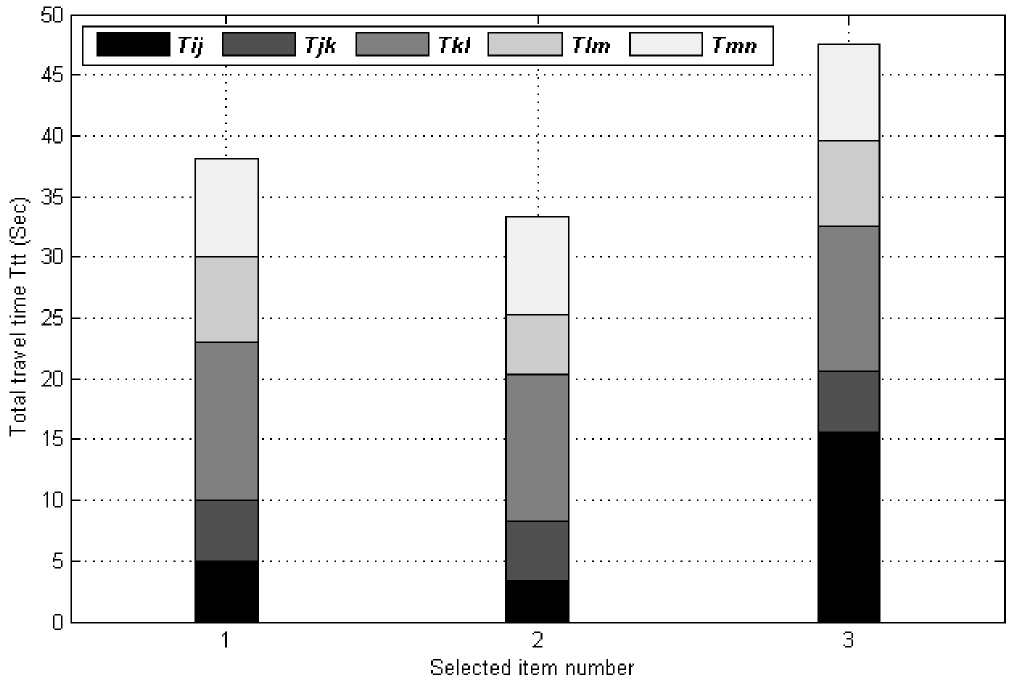


Figure 46: The results of selected items for five different stages with accumulating travel times.

Summary

This chapter describes the implementation of a pilot test based on an integration of hardware and software towards the development of an RFID-based management system and the results were obtained and analysed in a MATLAB environment. Also, the prototype of the proposed RFID-based management system was built and tested using near field communication (NFC) and far field communication (FFC), respectively. The developed RFID-based management system can automatically detect and identify locations of ordered items by displaying objects on GUI. Experimental results demonstrate the applicability of the developed optimisation algorithm implemented into the RFID-based inventory management system through the pilot test. It shows that the RFID-inventory management system can determine the optimal route for the pusher to travel in a sequence during the ordering process that gives a minimal overall travel time for all the ordered items to a specified collection point.

The objective function involves an optimisation of non-linear and multi-objective variables in such as (i) number of storage and retrieval (S/R) machines, (ii) dimensions of the SR and (iii) costs of building and operating warehouses and so on. One of the early studies in optimising the design of warehouses was reported by Basan et al. (1980). The study was aimed at seeking optimum dimensions of the warehouse corresponding to warehouse volume under storage strategies. Similarly, Ashayeri et al. (1985) illustrated a design model of the AS/RS that enables the determination of the influential parameters. Bafna et al. (1972) & Perry et al. (1983) presented a study using a combination of the analytical model the discrete event simulation when designing the warehouse. Rosenblatt et al. (1984) offered the design of warehouses in regard to the influence of the storage policy by considering the following costs: (i) cost of building the warehouse, (ii) costs of buying storage equipment, (iii) costs arising from overloading the warehousing system (temporary shortage of the storage space) and (iv) costs associated with one of particular storage policies. Although some researchers reported studies in optimisation of travel time, cost, service level and capacity utilisation individually based on requirements of warehouse design specified, these studies do not consider the optimisation of all the above parameters using the multi-objective approach providing a trade-off solution particularly in automated warehouses based on the literature review.

In practice, many engineering design problems are multi-objective problems as these often involve more than one design goal to be optimised. These design goals potentially impose conflicting requirements on the technical and economic performances of a given system design. To determine a trade-off solution in alternative design options between these conflicting design objectives, an optimisation problem with multiple objectives often need to be resolved. To facilitate the exploration of different multi-objective formulations, Pareto optimality concepts can be incorporated into optimisation algorithms as a decision maker. Multi-objective optimisation refers to an optimisation of multiple decision making objectives concurrently. These objectives are possibly conflicting and competing. In a multi-objective problem, however, it is often impossible to obtain a single optimal but a trade-off solution among a number of objectives, since there is a contradictory among antagonist objectives. For further details on multi-objective optimisation, it can be referred to publications by Coello et al., 2007; Miettinen, 1998; Collette and Siarry, 2011; and Rangaiah and Bonilla-Petriciolet, 2013.

Theoretically, a compact multi-objective optimisation can be formulated as follows:

$$\max/\min O(x) = (O_1(x), O_2(x), \dots, O_f(x))^T \tag{2.1}$$

subject to

$$g_i(x) \leq 0, i = 1, 2, 3, \dots, a \,|\, hj(x) = 0, j = 1, 2, 3, \dots, b. \tag{2.2}$$

Where

O number of objective functions

a and b number of constraints

$x \in B^z$ the decision variable vector

z number of independent variable x_i

In the multi-objective optimisation, unlike the single objective optimisation, there is no mono-dominant solution but a set of non-dominant solutions called Pareto (or non-dominant, non-inferior) solutions. Pareto solutions denote a set of compromised solutions between the conflicting objectives. Ahmadi et al. (2015) formulated a multi-objective optimisation electric model to integrate the generation of thermal units considering heat and power dispatch. The objective functions of the proposed multi-objective framework comprise simultaneous minimisation of cost and thermal units' emission as well as maximising heat generation. Mohammed et al. (2017) presented a development of a product distribution planner for a three-echelon green meat supply chain design in terms of issues including numbers and locations of facilities that should be opened in association with the product quantity flows. These issues were formulated into a fuzzy multi-objective programming model (FMOPM) with an aim to minimise the total cost of transportation and implementation, the amount of CO2 emissions in transportation and the distribution time of products from farms to abattoirs and from abattoirs to retailers, and maximise the average delivery rate in satisfying product quantity as requested by abattoirs and retailers. Ramesh et al. (2013) proposed a modified non-dominated sorting genetic algorithm-II (MNSGA-II) which was applied to a multi-objective reactive power planning problem by incorporating the concept of Dynamic Crowding Distance (DCD) in NSGA-II algorithm. Three conflicting objectives combined operating and VAR allocation cost minimisation, bus voltage profile improvement and voltage stability enhancement were considered. The IEEE 30-bus system, the 69-bus system and the IEEE 118-bus system were also considered. By using conventional weighted sum method with Covariance Matrix Adapted Evolution Strategy (CMA-ES), a reference Pareto-front was generated. Pishvaee et al. (2012) proposed a multi-objective fuzzy mathematical programming model for designing an environmental supply chain under inherent uncertainty of input data in such problem. The proposed model was able to consider the minimisation of multiple environmental impacts beside the traditional cost minimisation objective to make a fair balance between them. A life cycle assessment-based (LCA-based) method was applied to assess and quantify the environmental impact of different options for supply chain network configuration. Also, to optimise the proposed multi-objective fuzzy optimisation model, an interactive fuzzy solution approach was developed.

This chapter presents a development of a mathematical model using the multi-objective approach as an aid for optimising the design of a proposed RFID-enabled automated warehousing system. The developed model used for maximising the warehouse capacity utilisation and service level in terms of satisfying all demands of dispatching products from the warehouse, minimising the travel distance of products from a storage rack to a collection point and the total cost required for implementing RFID-related facilities into the proposed warehousing system. This chapter also includes an investigation into configuration of the proposed warehousing system focusing on the optimal number of racks and collection points that need be established.

8.1 Problem definition and model description

One of the main issues to be addressed is to optimise the design of the proposed RFID-enabled automated warehouse including the allocation of the optimum number of racks and collection points towards four objective functions (as illustrated in Figure 16 in chapter 4): (1) minimisation of total cost of implementing the warehouse, (2) maximisation of capacity utilisation of the warehouse, (3) maximisation of service level in terms of satisfying all demands of dispatching products from the warehouse and (4) minimisation of travel distance of products from racks to collection points. The following sets, parameters and decision variables were used in the formulation of the model:

Sets:

I	set of racks $i \in I$
J	set of collection points $j \in J$
K	set of departure points $k \in K$

Given parameters:

C_i^r	fixed cost required for establishing a RFID-enabled rack i
C_i^c	fixed cost required for establishing a collection point j
C_i^t	unit RFID tag cost per item at rack i
C_{ij}^{T}	unit transportation (T) cost per meter from collection point *i* to departure point *k*
C_j^l	unit labour cost per hour at collection point *j*
R_j^l	working rate (items) per labourer (l) at collection point *j*
d_{jk}	travel distance (meter) from collection point j to departure point k
W	transportation capacity (units) per forklift
$\mathrm{S_i}$	maximum supply capacity (units) of rack i
$\mathrm{S_j}$	maximum supply capacity (units) of collection point j
$\mathrm{D_j}$	demand (in units) of collection point j
t_{ij}^d cv	average travel distance (in meters) per item from rack *i* to collection point *j*

Decision variables

q_{ij}	quantity of units ordered from rack i to collection point j
q_{jk}	quantity of units dispatched from collection point j to departure point k
x_j	required number of labourers at collection point *j*
$\mathrm{y_i}$	1: if rack i is required 0: otherwise

y_j $\begin{cases} 1\text{: if collection point } j \text{ is required} \\ 0\text{: otherwise} \end{cases}$

The four objectives, which include a minimisation of total cost, a maximisation of capacity utilisation, maximisation of service level and minimisation of travel distance, are formulated as follows:

Objective function (1)

In this case, the total cost of establishing the RFID-enabled automated warehouse includes costs of establishing RFID-enabled racks, collection points, RFID tag, transportation of products and labours. Thus, minimisation of the total cost can be expressed below:

$$Min\ F_1 = \sum_{i\in I} C_i^r y_i + \sum_{j\in J} C_j^c y_j + \sum_{i\in I}\sum_{j\in j} C_i^t q_{ij} + \sum_{j\in J}\sum_{k\in K} C_{ij}^T \left\lceil q_{jk} / W_f \right\rceil d_{jk} + \sum_{i\in I} C_i^l x_j \tag{1}$$

Objective function (2)

Maximisation of capacity (C) utilisation is expressed as follows:

$$Max\ F_2 = \left(\sum_{i\in I} \frac{\left[(C_{actual}) - (C_{used}) \right]^2}{\sum i} \right)^{\frac{1}{2}} \tag{2}$$

Where $C_{actual} = \sum_{j\in J} \frac{q_{ij}}{S_i}$ and $C_{used} = \frac{\sum_{i\in I}\sum_{j\in J} q_{ij}}{\sum_{i\in I} S_i}$

Objective function (3)

To ensure the satisfaction of all demands of products delivered by the warehouse, this can be achieved by maximisation of service level, which is given by:

$$Max\ F_3 = \sum_{i\in I}\sum_{j\in J} \frac{q_{ij}}{D_i} \tag{3}$$

Objective function (4)

The travel distance of an in-store item from its location of a storage rack to a collection point can be minimised as follows:

$$Min\ F_4 = \sum_{i\in I}\sum_{j\in J} t_{ij}^{d} q_{ij} \tag{4}$$

There are a number of constraints which are included in the optimisation. The constraints are given as follows:

$$\sum_{i\in I} q_{ij} \le S_i\ y_i \qquad \forall j \in J \tag{5}$$

$$\sum_{j\in J} q_{jk} \le S_j\ y_j \qquad \forall k \in K \tag{6}$$

$$\sum_{i\in I} q_{ij} \ge D_j \qquad \forall j \in J \tag{7}$$

$$D_j \ge \sum_{k\in K} q_{jk} \qquad \forall j \in J \tag{8}$$

$$\sum_{j\in J} q_{ij} \le x_j\ \mathrm{R}_j^1 \qquad \forall\ \mathrm{i} \in I \tag{9}$$

$$q_{ij}, q_{jk}\ \ge 0,\ \forall i, j, k; \tag{10}$$

$$y_i, y_j\ \in \{0,1\},\ \forall i, j; \tag{11}$$

Equations 5 and 6 refer to the flow balance of a product travelling from a storage rack to a collection point and from a collection points to a departure point. Equations 7 and 8 refer to demands to be satisfied. Equation (9) determines the required number of labours at a collection point. Equations (10) and (11) limit the decision variables to binary and non-negative.

8.2 The optimisation methodology

Several approaches were reported in the literature to solve multi-objective optimisation problems. In this work, a fuzzy solution approach was proposed to transform the multi-objective model into a single-objective model which is formulated by considering each objective individually by minimising the secularised difference between value of each objective and its optimal value. Undesired deviations were used for being subtracted from the single objective function to obtain more accurate objective values.

A. Solution procedures

There are a number of methods proposed in the previous literature to deal with possibilistic programming models (e.g. Lai et al., (1992), Jimenaz et al., (2007) & Liang, (2006). The Jimenez et al. (2007) method is formed based on the strong mathematical concepts, i.e., expected interval and expected value of fuzzy numbers, also this method is computationally efficient to solve fuzzy linear problems as it can preserve its linearity and does not increase the number of objective functions and inequality constraints.

To solve the optimisation problem based on the developed multi-objective model, the solution procedures are expressed as follows:

1) Convert the developed model into an equivalent crisp model using Jiménez method (Jiménez et al., 2000). Accordingly, the equivalent crisp model can be formulated as follows.

$$Min\ F = \sum_{i\in I} \sum_{p=1}^{4} \frac{C_{ip}^{r}}{4} y_i + \sum_{j\in J} \sum_{p=1}^{4} \frac{C_{jp}^{c}}{4} y_j + \sum_{i\in I} \sum_{j\in j} \sum_{p=1}^{4} \frac{C_{ip}^{t}}{4} q_{ij}$$
$$+ \sum_{j\in J} \sum_{k\in K} \sum_{p=1}^{4} \frac{C_{ijp}^{T}}{4} \left\lceil q_{jk} / W_f \right\rceil d_{jk} + \sum_{i\in I} \sum_{p=1}^{4} \frac{C_{ip}^{l}}{4} x_j \tag{12}$$

$$Max\ F_2 = \left(\sum_{i\in I} \frac{\left[\left(C_{actual} \right) - \left(C_{used} \right) \right]^2}{\sum i} \right)^{\frac{1}{2}} \tag{13}$$

$$Max\ F_3 = \sum_{i\in I} \sum_{j\in J} \sum_{p=1}^{4} 4 \frac{q_{ij}}{D_{ip}} \tag{14}$$

$$Min\ F_4 = \sum_{i\in I} \sum_{j\in J} t_{ij}^{d} q_{ij} \tag{15}$$

Subject to:

$$\sum_{i\in I} q_{ij} \le S_i\ y_i \qquad \forall j \in J \tag{16}$$

$$\sum_{j\in J} q_{jk} \le S_j\ y_j \qquad \forall k \in K \tag{17}$$

$$\sum_{i\in I} q_{ij} \ge \frac{\lambda}{2} \frac{D_{j1} + D_{j2}}{2} + \left(1 - \frac{\lambda}{2} \right) \frac{D_{j3} + D_{j4}}{2} \qquad \forall j \in J \tag{18}$$

$$\frac{\lambda}{2} . \frac{D_{j1} + D_{j2}}{2} + \left(1 - \frac{\lambda}{2} \right) \frac{D_{j3} + D_{j4}}{2} \ge \sum_{k\in K} q_{jk} \qquad \forall j \in J \tag{19}$$

$$\sum_{j\in J} q_{ij} \le x_j \quad \frac{\lambda}{2}.\frac{x_{j1}+x_{j2}}{2}+\left(1-\frac{\lambda}{2}\right)\frac{x_{j3}+x_{j4}}{2}\mathrm{R}_j^1 \qquad \forall\ \mathrm{i}\in I \tag{20}$$

$$q_{ij}, q_{jk} \ \ge 0,\ \forall i, j, k; \tag{21}$$

$$y_i\ , y_j\ \in \{0,1\},\ \forall i, j; \tag{22}$$

2) Find the upper and lower bound (U, L) solution for each objective function. This can be obtained as follows for

Upper bound solutions:

$$Max\ F_1(U_1) = \sum_{i\in I} C_i^r y_i + \sum_{j\in J} C_j^c y_j + \sum_{i\in I}\sum_{j\in j} C_i^t q_{ij} + \sum_{j\in J}\sum_{k\in K} C_{ij}^T \left\lceil q_{jk} / W_f \right\rceil d_{jk} + \sum_{i\in I} C_i^l x_j \tag{23}$$

$$Max\ F_2(U_2) = \left(\sum_{i\in I} \frac{\left[(C_{actual}) - (C_{used}) \right]^2}{\sum i} \right)^{\frac{1}{2}} \tag{24}$$

$$Max\ F_3(U_3) = \sum_{i\in I}\sum_{j\in J} \frac{q_{ij}}{D_i} \tag{25}$$

$$Max\ F_4(U_4) = \sum_{i\in I}\sum_{j\in J} t_{ij}^d q_{ij} \tag{26}$$

Lower bound solutions:

$$Min\ F_1(L_1) = \sum_{i\in I} C_i^r y_i + \sum_{j\in J} C_j^c y_j + \sum_{i\in I}\sum_{j\in j} C_i^t q_{ij} + \sum_{j\in J}\sum_{k\in K} C_{ij}^T \left\lceil q_{jk} / W_f \right\rceil d_{jk} + \sum_{i\in I} C_i^l x_j \tag{27}$$

$$Min\ F_2(L_2) = \left(\sum_{i\in I} \frac{\left[(C_{actual}) - (C_{used}) \right]^2}{\sum i} \right)^{\frac{1}{2}} \tag{28}$$

$$Min\ F_3(L_3) = \sum_{i\in I}\sum_{j\in J} \frac{q_{ij}}{D_i} \tag{29}$$

$$Min\ F_4(L_4) = \sum_{i\in I}\sum_{j\in J} t_{ij}^d q_{ij} \tag{30}$$

3) Find the respective satisfaction degree μ(xi) for each objective function as follows:

$$\mu_1(F_1(x)) = \begin{cases} 1 & if\ F_1(x) \geq U_1 \\ \dfrac{F_1(x) - L_1}{U_1 - L_1} & if\ L_1 \leq F_1(x) \leq U_1 \\ 0 & if\ F_1(x) \leq L_1 \end{cases} \quad (31)$$

$$\mu_2(F_2(x)) = \begin{cases} 1 & if\ F_2(x) \geq U_2 \\ \dfrac{F_2(x) - L_2}{U_2 - L_2} & if\ L_2 \leq F_2(x) \leq U_2 \\ 0 & if\ F_2(x) \leq L_2 \end{cases} \quad (32)$$

$$\mu_3(F_3(x)) = \begin{cases} 1 & if\ F_3(x) \geq U_3 \\ \dfrac{F_3(x) - L_3}{U_3 - L_3} & if\ L_3 \leq F_3(x) \leq U_3 \\ 0 & if\ F_3(x) \leq L_3 \end{cases} \quad (33)$$

$$\mu_4(F_4(x)) = \begin{cases} 1 & if\ F_4(x) \geq U_4 \\ \dfrac{F_4(x) - L_4}{U_4 - L_4} & if\ L_4 \leq F_4(x) \leq U_4 \\ 0 & if\ F_4(x) \leq L_4 \end{cases} \quad (34)$$

4) Transform the crisp model obtained from step (1) to a single objective function using the developed solution method. The developed solution method function (F) is formulated as follows:

$$Min\ F = \left(\sum_{n=1}^{4} \sum_{f=1}^{4} \vartheta_n \mu_f(x) \right) - F_d, \quad \sum_{n=1}^{4} \vartheta_n = 1 \quad (35)$$

Set $\vartheta_n^* = \frac{\vartheta_n F_n^\bullet}{F_n^\bullet - F_n}$, then

$$F_d = \vartheta_1^* F_1 + \vartheta_2^* F_2 + \vartheta_3^* F_3 + \vartheta_4^* F_4 \quad (36)$$

$$= \frac{\vartheta_1 F_1^\bullet}{F_1^\bullet - F_1} F_1 + \frac{\vartheta_2 F_2^\bullet}{F_2^\bullet - F_2} F_Z + \frac{\vartheta_3 F_3^\bullet}{F_3^\bullet - F_3} F_3 + \frac{\vartheta_4 F_4^\bullet}{F_4^\bullet - F_4} F_4$$

(37)

Based on the aforementioned procedures, the developed method’s objective function can be written as follows.

$$Min\ F = \left(\vartheta_1 \mu_1 - \vartheta_2 \mu_2 - \vartheta_3 \mu_3 - \vartheta_4 \mu_4 \right) - \left(\frac{\vartheta_1 F_1^\bullet}{F_1^\bullet - F_1} F_1 + \frac{\vartheta_2 F_2^\bullet}{F_2^\bullet - F_2} F_2 + \frac{\vartheta_3 F_3^\bullet}{F_3^\bullet - F_3} F_3 + \frac{\vartheta_4 F_4^\bullet}{F_4^\bullet - F_4} F_4 \right)$$

Subject to equations (5)-(11).

5) Vary the weight combination set (ϑ) consistently for the four objectives to reveal Pareto-optimal solutions. Usually, the weight combination set is allocated by decision makers based on the importance of each objective.
6) Select the best Pareto-optimal solution using the proposed decision making method.

B. The decision making method: TOPSIS

The next step after revealing the Pareto solutions is to determine a best trade-off solution, the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) method was employed for revealing the best trade-off solution. TOPSIS is currently one of the most popular multiple criteria decision making (MCDM) methods in a number of application areas. This method was first developed by Hwang and Yoon (1981) for solving MCDM problems with the basic principle to choose the alternative which has the shortest distance from the positive ideal solution (best) and the farthest distance from negative-ideal solution (worst). In this research work, the TOPSIS was employed for revealing the best trade-off solution. This approach selects not merely the closest solution to the ideal solution, but also the farthest from the negative ideal solution (Ramesh et al., 2013). TOPSIS was implemented as follows:

Assume $\mathrm{PR}\text{-}\left\{\mathrm{PR_{op}} \middle| \text{o=1,2,...,x (number of pareto solutions); p =1,2,...,y (number of objectives)}\right\}$

where *PR* is a $x*y$ decision matrix, which represents the performance rating of alternative Pareto solutions with respect to the objective function values. Thus, the normalized selection formula is presented as follows:

$$NPR = \frac{PR_{op}}{\sum_{p=1}^{o} PR_{ap}} \tag{38}$$

The value of a decision can be measured by the entropy value as:

$$E_p = \frac{-1}{\ln\ \mathrm{x}} \sum_{o=1}^{x} PR_{op} \ln(PR_{op}) \tag{39}$$

The degree of divergence D_p of the average intrinsic information contained for *p* = 1, 2, 3, 4 can be calculated as:

$$D_p = 1 - E_p \tag{40}$$

The weight for each objective function value is given by:

$$w_p = \frac{D_p}{\sum_{k=1}^{y} D_k} \tag{41}$$

Thus, the objective weighted normalized value is given by:

$$v_{op} = w_o PR_{op} \tag{42}$$

The positive ideal solution AT and the negative ideal solution AT are taken to generate an overall performance matrix for each Pareto solution. These values can be expressed as:

$$\begin{aligned} AT^{+} &= (\max(v_{o1}) \quad \max(v_{o2}) \quad \max(v_{oy})) = (v_1^{+}, v_2^{+}, ..., v_y^{+}) \\ AT^{-} &= (\min(v_{o1}) \quad \min(v_{o2}) \quad \min(v_{oy})) = (v_1^{-}, v_2^{-}, ..., v_y^{-}) \end{aligned} \tag{43}$$

Distance between alternative solutions can be measured by the n-dimensional Euclidean distance. The separation of each alternative from the ideal solution is given as

$$D_p^{+} = \sqrt{\left\{ \sum_{o=1}^{y} (v_{po} - v_o^{+})^2 \right\}} \quad , \quad p = 1, 2, ..., x \tag{44}$$

$$D_p^{-} = \sqrt{\left\{ \sum_{o=1}^{y} (v_{po} - v_o^{-})^2 \right\}} \quad , \quad p = 1, 2, ..., x \tag{45}$$

The relative closeness to the ideal solution of alternative solutions with respect to objective function values is expressed as follows:

$$rc_p = \frac{D_p^{-}}{D_p^{+} + D_p^{-}}, \quad p = 1, 2, ..., x \tag{46}$$

Where $D_p^{-} \geq 0$ and $D_p^{+} \geq 0$, then, clearly, $rc_p \in [1,0]$**.** Select the trade-off solution with maximum rc_p or list the obtained solution in descending order based on rc_p.

8.3 Application and evaluation

In this section, a case study was used to investigate the applicability of the developed optimisation model and the performance of the proposed optimisation methodology. Table 14 shows the parameters used for application. The solver for the developed multi-objective model was LINGO[11].

Table 14: Application data ranges.

I = 12	S_i = 25K-35K
J = 15 K = 2	S_j = 20-29K
C_j^l = 6.5-9 (GBP)	d_{jk} = 20-45
C_i^r = 60-90 (KGBP)	t_{ij}^d = 40-75
C_i^t = 0.25 (GBP)	D_j = 150-360 K
C_{jk}^T = 0.4 (GBP) R_j^l = 100	d_{jk} = 20-45 C_j^c = 15-18 (KGBP)
W = 48	

8.3.1 Results and discussions

This section presents the computational results obtained based on the developed multi-objective model using the proposed integrated fuzzy solution approach for the problem previously defined.

The solution steps of the developed model are described as follows:

1) Obtain the upper and lower value for each objective function by solving them individually. The results are ({U_F, L_F}) = ({504, 1,230}, {0.66, 0.94}, {0.85, 0.99}, {400, 2,310}).
2) Find the respective satisfaction degree μ(xi) for each objective function. The satisfaction degrees are reported in Table 15.
3) Solve the crisp model as a single objective model using the developed solution method by an assignment of different combination of weight values with respect to the feasibility of each weight pair that is denoted by λ.
4) Select the best solution using TOPSIS, the determined score values of Pareto-optimal solutions are reported in Table 16.

Table 17 shows the obtained set of Pareto-optimal solutions based on the four objective functions. It also shows the number of racks and collection points that should be established. For instance, solution 1, which is obtained by an assignment of $\vartheta_1 = 1, \vartheta_2 = 0, \vartheta_3 = 0$ and $\vartheta_4 = 0$, has a minimum total cost of 504 thousand GBP, a maximum capacity utilisation of 66%, a maximum service level of 85% and a minimum travel distance of 400 km of all products. This solution offers six racks and nine collection points. Figure 47 illustrates the further comparison among the solutions in response to the four objective functions. It can be observed in Figure 47 that the Pareto optimal method cannot produce a better solution in one objection function without worsening its performance in the other objective functions. After obtaining a set of Pareto-optimal solutions, decision makers may determine a solution depending on their preferences or using a decision making algorithm. Note that the decision maker usually selects an acceptable solution belonging to the Pareto front. Identifying a set of Pareto optimal solutions is thus a key point for the decision maker's selection of a compromise solution satisfying all the objectives as better as possible (Chiandussi et al., 2012). The multi-objective optimisation problem (also called multi-criteria optimisation, multi-performance or vector optimisation problem) can then be defined as the problem of finding (Osyczka et al., 1985) ''*a vector of decision variables which satisfies constraints and optimises a vector function whose elements represent the objective functions*. These functions form a mathematical description of performance criteria which are usually in conflicting with each other. Hence, the term 'optimise' means finding such a solution which give the values of all the objective functions acceptable to the decision maker''. In this research work, TOPSIS was employed to select the best solution. As shown in Table 16, solution 6 is the best solution as its rc_p score is the highest 0.279 with the total cost of 795 thousand GBP, 84% capacity utilisation, 93%-check again these figures are fo Solution 4 service level and travel distance 1198 km for all ordered products. Also, it requires an establishment of nine racks to supply products to eleven collection points.

Table 15: Satisfaction degrees for objective functions.

$\mu(x_1)$	0.95	0.93	0.9	0.88	0.82	0.77	0.74	0.7	0.688	0.646	0.622	0.6	0.57	0.55
$\mu(x_2)$	0.7	0.73	0.75	0.77	0.79	0.8	0.84	0.85	0.88	0.90	0.92	0.97	0.98	0.99
$\mu(x_3)$	0.73	0.74	0.77	0.78	0.79	0.82	0.84	0.85	0.89	0.91	0.92	0.97	0.97	0.99
$\mu(x_4)$	0.97	0.96	0.95	0.93	93	0.91	0.9	0.88	0.86	0.84	0.81	0.79	0.76	0.72

Table 16: Score values of Pareto-optimal solution using TOPSIS.

Solution	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Score	0.245	0.234	0.266	0.245	0.2544	0.279	0.273		0.244	0.249	0.256	0.249	0.271	-

Table 17: Computational results.

		350 non-zero elements, 59 constraints, 111 total variables, 59 integer variables					
Feasibility level	***#***	***Min (F_1) (KGBP)***	***Max (F_2) (%)***	***Max (F_3) (%)***	***Min (F_4) (Km)***	***Open racks***	***Open collection points***
0.3	1	504	0.66	0.85	400	6	9
0.35	2	564	0.68	0.85	680	6	9
0.4	3	595	0.71	0.87	873	7	8
0.45	4	678	0.78	0.89	932	7	8
5	5	720	0.80	0.92	1011	8	9
0.55	**6**	**795**	**0.84**	**0.93**	**1198**	**9**	**11**
0.6	7	844	0.86	0.94	1230	10	11
0.65	8	894	0.89	0.95	1342	10	12
0.7	9	940	0.90	0.96	1555	11	13
0.8	10	978	0.92	0.97	1701	11	13
0.85	11	998	0.93	0.98	1890	12	13
0.9	12	1064	0.93	0.98	2030	12	13
0.95	13	1099	0.94	0.99	2197	13	14
1	14	1120	0.94	0.99	2280	13	14

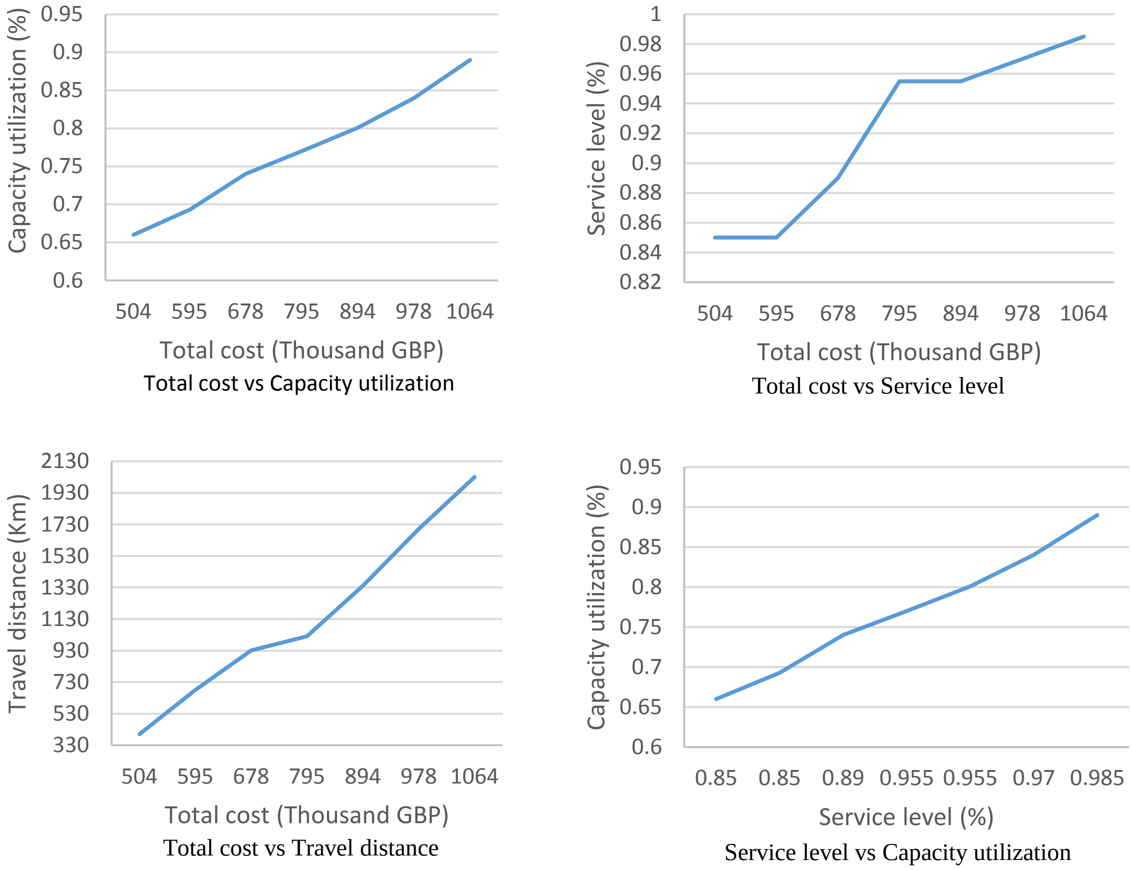


Figure 47: Comparison among the obtained objective function values.

Summary

This chapter presents a study in optimisation of the proposed automated warehouse using the multi-objective optimisation approach. A multi-objective model was developed and used for (1) optimising the design the proposed RFID-enabled warehousing system in determining an optimum number of storage racks and collection points that need be established for the warehouse, and (2) obtaining trade-off decisions by measuring four conflicted objectives: minimisation of the total cost, maximisation of capacity utilisation, maximisation of service level in terms of satisfying all demands of dispatching products from the warehouse and minimisation of travel distance in the warehouse. To obtain Pareto-optimal solutions based on the developed model, an integrated fuzzy solution approach was proposed. Subsequently, a decision making method was applied to select the best Pareto-optimal solution. A case study was applied and the results demonstrate the applicability and validation of the developed model.

Chapter 9 Cost analysis, benefits and limitations – a real case study

The University of Portsmouth library converted their current EM barcode Library self-service and security solutions to a RFID solution in 2012. The implementation of the RFID system enables the University of Portsmouth library service to improve dramatically and meet their self-service aspiration enabling higher levels of throughput to deliver improved customer service levels and return on investment.

9.1 Cost estimates

Table 18 provides an RFID implementation cost estimates for the library at University of Portsmouth by the Bibliotheca Company. It lists each component description, quantity needed and unit price.

Table 18: Self-service and security solution cost.

Description	Qty.	Unit price
smartserve™ 400 - barcode user ID included	5	£6,995.00
smartserve™ 400 payment frame **RRP £795.00/ unit incentive 5 x free of charge*	5	£795.00
smartserve™ 400 Chip & PIN **RRP £595.00/ unit incentive 5 x free of charge*	5	£595.00
smartadmin™ Software *remote monitoring software per kiosk per year*	5	£99.00
smartstation™ 100 **RRP £825.00/ unit incentive 5 x free of charge*	5	£750.00
smartstation™ 100 **RRP £825.00/unit Incentive price @ £750.00/unit*	5	£750.00
smartlabel™ 200 **RRP £0.14p/ label incentive price £0.12p/ label*	430,000	£0.12p
smartgate™ 300 single aisle	1	£4,990.00
smartgate™ 300 single aisle ramp main exit	1	£550.00
smartgate™ manager server licence	1	£500.00
smartgate™ manager client licence main exit gate & gates for refurbishment	2	£75.00
smartgate™ 300 dual aisle **RRP £7,495.00 incentive £4,990.00 for refurbishment* *NO RAMP quoted*	1	£4,990.00
Smartstock™ 300 **RRP £3,795.00/unit incentive £3,495.00/ unit*	3	£3,495.00
Site Survey	1	£400.00
Installation/Implementation days	4	£550.00
Delivery Freight at cost	1	£1900.00
Total Exc VAT		£116,985.00

9.1.1 Cost analysis for the RFID system vs barcodes

Table 19 lists the total implementation cost and running cost for both barcoding and RFID technologies at the library of the University of Portsmouth. These figures were provided by Ken (Project manager at University of Portsmouth). The barcode running costs were estimated for each year and was terminated end in 2011, and the RFID running costs were estimated for each year starting at 2012 and its still currently ongoing project.

Table 19: Costs for RFID and barcodes at the university of Portsmouth library.

Type	RFID	Barcodes
Starting cost	£116,985	£60,255
Running cost	£6,039	£8,350 per annum

In other aspects, time saving, fast accessing of books and elimination of manual errors are the main benefits of the RFID reported at the library. RFID can also be used in library as anti-theft systems. There are some potential savings using RFID because a single RFID tag can serve many different functions, compared to a barcode. The library saves some time in processing new items because each item is attached with an RFID tag. However, financial savings were not the goal of their RFID implementation for the library at the University of Portsmouth, although it can be used for that purpose through staff savings. Decision makers were looking for it to deliver service transformation to be self-service. The implementation of the RFID system enables the University of Portsmouth library service to improve dramatically and meet their self-service aspiration enabling higher levels of throughput to deliver improved customer service levels and return on investment.

9.1.2 The interview with project manager

An Interview was conducted with the project manager working at a strategic level within the library at University of Portsmouth. The interview was free flowing using a semi-structured approach, which allows the questioning and discussion greater flexibility, offering the ability to adapt questions throughout the interview. Interview focused on RFID deployment discovering the advantages and disadvantages of both barcode and RFID methods so that the data can be effectively analysed.

9.1.3 The interview method includes the questions in such as:

1. General Information
    a. What is the name of the organisation you work for?
    b. What is your position in the library?
    c. Which technology does your organisation use, barcodes, RFID or both?
2. How does the RFID system improve the efficiency within the library?
3. Books (stock) loss?
4. Real time inventory?
5. Has the performance of the library operations been improved?

A significant factor using RFID can offer fully automated reading of all tagged items, whereas barcodes generally need some form of manual manipulation and scanning. Also, application of RFID is less prone to human error. RFID allowed University of Portsmouth library to achieve over 95% performance efficiency of issuing books. In handling returns, an automated sorter pre-sorts books into broad areas reducing the time taken to return books back to the shelves from a purely manual process. RFID provides a more robust security system so that stock loss has been reduced due to such as stealing books, miss-shelving or being hidden as the handheld scanner can be used to locate items much more effectively. By using RFID system at the library, human errors have significantly been reduced. However, errors do occur in the incorrect programming of the RFID tags, although RFID provides a much more accurate record of the items in the Library and the ability to locate individual items much more effectively. Nevertheless, the library does not use the RFID system for real time inventory as this does not give sufficient operational advantage to justify the investment necessary in smart shelving. Implementation of the RFID system was the starting point for a range of process change within the Library in which has been aimed at improving efficiency and providing a better service for their customers.

The interview was also carried out with the project manager who was in charge of this project into the following issues:

- How is the error comparable between RFID and Barcodes system?
- How efficient tracking system when items such as books were remotely placed?
- How far is the maximum distance to track?
- What happens beyond the library?

RFID has enabled the University library to reduce manual handling activities associated with the issue of library stock by approximately 95% and with returns by approximately 50% freeing up staff time to provide additional services such as the welcome desk, roaming support and online chat support. The disparity in manual handling reduction between ''issue'' and ''return'' is due to the nature of automatic sortation which still requires items to be retrieved from a bin box manually. However, this process ~~is~~ significantly takes less time intensive than sorting every individual item by hand. Machine sorting is 100% reliable whereas human sorting with an experienced member of staff is at best 95% reliable with the number of items being handled. This reduces the human error count for items being miss-shelved considerably.

The use of RFID handheld readers (scanning process) allows the University library staff to locate items quicker that have been miss-shelved, by either customer directly or by students, or items that have been returned but were not removed from customers account in the library management software. These processes used to be very labour-intensive work as they involved members of staff visually scanning each item on the shelf. Whenever a specific item is needed, the RFID handheld can be used to search an item at the shelf for the presence of an RFID tag that is associated with a specific item. With most ultra-high frequency (UHF) tags that work well for item tracking, read ranges of 5-8 feet might be no problem. When doing activities within library manually it however takes around four weeks to check each shelf using a team of 5-10 staff members. By using the RFID handheld reader, tasks can be achieved/undertaken within approximately a day or two days at a maximum by only one member of staff representing a significant increase in operational efficiency which again allowed staff to be deployed to activities with greater value for library customers. It was reported by the project manager that without the introduction of RFID we might not have been able to introduce these new services and might have lost out on significant customer service advances or been able to achieve the customer service excellence accreditation’’.

Summary

This chapter presents a study in cost analysis, benefits and limitations observed based on a real case study regarding the implementation of the RFID technology into the library at the University of Portsmouth. A cost comparative study between the barcode system and the RFID system was provided. This was followed by the consideration of labour, human errors, and efficiency by looking into the following issues: How is the error comparable between the RFID system and the barcodes system at the library of the University; how efficient the RFID tracking system is when items such as books were remotely place? How far is the maximum distance to track? what happens beyond the library? and other issues based on an interview with the project manager at the university of Portsmouth library.

Chapter 10 Summary, discussions, conclusions and future work

This thesis presents an investigation into an RFID-inventory management system for future generation automated warehousing systems through developments of a number of design methodologies and integration approaches using fast-growing IT technologies such as radio frequency identification (RFID) tags, wireless sensors and communication networks. The thesis also presents a study in development of a ~~using~~ multi-objective optimisation model for obtaining trade-off decisions based on a number of conflicting objectives: minimisation of the total cost, maximisation of capacity utilisation, maximisation of service level and minimisation of travel distance within the proposed warehousing system.

Chapter 1 provides an introduction, background and research problems that motivated this work to be investigated. Chapter 2 presents the findings about warehouse operations in retail industry through a survey to identify some companies' current state of warehouses and operations in their organisation, and expectations in future generation warehouses. Chapter 3 presents studies through the literature review in conventional warehousing systems (manual/automated) and RFID-based automated warehouse systems and other related research work and applications in logics and supply chain sectors. The literature review is particularly focused on research work in warehouse inventory management systems which are discussed in order to identify the research issues that need to be addressed. Besides, advanced planning and scheduling methods were discussed for production planning and scheduling systems like MRP/ERP systems and lean management method. The Internet of Things (IoT), was also discussed within this chapter. The chapter also examines RFID and sensor network technologies including the background of the RFID and its application mainly for supply chain and logistics sectors and review the applications that have been established by researchers. A comparison between barcodes and RFID methods was provided within this chapter. Travel time covers a substantial part of picking processes in warehouses in which the item can be dispatched to travel from the storage rack to the collection point, the relationship between the operation and cost in the warehouse was also explained. Chapter 4 describes and discusses the key components of the proposed RFID-based warehousing management system. This includes RFID-related components, their mechanisms and features, and applications and its implementation. In chapter 5, a material-handling solution was constructed based on the optimal algorithm in order to generate the shortest pick-up sequence and route for the material handling equipment. Two scenarios based on single item and multiple items are explained for the measurement of the storage and retrieval system. Job scheduling plays an important role in efficiency and productivity of warehousing operations. The RFID-enabled warehousing system allows an item to be stored randomly at varying locations wherever a storage place is available, i.e., the same type of items may have multiple locations. Also, the RFID-enabled warehouse management system is capable of identifying a dispatched item by issuing a priority to the selected item based on assignment rules. A step by step process is used to explain all aspects of the developed algorithm. Chapter 6 presents the development in the RFID-based management system integration approach. The concept of integration enables RFID components to be embedded within the mechanism infrastructure of the proposed RFID-enable warehousing system in order to synchronise the warehouse operations and update the inventory data in a real-time manner. This includes an integration of hardware and software applications. The key components of the RFID inventory management system for a pilot test were discussed and identified in this research study. RFID system is used to allow users to improve accuracy, provides better information/data control management, sufficient data processing speeds and enhances security and reduce errors through automation. Chapter 7 illustrates the experimental results through a pilot test based on the prototype of the proposed RFID-based inventory management system. The developed RFID-based management system can automatically detect and identify a number of locations of the ordered item and display these in a row and column of a storage rack. Based on the algorithm developed in the MATLAB environment, the system has the capability of issuing a demand to dispatch the ordered item by assigning a priority to the selected item which can also be displayed and manipulated via a GUI**.** The simulation result was generated by the RFID-inventory management system according to the pre-defined selection rules by issuing a priority to be given to the selected item. The mechanical control system then initialises a demand to push the selected item onto an output conveyor and this item will be transported along the RFID-guided route to the collection point. The developed programming model of the RFID-enabled inventory management system can generate the priority list of selected items to travel in a sequence from the first item with a longest travel time to the last item with a least travel time, accordingly. Furthermore, Chapter 8 illustrates the study aimed at developing a multi-objective optimisation model for gaining a trade-off decision by measuring four conflicting objectives: minimisation of the total cost, maximisation of capacity utilisation, maximisation of service level to satisfy all demands of dispatching products from the warehouse and minimisation of travel distance in the warehouse. By examining the feasibility and applicability using a case study based on the develop model, the optimal solutions can be subtracted from the objective functions. This also leads to an insight into a compromised solution between conflicting objectives for decision makers. Chapter 9 shows the cost analysis, benefits and limitations regarding RFID implementation and a cost compression study between the previous barcode system and the newly implemented RFID system based on a real case study. Chapter 10 provides a summary of this work and the conclusions and recommend the future work.

In supply chains and logistics sectors, accuracy of inventory data is essential as these information data can be crucial for warehouse operations, SKU planning, management and control of incoming and outgoing goods. To yield a desired performance, it is necessary to ensure the operation of the warehouse work effectively. An effective real-time inventory management system is also the foundation of a successful e-commerce and online ordering that are growing at the exponential rate today. This PhD research work was aimed to investigate and develop the design methodology and the integration approach through which the RFID-enabled inventory management system can perform an automatic availability check and update real-time information data of ordered items from the warehouse database. Simultaneously, the RFID-embedded mechanism of the AS/RR can automatically dispatch these items from the warehouse without any human operation. Within the RFID-inventory management system, a selection algorithm was developed to seek an optimal solution to determine a selected item with a longest travel time and subsequently issue a priority to this item to be dispatched first. This includes a transaction database which allows a manipulation of RFID-tracked items under pre-defined rules by assigning a priority to one of selected items.

The average travel time for the movement of the pusher was also determined by considering both movement of the pusher with a constant velocity and with an acceleration and declaration. Different analytical approaches showed that the proposed analytical travel time models perform better in the constant velocity compared to result of acceleration and declaration in which the largest deviations in average travel time up to 4% were noticed with respect to acceleration and declaration. The results, which were demonstrated in constant velocity and acceleration and declaration, respectively, confirmed that there is not much significant deviation found in the average travel time between constant velocity and acceleration and declaration. Therefore, the simplified model for the travel time using constant velocity was considered to be more realistic for this model.

A pilot test was carried out to examine the developed algorithm applied into the RFID-based management system which, in theory, has a capability of interacting with the mechanical control system of the RFID-embedded AS/RR. To synchronise these systems to act coordinately, both the warehouse RFID-inventory management system and the warehouse control system of the AS/RR need to be integrated through a developed interface which allows an effective communication between these two systems.

A multi-objective optimisation approach was also developed to optimise the design of the proposed RFID-enabled automated warehousing system based on four conflicting objectives in order to obtain trade-off solutions aimed at maximising the warehouse capacity utilisation and service level in terms of satisfying all demands of dispatching products from the warehouse, minimising the travel distance of products from a storage rack to a collection point and the total cost required for implementing RFID-related facilities into the proposed warehousing system. The study also includes an approach to determine the optimal number of racks and collection points that should be established when designing the proposed warehouse. At the first stage, an integrated fuzzy solution approach was used to obtain Pareto-optima solutions. At the second stage, TOPSIS was employed to reveal the best Pareto solution. Subsequently, solution 6 in Table 16 was selected as the best solution since it revealed the highest score. This score represents the nearest solution value from the ideal solution and the furthest from the negative (worst) solution. Arguably, TOPSIS does not involve or boost the optimisation since it can only help the decision makers in selecting the final solution. The results showed that the developed multi-objective model can be used as an aid for decision makers to obtain a cost-effective design of an RFID-enabled automated warehousing system towards the optimisation of conflicting objectives. A case study was also used for examining the feasibility and applicability of the developed approach. The experiment shows that the developed

RFID-based management system can automatically detect and identify locations of ordered items by displaying objects on GUI. Experimental results demonstrate the applicability of the developed optimisation algorithm implemented into the RFID-based inventory management system. It also shows that the RFID-inventory management system can determine the optimal route for the pusher to travel in a sequence during the ordering process that gives a minimal overall travel time for all the ordered items to a specified collection point. Further, a study in cost analysis was conducted based on the implementation of the RFID technology at the University of Portsmouth library. This includes an outcome through an interview with the project manager for the benefits and limitations when replacing the previous barcode system by the RFID system.

10.1 The recommended future work

The pilot test was executed based on a limited number of RFID tagged items due to the restriction of the research budget. In a real warehouse, however, there are a large number of RFID-tagged items which need to be tracked and processed in a real time manner through the integrated information systems. Within such a large scale environment, RFID signal-overlapping and collision can cause a serious problem to synchronise the operations of the entire automated warehouse. Thus, it is highly recommended for the future work to employ a suitable distributed multi-channel reader anti-collision approach for the proposed RFID-enabled warehouse system at a large scale.

In recent years, it has been widely reported that the Internet of Things (loT) will be an industrial revolution that may dramatically alter the ways in manufacturing, energy, agriculture, transportation, supply chain and logistics and other industrial sectors. It mayalso fundamentally transform how people will work through new interactions between humans and machines. It may also change the basis of competition, redraw industry boundaries and create a new wave of retail companies just as the current. The IoT factory automation concept can also result in changes of supply chain organization, operations and information management. One of the challenges is that the warehouse management system (WMS) and the warehouse control system (WCS) must be able to be not just integrated to establish a new autonomous system and but also it supports new autonomous smart devices and multiple connectivity options. RFID makes it possible to extend the fundamental abstraction of the world wide web (www) to the physical world. Eventually, every interesting physical object can be connected to a global network opening up the possibility for an Internet of Things (IoT), although this expectation is still far from the existing world.

References

Agarwal, A., & Madan, A.K. (2015). A Review of Analytical Travel Time Models in Automated Storage and Retrieval Systems. *Journal of Basic and Applied Engineering Research,* 2, 1372-1376.

Ahmadi, A. Moghimi, H. Nezhadc, A.E. Agelidis, V.G. Sharaf, A.M. (2015). Multi-objective economic emission dispatch considering combined heat and power by normal boundary intersection method, *Electric Power Systems Research,* 129, 32–43.

Anderson, J.C. and Schroeder, R.G. (1984). Getting results from your MRP system. *Business Horizons*, 27, 57-64

Andrew, L. M. (2006). A lean route to manufacturing survival. *Assembly Automation*, 26, 265– 272.

Ashayeri, J., & Gelders, L. F. (1985). Warehouse design optimisation. *European Journal of the Operational Research,* 21, 285-294.

Ashayeri, J., Gelders, L. F. (1985). A microcomputer-based optimisation model for the design of automated warehouses, *International Journal of Production Research*, 23, 4, 825–839.

Baars, H., Kemper, H.G., Lasi, H. & Siegel, M. (2008). Combining RFID technology and business intelligence for supply chain optimisation scenarios for retail logistics. *Proceedings of the 41st Hawaii International Conference on System Sciences,*(pp.1-10)

Bafna, K. M., Reed, R. (1972). An Analytical Approach to Design of High-Rise tacker Crane Warehouse Systems. *Journal of Industrial Engineering*, 4, 10, 8–14.

Bagchi, U., Guirida, A., O'Neill, L., Zeng, A., & Hayya, J. (2007). The effect of RFID on inventory management and control*. Springer series in advanced manufacturing*. 71-92.

Ballé, F, Ballé, M. (2005). Feel the force of flexible manpower. *IET Manufacturing Engineer*, 84, 20-5.

Baysan, S. Ustundag, A. (2013). *The Value of RFID: Benefits vs. Costs.* Retrieved from web address: https://books.google.co.uk/books?isbn=1447143450.

Bottani, E., & Rizzi, A. (2008). Economical assessment of the impact of RFID technology and EPC system on the fast-moving consumer goods supply chain. *International Journal of Production Economics, 112*, 548-569.

Brown, D. (2007). *RFID Implementation*. New York: McGraw-Hill Communications.

Brusey, J. and McFarlane, D.C. (2009). Effective RFID-based object tracking for manufacturing. *International Journal of Computer Integrated Manufacturing*, 22, 638-647.

Çakıcı, Ö.,E. Groenevelt, H. Seidmann, A. (2009). A case inquiry: can rfid help reduce costs in medical imaging? *Radiology Business Journal*, 2, 50–52.

Cao, Y., Li, W. Song, W. and Chaovalitwongse, W., A. (2013). Collaborative Material and Production Tracking in Toy Manufacturing. *In IEEE 17th International Conference on Computer Supported Cooperative Work in Design (CSCWD)*, 645–650.

Chao, C.C., Yang, J.M., & Jen, W.Y. (2007). Determining technology trends and forecasts of RFID by a historical review and bibliometric analysis from 1991 to 2005. *Technovation,* 27, 268-279.

Chawla, V., & Ha, D.S. (2007). An overview of passive RFID. *IEEE Communication Magazinee*, 45, 11-17.

Chen, R.S., Tu, M.A., & Jwo, J.S. (2010). An RFID-based enterprise application integration framework for real-time management of dynamic manufacturing processes. *International Journal of Advanced Manufacturing Technology, 50*, 1217–1234.

Chiandussi, G. Codegone, M. Ferrero, S. Varesio, F.E. (2012). Comparison of multi-objective optimization methodologies for engineering applications, *Computers & Mathematics with Applications* 63(5), 912-942.

Chomka, S. (2003). Radio tagging too pricey, claim many companies, *Food Manufacture*, 78,13.

Chow, H.K.H., Choy, K. L., Lee, W. B., & Lau, K. C. (2006). Design of a RFID case-based resource management system for warehouse operations. *Expert Systems with Applications*, *30*(4), 561-576.

Cusumano, M.A. (1994). The Limits of Lean. *Sloan Management Review*, 35 (4), 27-32.

De Koster, R., Le-Duc, T., and Roodbergen, K.J. (2007). Design and control of warehouse order picking: a literature review. *European Journal of Operational Research* 182(2), 481-501.

Deavours, D.D. (2009). *A Circularly Polarized Planar Antenna Modified for Passive UHF RFID.* IEEE International Conference on RFID.

Deb, K. (2001). Multi-Objective Optimisation using Evolutionary Algorithms, New York: John Wiley & Sons.

Delaunay, C., Sahin, E., & Dallery, Y. (2007). A literature review on investigations dealing with inventory management with data inaccuracies. *RFID Eurasia.* 1st Annual, 1-7.

Dennis, P. (2007). Lean production simplified. New York: *Productivity Press*.

Doerr, K.H., Gates, W.R., & Mutty, J. E. (2006). A hybrid approach to the valuation of RFID /MEMS technology applied to ordnance inventor. *International Journal of Production Economics,* 103, 726-741.

Dolgui, A., & Proth, J.M. (2008). RFID technology in supply chain management: State of the art and perspectives. *Proceedings of the 17th World Congress: The International Federation of Automatic Control* (pp. 4465-4475). Seoul, Korea.

Ebrahimi, S. Sharifian, S. Bastani, P (2015). Readiness of hospitals affiliated with Tabriz University of Medical Sciences to Face Disasters. *Journal of Health Management,* 3(1).

Ergen, E., Akinci, B., & Sacks, R. (2007). Life-cycle data management of engineered to-order components using radio frequency identification. *Advanced Engineering Informatics, 21*, 356-366.

Evangelatos, O., Samarasinghe, K. and Rolim, J. (2012). Evaluating design approaches for smart building systems,”in Mobile Adhoc and Sensor Systems (MASS), *IEEE 9th International Conference* , 1–7.

Ferguson, R. (2007). Berkeley's Mesh Network: Dust in the RFID Wind. *eWeek.* Retrieved from: http://www.eweek.com

Gambon, J. (2009). Benefits Up and Down the Ski Slope. *RfidJournal*. Retrieved from: http://www.rfidjournal.com

Gen, M. and Cheng, R. (1997). Genetic Algorithms and Engineering Design, New York: John Wiley & Sons

Ghobbar, A. A. and Friend C. H. (2004). The material requirements planning system for aircraft maintenance and inventory control: a note. *Journal of Air Transport Management* 10, 217–221.

Grant, D.B., Lambert, D.M., Stock, J.R., and Ellram, L.M. (2006). *Fundamentals of logistics management.* European edition. UK: McGraw-Hill Education

Gupta, S. and Jain, S. K. (2013). A literature review of lean manufacturing. *International Journal of Management Science and Engineering Management*, 8, (4), 241–249.

Hamid, A. A., Agus, A. and Hassan, M., E. (1991). Computerised materials requirement planning in manufacturing companies in Malaysia. *International Journal of Production Economics,* 25, 73-79.

Harrop, P., & Das, R. (2010). Active RFID and sensor networks 2009-2019.

Hedgepeth, W.,O. (2006). RFID Metrics: Decision Making Tools for Today's Supply Chains CRC Press, Boca Raton, FL.

Henrici, D., (2008). *RFID Security and Privacy.* Berlin. Springer-velag Berlin Heidelberg.

Hines, P. Holwe, M. and Rich, N. (2004). Learning to evolve: A review of contemporary lean thinking. *International Journal of Operations & Production Management*, 24 (9/10), 994-1011.

Hou, J.L., & Huang, C.H. (2006). Quantitative performance evaluation of RFID applications in the supply chain of the printing industry. *Industrial Management 8 Data Systems,* 106, 96-123.

Hu, Y.H., Huang, S.Y., Chen, C., Hsu, W., Toh, A.C. Loh, C.K., & Tiancheng, S. (2005). Travel time analysis of a new automatedstorage and retrieval system. *Computers & Operations Research*, 32, 1515–1544.

Huang, S., Wang, Q., Batta, R., & Nagi, R. (2015). An integrated model for site selection and space determination of warehouses. *Computers & Operations Research*, 62, 169–176.

Huber, N., & Michael, K. (2007). Vendor perceptions of how RFID can minimise product shrinkage in the retail supply chain. *RFID Eurasia, 1st Annual* (pp. 1-6).

Hunt, V. D., Puglia, M., & Puglia, A. (2007). *A guide to radio frequency identification.* Technology Research Corporation.

Hwang, C. L. and Yoon, K. (1981). Multi Attribute Decision Making Methods and Applications,"Springer-Verlag, Berlin Heidelberg, 259.

Hwang, H. Lee, SB. (1990). Travel time models considering the operating characteristics of the storage and retrieval machine. *Int J Prod Res,* 28, 1779–1789.

Impinj. (2015) How Do RFID Systems Work? *Impinj.* Retrieved (2015). from: http://www.impinj.com/resources/about-rfid/ how-do-rfid-systems-work

Impinj. (2015) RFID Standards. *Impinj.* Retrieved (2015). from: http://www.impinj.com/resources/about-rfid/rfid-standards

Impinj. (2015). The different types of RFID systems. *Impinj.* Retrieved (2015) from: http://www.impinj.com/resources/about-rfid/the-different-types-of-rfid-systems.

Jehng, W.K., Peng, S., & Huang, W.H.(2008). using LabVIEW to integrate RFID system and database for supply chain efficiency improvement. *International Journal of Intelligent Control and Systems*, 13, 189-195.

Jian, M.-S. (2010). RFID System Integration and Application Examples. *Radio Frequency Identification Fundamentals and Applications, Bringing Research to Practice* (chapter 14).

Jiménez López, M., Rodríguez Uría, M.V., Parra, M.A., & Bilbao, A. (2000). Solving a possibilistic linear program through compromise programming. *Mathware and Soft Computing*, 7, 175-184.

Kärkkäinen, M. (2003). Increasing efficiency in the supply chain for short shelf life goods using RFID tagging. *International Journal of Retail & Distribution Management,* 31, 529 – 536.

Kim, E.Y., Ko, E., Kim, H., & Koh, C.E. (2008). Comparison of benefits of radio frequency identification: Implications for business strategic performance in the US and Korean retailers. *Industrial Marketing Management*, 37,797-806.

Kim, S., & Garrison, G. (2010). Understanding users' behaviors regarding supply chain technology: determinants impacting the adoption and implementation of RFID technology in South Korea. *International Journal of Information Management, 30*(5), 388-39.

Kodaka, K., Niwa, H., & Sugano S. (2009). Rotation-based dynamic localization at an initial dead-zone avoidance stage on an rfid tag lattice. *Journal of Robotics and Mechatronics, 21*(4), 460–468.

Landt, J. (2001). *Shrouds of Time: The History of RPID.* AIM Publications, Pittsburgh, PA.

Landvater, D., (1985). How do you compare to 1,000 other companies? Infosystems, 32 (1).

Lee, S. G. Souza, R. de. Ong, E. K. (1996). Simulation modelling of a narrow aisle automated storage and retrieval system (AS/RS) serviced by rail-guided vehicles. *Computers in Industry*, 30,241-253.

Lee, W.-S., & Yu, J.-W. (2015). Selectable sectoral antenna array using a quadruple feeding network for item-level tagging in UHF RFID applications. *Microwave and Optical Technology Letters, 57*, 1523–1526.

Lee, Y.M., Cheng, F., & Leung, Y. T. (2004). Exploring the impact of RFID on supply chain dynamics*. In 2004 Winter Simulation Conference R .G. Ingalls, M. D. Rossetii, J. S. Smith, and B. A. Peters (Eds.),* 1145-1152.

Lefebvre, L.A., Lefebvre, E., Bendavid, Y., Wamba, S.F., & Boeck, H. (2006). RFID as an enabler of B-to-B e-commerce and its impact on business processes: A pilot study of a supply chain in the retail industry. *In Proceedings of the 39th Hawaii International Conference on System Sciences,* 6, 1-10.

Lerher, T., Ekren, B.Y., Dukic, G., & Rosi, B. (2015). Travel time model for shuttle-based storage and retrieval systems. *International Journal of Advanced Manufacturing Technology,* 78, 9-12.

Lerher, T., Potrc, I., & Sraml, M. (2013). Designing automated warehouses by minimising investment cost using genetic algorithms. *Progress in material handling research: 2010. Charlotte: The Material Handling Industry of America*, 237–253.

Lerher, T., Potrc, I., Sraml, M., & Tollazzi, T. (2010). Travel time models for automated warehouses with aisle transferring storage and retrieval machine. *European Journal of Operational Reserch,*205, 571-583.

Lerher, T., Šraml, I., Borovinšek, M., & Potrč, I. (2013). Multi-objective optimisation of automated storage and retrieval systems. *Annals of faculty of mechanical engineering-International journal of Engineering*, 187-194.

Lerher,T., Sraml, M., Kramberger, J., Potrc, I., Borovinsek, M., & Zmazek, B. (2006). Analytical Travel time model for multi aisle automated storage and retrieval systems. *The International Journal of Advanced Manufacturing Technology*. 30, 340-356.

Leung, Y.T., Cheng, F., Lee, Y.M., & Hennessy, J.J. (2007). *A Tool Set for Exploring the Value of RFID in a Supply Chain.* Springer series in advanced manufacturing.

Lingle, R. (2007). RFID smart shelves and cabinets. *Packaging World.* Retrieved from: http://www.healthcarepackaging.com/trends-and-issues/traceability-and-authentication/rfid-smart-shelves-and-cabinets

Liu, C.M., & Chen, L.S. (2009). Applications of RFID Technology for improving production efficiency in an integrated-circuit packaging house. *International Journal of Production Research*, 47, 2203-2216.

Liu, C-M., Chen, L.S. (2009). Applications of RFID technology for improving production efficiency in an integrated-circuit packaging house. *International journal of production research*, 47, 2203-2216.

Liu, D., Mou, M., Lu, M., & Wu, Y. (2014). Travel Time Model of a New Compact Storage System. *International Journal of Control and Automation,* 7, 447-460.

Liu, G., Mao, L., Chen, L., & Xie, S. (2014). Locatable-Body Temperature Monitoring Based on Semi-Active UHF RFID Tags. *Sensors, 14*, 5952-5966.

Liu, G., Yu, W., and Liu, Y. (2006). Resource Management with RFID Technology in Automatic Warehouse System. *IEEE/RSJ International Conference On Intilegent Robots And Systems*, Beijing, 3706-3711.

Liu, Y., & Wang, D. (2009). An RFID middleware business process integration framework based on EPC modeling and complex event processing. *International Conference on Computer Sciences and Convergence Information Technology*, Seoul, 64-69.

Lwiki, T. Ojera, P.B. Mugenda, N.G. and Wachira, V.K. (2013). The Impact of Inventory Management Practices on Financial Performance of Sugar Manufacturing Firms in Kenya. *International Journal of Business, Humanities and Technology*, 3 (5), 75-85.

Lwiki, T., Ojera, P., B. Mugenda, N. G., Wachira, V., K. (2013). The Impact of inventory Management Practices on Financial Performance of Sugar Manufacturing Firms in Kenya. *International Journal of Business, Humanities and Technology,* 3, 75-85.

Ly, M. (2006). *Automated Checkout System Using Radio Frequency ID Tags.* Monmouth University, New Jersey, United States. Readiness Assessment Report for A&P Supermarkets.

Ma, H., Su, S., Simon, D., & Fei, M. (2015). Ensemble multi-objective biogeography-based optimisation with application to automated warehouse scheduling. *Engineering Applications of Artificial Intelligence*, 44, 79–90.

Ma, X., and Liu, T. (2011). The Application of Wi-Fi RTLS in Automatic Warehouse Management System. *In IEEE International Conference on Automation and Logistics (ICAL)*, 64–69.

Marphy, Jr. P.R., & Wood, D.F. (2001). *Contemporary Logistics*. New Jersey: Pearson Education.

McCathie, L. (2004). *The advantages and disadvantages of barcodes and radio frequency identification in supply chain management*. University of Wollongong, Australia.

McFarlane, D., Sarma, S., Chirn, J., Wong, C., & Ashton, K. (2003). Auto ID systems and intelligent manufacturing control. *Engineering Applications of Artificial Intelligence, 16,* 365-376.

McGuinness, K. (2008). *The Readiness of High-Technology Manufacturing companies*

Messac, A. Optimisation in Practice with MATLAB®: For Engineering Students and Professionals, 1st Edition, 2015, Cambridge University Press.

Ming, K.L., Witold, B., and Stephen, C.H. (2013). RFID in the warehouse: A literature analysis (1995-2010) of its applications, benefits, challenges and future trends. *International Journal of Production Economics.* 145, 409-430.

Moeller, K. (2011). Increasing warehouse order picking performance by sequence optimisation, *Procedia - Social and Behavioral Sciences*, 20, 177–185,.

Mohammed, A. Wang, Q. (2017). The fuzzy multi-objective distribution planner for a green meat supply chain, *International Journal Production Economics,* 184, 47-58.

Mourtzis, D., Papakostas, N., Makris, S., Xanthakis, V., & Chryssolouris, G. (2008). Supply chain modelling and control for producing highly customized products. *CIRP Annals - Manufacturing Technology, 57*, 451-454.

Ne´meth,P.,Toth,L.,Hartvanyi,T. (2006). Adapting RFID in supply chains . IEEE 3rd International Conference on Mechatronics ,263–266.

Nikitin, P., & Rao, K. V. S. (2008). Antennas and Propagation in UHF RFID Systems. *IEEE International Conference on RFID,* 277–288.

Niu, N., Xu, L. D. and Bi, Z. (2013). Enterprise Information Systems Architecture-Analysis and Evaluation. *IEEE Transactions on Industrial Informatics 9*, 2147–2154.

Osyczka, A. (1985) 7 – Multicriteria optimization for engineering design, *Design Optimization*, Academic Press, 193–227.

Park, C.-S. (2014). Security Mechanism Based on Hospital Authentication Server for Secure Application of Implantable Medical Devices. *BioMed Research International*, *2014*, 543051.

Park, Y., & Yoo, J. (2008). An intelligent Middleware Platform and Framework for RFID Reverse Logistics. *International Journal of Future Generation Communication and Networking.*

Perry, R. F., Hoover, S. F., Freeman, D. R. (1983). Design of Automated Storage and Retrieval Systems using Simulation Modeling, Institute of Industrial Engineers, Atlanta, Georgia, ICAW Proceedings, 57–63.

Pigni, F., & Ravarini, A. (2008). RFID in the fashion industry: Evidences and lessons learnt from an anti-counterfeiting project. *In Proceedings of the Fourteenth Americas Conference on Information Systems,* (pp. 1-8).

Pishvaee, M.S. Razmi, J. (2012). Environmental supply chain network design using multi-objective fuzzy mathematical programming, *Applied Mathematical Modelling,* 36 (8), 3433–3446.

Poon, K. T., Choy, K. L., & Lau, H. C. (2008). A RFID-based location tracking scheme for inbound operations in warehouse environment. In: *Management of Engineering & Technology, 2008. PICMET (2008). Portland International Conference on IEEE,* 872-877.

Poon, T.C., Choy, K.L., Chow, H.K.H., Lau, H.C.W., Chan, F.T.S., & Ho, K.C. (2009). A RFID case-based logistics resource management system for managing order-picking operations in warehouses. *Expert Systems with Applications*, 36, 8277-8301.

Qiu, X., Huang, G.Q. (2013). Supply Hub in Industrial Park (SHIP): The value of freight consolidation. *Computers & Industrial Enginnring,* 65, 16-27.

Rakotondrabe, M., Yassine, H. Clevy, C. and Lutz, P. (2011). Automation of Assembly and Packaging at the Micro/Nano- Scale. *In IEEE Conference on Automation Science and Engineering (CASE),* 1–5.

Ramesh, S., Kannan, S., & Baskar, S. (2013). Application of modified NSGA-II algorithmto multi-objective reactive power planning. *Appl. Soft Comput*ing,12, 2013, 741–753.

RFID tags. (2015). Connectivity of the Internet of Things, Retrieved from: https://www.google.co.uk/search?q=rfid+tags&biw=1920&bih=974&source=lnms&tbm=isch&sa=X&sqi=2&ved=0ahUKEwiFzMi24N_PAhXjNJoKHQ-iDtwQ_AUIBygC.

Roberti, M. (2003). Analysis: RFID Wal-Marts network effect. (Online journal) Retrieved from: http://www.cioinsight.com

Roberti, M. (2003). RFID’s Momentous Week, RFID journal, available at: https://www.rfidjournal.com/articles/pdf?464

Roberti, M. (2004). Wal-Mart Begins RFID Rollout. *RfidJournal*. Retrieved from: http://www.rfidjournal.com.

Rosenblatt, M. J., Roll, J. (1984). Warehouse design with storage policy considerations, *International Journal of Production Research*, 22, 5, 809–821.

Ross, A.D., Twede, D., Clarke, R.H., & Ryan, R.H. (2009). A framework for developing implementation strategies for a radio frequency identification (RFID) system in a distribution centre environment. *Journal of Business Logistics*, 30, 157-183.

Sahin, E., & Dallery, Y. (2007). A literature review on the impact of inventory data record inaccuracies on inventory management and the potential of the RFID technology to tackle this issue. *Ecole Centrale Paris*, 2007.

Saygin, C. (2007). Adaptive inventory management using RFID data. *The International Journal of Advanced Manufacturing Technology, 32*, 1045-1051.

Schenone, M., Mangano, G., Gabrina, S. (2016). Analysis of AS/RS travel times in class-based storage environment through a simulation approach. *Computational Science and Systems Engineering,* 170-177.

Seth, D., & Gupta, V. (2005). Application of value stream mapping for lean operations and cycle time reduction: An Indian case study. *Production Planning and Control*, 16, 44–59.

Shaw, T. (2002). Reliability Measures for Highway Systems and Segments. *TRANSYSTEMS Corporation*.

Singh, B., Garg, S. K., Sharma, S. K., & Grewal, C. (2010c). Lean implementation and its benefits to production industry. *International Journal of Lean Six Sigma*, 1, 157–168.

Song, H., Shin, V. and Jeon, M. (2012). Mobile Node Localization Using Fusion Prediction-Based Interacting Multiple Model in Cricket Sensor Network. *IEEE Transactions on Industrial Electronics*, 59, 4349–4359.

Sounderpandian, J., Boppana, R.V., Chalasani, S., & Madni, A.M. (2007). Models for cost-benefit analysis of RFID implementations in retail stores. *IEEE Systems Journal,* 1*,* 105-114.

Squire, J. A. M. S., E. Baber, C. Absher, B. and Kendzia, T. (2014). Robo-Tic: Development of a Tick-Eliminating Robot. *IEEE Potentials,* 33, 12–16.

Taguchi, M., & Mizuno, H. (2006). Analysis of Dead Zone of RFID System, *Proceedings of 2006 IEEE Antennas and Propagation Society International Symposium, Albuquerque*, *558,* 4759-4762.

Ting, J.S.L., & Tsang, A.H.C. (2012). Design of an RFID-based Inventory Control and Management System: A Case Study. *The West Indian Journal of Engineering,* 34, 70-79.

To Adopt and Use Radio Frequency Identification (RFID): A Case Study of the Medical Device Sector in Ireland. National University of Ireland Galway, Ireland. Retrieved from: http://hdl.handle.net/10379/358.

Tompkins, J.A., White, J.A., Bozer, Y.A., Frazelle, E.H. and Tanchoco, J.M.A. (2003). *Facilities Planning,* (NJ: John Wiley & Sons).

Turcu, C., Cerlincă, M., Cerlincă, T., Prodan, R., Turcu, T., Gîză, F., & Popa1, V. (2007). An Integrated RFID-Based B2B System for Supply Chain Logistics and Warehousing. *International Journal of Computers and Communications*, 1, 90-98.

Tzeng, S.F., Chen, W.H., & Pai, F.Y. (2008) Evaluating the business value of RFID: Evidence from five case studies. *International Journal of Production Economics*, 112, 601-613.

Vasili, M.R. Tang, S.H. S Homayouni, M. and Ismail, N. (2006). Compersion of different dwell point polices for split-platform automated storage and retrieval system. *International Journal of Engineering and Technology*, 3, 91-106.

Vermesan, O., Friess. (2013). *Internet of Things- Converging Technologies for Smart Environments and integrated Ecosystems*. Denmark, River publishers.

Wamba, S.F., Lefebvre, L.A., & Lefebvre, E. (2007). Integrating RFID technology and the EPC network into a b2b retail supply chain: a step toward intelligent business processes. *Journal of Technology Management and Innovation, 2*, 114-124.

Wang, H., Chen, S., & Xie, Y. (2010). An RFID-based digital warehouse management system in the tobacco industry: a case study. *International Journal of Production Research, 48*, 2513-2548.

Wang, L. Xu, L.D. Bi, Z. Xu, Y. (2014). Data cleaning for RFID and WSN integration, IEEE Transactions on Industrial Informatics, vol.10, pp.408 – 418,.

Wang, L.C., Lin, Y.C., & Lin, P.H. (2007). Dynamic mobile RFID-based supply chain control and management system in construction. *Advanced Engineering Informatics,* 21, 377-390.

Wang, Q., Alyahya, S., Bennett, N. & Dhakal, H. (2015). An RFID-enabled automated warehousing system. *International Journal of Materials, Mechanics and Manufacturing*, 3, 287-239.

Wang, Q., McIntosh, R., & Brain, M. (2010). A new-generation automated warehousing capability. *International Journal of Computer Integrated Manufacturing*, 6, 565-537.

Wang, X., & Adams, M. (2011). Warehousing and distribution centres. In *Intermodal transportation: Moving freight in a global economy*, 1-22.

Werb, J., and Lanzl, C. (1998). Designing a Positioning System for Finding Things and People Indoors. *IEEE Spectrum*, 35, 71–78.

Williams, S. Taylor, M. Irland. J. Metha, A. (2014). *RFID Technology in Forensic Evidence Management: An Assessment of Barriers, Benefits, and Costs.* Retrieved from web address: http://dx.doi.org/10.6028/NIST.IR.8030

Won, S., Golnaraghi, F. and Melek, W. W. (2009). “A Fastening Tool Tracking System Using an IMU and a Position Sensor with Kalman Filters and a Fuzzy Expert System.” IEEE Transactions on Industrial Electronics 56 (5): 1782–1792.

Xiaoyong, S., Chu, C.-C., Prabhu, B.S., & Gadh, R. (2007). On the Identification Device Management and Data Capture via WinRFID Edge-Server. *IEEE Systems Journal* – ISJ-8.

Xu , Z., Ming, X.G., Zhou, J. Song , W., He, L., & Miao Li. (2013). Management optimisation based on dynamic SKU for RFID-enabled warehouse management in the steel supply chain. *International Journal ofProduction Research*, 51, 2981-2996.

Yahong, H., Ying, H.S., Chuanyu, C., Wen-Jing, h., Cheong, T.A., & Kit, L.C. (2003). Travel time analysis of a new Automated Storage and Retrieval System. *IEEE Emerging Technologies and Factory Automation,*1, 75-81.

Yang, H. (2010). *Integrated ZigBee RFID sensor networks for resource tracking and monitoring in logistics management.* Thesis. Loughborough University, UK.

Zhai, C. Zou, Z. Zhou, Q. Mao, J. Chen, Q. Tenhunena, H. Lirong, Z. and Xu, L. (2016). A 2.4-GHz ISM RF and UWB Hybrid RFID Real-Time Locating System for Industrial Enterprise Internet of Things (IoT)*, Enterprise Information System*, published online.

Zhang, T., Wang, X., Liu, X., Chu, J., & Cui, P. (2010). Automotive green supply chain management based on the RFID technology. (ICAMS 2010 - Proc. 2010). *IEEE International Conference on Advanced Management Science,* 2, 617-619.

Zhou, W. (2008). RFID and item-level information visibility. *European Journal of Operational Research*, 198, 252-258.

Zou, Z., Chen, Q. Uysal, I. and Zheng. L., R. (2014). Radio Frequency Identification Enabled Wireless Sensing for Intelligent Food Logistics. *Philosophical Transactions A of the Royal Society*, 372.

Zuehlke, D. (2010). Smartfactory-Towards a Factory-of-Things. *Annual Reviews in Control*, 34, 129–138.

Appendix

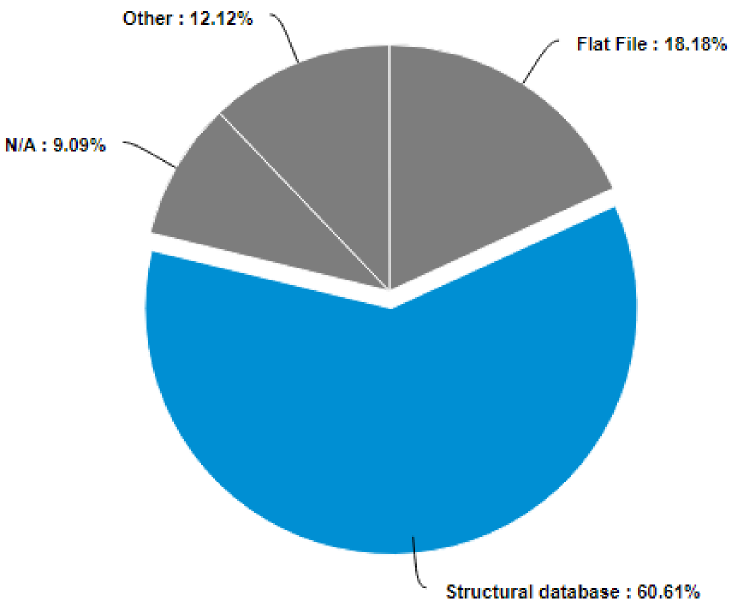
Appendix A

Respondents		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Respondent_1	1	3.0	3.0	3.0
	Respondent_2	1	3.0	3.0	6.1
	Respondent_3	1	3.0	3.0	9.1
	Respondent_4	1	3.0	3.0	12.1
	Respondent_5	1	3.0	3.0	15.2
	Respondent_6	1	3.0	3.0	18.2
	Respondent_7	1	3.0	3.0	21.2
	Respondent_8	1	3.0	3.0	24.2
	Respondent_9	1	3.0	3.0	27.3
	Respondent_10	1	3.0	3.0	30.3
	Respondent_11	1	3.0	3.0	33.3
	Respondent_12	1	3.0	3.0	36.4
	Respondent_13	1	3.0	3.0	39.4
	Respondent_14	1	3.0	3.0	42.4
	Respondent_15	1	3.0	3.0	45.5
	Respondent_16	1	3.0	3.0	48.5
	Respondent_17	1	3.0	3.0	51.5
	Respondent_18	1	3.0	3.0	54.5
	Respondent_19	1	3.0	3.0	57.6
	Respondent_20	1	3.0	3.0	60.6
	Respondent_21	1	3.0	3.0	63.6
	Respondent_22	1	3.0	3.0	66.7
	Respondent_23	1	3.0	3.0	69.7
	Respondent_24	1	3.0	3.0	72.7
	Respondent_25	1	3.0	3.0	75.8
	Respondent_26	1	3.0	3.0	78.8
	Respondent_27	1	3.0	3.0	81.8
	Respondent_28	1	3.0	3.0	84.8
	Respondent_29	1	3.0	3.0	87.9
	Respondent_30	1	3.0	3.0	90.9
	Respondent_31	1	3.0	3.0	93.9
	Respondent_32	1	3.0	3.0	97.0
	Respondent_33	1	3.0	3.0	100.0
	Total	33	100.0	100.0	

1- Do you use database? If so, what types of database do you use?

Q1

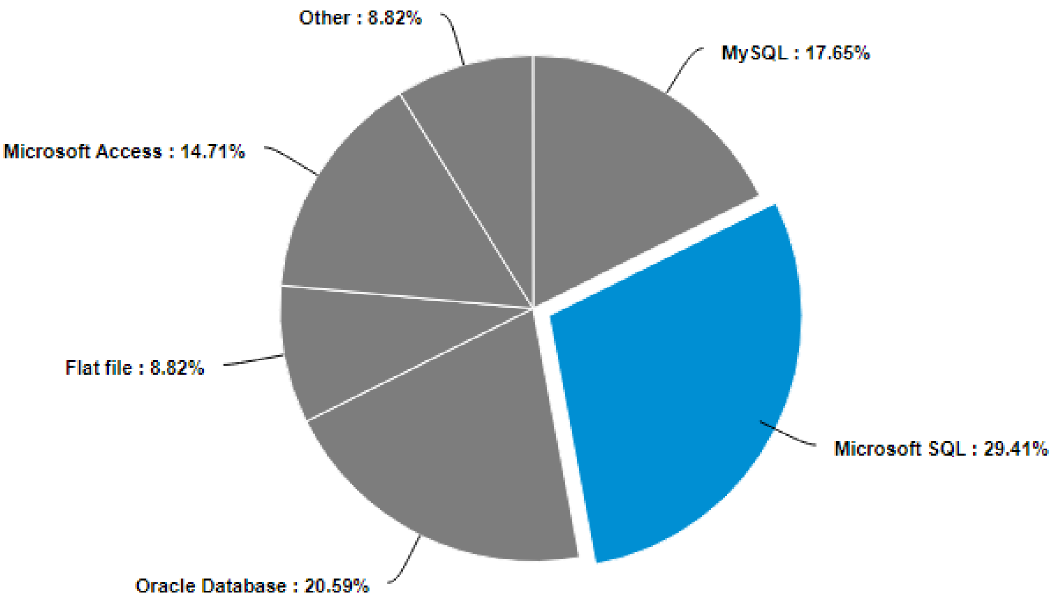
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Flat file	6	18.2	18.18	18.2
	Structural database	21	63.6	60.6	81.8
	N/A	4	12.1	12.12	93.9
	Other	2	6.1	9.09	100.0
	Total	33	100.0	100.0	



2- What database do you use?

Q2

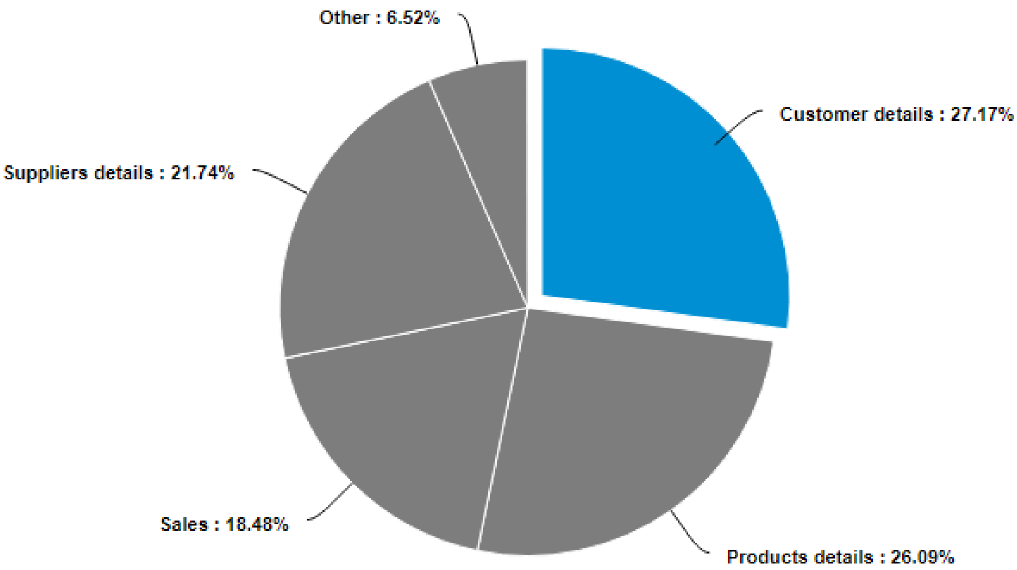
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	MySQL	6	18.2	17.65	18.2
	Microsoft SQL	10	30.3	29.41	48.5
	Oracle Database	7	21.2	20.59	69.7
	Flat file	3	9.1	8.82	78.8
	Microsoft Access	5	15.2	14.71	93.9
	Other	2	6.1	8.82	100.0
	Total	33	100.0	100.0	



3- What do you currently store in your database? (Select all that apply)

Q3

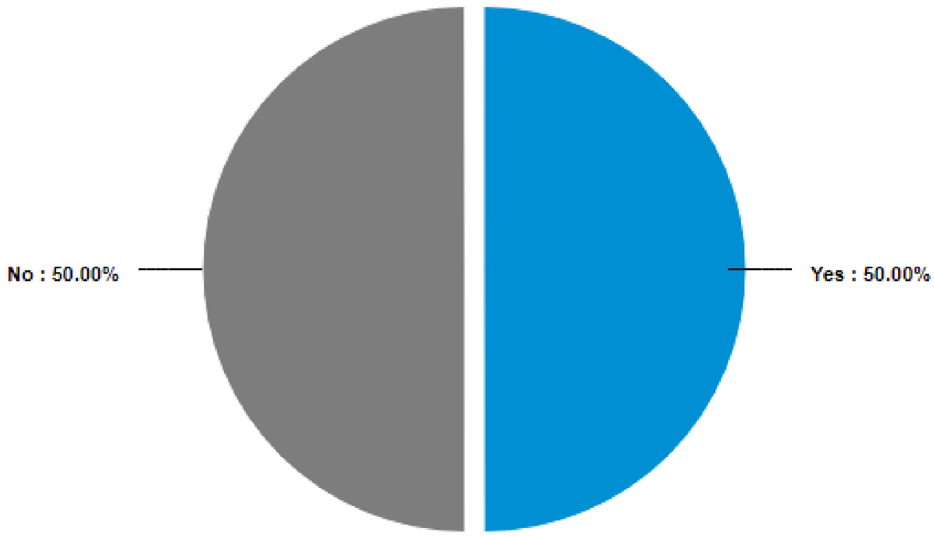
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Customer details	4	12.1	27.1	12.1
	Products details	4	12.1	26.9	24.2
	Sales	4	12.1	18.48	36.4
	Suppliers details	5	15.2	21.74	51.5
	Other	2	6.1	6.52	57.6
					100.0
	Total	33	100.0	100.0	



4- Does your database link with enterprise resource planning (ERP)?

Q4

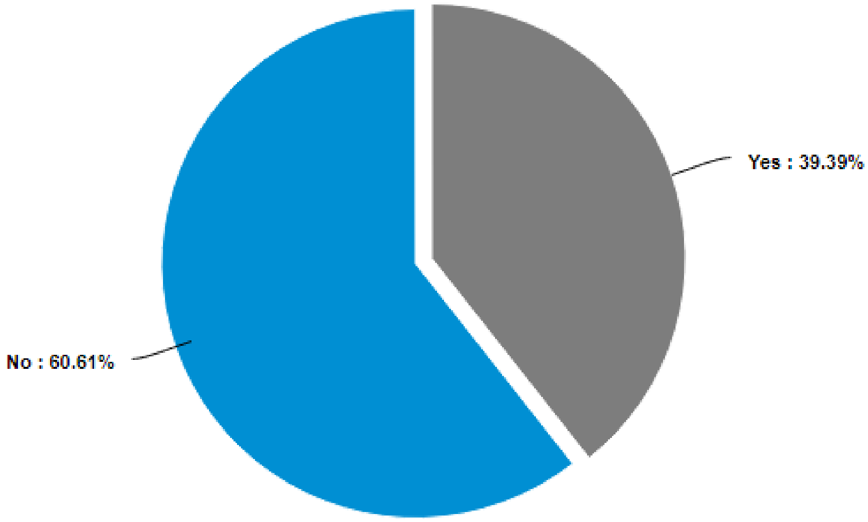
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Yes	17	51.5	50.00	51.5
	No	16	48.5	50.00	100.0
	Total	33	100.0	100.0	



5- Does your ERP have integrated warehouse management? If so, does it give you enough information to measure operators' productivity?

Q5

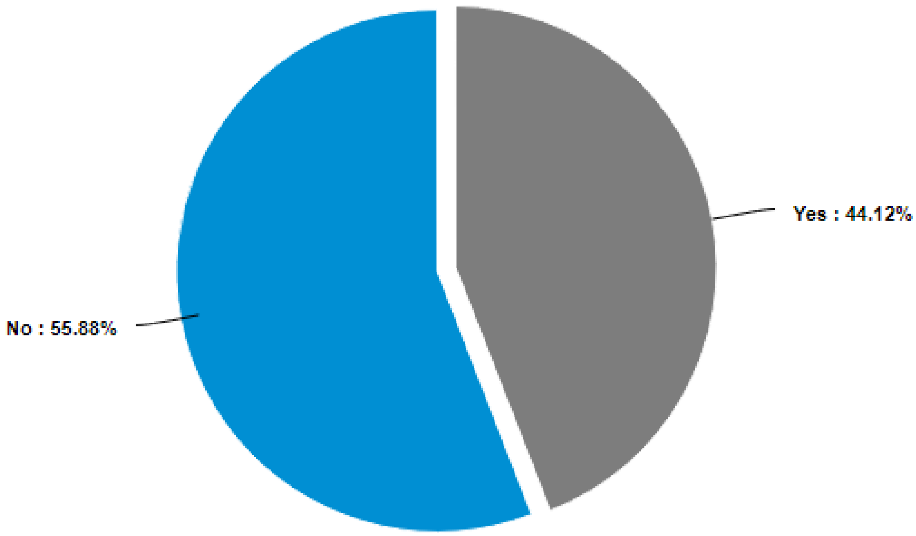
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Yes	13	39.4	39.39	39.4
	No	20	60.6	60.61	100.0
	Total	33	100.0	100.0	



6- Do you use material requirement planning (MRP) or other predictive planning?

Q6

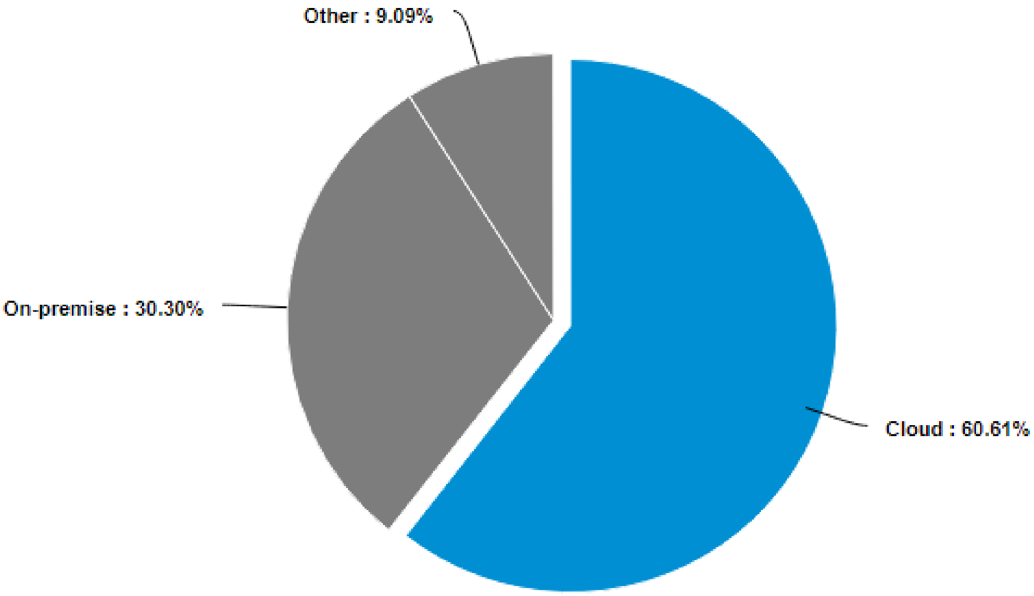
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Yes	15	45.5	44.12	45.5
	No	18	54.5	55.88	100.0
	Total	33	100.0	100.0	



7- Is your database cloud based or on premise solution?

Q7

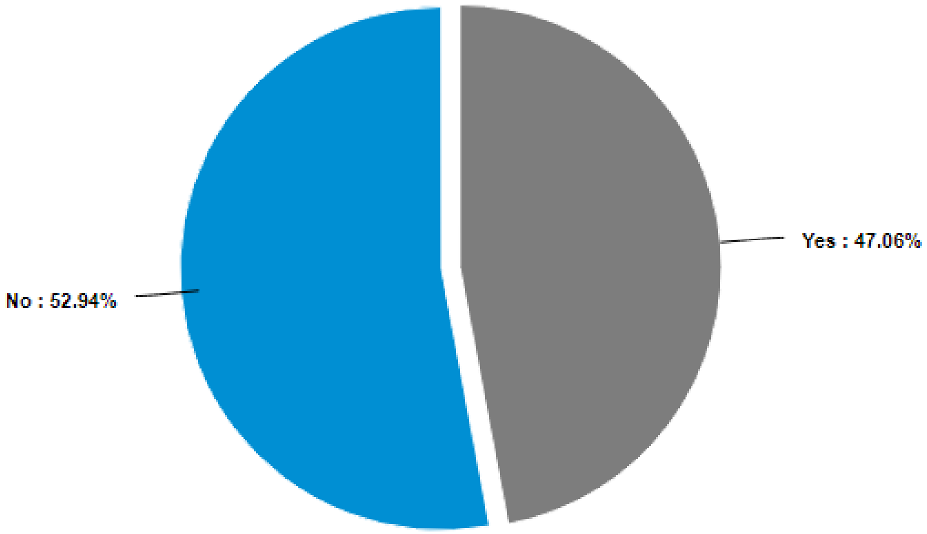
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Cloud	20	60.6	60.6	60.6
	On-premise	10	30.3	30.3	90.9
	Other	3	9.1	9.09	100.0
	Total	33	100.0	100.0	



8- Do you use customer relationship management (CRM)?

Q8

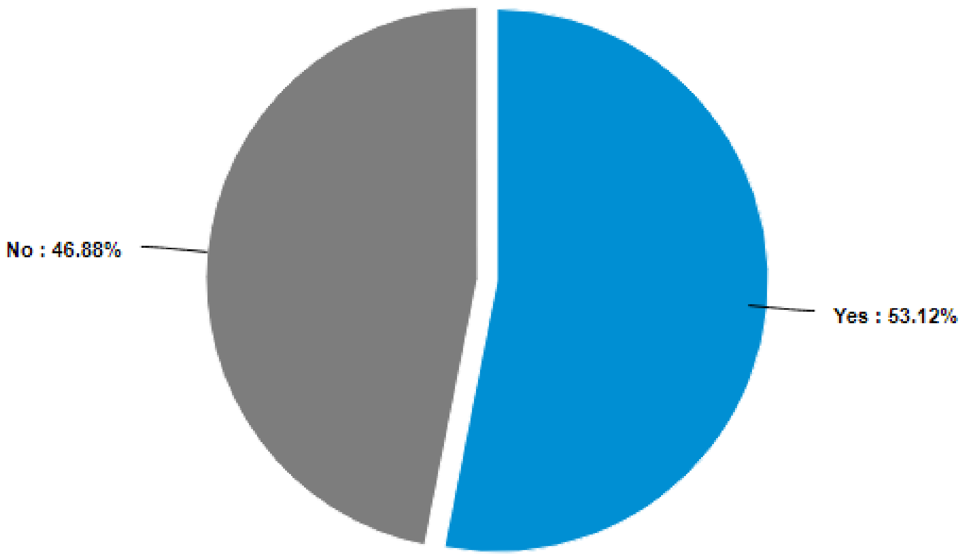
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Yes	16	48.5	47.06	48.5
	No	17	51.5	52.94	100.0
	Total	33	100.0	100.0	



9- Do you use application programming interface (API)?

Q9

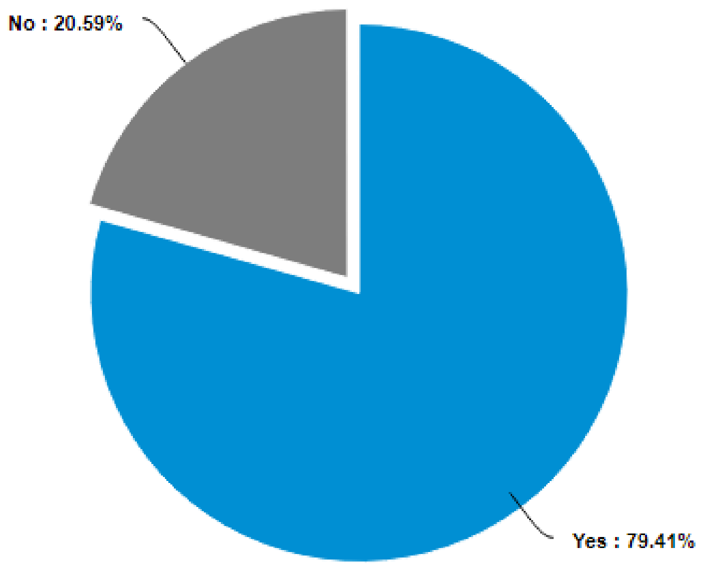
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Yes	17	51.5	53.21	51.5
	No	16	48.5	46.88	100.0
	Total	33	100.0	100.0	



10- Do you or the company you work for have a warehouse?

Q10

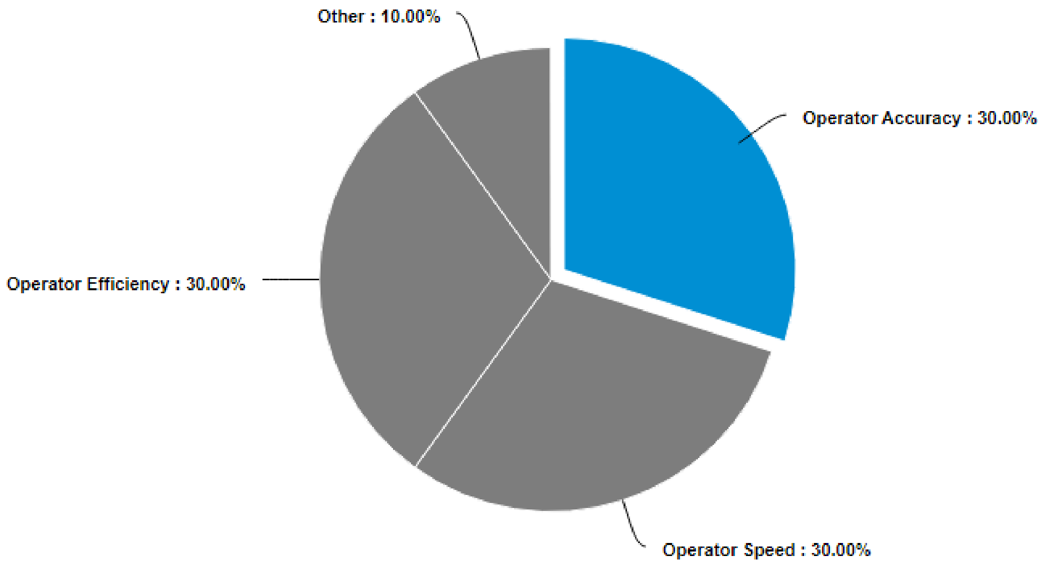
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Yes	27	81.8	81.8	81.8
	No	6	18.2	18.2	100.0
	Total	33	100.0	100.0	



11- What aspect of your operators' performance do you need/want to measure?

Q11

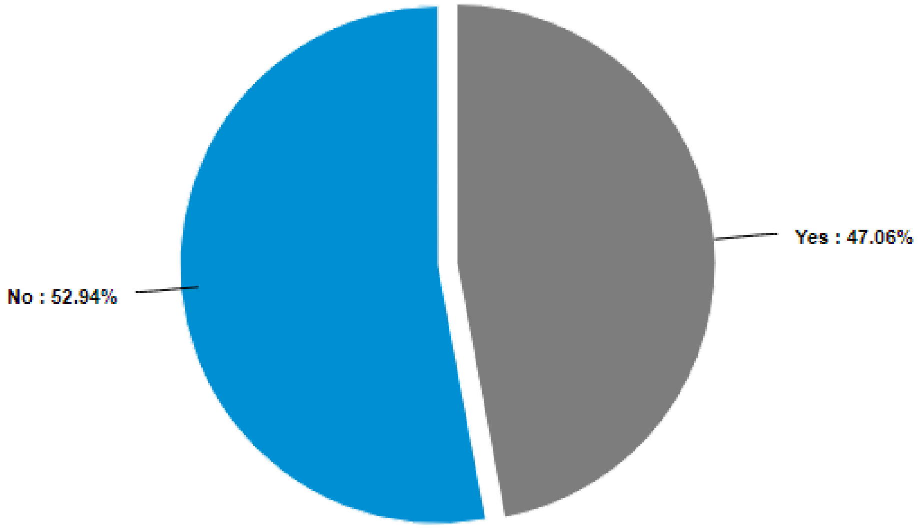
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Operator Accuracy	10	30.3	30.00	30.3
	Operator Speed	10	30.3	30.00	60.6
	Operator Efficiency	10	30.3	30.00	90.9
	Other	3	9.1	10.00	100.0
	Total	33	100.0	100.0	



12- Do you use key performance indicator (KPI) to measure performance within the warehouse?

Q12

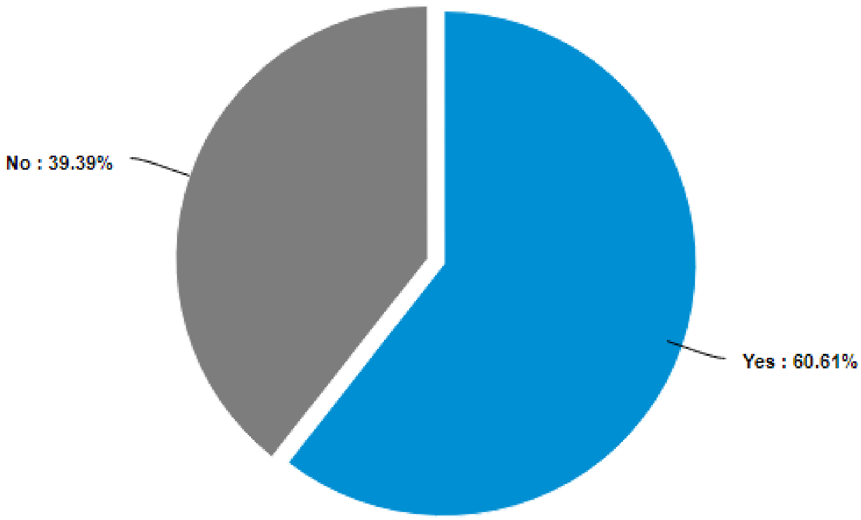
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Yes	16	48.5	47.06	48.5
	No	17	51.5	52.94	100.0
	Total	33	100.0	100.0	



13- Have you heard of or came across an automated warehouse system?

Q13

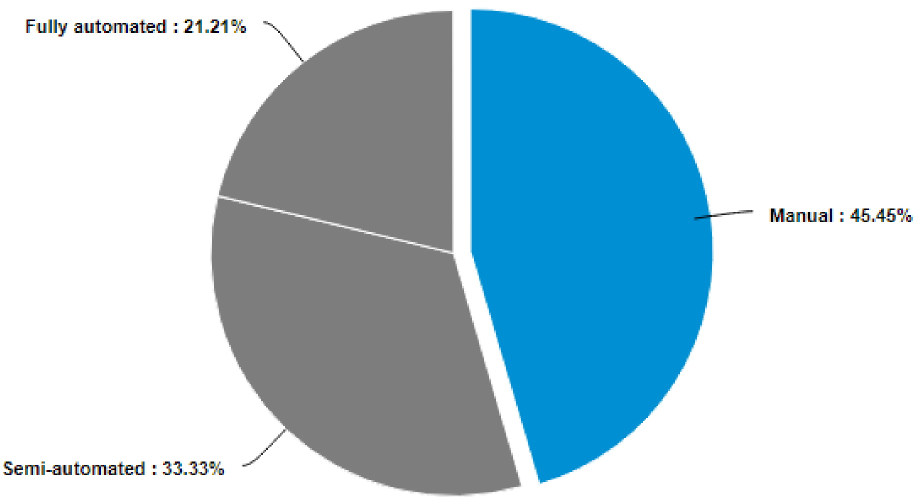
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Yes	20	60.6	60.61	60.6
	No	13	39.4	39.39	100.0
	Total	33	100.0	100.0	



14- Do you consider your warehouse to be: manual, semi-automated or fully automated?

Q14

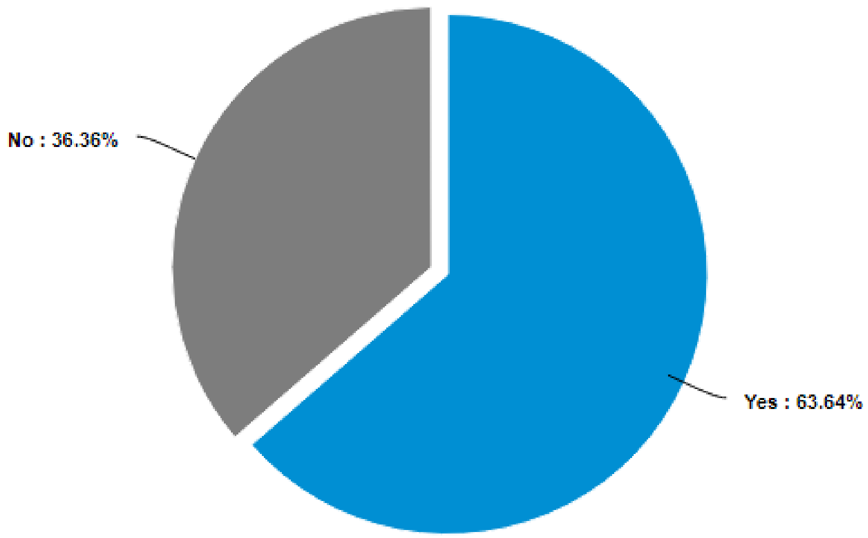
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Manual	15	45.5	45.45	45.5
	Semi-automated	11	33.3	33.33	78.8
	Fully automated	7	21.2	21.21	100.0
	Total	33	100.0	100.0	



15- Does your business require real time inventory?

Q15

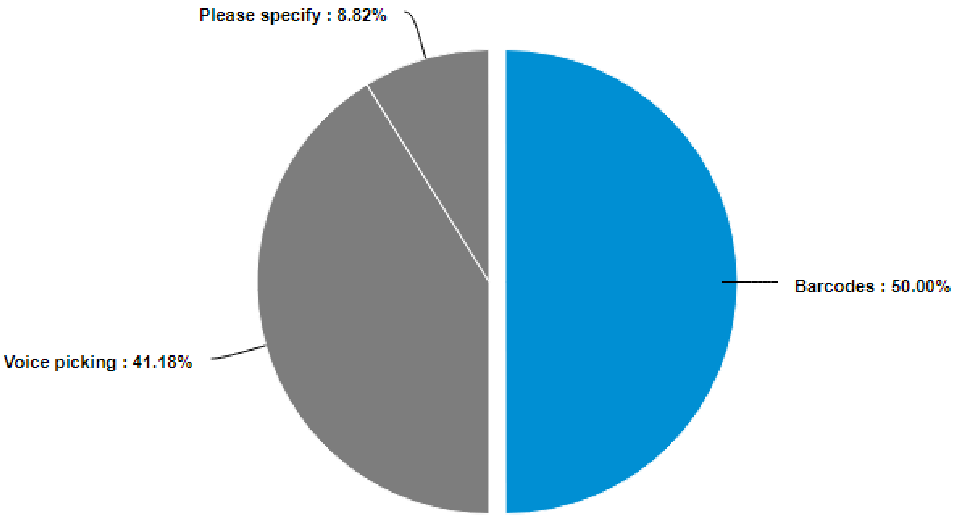
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Yes	21	63.6	63.64	63.6
	No	12	36.4	36.36	100.0
	Total	33	100.0	100.0	



16- Do you use barcode, voice picking or any other technology within your warehouse?

Q16

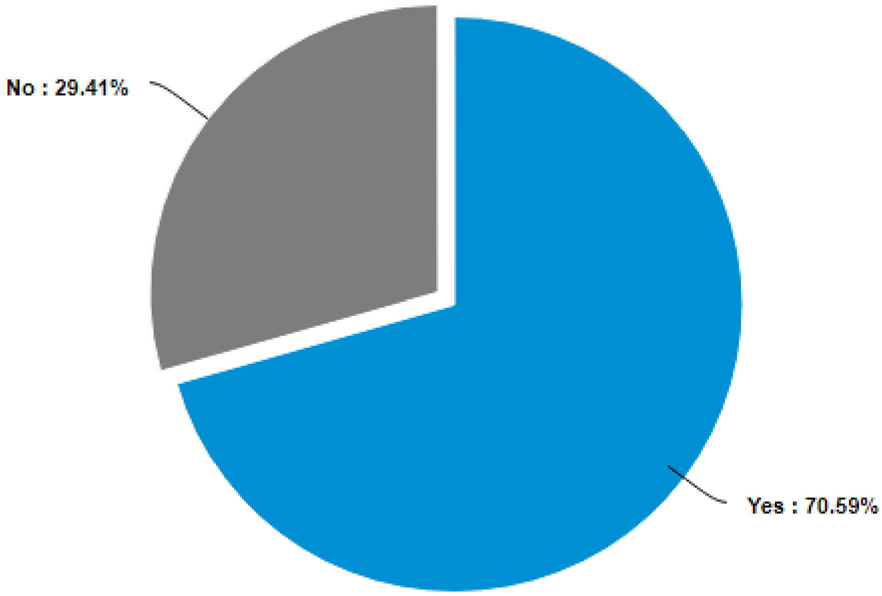
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Barcodes	17	51.5	50.00	51.5
	Voice picking	14	42.4	41.18	93.9
	Please Specify	2	6.1	8.82	100.0
	Total	33	100.0	100.0	



17- Have you heard of radio frequency identification (RFID)?

Q17

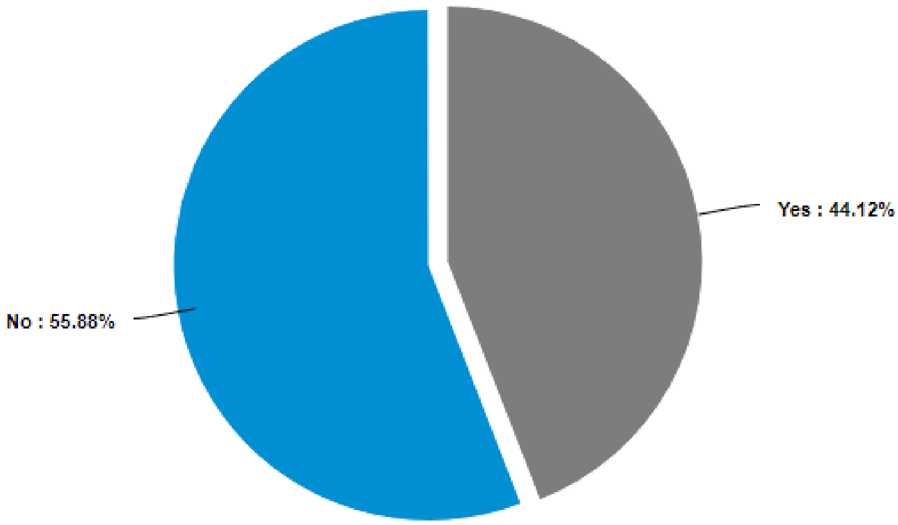
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Yes	23	69.7	70.59	69.7
	No	10	30.3	29.41	100.0
	Total	33	100.0	100.0	



18- Have you heard of RFID based warehouse management system?

Q18

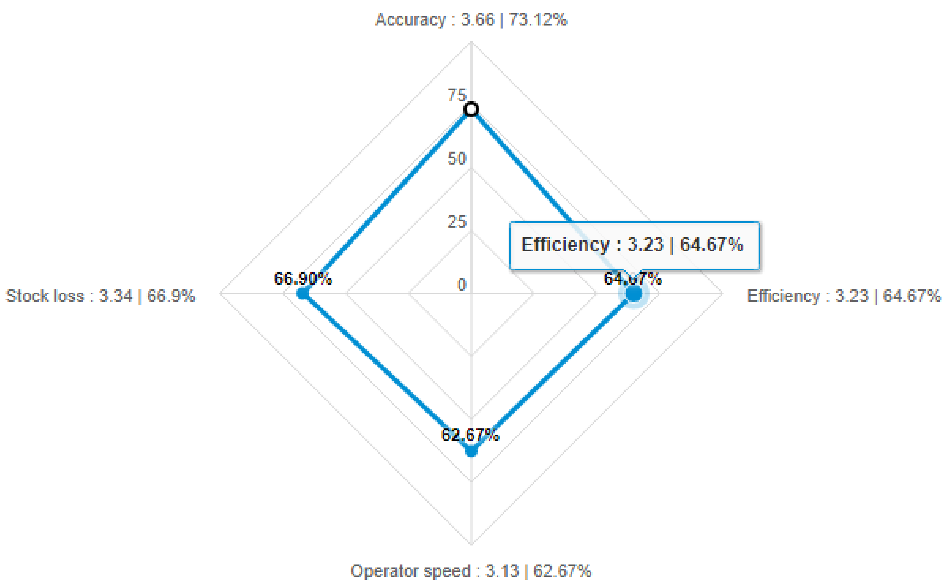
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Yes	15	45.5	44.12	45.5
	No	18	54.5	55.88	100.0
	Total	33	100.0	100.0	



19- How do you rate the following attributes in your warehouse management system?

Q19

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Accuracy	5	15.2	73.12	15.2
	Efficiency	5	15.2	64.67	30.3
	Operator speed	4	12.1	62.67	42.4
	Stock loss	4	12.1	69.9	54.5
	All	15	45.5		100.0
	Total	33	100.0	100.0	



20- What is the estimated percentage in human errors to pick up 100 items in a manual warehouse?

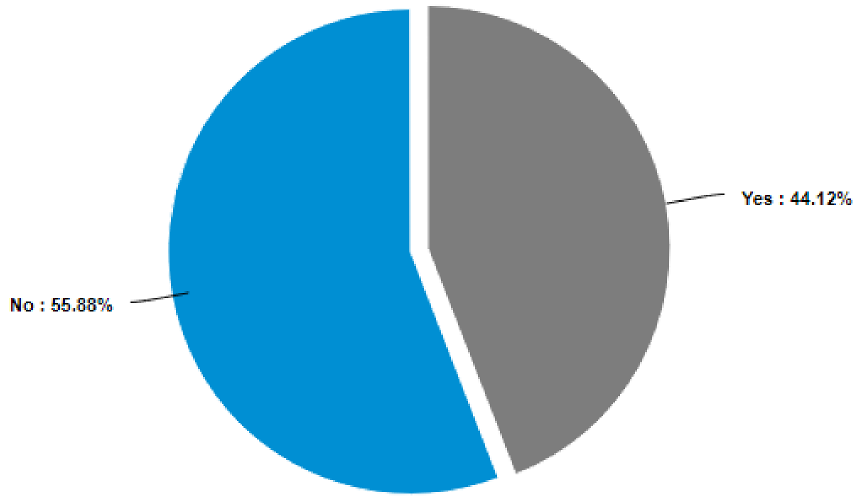
Q20

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1%-25%	17	51.5	51.5	51.5
	26%-50%	5	15.2	15.2	66.7
	51%-75%	4	12.1	12.1	78.8
	76%-100%	7	21.2	21.2	100.0
	Total	33	100.0	100.0	

21- Does your business provide ecommerce service?

Q21

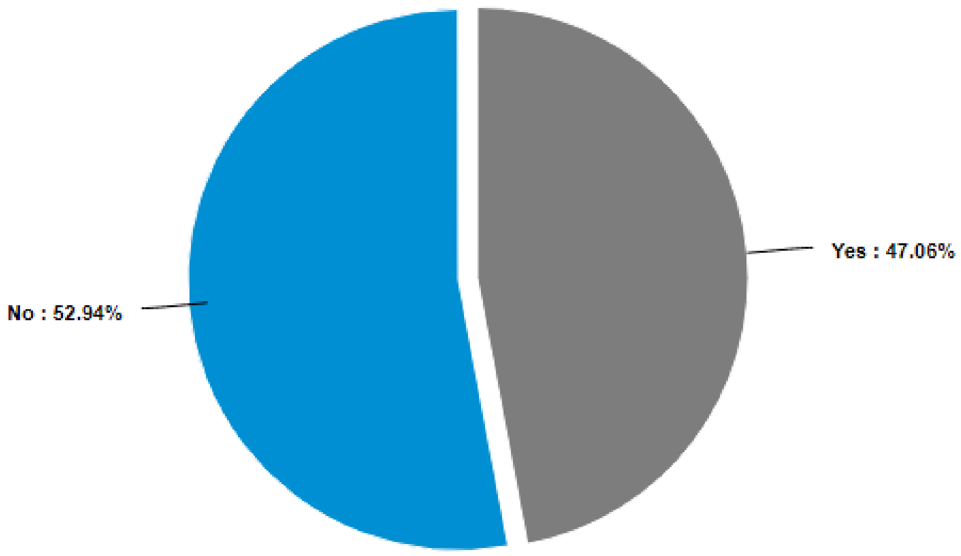
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Yes	15	45.5	44.12	45.5
	No	18	54.5	55.88	100.0
	Total	33	100.0	100.0	



22- Do you incentivise the use of ecommerce by means of cost reduction?

Q22

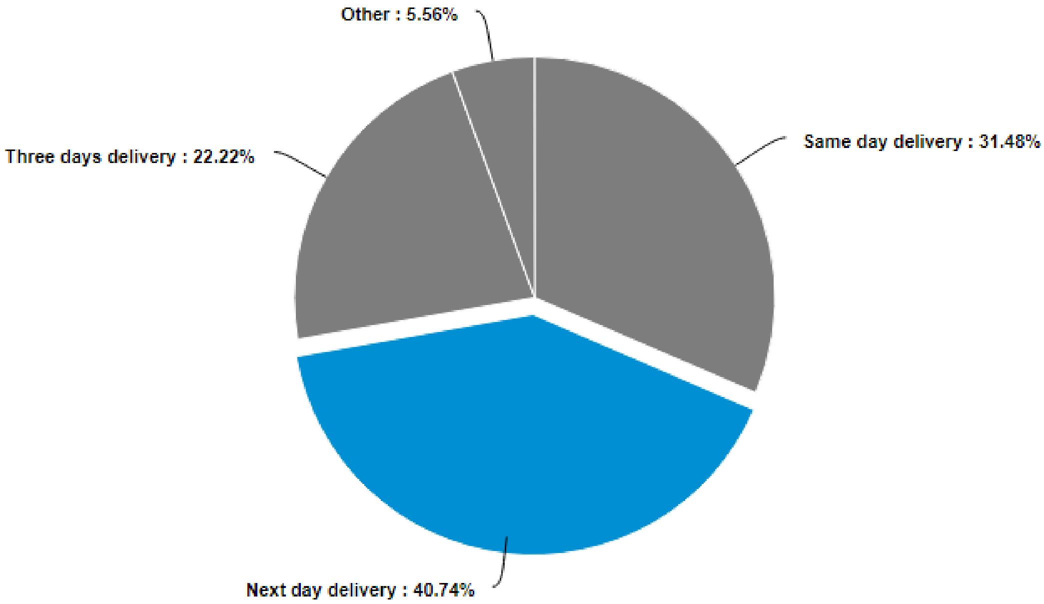
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Yes	16	48.5	47.06	48.5
	No	17	51.5	52.94	100.0
	Total	33	100.0	100.0	



23- What delivery options do you provide? (select all that apply)

Q23

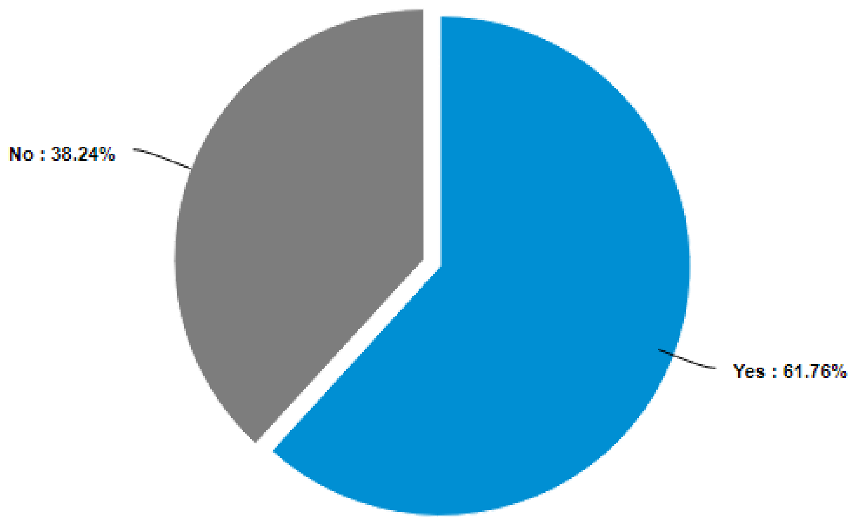
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Same day delivery	9	27.3	31.48	27.3
	Next day delivery	15	45.5	40.74	72.7
	Three days' delivery	8	24.2	22.22	97.0
	Other	1	3.0	5.56	100.0
	Total	33	100.0	100.0	



24- Do your customers require flexibility for delivery window?

Q24

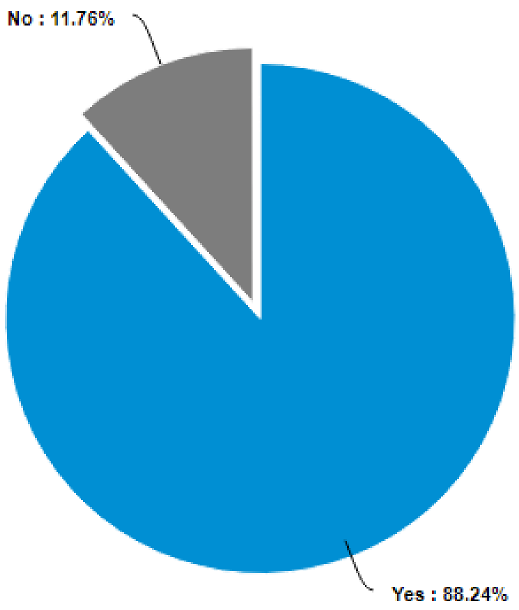
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Yes	21	63.6	61.76	63.6
	No	12	36.4	38.24	100.0
	Total	33	100.0	100.0	



25- Is the speed of delivery an important factor?

Q25

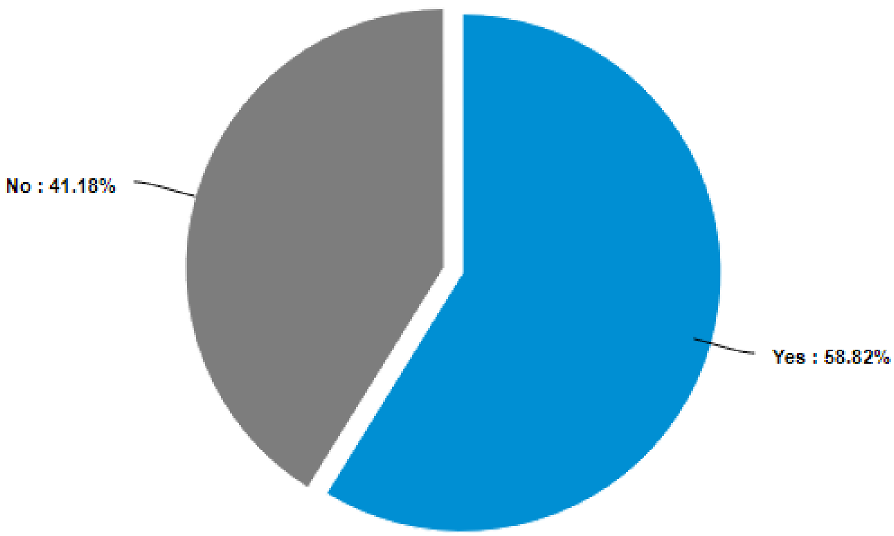
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Yes	30	90.9	88.24	90.9
	No	3	9.1	11.76	100.0
	Total	33	100.0	100.0	



26- Do you provide reserve and collect service?

Q26

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Yes	20	60.6	58.82	60.6
	No	13	39.4	41.18	100.0
	Total	33	100.0	100.0	



27- How do you rate future generation automated warehouse system?

Q27

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	30%	1	3.0	3.0	3.0
	31%-50%	2	6.1	6.1	9.1
	51%-75%	3	9.1	9.1	18.2
	76%-100%	27	81.8	81.8	100.0
	Total	33	100.0	100.0	

Appendix B

Table 20.B: Summary of related studies.

Authors	Year	Model	Findings / Developments
Wang et al	2010	RFID	Defined a set of event-condition-action (ECA) rules to improve the feasibility and flexibility of the digital warehouse management system in a tobacco company
Ming et al	2013	RFID	Examined the previous and current status and a future trend in terms of RFID-related applications, benefits and obstacles providing a generic view in the field for researchers.
Chow et al	2006	RFID	Proposed an RFID-based resource management system (RFID-RMS), used for logistics providers to enhance warehouse operations by means of tracking and optimising resources utilisation
Poon et al	2009	RFID	Simplification of RFID implementation procedure, an improvement in visibility of warehouse operations and an enhancement of productivity of the warehouse
Ting et al	2012	RFID	Proposed an RFID-based inventory control and management system for manufacturing enterprises. It aimed to collect accurate real-time data relating to transactions of physical stock items for enhancing product life cycle management
Uckun et al	2008	RFID	Proposed a model to maximise the expected profit by seeking an optimum number of warehouses using the RFID techniques to minimise the total costs
Anssens et al	2010	RFID	Proposed a solution to improve the reliability of RFID reader in warehouse, to synchronize reader’s beams.
Sahin et al	2007	RFID	Examined a solution for the issue of data inaccuracy of warehouse inventories

Cakici et al	2011	RFID	Analysed the incremental benefits of using RFID tags over barcodes for pharmaceutical inventory management
Xu et al	2013	RFID	Introduced a useful and comprehensive warehouse management optimization method based on dynamic storage keeping unit (SKU) management
Liu et al	2009	RFID	Implemented an electronic control system to improve the production efficiency in a local integrated-circuit (IC) packaging house.
Turcu et al	2007	RFID	Examined the potential benefits generated by integration of an RFID system with business-to-business (B2B) applications and subsequently proposed an integrated RFID-B2B system.
Jehng et al	2008	RFID	Investigated an automatic conveyor system on which the material flow can be monitored and traced in a real time manner using RFID tags
Yoo et al	2008	RFID	The work proposed a network infrastructure that supports logistic activities for the entire process from a recycling of product materials to a disposal by adding reverse logistics to the existing forward logistics.
Rouwenhorst et al.	2000		Stated that efficiency and effectiveness in any distribution network is largely determined by the operation of the nodes in the network, i.e., the warehouses
Xue et al	2011	RFID	Introduced the robot technology into the automated warehouse, which aims to improve S/R efficiency
Rashad et al	2011	Wireless communication	Improved existing warehouse management system by implementing wireless technology for controlling ASAR system during the operation.
Brusey et al	2009	RFID	The research presented an approach for making best use of RFID data evaluated in the perspective of a laboratory

			manufacturing system that produces customized gift boxes.
Xiaoguang et al	2008	RFID&WSN	Implemented an adaptive communication framework of the warehouse management based on RFID and Wireless Sensor Network (WSN)
Li et al	2011		Introduced a robot automatic system intelligent warehouse based on RFID technology
Chen et al	2010	RFID	Proposed an RFID-based enterprise application integration (EAI) approach for the real-time management of dynamic manufacturing processes. A prototype system was developed to demonstrate the applicability of the proposed method in a shop floor environment
Irani et al	2010	RFID	Provided a comprehensive and systematic survey of the literature pertaining to RFID related research issues in order to ascertain the current 'state of play' of the field along a number of dimensions. The objectives are:1) to analyse the distribution/trend of RFID research across subject category, source titles (journals), geographical locations, document types and year of publications; 2) to determine the frequently published authors and productive institutions for conducting RFID related research; 3) to explore the trend of topics/research issues and utilised methods; and finally (4) to synthesis the existing research to develop a research and may guide the practitioner for implementing and managing RFID applications in both public and private sectors
Srujana et al	2013	RFID	Developed an RFID-based library management system using MATLAB
Ahsan et al	2010	RFID	Aimed at developing a model for mobile application in order to track patients' movements in a hospital. Also the main

			components of an RFID system are identified
Brezovnik et al	2015	AS/RS	Conducted a study to provide a solution for AS/RS planning and operation. It simultaneously address structural, operational and control features of the AS/RS
Ye Lu	2008	RFID	Proposed a new RFID general framework based on middle ware data cleaning in bus park information integration system.
Chen et al	2010	RFID	Proposed an RFID-based enterprise application integration (EAI) approach for the real-time management of dynamic manufacturing processes. A prototype system was developed to demonstrate the applicability of the proposed method in a shop floor environment
Herageu et al	2005	Warehouse design	Proposed a mathematical model and a heuristic algorithm that jointly determine product allocation to the functional areas in the warehouse as well as the size of each area using data readily available to a warehouse manager
Kabadurmus et al	2007	RFID	Addressed an effective methodology to reveal appropriate operational settings for any RFID system. The purpose of this study is (1) to present an organized, concise methodology for identification of influential factors of any RFID system (2) to evaluate operational parameters on RFID controlled conveyor system.
Hu et al	2005	Travel time	Presented a new kind of S/R mechanism that enables AS/RS to efficiently handle very heavy loads. Also developed a continuous travel-time model for the new AS/RS under the *stay* dwell point policy.
Liu et al	2014	UHF RFID tags	Demonstrated a combined way to perform both RFID real-time remote monitoring of body temperature and location of the respective body.

Al-Naima et al	2012	RFID	Proposed a simulation system for the vehicle traffic congestion estimation (VTCE) based on RFID. The RFID reader will read the vehicle tags and transfer the necessary information to a database in a central computer system (CCS).
De Koster et al	2008	AS/RS	Considered a newly designed compact three-dimensional automated storage and retrieval system (AS/RS). The system consists of an automated crane taking care of the pallets movements in the horizontal and vertical direction
Lerher et al	2010	Travel time	Presented analytical travel time model for the computation of travel time for automated warehouses with the aisle transferring S/R machine (in continuation multi-aisle AS/RS). These models consider the operating characteristics of the storage and retrieval machine such as acceleration and deceleration and the maximum velocity
Lerher et al	2015	Travel time	Presented analytical travel time model for the computation of travel (cycle) time for shuttle-based storage and retrieval systems (in continuation SBS/RS). The proposed model considers the operating characteristics of the elevators lifting table and the shuttle carrier, such as acceleration and deceleration and the maximum velocity
Yang et al	2015	AS/RS	Examined the joint optimization of storage location assignment and storage/retrieval scheduling in multi-shuttle automated storage/retrieval systems (AS/RSs) under shared storage, in which the reuse of empty location yielded by retrieval operation is allowed.
Kuan et al	2005	RFID	Describes the experience of developing a RFID system coupling with an inventory management system, with currently is installed on the RAPIDTECH company in Taiwan.

Ballestín et al	2013	RFID	The objective of this reserch is threefold, to propose and compare different offline and online policies for the scheduling of warehouse operations, to design a tool that allows the decision maker to compare policies and environments without putting them into practice, and to study the benefits that can be obtained if RFID is used in a particular type of warehouse. Authors developed a stylised model that captures and generalises the main characteristics of the structure, routing and sequencing operations of a given real warehouse.
Badole et al	2013	RFID	Presented the impact of RFID in warehouse management of perishable products. It provides mathematical framework to assess the benefits of RFID in warehouse management. It helps management in the variety of ways including improvement in receiving and shipping processes, reduction in cycle counting efforts, reduction in stock outs/excess inventory, decreased counterfeiting, decreased returns, and reduction in inventory loss due to shrinkage and obsolescence.

Appendix C

C.1 MATLAB

MATLAB is a language in an interactive environment for developing algorithms, analysing and visualizing data and performing numeric computation. Users can import data into MATLAB from files, other applications or external devices. Once the data is in MATLAB, it can be 'explore' and 'analyse' it through built in engineering and mathematical functions and plots and visualisations. The MATLAB language support the vector and matrix operations that a fundamental to scientific and engineering problems. Command can be executed one at the time providing immediate results; this lets a user to explore multiple approaches in obdurate to an optimal solution. A user can create scripts and functions to re-use and automate such work. Developments tools allow users to implement algorithms efficiently and optimise their performance. MATLAB provides the features of a traditional programming language as well as layout tools for designing costume, graphical user interfaces. Add-on tool boxes extend the MATLAB environment to solve problems in a range of applications including signal processing in communications, video and image processing, control design and computational biology. The use of MATLAB can significantly increase efficiency in development, by keeping the code simple, readable and short. MATLAB facilitates data analysis and display of information (Daniel et al., 2007). Additional features include useful toolboxes, including database and instrument control settings. The MATLAB layout is illustrated in the following Figure 1.C.1.1

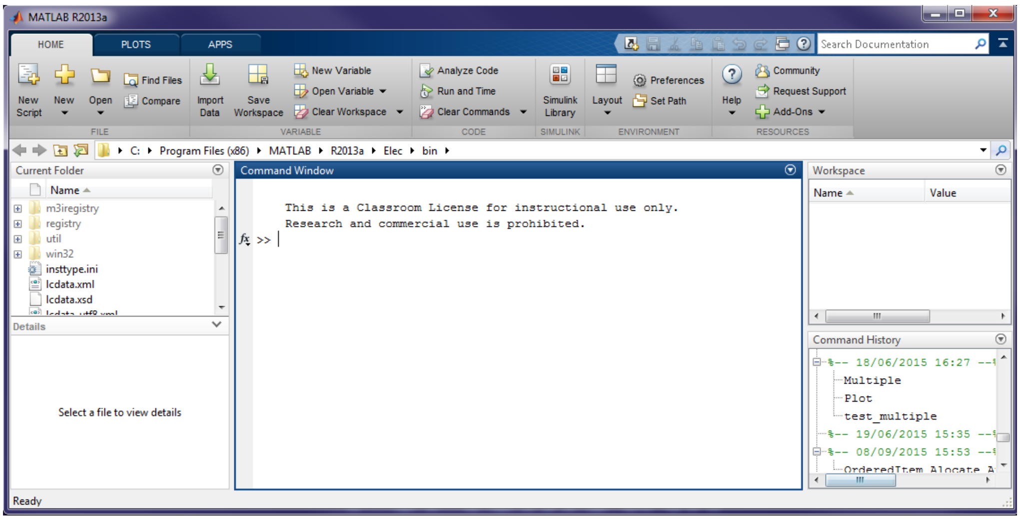


Figure 48.C.1.1 Screen shot of the MATLAB layout.

The desktop includes these panels:

1. **Current Folder:** Access your files.

2. **Command Window:** Enter commands at the command line, indicated by the prompt (>>).

3. **Workspace:** Explore data that you create or import from files.

4. **Command History:** View or rerun commands that you entered at the command line.

Table 21.C.1.1: MATLAB programming codes.

```
% Part 1: Database
% The database contains two sections, for which section 1 is starts with
"Tag"
% stands for the barcode of the items and section 2 is starts with "Name"
that
% indentify the what exactly the items are

% Section 1: Barcode
Tag_1_1=char('ABCDMMMM20140101', 'DEFGSTUR00000000', 'GHIYMMMM20140201',
'RTTUCCCC20140302', 'HELLYYYY20140304', 'HEWWCHCH20140404',
'HSALMMMM20140510', 'HALYGGGG20140709', 'SUNSHINE20140606');
Tag_1_2=char('ABCDWXYZ20140909', 'DEFGSSSS20140505', 'GHSTKLMN00000000',
'RTHANAYZ20140507', 'HILAHOLD20140919', 'HAKIMMMM20140616',
'MAMAJJJJ20141011', 'ALYAHYAS00000000', 'SUNRISEE20141214');
Tag_1_3=char('ABGFCCCC20141111', 'DSTGYYYY20141212', 'GHSTCHCH20140620',
'ABCDSTUR00000000', 'HILABBBB20141215','BANDFFFF20140617',
'BABAMAMA20141012','ALYAWWWW20140123', 'WXYZMMMM20140101');
Tag_1_4=char('BCDCSSSS20150101', 'DRMRJJJJ20141230', 'GHYGZZZZ20140808',
'RTTIGGGG20140709', 'WORLDWIL00000000','BADEOOOO20140620',
'TELLMEYA20141015', 'MALYAHYA20140131', 'RSTUFZXY20140111');
Tag_1_5=char('ABDUZZZZ20140506', 'DDEFRRTT20141225', 'GHIYAHYA00000000',
'RAMIRAMI20140208', 'HANWCHCH20140219', 'DREAMMMM20141221',
'DINNGGGG20140810', 'RAAFHAHA20140710','MAJETTTT20130909');
Tag_1_6=char('ABGFSSSS20141113', 'DSTGJJJJ20131213', 'KLHYZZZZ20140622',
'ABCAGGGG20140525', 'WARABBBB20141216','BANDIIII20140619',
'RGBAYYYY20141031','ALBAIIII20140405', 'HANIGMMA20140415');
Tag_1_7=char('ABGGFFFF20140617', 'SALEYYYY20141202', 'SAMICCCC20131010',
'ERUPECAR20131012', 'HIBYTTTT20141204','BANDYLTD20140719',
'DADYWWWW20131011','ABRAHIMS00000000', 'HABICHCH20140520');
Tag_1_8=char('ABGGSSSS20140617', 'ALBAJJJJ20141213', 'MADIZZZZ20131016',
'MACCAMAD20131028', 'RIYADHGF20141218','BURICHCH20140722',
'DAMAOOOO20131014','AHMEIIII20131101', 'WASEBBBB20141215');
Tag_1_9=char('OSAMABIN20140911', 'TAIFYYYY20131214', 'ALYAHYAS00000000',
'TBOOCCCC20140526', 'HEATYYYY20141116','PORTCHCH20140621',
'SOUATTTT20141013','BRIGHTON20130405', 'BATHBRIS20130417');

% Section 2: Name
% Bearing in mind the length of each char has been modified by manually
% adding some space at the end. This is to make sure each variable has
% exactly same length and it is important and necessary for the data
% processing. The reason is that different items have different names and
```

```
% for what the chars amount of each item is different. Mismatch length will
% result in programme crashing down.
% Further improvement will be considered in the future
Name_1_1=char('Milk     ', 'pen      ', 'Milk     ', 'Coke     ','Yogurt
','Cheese   ','Milk     ','Eggs     ','Ice-cream');
Name_1_2=char('Sugar    ','Salt     ','CD       ','Juice    ','Honey
','Milk     ','Jam      ','Cable    ','Fanta    ');
Name_1_3=char('Cock     ','Yogurt   ','Cheese   ', 'DVD      ','Bread
','Beans    ','Orange   ','Water    ','Milk     ');
Name_1_4=char('Salt     ', 'Jam      ', 'Butter   ', 'Eggs
','Headphone','Olives   ','Chicken  ','Tomato   ','Biscuits ');
Name_1_5=char('Butter   ','Pasta    ','Speaker  ','Coffee   ','Cheese
','Milk     ','Eggs     ','Banana   ','Tea      ');
Name_1_6=char('Salt     ', 'Jam      ', 'Butter   ', 'Eggs     ','Bread
','Oil      ','Yogurt   ','Oil      ','Yogurt   ');
Name_1_7=char('Beans    ', 'Yogurt   ', 'Cock     ','Bread    ','TEA
','Orange   ','Water    ','Charger  ','Cheese   ');
Name_1_8=char('Salt     ', 'Jam      ', 'Butter   ', 'Eggs     ','COFFEE
','Cheese   ','Olives   ','Oil      ','Bread    ');
Name_1_9=char('Milk     ', 'Yogurt   ', 'Game     ', 'Coke     ','Yogurt
','Cheese   ','TEA      ','Lamb     ','Onion    ');
PP=[9;1]; % pusher position

%
% Section3: Define the value of the corresponding characteristics
Hf=0.4; % height of shelf unit
rack=9; % rack number of a shelf
L=0.5; % length of shelf unit
Lsc=0.25; % length between the edge of the spiral and the conveyor system
Lss=0.5; % length of each single spiral
Lsp=1.5; % length between end of spiral and collection point
D=0.5; % depth of shelf unit
Vc=0.2; % speed of conveyor
Vp=0.3; % speed of pusher movement
Vpp=0.1; % speed of a pusher to push the item out
Vs=0.2; % speed of spiral movement

%--------------------------------------------------------------------------
% The time characteristics need to be calculated are as follows:
% Tm: the time for the pusher to move to the ordered item.
% Tp: time for the pusher to push out the ordered item.
% Ts: time for the item to move on the conveyor to the spiral.
% Ti: time of the movement of the item on the spiral.
% Te: time between the edge (end) of the spiral and the collection point.
% Tt: total time to get the ordered item.
%==========================================================================
% Part 2: Data Processing
disp('Please Input The Name of Ordered Item!')
OrderedItem='Milk     '; % Change the name of ordered item, this syntax
will be improved later

%--------------------------------------------------------------------------
% Find and save the location information which contains the ordered item
No=0; % Starting number of ordered item
Location=[]; % For storing the location information of ordered item
 for i=1:9
     for j=1:9
         eval(['Name=Name_1_' num2str(i) '(j,:);'])
         if isequal (Name , OrderedItem)==1
             No=No+1; % the location number increase, final value of No
give
```

```
                    % the information of how may locations contains the
                    % ordered item
               Lo=[i;j]; % the location which contains the ordered item
               Location=[Location Lo]; % save the location information
           else
               No=No+0;
           end
       end
   end
%--------------------------------------------------------------------------
% Find and save the information of expiry date for all location which
% contains the ordered item
Barcode=[]; % To save the barcode of ordered item at different locations
ExpiryDate=[]; % To save the expiry date of ordered item at different
               % locations in string format
 for k=1:No
     eval(['Tag=Tag_1_' num2str(Location(1,k)) '(' num2str(Location(2,k))
',:);' ])
     Barcode=[Barcode;Tag];
     Date=Tag(1,end-7:end); % extract the information of expiry date
     ExpiryDate=[ExpiryDate;Date];
 end
%--------------------------------------------------------------------------
% Check if the ordered item has expiry date?
if isequal(ExpiryDate(1,:)>0, [1 1 1 1 1 1 1 1])==1
   % If the ordered item has expiry date,
   disp('The ordered item has expiry date!')
   disp('Milk!')
   Expiry=[]; % To save the expiry date of ordered item at different
locations
              % in number format
   if No==1
      % if No=1, it means only one location contains the ordered item
      Location1=Location;
      %-------------------------------------------------------------------
      % Calculate the computation time
      Tm=sqrt((PP(1)*Hf-Location1(1)*Hf)^2+(PP(2)*L-Location1(2)*L)^2)/Vp;
      Tp=D/Vpp;
      Ts=((Location1(2)-0.5)*L+Lsc)/Vc;
      Ti=(rack-Location1(1))*Lss/Vs;
      Te=Lsp/Vc;
      Tt=Tm+Tp+Ts+Ti+Te;
      %-------------------------------------------------------------------
      disp('The time to get the ordered item is:')
      disp(Tt)
      PP=Location1;
   else
       for m=1:No
           A=str2num(ExpiryDate(m,:)); % transfer the string to number for
facilitaing
                                       % the expiry date study
           Expiry=[Expiry A];
       end
       NewData=sort(Expiry); % sort the array in ascending order
       if NewData(1)==NewData(end)
          disp('The ordered item at different locations have same expiry
date!')
          Loca=[];
              TT=[]; % empty array for saving the computation time at
multiple locations
              for m=1:No
```

```
                if Expiry(m)==NewData(1)
                   Loc=Location(:,m);
                   Loca=[Loca Loc];
                end
            end
            for n=1:length(Loca)
                Location1=Loca(n);
                %----------------------------------------------------------
                % Calculate the computation time
                Tm=sqrt((PP(1)*Hf-Location1(1)*Hf)^2+(PP(2)*L-
Location1(2)*L)^2)/Vp;
                Tp=D/Vpp;
                Ts=((Location1(2)-0.5)*L+Lsc)/Vc;
                Ti=(rack-Location1(1))*Lss/Vs;
                Te=Lsp/Vc;
                Tt=Tm+Tp+Ts+Ti+Te;
                %----------------------------------------------------------
                TT=[TT Tt];
            end
            T_min=min(TT);
            disp('The time to get the ordered item is:')
            disp(T_min)
            for n=1:length(Loca)
                if TT(n)==T_min
                   Location2=Loca(:,n); % Samllest computation time
location
                end
            end
            PP=Location2;
       else
          disp('The ordered item at different locations have different
expiry dates!')
          if sum(Expiry==NewData(1))==1
             % the NewData(1) is the minimun date so it is also the one
             % which is more close to expire date. If the value of
             % sum(ExpiryDate==NewData(1)) is 1, it means only one location
             % contains the ordered item with cloest expire date. If not,
             % there will be multiple locations.
            for m=1:No
                if Expiry(m)==NewData(1)
                   Location1=Location(:,m);
                end
            end
            %-------------------------------------------------------------
            % Calculate the computation time
            Tm=sqrt((PP(1)*Hf-Location1(1)*Hf)^2+(PP(2)*L-
Location1(2)*L)^2)/Vp;
            Tp=D/Vpp;
            Ts=((Location1(2)-0.5)*L+Lsc)/Vc;
            Ti=(rack-Location1(1))*Lss/Vs;
            Te=Lsp/Vc;
            Tt=Tm+Tp+Ts+Ti+Te;
            %-------------------------------------------------------------
            disp('The time to get the ordered item is:')
            disp(Tt)
            PP=Location1;
          else
            Loca=[];
            TT=[]; % empty array for saving the computation time at
multiple locations
            for m=1:No
```

```
                    if Expiry(m)==NewData(1)
                       Loc=Location(:,m);
                       Loca=[Loca Loc];
                    end
                end
                for n=1:length(Loca)
                    Location1=Loca(:,n);
                    %--------------------------------------------------------
                    % Calculate the computation time
                    Tm=sqrt((PP(1)*Hf-Location1(1)*Hf)^2+(PP(2)*L-
Location1(2)*L)^2)/Vp;
                    Tp=D/Vpp;
                    Ts=((Location1(2)-0.5)*L+Lsc)/Vc;
                    Ti=(rack-Location1(1))*Lss/Vs;
                    Te=Lsp/Vc;
                    Tt=Tm+Tp+Ts+Ti+Te;
                    %--------------------------------------------------------
                    TT=[TT Tt];
                end
                T_min=min(TT);
                disp('The time to get the ordered item is:')
                disp(T_min)
                for n=1:length(Loca)
                    if TT(n)==T_min
                       Location2=Loca(:,n); % Samllest computation time
location
                    end
                end
                PP=Location2;
            end
        end
    end
else
    % If the ordered item have no expiry date,
    disp('The ordered item have no expiry date!')
    if No==1
       % if No=1, it means only one location contains the ordered item
       Location1=Location;
       %------------------------------------------------------------------
       % Calculate the computation time
       Tm=sqrt((PP(1)*Hf-Location1(1)*Hf)^2+(PP(2)*L-Location1(2)*L)^2)/Vp;
       Tp=D/Vpp;
       Ts=((Location1(2)-0.5)*L+Lsc)/Vc;
       Ti=(rack-Location1(1))*Lss/Vs;
       Te=Lsp/Vc;
       Tt=Tm+Tp+Ts+Ti+Te;
       %------------------------------------------------------------------
       disp('The time to get the ordered item is:')
       disp(Tt)
       PP=Location1;
    else
        Loca=[];
        TT=[]; % empty array for saving the computation time at multiple
locations
        for m=1:No
            if Expiry(m)==NewData(1)
               Loc=Location(:,m);
               Loca=[Loca Loc];
            end
        end
        for n=1:length(Loca)
```

```
            Location1=Loca(:,n);
            %---------------------------------------------------------------
-
            % Calculate the computation time
            Tm=sqrt((PP(1)*Hf-Location1(1)*Hf)^2+(PP(2)*L-
Location1(2)*L)^2)/Vp;
            Tp=D/Vpp;
            Ts=((Location1(2)-0.5)*L+Lsc)/Vc;
            Ti=(rack-Location1(1))*Lss/Vs;
            Te=Lsp/Vc;
            Tt=Tm+Tp+Ts+Ti+Te;
            %---------------------------------------------------------------
-
            TT=[TT Tt];
        end
        T_min=min(TT);
        disp('The time to get the ordered item is:')
        disp(T_min)
        for n=1:length(Loca)
            if TT(n)==T_min
               Location2=Loca(:,n); % Samllest computation time location
            end
        end
        PP=Location2;
    end
end
```

MATLAB toolbox supports communications using open database connectivity (ODBC) with a compatible database such as Microsoft SQL. An ODBC is a middleware application programming interface (API) that can be used for accessing the database management system as shown in Figure 2.C.1.2

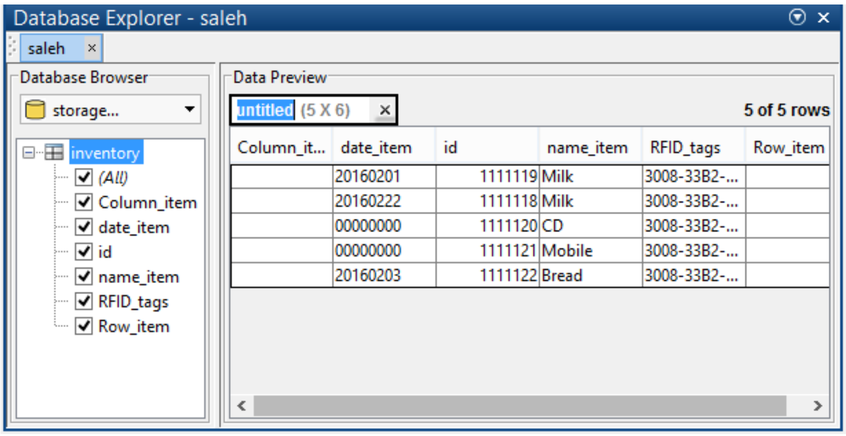


Figure 49.B.1.2 Screen shot of manipulating the RFID data using MATLAB functions.

Appendix D

D.1 GUI using MATLAB

MATLAB functions via the use of a graphical user interface development environment (GUIDE) which offers a range of tools to make GUIs, including a figure window that contains text graphics, panels, buttons, and menus, which enables a more simplified process of development for UIs. The GUIDE Layout Editor can be used to populate a UI simply through clicking and dragging the UI components, e.g. panels, buttons, text fields, sliders, and other features within the layout area as required. Also menus or context menus for the UI can be adjusted in this way, changing the components look and feel, whether aligned parallel to other objects or listing them hierarchically. A program file is automatically generated by GUIDE. In this research, there are two methods of displaying processed data using the MATLAB environment; one way it can be displayed is in a command window, and another way is using a GUI. The benefit of displaying this information in the command window is for presenting the data for correlating its accuracy, whereas the GUI has the advantage of highly effective visuals. In this project, the first way was used for near field as according to the timeframe of implementing this system and the GUI is used to display both near field and far field, generically.

Table 22.D.1.1: Graphical user interface (GUI) programming code.

```
function varargout = GUI_Office(varargin)
% GUI_OFFICE M-file for GUI_Office.fig
%      GUI_OFFICE, by itself, creates a new GUI_OFFICE or raises the
existing
%      singleton*.
%
%      H = GUI_OFFICE returns the handle to a new GUI_OFFICE or the handle
to
%      the existing singleton*.
%
%      GUI_OFFICE('CALLBACK',hObject,eventData,handles,...) calls the local
%      function named CALLBACK in GUI_OFFICE.M with the given input
arguments.
%
%      GUI_OFFICE('Property','Value',...) creates a new GUI_OFFICE or
raises the
%      existing singleton*.  Starting from the left, property value pairs
are
%      applied to the GUI before GUI_Office_OpeningFcn gets called.  An
%      unrecognized property name or invalid value makes property
application
%      stop.  All inputs are passed to GUI_Office_OpeningFcn via varargin.
```

```
%
%      *See GUI Options on GUIDE's Tools menu.  Choose "GUI allows only one
%      instance to run (singleton)".
%
% See also: GUIDE, GUIDATA, GUIHANDLES

% Edit the above text to modify the response to help GUI_Office

% Last Modified by GUIDE v2.5 10-Mar-2015 19:23:04

% Begin initialization code - DO NOT EDIT
gui_Singleton = 1;
gui_State = struct('gui_Name',       mfilename, ...
                   'gui_Singleton',  gui_Singleton, ...
                   'gui_OpeningFcn', @GUI_Office_OpeningFcn, ...
                   'gui_OutputFcn',  @GUI_Office_OutputFcn, ...
                   'gui_LayoutFcn',  [] , ...
                   'gui_Callback',   []);
if nargin && ischar(varargin{1})
    gui_State.gui_Callback = str2func(varargin{1});
end

if nargout
    [varargout{1:nargout}] = gui_mainfcn(gui_State, varargin{:});
else
    gui_mainfcn(gui_State, varargin{:});
end
% End initialization code - DO NOT EDIT


% --- Executes just before GUI_Office is made visible.
function GUI_Office_OpeningFcn(hObject, eventdata, handles, varargin)
% This function has no output args, see OutputFcn.
% hObject    handle to figure
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)
% varargin   command line arguments to GUI_Office (see VARARGIN)

% Create the data to plot
Data_warehouse=imread('warehouse.jpg','jpg');
image(Data_warehouse);
colormap bone
hold on


% Choose default command line output for GUI_Office
handles.output = hObject;

% Update handles structure
guidata(hObject, handles);

% UIWAIT makes GUI_Office wait for user response (see UIRESUME)
% uiwait(handles.figure1);

% --- Outputs from this function are returned to the command line.
function varargout = GUI_Office_OutputFcn(hObject, eventdata, handles)
% varargout  cell array for returning output args (see VARARGOUT);
% hObject    handle to figure
% eventdata  reserved - to be defined in a future version of MATLAB
```

```
% handles    structure with handles and user data (see GUIDATA)

% Get default command line output from handles structure
varargout{1} = handles.output;


function edit1_Callback(hObject, eventdata, handles)
% hObject    handle to edit1 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

% Hints: get(hObject,'String') returns contents of edit1 as text
%        str2double(get(hObject,'String')) returns contents of edit1 as a
double


% --- Executes during object creation, after setting all properties.
function edit1_CreateFcn(hObject, eventdata, handles)
% hObject    handle to edit1 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    empty - handles not created until after all CreateFcns called

% Hint: edit controls usually have a white background on Windows.
%       See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end


% --- Executes on button press in search_pushbutton.
function search_pushbutton_Callback(hObject, eventdata, handles)
% hObject    handle to search_pushbutton (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

prompt = {'Enter the key words of wanted item:'}; % Display the text
answer = inputdlg(prompt); % output the typed text
var=answer(1);
% save('Input','var')
load database
[m n]=size(databset_warehouse);
location=[];
for k=1:m
    Da=databset_warehouse(k,4);
    if isequal(var,Da)==1
       location=[location k];
    end
end
date=min(str2num(cell2mat(databset_warehouse(location,2))));
if date>0
    A=str2num(cell2mat(databset_warehouse(:,2)))==date;
    B=find(A==1);
%     row=str2num(cell2mat(databset_warehouse(B,1)));
%     col=str2num(cell2mat(databset_warehouse(B,6)));
    row=cell2mat(databset_warehouse(B,1));
    col=cell2mat(databset_warehouse(B,6));
else
    date=0;
```

```
    B=location(1);
    row=cell2mat(databset_warehouse(B,1));
    col=cell2mat(databset_warehouse(B,6));
end
result=[location(1) row col B length(location) date];
save('result','result')
plot(col,row,'bo', 'MarkerSize', 10); % plot and mark the wanted location
in the map

% --- Executes on button press in display_pushbutton.
function display_pushbutton_Callback(hObject, eventdata, handles)
% hObject    handle to display_pushbutton (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)
unilogo=imread('LogoUni.jpg');
load database
load result
name=cell2mat(databset_warehouse(result(1),4));
ava=num2str(result(5));
loca=num2str([result(2) result(3)]);
if result(6)>0
    EDate=num2str(result(6));
    ID=num2str(cell2mat(databset_warehouse(result(4),3)));
else
    EDate='No expiry date for this item.';
    ID=num2str(cell2mat(databset_warehouse(result(4),3)));
end

h=msgbox({['Item name: ', name]; ['Item ID: ',ID]; ['Expiry date: ' EDate];
...
    ['Item availability: ', ava]; ['Item location: ', loca]}, 'Item
Information','custom',unilogo);

% --- Executes on button press in clear_pushbutton.
function clear_pushbutton_Callback(hObject, eventdata, handles)
% hObject    handle to clear_pushbutton (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)
delete(findobj(gca,'Type','line','Marker','+'));
delete(findobj(gca,'Type','line','Marker','o'));

% --- Executes during object creation, after setting all properties.
function axes1_CreateFcn(hObject, eventdata, handles)
% hObject    handle to axes1 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    empty - handles not created until after all CreateFcns called

% Hint: place code in OpeningFcn to populate axes1

% --- Executes on button press in pushbutton4.
function pushbutton4_Callback(hObject, eventdata, handles)
% hObject    handle to pushbutton4 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

% Display all the tagged item in the map
plot([50,100,140,130,190],[40,90,50,135,100],'r+', 'MarkerSize', 10);
```

Appendix E

E.1 Hardware component

RFID-based warehousing management system consists of the following elements:

RFID Reader

RFID tags

Serial to USB converter

Personal computer.

Arduino is an open-source physical computing platform based on a simple I/O board and a development environment that implements the Processing/Wiring language. Arduino can be used to develop stand-alone interactive objects or can be connected to software on your computer (e.g. Flash, Processing, MaxMSP). The Arduino has the ability to be installed to any type of operating system and could be powered and programmed via the built in USB connection. The programming functionality using C++ enhances the ability to use this board. The Arduino is an open source platform, which means that it has large number of technical documentation and support.

Figure 50.E.1.1: Arduino Uno Rev.3 (ATmega328).

Near field communication (NFC) is a set of standards for smartphones and similar devices to establish radio communication with each other by touching them together or bringing them into close proximity, usually no more than a few centimetres. Present and anticipated applications include contactless transactions, data exchange, and simplified setup of more complex communications such as Wi-Fi.

Figure 51.E.1.2: RFID 13.56 MHz / NFC Card. (Tags)

Overview

ID12-LA and the ID20-LA series are small footprint 2.8-5.0volt reader modules that support ASCII, Wiegand26 and Magnetic ABA Track2 data formats. The modules are pin and function compatible with the ID2/12/20 series.

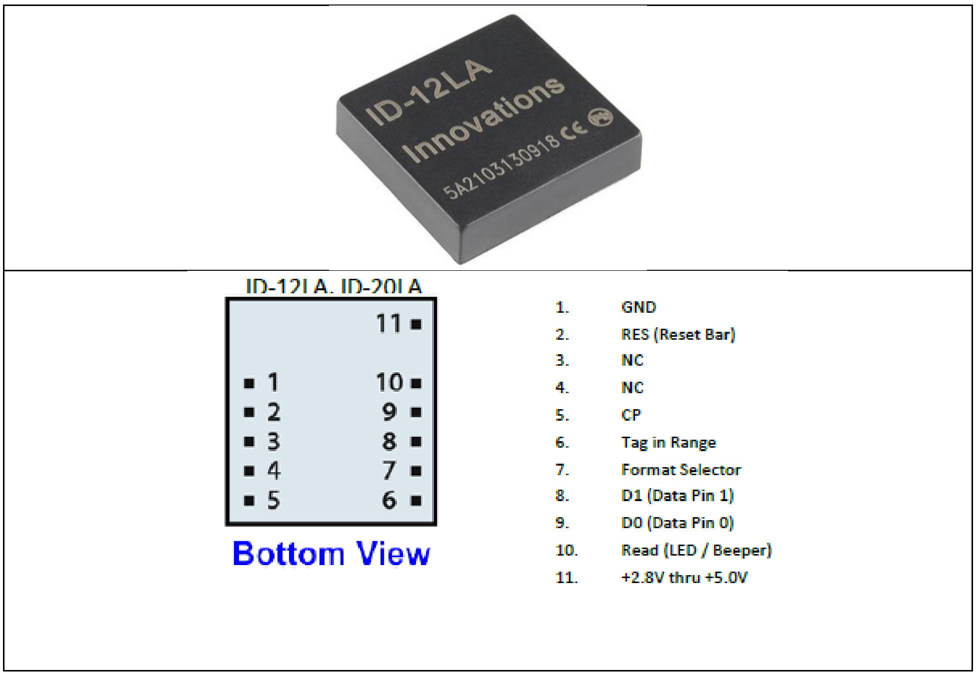


Figure 52.E.1.3: The ID-12 reader module.

RFID reader (ID-12) with Arduino

The RFID ID-12 is a simple reader that reads 125 kHz (EM 4001 or compatible) tags. The datasheet provides data structure, wiring and pinout details as shown in Figure 6.E.1.4.

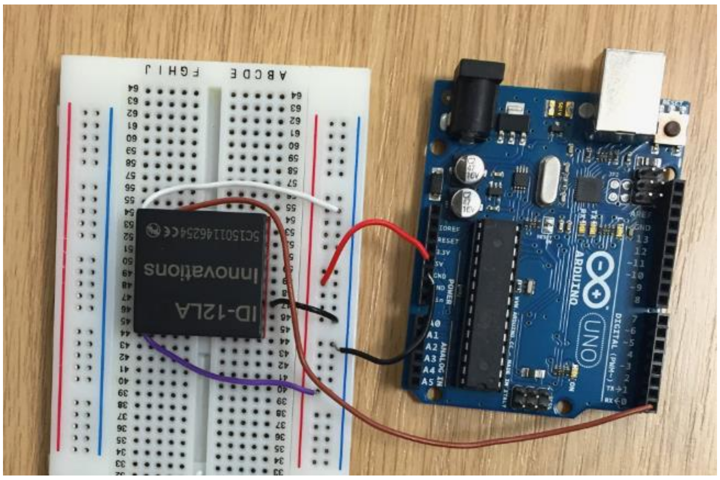


Figure 53.E.1.4: The Arduino interface.

Table 23.E.1.1: Basic description of the testing equipment.

Reader specification	
Name	Impinj RFID reader
Frequency	902~928 MHz
Antenna	far-field antenna

Antenna	Passive 
Frequency	902~928 MHz
Antenna	Linear

Tag	
Nature	Passive (middle)

RFID tags used in this study

The security requirements in an RFID system depends on the type and sensitivity of data some RFID tags may have additional security layers and require passwords or identification codes. This may affect functionality of RFID tag. Most applications of the RFID tag employ a unique identifier which can be located via its row tag database (RTD). As the majority of system users have access to a network, the RFID information relating to the tagged items can also be accessed diverse types and amounts of RFID data are restricted by limitations of the database operations and settings. RFID tag selection is part of any RFID implementation. There are several HF RFID tags standards are used, which are as follow:

1. RFID passive tag (near-field communication)

ISO 15693 standard for tracking items.

ECMA-340 and ISO/IEC 18092 standard for Near Field Communications (NFC).

ISO/IEC 14443 A and ISO/IEC 14443 standards for MIFARE technology, which is used in smart cards.

JIS X 6319-4 standard for FeliCa which is used in a smart card system for electronic money cards.

2. RFID passive tag (far-field communication)

Table 24.E: Characteristics of passive RFID tags used in this research for far-field antenna.

Device type	Class 1 Generation 2 passive UHF RFID transponder
Air interface protocol	EPCGlobal Class1 Gen2 ISO 18000-6C
Operational frequency	Global 860-960MHz
IC type	Impinj Monza 4QT & Impinj Monza 4E.
Memory configuration	With Monza 4QT:EPC 128 bit; User 512 bit; TID 96 bit With Monza 4E:EPC 496 bit; User 128 bit; TID 96 bit
Read Range	(EU on plastic up to 12,5 m/ 41 ft, EU on cardboard up to 11 m/ 36 ft, US on plastic up to 12 m/ 39 ft and US on plastic up to 10,5 m/ 34 ft).
Application surface materials	Non-metallic surfaces.

Appendix F

F.1 Visual Studio Project

Table 7.F.1.1 shows the SDK programming code (C#) for processing RFID data in the MVS environment.

Table 25.F.1.1: RFID application using MVS.

```
using RfidTracker.Domain;

namespace RfidTracker.FluentApi
{
    public class RfidAntennaBuilder
    {
        private static RfidAntenna _rfidAntenna;

        public RfidAntennaBuilder()
        {
            _rfidAntenna = new RfidAntenna();
        }

        public static RfidAntennaBuilder DefaultLocation()
        {
            return new RfidAntennaBuilder();
        }

        public static RfidAntenna Build()
        {
            return _rfidAntenna;
        }

        public RfidAntennaBuilder WithName(string name)
        {
            _rfidAntenna.Name = name;
            return this;
        }

        public RfidAntennaBuilder WithLocation(Location location)
        {
            _rfidAntenna.Location = location;
            return this;
        }

        public RfidAntennaBuilder WithLocation(string floor, string room, string
shelf)
        {
            var location = new Location();
            location.Floor = floor;
            location.Room = room;
            location.Shelf = shelf;
            _rfidAntenna.Location =  location;
            return this;
        }
    }
}
```

```csharp
using System;
using System.Collections.Generic;
using System.Linq;
using System.Text;
using System.Threading.Tasks;
using RfidTracker.DataLayer;
using RfidTracker.Communications;

namespace RfidTracker.Reader
{
    public static class RfidControllerFactory
    {
        public static IRfidController GetRfidController(IUnitOfWork unitOfWork)
        {
            if (unitOfWork.UseRfidSimulation)
            {
                return new RfidControllerSimulator(unitOfWork);
            }
            return new RfidController(unitOfWork.SystemProperties.ToList());
        }
    }
}
```

```csharp
using System;
using System.Collections.Generic;
using System.Linq;
using System.Text;
using System.Threading.Tasks;
using RfidTracker.DataLayer;
using RfidTracker.Domain;
using RfidTracker.Communications;

namespace RfidTracker.Reader
{
    public class Program
    {
        private static IUnitOfWork _unitOfWork;
        private static IRfidController _rfidController;

        static void Main(string[] args)
        {
            DisplayWelcomeMessage();
            Initialise();
            RfidController.RunReader();

            Console.WriteLine("");
            Console.WriteLine("Finished: Press any key to stop the program.");
            Console.WriteLine("");
        }

        private static IUnitOfWork UnitOfWork
        {
            get { return _unitOfWork; }
        }

        private static IRfidController RfidController
        {
            get { return _rfidController; }
```

```
        }

        private static void DisplayWelcomeMessage()
        {
            Console.ForegroundColor = ConsoleColor.DarkGreen;
            Console.WriteLine("*************************");
            Console.WriteLine("Welcome to the RFID Reader");
            Console.WriteLine("*************************");
            Console.WriteLine(string.Empty);
            Console.WriteLine("Press <enter> to start.");
            Console.ReadLine();
            Console.WriteLine(string.Empty);
            Console.WriteLine("Starting  . . .");
            Console.WriteLine(string.Empty);
        }

        private static void Initialise()
        {
            _unitOfWork = new UnitOfWork();
            _rfidController = RfidControllerFactory.GetRfidController(UnitOfWork);
            _rfidController.RfidTagRead += RfidControllerRfidTagRead;
            _rfidController.RunReader();
            Console.ReadLine();
        }

        private static void RfidControllerRfidTagRead(object source,
RfidTagReadEventArgs rfidTagReadEventArgs)
        {
            var message = string.Format("{0} {1} {2} {3}",
rfidTagReadEventArgs.RfidTag, rfidTagReadEventArgs.Hostname,
rfidTagReadEventArgs.IpAddress, rfidTagReadEventArgs.PortNumber);
            Console.WriteLine(message);


            UnitOfWork.ProcessRfidReadEvent(rfidTagReadEventArgs);

        }
    }
}
```

```
<?xml version="1.0" encoding="utf-8"?>
<configuration>
  <configSections>
    <!-- For more information on Entity Framework configuration, visit
http://go.microsoft.com/fwlink/?LinkID=237468 -->
    <section name="entityFramework"
type="System.Data.Entity.Internal.ConfigFile.EntityFrameworkSection, EntityFramework,
Version=6.0.0.0, Culture=neutral, PublicKeyToken=b77a5c561934e089"
requirePermission="false" />
  </configSections>

  <connectionStrings>
    <!-- To change the database, change the Catalog to RfidTrackerWarehouse -->
    <add name="RfidTrackerDatabase"
         connectionString="Data Source=(LocalDb)\Projects;Initial
Catalog=RfidTrackerWarehouse;Integrated Security=SSPI"
         providerName="System.Data.SqlClient" />
  </connectionStrings>

  <startup>
```

```
    <supportedRuntime version="v4.0" sku=".NETFramework,Version=v4.5" />
  </startup>
  <entityFramework>
    <defaultConnectionFactory 
type="System.Data.Entity.Infrastructure.LocalDbConnectionFactory, EntityFramework">
      <parameters>
        <parameter value="v11.0" />
      </parameters>
    </defaultConnectionFactory>
    <providers>
      <provider invariantName="System.Data.SqlClient" 
type="System.Data.Entity.SqlServer.SqlProviderServices, EntityFramework.SqlServer" />
    </providers>
  </entityFramework>
</configuration>
```

```
  // Set the latest location
            Console.WriteLine("Updating Location for '{0}'", trackedItem.Lastname);
            trackedItem.LatestLocationId = rfidAntenna.LocationId.Value;


            // Add the tracked item event
            var tracketItemEvent = new TrackedItemEvent();
            tracketItemEvent.Id = Guid.NewGuid();
            tracketItemEvent.EventDate = System.DateTime.Now;
            tracketItemEvent.LocationId = rfidAntenna.LocationId.Value;
            tracketItemEvent.TrackedItemId = trackedItem.Id;
            TrackedItemEvents.Add(tracketItemEvent);

            try
            {
                SaveChanges();
            }
            catch (DbEntityValidationException e)
            {
                foreach (var eve in e.EntityValidationErrors)
                {
                    Console.WriteLine("Entity of type \"{0}\" in state \"{1}\" has the 
following validation errors:",
                        eve.Entry.Entity.GetType().Name, eve.Entry.State);
                    foreach (var ve in eve.ValidationErrors)
                    {
                        Console.ForegroundColor = ConsoleColor.DarkRed;
                        Console.WriteLine("- Property: \"{0}\", Error: \"{1}\"", 
ve.PropertyName, ve.ErrorMessage);
                        Console.ForegroundColor = ConsoleColor.DarkGreen;
                    }
                }
                throw;
            }
            catch (Exception ex)
            {
                Console.ForegroundColor = ConsoleColor.DarkRed;
                Console.WriteLine(ex.Message);
                Console.ForegroundColor = ConsoleColor.DarkGreen;
            }
        }

    }
}
```

Workflow: Read Tags

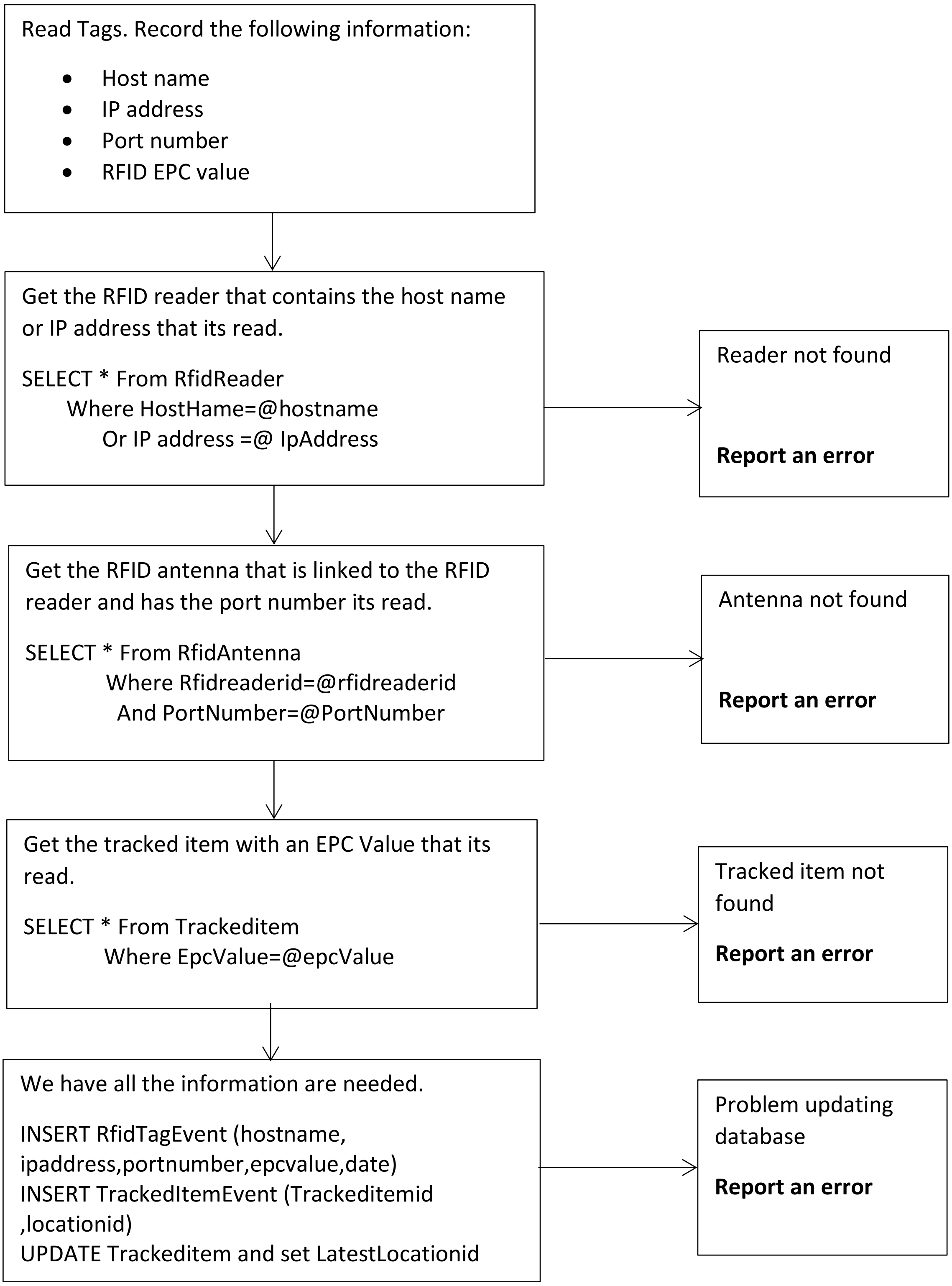


Figure 54.F.1.1: Workflow acquires an RFID tag using a MVS environment.

Appendix G

G.1 Opening the RFID Database

RFID Database: The RFID database is implemented using Microsoft SQL Server: RFID Tracker Warehouse. Open SQL Server Management Studio to view the databases. The Server name is (localdb)\Projects.

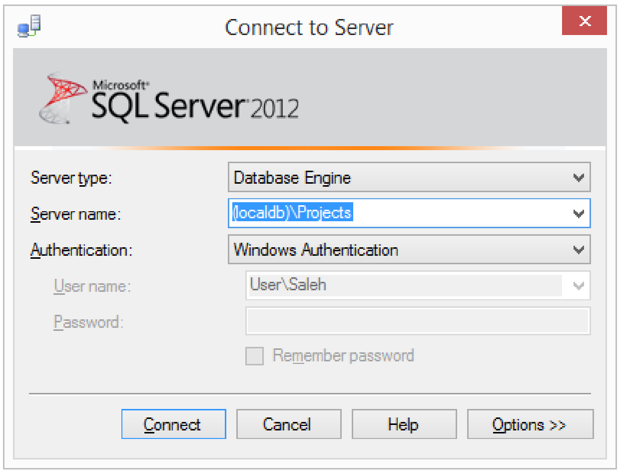


Figure 55.G.1.1: Screen shot of the Microsoft SQL layout.

After connecting to the database server (using the screen above), created databases will be shown as RFID Tracker Warehouse.

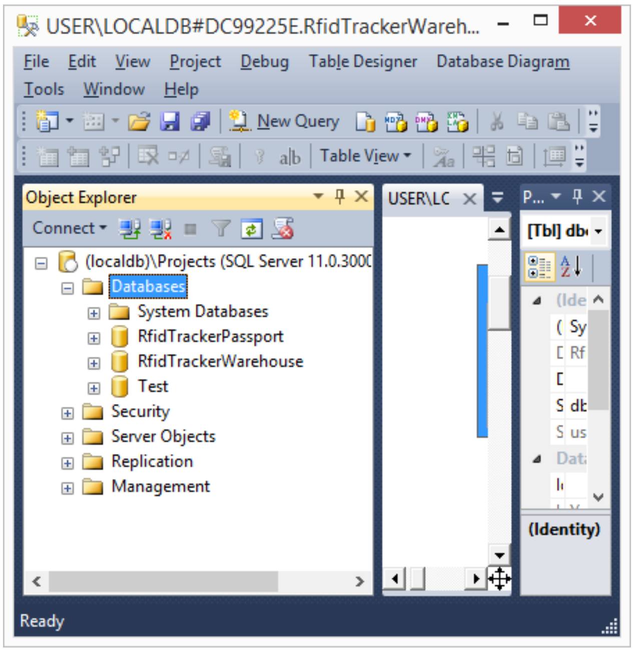


Figure 56.G.1.2: Screen shot of the RFID database tracker warehouse within SQL server.

Ensure that the application is setup to seed the warehouse database.

Goto the RfidTracker.DataLayer project
Open the file ‘DatabaseInitialiser’
select to seed the Warehouse – just make sure only one of them is commented out / set to run.

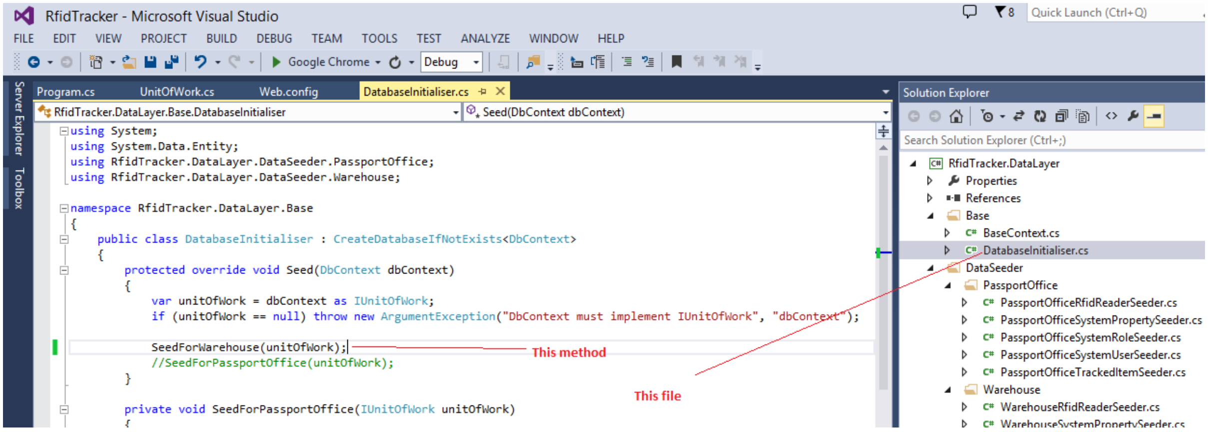


Figure 57.G.1.3: Screen shot of the RFID database Initialiser within MVS.

Compile the Application and Run it.

Compile by selecting Build → Build Solution from the main menu
Then this could be run by selecting the run ‘Google Chrome’ from the main toolbar if applicable.

F.2 Running the RFID reader console

This section shows you how to run the RFID reader console application.

Step 01 – Set the Startup Project

Open Visual Studio and load the Project

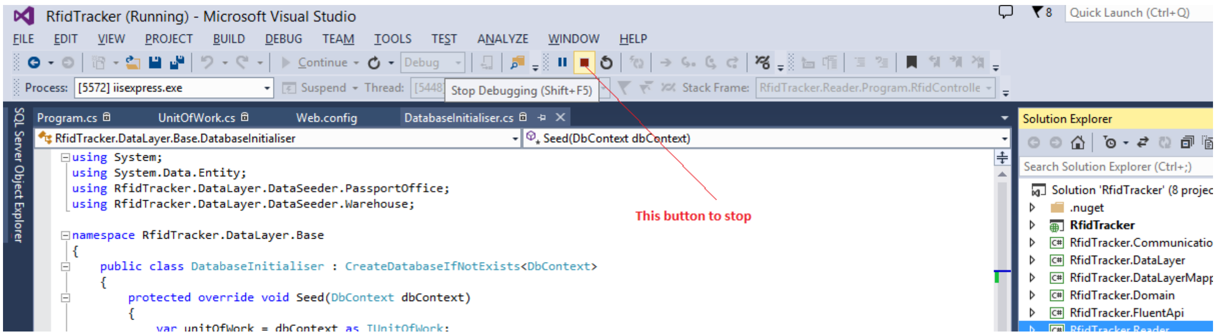


Figure 58.G.2.1: Screen shot of the Microsoft Visual Studio layout.

In the Solution Explorer right click the RFID Tracker. Reader project and select ‘Set as Start-up Project’

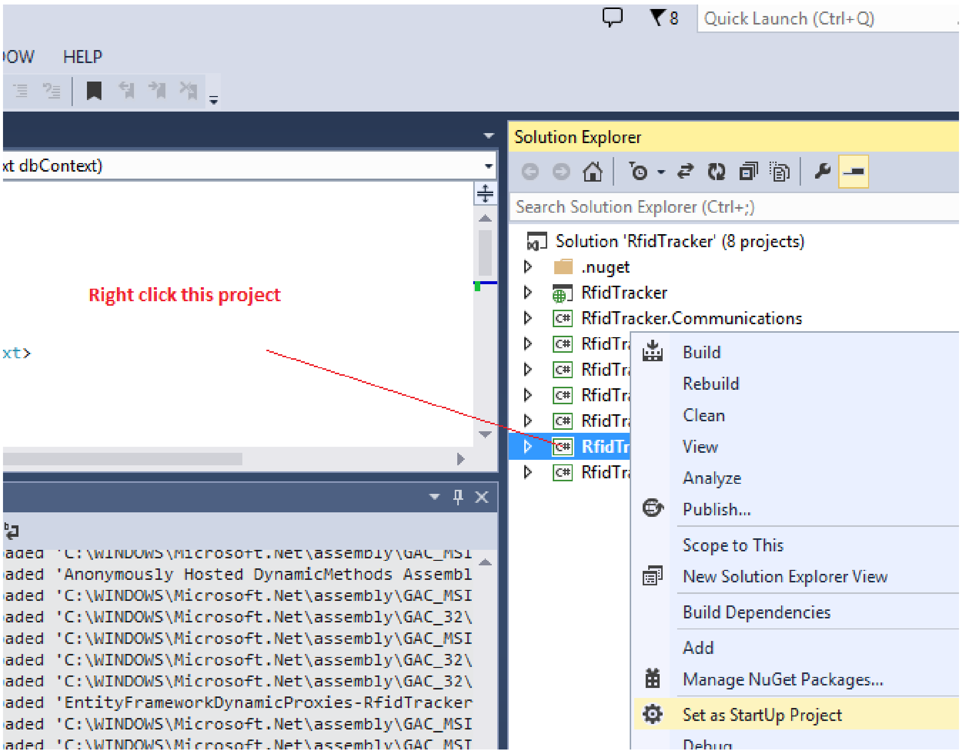


Figure 59.G.2.2: screen shot of Setting up an RFID tracker reader as Start-up Project.

Step 02 – Application Configuration.

The RfidTracker.Reader project has its own config file which tells it which database to use.

Ensure it is correct

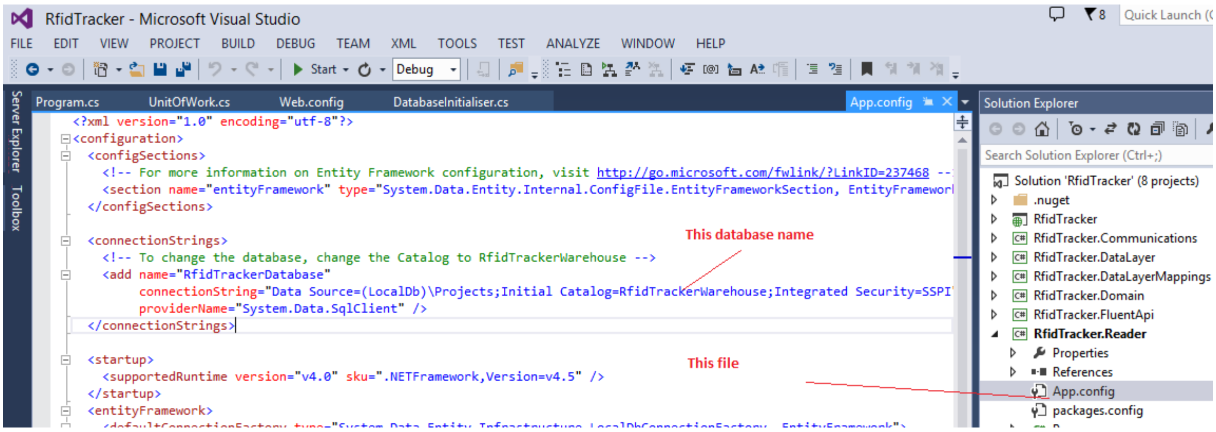


Figure 60.G.2.3: screen shot of Application configuration within MVS.

Step 03 – Build and Run

Build → Build Solution from the main menu.
The run using F5
The simulation engine simulates some tracked items moving.
When it completes you can verify the data in the database.

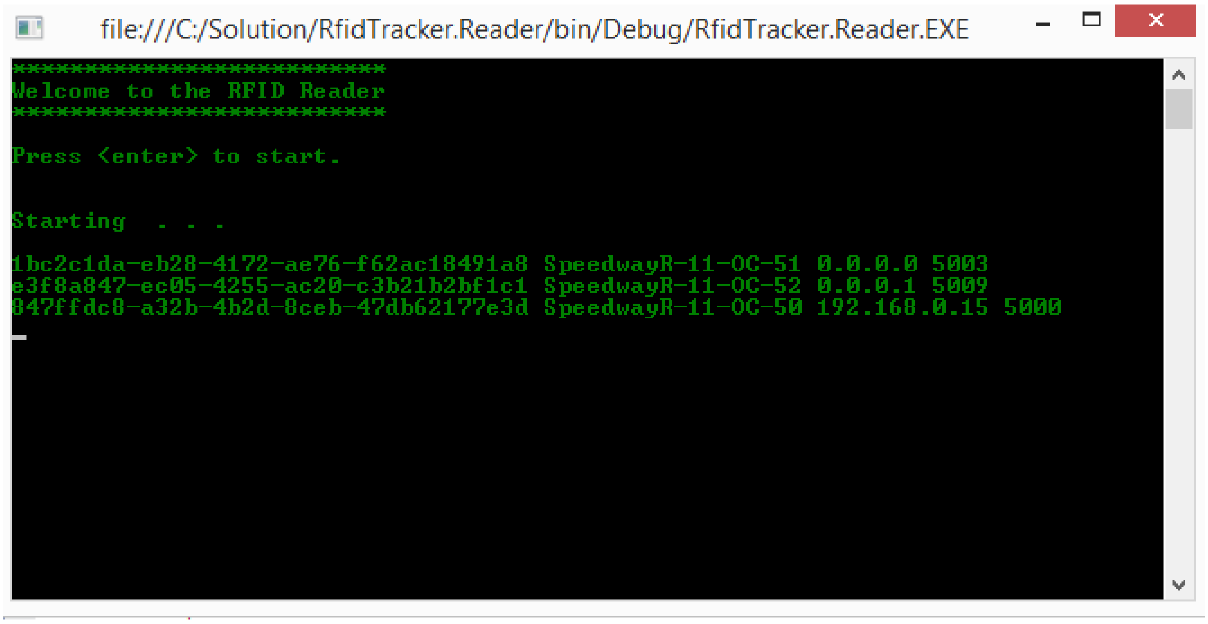


Figure 61.G.2.4: The MVS simulator window.

Table 26.G.1.1: Processing data and record in the RFID database.

```sql
USE [RfidTrackerWarehouse]

-- Get the last 10 records from the tag event table

SELECT TOP 10 * FROM [dbo].[RfidTagEvent]     ORDER BY [DateAndTime] DESC

-- Get the last 10 records from the tracked item event table

SELECT TOP 10 * FROM [dbo].[TrackedItemEvent] ORDER BY [EventDate] DESC

-- Get the items that moved!

SELECT *

  FROM [dbo].[TrackedItem]

 WHERE [Id] IN (SELECT TOP 10 [TrackedItemId]

                FROM [dbo].[TrackedItemEvent]

                          ORDER BY [EventDate] DESC)
```

Appendix H

H.1 RFID Database Schema

The following section describes the RFID database table for the future work.

System Property

This table stores the system settings

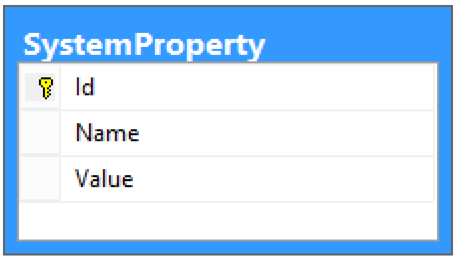
SELECT * FROM dbo.SystemProperty

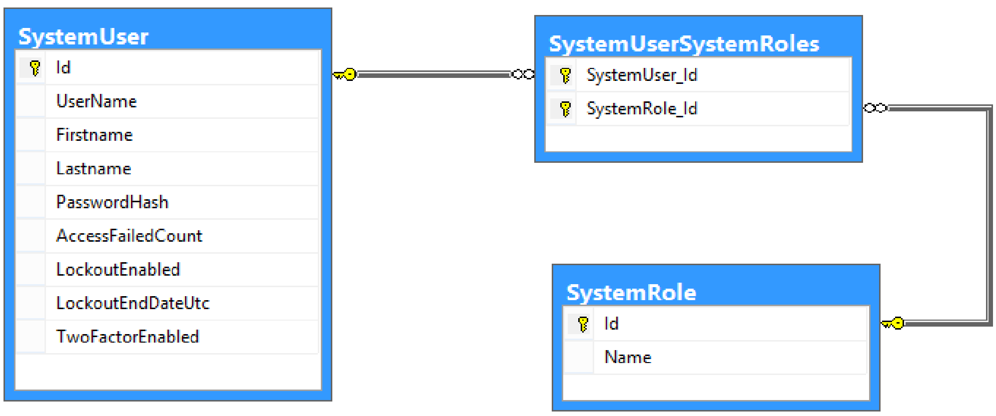
Users and Roles

Stores users and roles, these are used for storing the passwords. Passwords are encrypted. There is only one role at this stage – admin. The system can easily be extended to have more roles.

RFID Readers, Antennae and Locations

A reader will be linked to many antennas; each antenna is linked to one location.





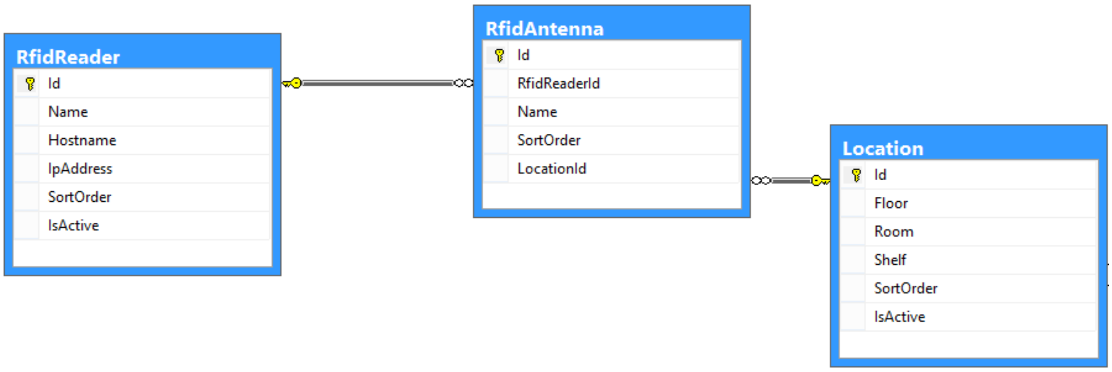


Figure 62.H.1.1: Information stored in the RFID database.

Tracked Items

The system stores tracked items. (Inventory items) Each tracked item has a latest location. When an RFID event occurs (i.e. when we read an RFID tag), we record the tag event and then update the tracked item event table and the latest location. This allows us to record the movements of tracked items and also record the latest location of an item.

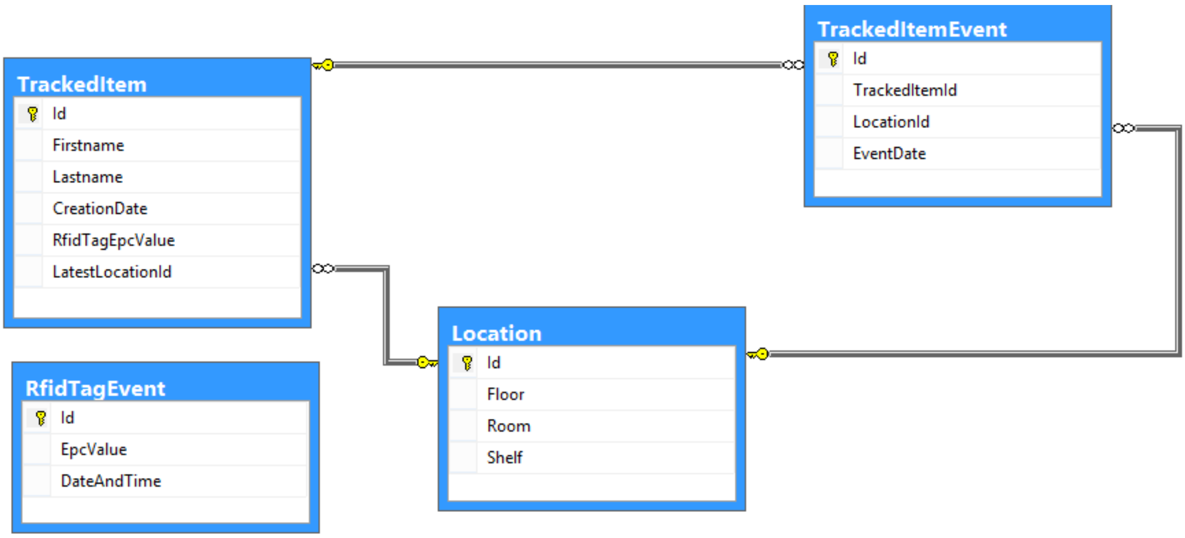


Figure 63.H.1.2: Tracked Items within RFID database.

Accessing the Database

Use SQL Server Management Studio to access and look at the data in the database.

SELECT – to read data
UPDATE – to update a record
INSERT – to insert records
DELETE – to delete records.

Appendix I

H.1 Simulation

Table 27.I.I.1: simulation programming code for single item

```
x=1:5;
y=[2 4 7 3 5]
z=[20 44 50 12 27];

plot3(x,y,z,'o',x:1,y:[2],z:[20],'*')

grid on

legend('items','Least travel time')
xlabel('Row of the ordered item')
ylabel('Column of the ordered item')
zlabel('Travel time (Min)')
title('Total travel time across the grid in a single-item')
```

Table 28.I.1.2: Simulation programming code for multiple items

```
x=1:10;
y=[2 4 7 3 5 2 3 6 4 8]
z=[20 44 50 12 27 25 33 45 55 37];

plot3(x,y,z,'o')

grid on

legend('Selected items')
xlabel('Row of the ordered items')
ylabel('Column of the ordered items')
zlabel('Travel time (Min)')
title('Total travel time across the grid')
```

Table 29.I.1.3: Example of analysis of items selection process.

```
x=[5 4 3]
y=[3 4 5]
z=[23 44 15];

plot3(x,y,z,'o',x,y,z,'*')
grid on
legend('Selected items','First item to arrive')

xlabel('Row of the ordered items')
ylabel('Column of the ordered items')
zlabel('Travel time(Min)')
title('Total travel time across the grid in multiple items')
```

```
x=[5 4 3]
y=[3 4 5]
z=[23 44 15];

plot3(x,y,z,'o',x:5,y:3,z:23,'*')
grid on
legend('Selected items','First item to arrive')

xlabel('Row of the ordered items')
ylabel('Column of the ordered items')
zlabel('Travel time(Min)')
title('Total travel time across the grid in multiple items')
```

Figure 17.I.1.1 shows the MATLAB simulation result which determines an item with a least travel time among ordered items of the same type to a collection point in an AR/RR. It indicates that the item at location (1, 2) has a least travel time of 20 seconds and thus this item was selected and dispatched to a collection point. The result was generated by the RFID-inventory management system according to the pre-defined selection rules and the system subsequently issues a priority to be given to the selected item. The mechanical control system then initialise a demand to push the selected item onto an output conveyor and this item will be transported along the RFID-guided route to the collection point.

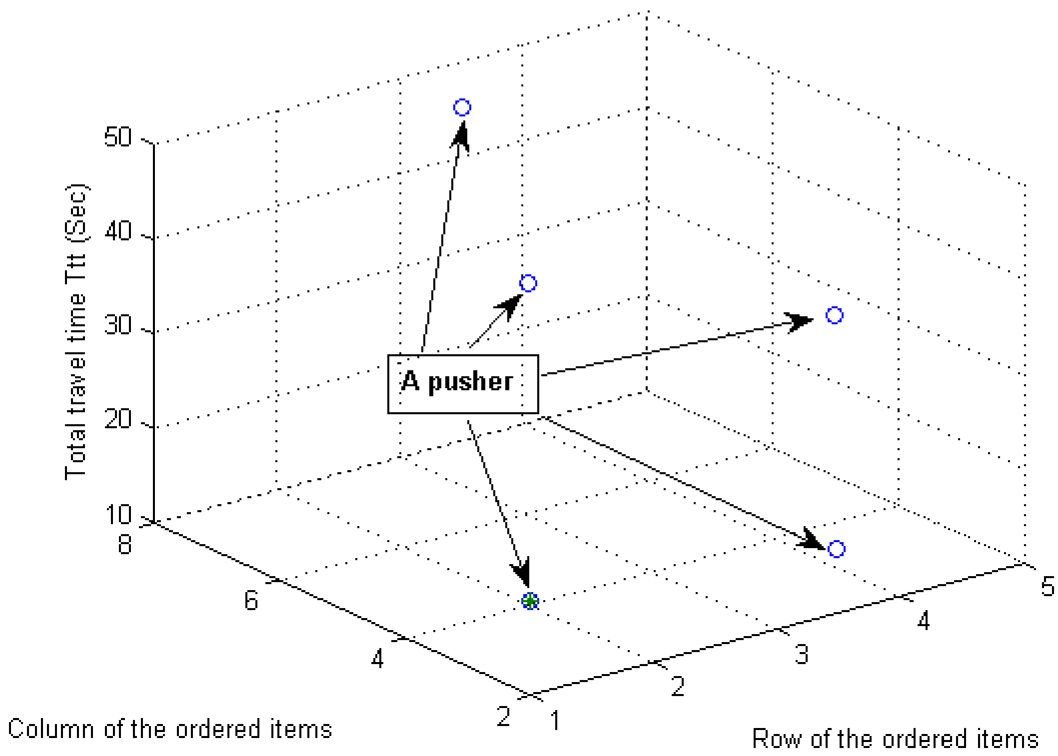


Figure 64.I.1.1: Determination of a least travel time among ordered items in the same type.