Selection Process of Auto-ID Technology in Warehouse Management: A Delphi Study

A thesis submitted in fulfilment of the requirement for the degree of Doctor of Philosophy

By

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ABSTRACT

In a supply chain, a warehouse is a crucial component for linking all chain parties. Automatic identification and data capture (auto-ID) technology, e.g. RFID and barcodes are among the essential technologies in the 21st century knowledge-based economy. Selecting an auto-ID technology is a long term investment and it contributes to improving operational efficiency, achieving cost savings and creating opportunities for higher revenues. The interest in auto-ID research for warehouse management is rather stagnant and relatively small in comparison to other research domains such as transport, logistics and supply chain. However, although there are some previous studies that explored factors for the auto-ID selection decision in a warehouse environment, those factors (e.g., operational factors) have been examined separately and researchers have paid no attention to all key factors that may potentially affect this decision. In fact, yet there is no comprehensive framework in the literature that comprehensively investigates the critical factors influencing the auto-ID selection decision and how the factors should be combined to produce a successful auto-ID selection process in warehouse management.

Therefore, the main aim of this research is to investigate empirically the auto-ID technology-selection process and to determine the key factors that influence decision makers when selecting auto-ID technology in the warehouse environment. This research is preceded by a comprehensive and systematic review of the relevant literature to identify the set of factors that may affect the technology selection decision. The Technology-Organisation-Environment (TOE) framework has been used as lens to categorise the identified factors (Tornatzky & Fleischer, 1990). Data were collected by conducting first a modified (mixed-method) two-round Delphi study with a worldwide panel of experts (107) including academics, industry practitioners and consultants in auto-ID technologies. The results of the Delphi study were then verified via follow-up interviews, both face-to-face and telephone, carried out with 19 experts across the world. This research in nature is positivist, exploratory/descriptive, deductive/inductive and quantitative/qualitative. The quantitative data were analysed using the statistical package for social sciences, SPSS V.18, while the qualitative data of the Delphi study and the interviews were analysed

manually using quantitative content analysis approach and thematic content analysis approach respectively.

The findings of this research are reported on the motivations/reasons of warehouses in seeking to use auto-ID technologies, the challenges in making an auto-ID decision, the recommendations to address the challenges, the key steps that should be followed in making auto-ID selection decision, the key factors and their relative importance that influence auto-ID selection decision in a warehouse. The results of the Delphi study show that the six major factors affecting the auto-ID selection decision in warehouse management are: organisational, operational, structural, resources, external environmental and technological factors (in decreasing order of importance). In addition, 54 key sub-factors have been identified from the list of each of the major factors and ranked in decreasing order of the importance mean scores. However, the importance of these factors depends on the objectives and strategic motivations of warehouse; size of warehouse; type of business; nature of business environment; sectors; market types; products and countries.

Based on the Delphi study and the interviews findings, a comprehensive multi-stage framework for auto-ID technology selection process has been developed. This research indicates that the selection process is complex and needs support and closer collaboration from all participants involved in the process such as the IT team, top management, warehouse manager, functional managers, experts, stockholders and vendors. Moreover, warehouse managers should have this process for collaboration before adopting the technology in order to reduce the high risks involved and achieve successful implementation.

This research makes several contributions for both academic and practitioners with auto-ID selection in a warehouse environment. Academically, it provides a holistic multi-stage framework that explains the critical issues within the decision making process of auto-ID technology in warehouse management. Moreover, it contributes to the body of auto-ID and warehouse management literature by synthesising the literature on key dimensions of auto-ID (RFID/barcode) selection decision in the warehouse field. This research also provides a theoretical basis upon which future research on auto-ID selection and implementation can be built. Practically, the findings provide valuable insights for warehouse managers and executives associated with auto-ID selection and advance their understanding of the issues involved in the technology selection process that need to be considered.

Keywords

Auto-Identification Technology, Radio Frequency Identification (RFID), Barcode, Warehouse Management, Selection Process, Delphi Study

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***All Praise be unto ALLAH, the Almighty, the Glorious*.**
***And to his final messenger MUHAMMED (Peace be upon him, his family and his* companions)**

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Dedications

Finally, this thesis is dedicated to:

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Without you, I have no form or shadow.

Author’s Declaration

I, Mayadah Hassan, declare that the ideas, research work, analyses and conclusions reported in my PhD thesis *“A Development Framework for the Selection Decision Process of Auto - Identification Technologies in Warehouse Management: An International Delphi Study”* are entirely my effort, except where otherwise acknowledged. Also, I certify that this thesis contains no material that has been submitted previously, in whole or in part, for the award of any other academic degree or diploma. Except where otherwise indicated, this thesis is my own work.

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3. Hassan, M., Ali, M., and Aktas, E. (2011). An Experimental Study for Evaluating The Reading Performance of Semi-Passive RFID Tags To Enhance Locating of Warehouse Resources. *European, Mediterranean & Middle Eastern Conference on Information Systems (EMCIS),* Athens, Greece, May.

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Auto-ID	Automatic Identification
WMSs	Warehouse Management Systems
RFID	Radio Frequency Identification
SKU	Stock Keeping Units
ERP	Enterprise Resource Planning
TOE	Technology Organisation Environment
DOI	Diffusion of Innovation
TAM	Technology Acceptance Model
TPB	Theory of Planned Behaviour
UTAUT	Unified Theory of Acceptance and Use of Technology
BITA	Business/IT-Alignment
GSL	Group Sense Limited
IT	Information Technology
IS	Information System
ROI	Return On Investment

CHAPTER 1

INTRODUCTION

1.1 Introduction

A supply chain is an important channel for supporting flow of goods, money and sharing information among all chain parties including, suppliers, manufacturing and storage facilities, distributors and customers for facilitating the core business functions of the production, sale, and delivery of a particular product (Kaihara, 2003; Liu et al., 2005). Due to the effects of globalisation, many companies have expanded their businesses to global locations. Logistics experts have to deal with many channel partners who may be spread over longer distances and demand greater variety of products, more statutory requirements and documentation (Vogt et al., 2005). Enterprises (e.g., manufacturing) have changed their production mode from the traditional mass production to mass customisation in order to facilitate increasing global market competition. Thus, the current supply chain networks are getting increasingly complicated. Supply chain management (SCM) has become one of the key success factors for effectively integrating material flows, money and related information between upstream and downstream entities (Soroor & Tarokh, 2006). In this globalised demand and supply environment, effective supply chain management (SCM) enhances both productivity and customer service (Soroor & Tarokh, 2006).

Supply chain functions including warehousing are essential for linking and integrating all supply chain parties and for ensuring smooth materials flows within the network (Gu et al., 2007). A warehouse is a crucial component for linking the upstream (production) and downstream (distribution) partners in a supply chain. Warehouse operations are either labour or capital-intensive and their performance affects the productivity and the operational costs of a warehouse as well as the entire supply chain (Harmon, 1993; Gu et al., 2007). With such an arrangement, it is necessary to facilitate data sharing and provide the location information of the warehouse resources such as stock-keeping units (SKUs), pallets and racks, pallet trucks and forklifts and warehouse staff members (labour). This will lead to facilitate manufacturing operations, minimise inventory levels, reduce order processing, storage, and transhipment costs, and enhance productivity within facilities (Vogt et al., 2005). Therefore, information systems such as warehouse management systems (WMSs), which use different automatic identification and data capture (auto-ID) technologies, e.g. barcode and radio frequency identification (RFID), have been implemented for handling warehouse resources and monitoring operations (Faber et al., 2002).

Automatic Identification and Data Capture (auto-ID) technologies are a wide category of information collection techniques that are used to automatically identify objects, humans and animals, retrieve information carried by the objects, enter information into a database, and update the stored information about objects (Waldner, 2008). The major categories of Auto-ID technologies are: barcode technology, optical character recognition (OCR) systems, voice recognition, biometric systems, smart cards, and radio frequency identification (RFID) technology, (Finkenzeller, 1999; Wyld, 2006). Among these technologies, barcode technology is mature and is the most commonly used in a warehouse environment, while RFID technology is considered as a substitute for barcode technology in the warehouse field (Lu & Sy, 2009; Guo et al., 2009). On the other hand, optical character recognition (OCR) systems, voice recognition, biometric systems and smart cards are not widely used in the warehousing industry (Lu and Sy, 2009).

Deciding on the type of auto-identification (auto-ID) technology is a key aspect of strategic decision-making for warehousing companies or manufacturers operating large warehouses (Karagiannaki et al., 2011; Lim et al., 2013). The optimum auto-ID technology may offer and sustain the competitive advantage of a company (Poon et al., 2009; Ilie-Zudor et al., 2011). The number of warehousing companies considering auto-ID technology continues to increase (Sarac et al., 2010), but they there is a wide range of factors potentially affecting the decision to use auto-ID technologies. Also, auto-ID selection decisions eventually face the barrier on what to consider for ROI evaluation. Therefore, a study of the key factors/issues faced by warehouse managers seems necessary in both practical and theoretical terms. Also, it is crucial to understand how the critical factors should be combined in order to produce a successful auto-ID selection process.

1.3 Background and Motivation of the Research

In a supply chain, a warehouse is an essential component linking all chain parties. The performance of the warehouse operations, which are either labour or capital-intensive, not only influences the productivity and operation costs of a warehouse, but also the whole supply chain (Gu et al., 2007). In today's business environment, a warehouse can be as simple as a garage-like area at a self-storage facility or as complex as a massive facility that not only stores items, but also simultaneously supports different value-adding activities (Karagiannaki et al., 2011). Warehouse operations are no longer confined to inventory storage and protection of goods, but include various operations ranging from receiving, put away, order picking, packaging of items and after sales services, to light assembly and inspection (Farzelle, 2002b; Higginson & Bookbinder, 2005; Maltz & DeHoratious, 2004; Van Den Berg, 2007; Poon et al., 2011b). Given such diversity, and despite some similarities, each warehouse differs from the others in many ways.

Automatic identification (auto-ID) technologies such as barcode and radio frequency identification (RFID) are among the essential technologies in the 21st century knowledge-based economy (Lim et al., 2013). Auto-ID technologies have been adopted to facilitate the collection and sharing of data in a warehouse environment. The number of warehousing companies considering auto-ID technology continues to increase (Sarac et al., 2010). An auto-ID technology is a long-term investment and it contributes to improving operational efficiency, achieving cost savings and creating opportunities for higher revenues (Ilie-Zudor et al., 2011; and Lim et al., 2013). There is no doubt about the increasing popularity of auto-ID technologies in the business world. However, it can also be seen that the interest in auto-ID research for warehouse management has been less prominent than in other application domains such as transport, logistics and the supply chain (Sarac et al., 2010; Karagiannaki et al., 2011; Lim et al., 2013).

Deciding on the type of auto-ID technology is a long term investment for warehousing companies or manufacturers operating large warehouses (Karagiannaki et al., 2011; and Lim et al., 2013). Auto-ID selection decisions eventually face the barrier on what to consider for the economic impact/ (ROI) analyse (Fleisch & Tellkamp, 2005; Sarac et al. 2010). Choosing the right auto-ID technology for a warehouse environment is a key decision factor for warehouse managers in order to (Poon et al., 2009; and Ilie-Zudor et al., 2011):

- locate warehouse resources efficiently;
- support warehouse operations effectively;
- achieve cost savings;
- create opportunities for higher revenues;
- achieve an acceptable/positive rate of return on investment (ROI); and
- sustain the competitive advantage of a warehouse.

In the context of making the auto-ID selection decision, many researchers have explored criteria/factors of the auto-ID selection decision in the supply chain (Brown & Bakhru., 2007; Kang & Koh, 2002; Fontanella, 2004; Lee et al., 2004; Fleisch & Tellkamp, 2005; Angeles, 2005; Lahiri, 2005; Rekik et al., 2006; Wyld, 2006; Lefebvre et al., 2006; Wamba et al. 2007; Goel, 2007; Huber et al., 2007; Lin & Lin, 2007; Miller, 2007; Lee and Ozer, 2007; Leung et al., 2007, White et al., 2008; Bottani & Rizzi, 2008; Sarac et al., 2010; Ilie-Zudor et al., 2011; Pfahl & Moxham 2012; Laosirihongthong et al., 2013). They have examined these factors separately to help decision makers to obtain the optimum auto-ID technologies. However, the literature on the decision about auto-ID selection in the warehouse environment is limited, with few studies that discuss the factors affecting decisions in this context (Porter et al., 2004; Vijayaraman & Osyk, 2006; Van De Wijngaert et al., 2008; Liviu et al., 2009; Poon et al., 2009; Karagiannaki et al., 2011; and Osyk et al., 2012).

Previous studies have not considered the key factors affecting the process of making the selection of auto-ID in warehouse management as a whole. The choice of barcode or RFID is not straightforward, but a number of issues/factors influence the selection that comprises a series of decisions (Poon et al., 2011a; and Ilie-Zudor et al., 2011). Different auto-ID technologies and warehouses have different characteristics and that might affect the value of auto-ID in the warehouse context (Karagiannaki et al., 2011). To understand the auto-ID technology-selection process in a warehouse context, it is important to take heed of all key factors that influence this decision (Ilie-Zudor et al., 2011; Pero & Rossi 2013). However, warehouse managers and/or auto-ID project managers may find it difficult to consider the large number of factors that would affect the selection decision. In addition, they may find that identifying the factors will not be enough without understanding how the factors should be combined to produce a successful auto-ID selection process (Poon et al., 2009; Ilie-Zudor et al., 2011; Pero & Rossi 2013). Pero and Rossi (2013) have stated that warehouse managers should follow several steps before any auto-ID technology is selected for implementation.

Some of the key IS theories on technology adoption are the Technology Acceptance Model (TAM) (Davis Jr, 1986), Theory of Planned Behaviour (TPB) (Ajzen, 1985), Unified Theory of Acceptance and Use of Technology (UTAUT) (Venkatesh et al., 2003), Diffusion of Innovation (DOI) (Rogers, 1995) and Technology–Organisation–Environment (TOE) (Tornatzky & Fleischer, 1990). However, in this research, only the DOI and the TOE have been discussed because they are used at the organisation level, while TAM, TPB and UTAUT are used at the individual level (Oliveira and Martins 2011).

Consistent with recent studies (e.g. Ilie-Zudor et al., 2011; Pero & Rossi 2013) and based on the review of the literature, this research finds a need to fill a knowledge gap stemming from the absence of a comprehensive framework that collectively investigates the critical factors influencing the auto-ID selection decision and how the factors should be combined to produce a successful auto-ID selection process in warehouse management. This provides a theoretical basis upon which future research on auto-ID selection and implementation could be built. In addition, the proposed framework should give practitioners a better understanding of the various phases involved so that the whole auto-ID selection process can be easily understood and applied in a warehouse environment.

1.5 Research Aim and Objectives

Selecting an auto-ID technology is a long term investment and it contributes to improving operational efficiency, achieving cost savings and creating opportunities for higher revenues. Auto-ID selection decisions eventually face the barrier on what to consider for ROI evaluation. The choice of auto-ID is not straightforward, but a number of key factors influence the selection which comprises a series of decisions. Therefore, understanding the auto-ID technology-selection process in a warehouse field requires that all key factors that influence this decision are taken into account. Also, it is essential to understand how those factors should be combined in order to produce a successful auto-ID selection process.

Therefore, the main aim of this research is to determine the key factors that influence decision makers when selecting auto-ID technologies in the warehouse environment and to investigate empirically the auto-ID technology-selection process.

In order to achieve the research aim, these are the objectives of this study:

- To identify the critical factors that influence the auto-ID selection decision by reviewing the existing literature.
- To design an appropriate conceptual research framework.
- To conduct an international Delphi study to investigate the key factors and their relative importance affecting the auto-ID selection decision.
- To conduct in-depth interviews in order to refine and verify the Delphi results.
- To develop a comprehensive framework for the selection process of auto-ID technology in the warehouse field.
- Finally, based on empirically verified results, the researcher describes the implications that emerge from the study for practice and future academic research in auto-ID technology and warehouse management.

1.6 Research Questions

In order to achieve these objectives, this research addresses four questions. The justification/explanation for each research question is presented below:

Auto-ID technologies have been adopted to facilitate the collection and sharing of data in a warehouse environment. Although previous research indicates that the number of warehousing companies considering auto-ID technology continues to increase (Sarac et al., 2010; Poon et al., 2011; Lim et al., 2013), there has been little work done on warehouse management motivations for using auto-ID technologies. Therefore, the first question of this research is as follow:

> **RQ1.** What are the motivations/reasons of warehouses that seek to use auto-ID technologies?

According to Ilie-Zudor et al. (2011), the choice of auto-ID (barcode/RFID) is not a single choice, but a number of issues/challenges influence the selection that is comprised of a series of decisions. Previous studies did not pay attention to problems in auto-ID selection decisions and recommendations to overcome them. Therefore, this research attempts to address this gap and answering the following question:

> **RQ2.** What are the challenges in making an auto-ID decision and the recommendations to address the challenges?

Some researchers such as Adhiarna et al. (2011) have stated that the importance of the various factors that influence the auto-ID selection decisions may change significantly over time. Thus, in this research the relative importance of major factors ad sub-factors will be investigated in order to determine the chronological order of these factors. As a result, these factors and other key activities will be arranged according to their chronological order and that will help to understand the entire auto-ID selection process in warehouse management (Pettigrew, 1997; Aladwani, 2001; Robey et al., 2002; Adhiarna et al., 2011). Therefore, this research addresses the following question:

> **RQ3.** What is the relative importance of major factors and sub-factors affecting auto-ID selection decisions in the warehouse field?

Finally, scholars such as Ilie-Zudor et al. (2011); and Poon et al. (2011a) mention that the choice of auto-ID is not a straightforward, but a wide range of factors affect the selection decision, and they call for more investigation of a number of factors influencing auto-ID adoption to provide a step-by-step guide for choosing the right auto-ID system for a particular organisation's needs. In addition, Poon et al. (2009); Ilie-Zudor et al. (2011); and Pero and Rossi (2013) have indicated that warehouse managers and/or auto-ID project managers may find it difficult to consider the large number of factors that would affect the selection decision without understanding how the factors should be combined to produce a successful auto-ID selection process. Moreover, Porter et al. (2004); Poon et al. (2009); and Sarac et al. (2010) comment that the warehouse managers should follow several steps before any auto-ID technology is selected for implementation. Therefore, this research addresses the following question in order to investigate the auto-ID selection process from its inception to its completion.

> **RQ4.** What are the key steps in the selection process of auto- ID technologies in a warehouse environment?

1.7 Research Methodology

To achieve the research objectives, the research design relied on two phases, as shown in Figure 1.1. After reviewing and analysing the existing literature review, a modified (mixed-method) two-round Delphi study (Dalkey & Helmer, 1963; McKenna, 1994) was conducted in the first phase using a worldwide panel of 107 experts including academics, industry practitioners and consultants in auto-ID technologies. This was a combination of exploratory and descriptive research (Cunliffe & Australia, 2002). The objective was to identify key factors and their relative importance that influence auto-ID selection decisions in warehouse management.

The second phase incorporated follow-up interviews, both face-to-face and by telephone, using 19 experts across the world for verification (Skulmoski et al., 2007; Hasson & Keeney, 2011). The objective was to discuss in-depth to verify and refine the results of the Delphi study. The two-round Delphi study and the follow-up interviews were sufficient for providing enough data to develop a comprehensive framework for the selection process of auto-ID technology in warehouse management.

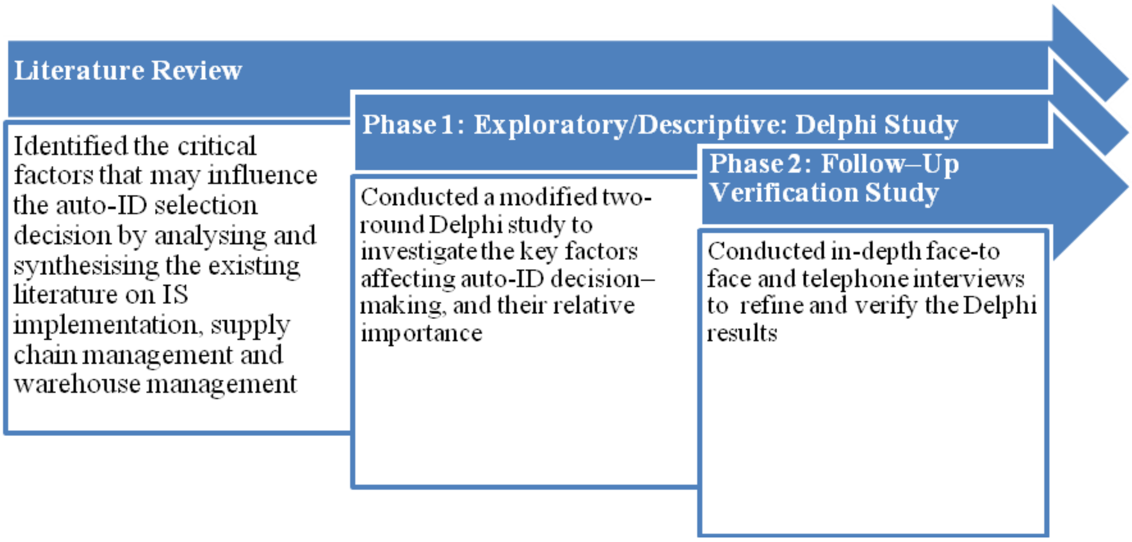


Figure 1.1 Research Design

An international Delphi study was used in this research because the importance of the various factors affecting the selection decision may vary significantly among different countries (Adhiarna et al., 2011). In addition, a mixed-method research approach has been utilised in this research in order to benefit from the strength of both quantitative and qualitative methods (Creswell, 2003). The analysis resulted in key activities that were combined to form the framework of the auto-ID selection process in warehouse management.

1.8 Thesis Outline

The outline of this thesis is based on the methodology developed by Phillips and Pugh, (2010) which includes four elements: (a) background theory; (b) focal theory; (c) data theory; and (d) contribution. The background theory, which is presented in Chapter 2, discusses the research area based on a comprehensive literature review. Next, the focal theory develops an overall conceptual framework which is introduced in Chapter 3. Then, the data theory is concerned with issues such as: (a) developing a suitable research strategy for this study (b) selecting an appropriate research method and (c) developing a research protocol. These issues are discussed in Chapter 4. In Chapter 5, the data theory also deals with the process of collecting and analysing the data. Finally, the result of this research is the novel contribution, presented in Chapters 6 and 7.

Each of the seven chapters in this thesis addresses a specific part of the study. The outline of the thesis is shown in Figure 1.2 below, followed by brief explanations of each chapter in the thesis.

- **Chapter 1: Introduction (Background Theory)**

This chapter begins by offering a general introduction to the nature and intent of the research problem. It starts by providing the background to the research topic which is auto – ID selection decision in the warehouse management. Then, the aim and objectives of the research are set and the research questions are presented. Thereafter, a summary of the research methodology is given and a justification for the research through its main contributions is provided along with a brief description of each chapter.

- **Chapter 2: Literature Review (Background Theory)**

This chapter starts by providing a general overview of the literature on the warehouse roles and characterisations. It also provides a valuable comparative analysis of different auto- ID technologies which have been used in a warehouse environment such as barcode, active RFID, passive RFID and semi-passive RFID systems. Moreover, details about the main factors and sub-factors relevant to the auto-ID selection decision in a warehouse environment are presented. This chapter then focuses on the decision making process and concludes that there is a lack of studies in the literature regarding the selection process of auto-ID technology in the warehouse management.

- **Chapter 3: Developing a Conceptual Framework (Focal Theory)**

The aim of this chapter is to present an overall theoretical conceptual framework for the diverse factors affecting the selection decision of auto - ID Technology for warehouse management which arose from the literature review in Chapter. 2**.** The technology–organization–environment (TOE) framework derived by Tornatzky and Fleischer (1990) was used as a lens to categorise the identified factors into six categories: structural, operational, resources, organisational, technological, and external environment. This conceptual framework can be used as a tool to help practitioners and decision-makers with auto-ID selection in the warehouse environment. It can also benefit researchers in understanding the selection process of RFID and barcode systems in the warehouse management.

- **Chapter 4: Research Methodology (Data Theory - One)**

After completing the theoretical part, Chapters 2 and 3, this chapter presents the practical arena to test and validate the proposed conceptual framework. In order to achieve the aim and objectives of the research, this chapter presents the research methodology and design employed in this study. It provides the underpinnings of the research philosophy, strategies, methods, Delphi study process, interview protocol, and units of analysis used in this research. A detailed empirical research process roadmap is described in Chapter 4. Finally, the chapter discusses validity and reliability issues as well as the trustworthiness of this study.

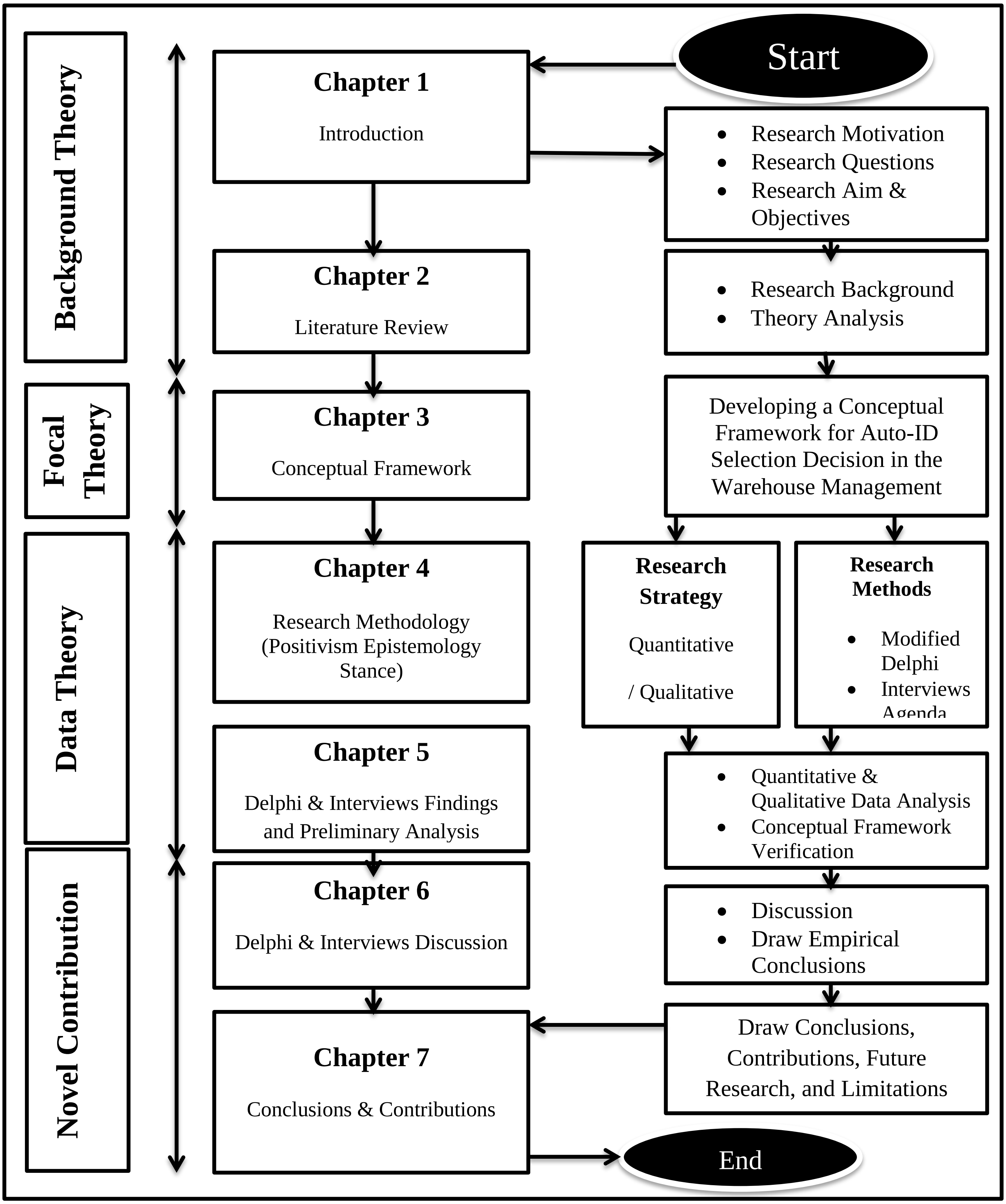


Figure 1.2 Thesis Outline

- **Chapter 5: Delphi Study, Interviews and Research Findings (Data Theory - Two)**

This chapter then provides a description of the findings of the Delphi study and the interviews that have been conducted with a worldwide panel of experts. This chapter offers an empirical analysis of these studies on the main issues of this research including: (a) the motivations of warehouses that seek to use auto-ID technology (b) the key steps in the selection process of auto- ID technology in the warehouse environment (c) the most difficult problem in making an auto-ID decision and the ways to overcome the problem as well as (d) the importance of major factors and sub-factors affecting auto-ID selection decision in the warehouse field.

- **Chapter 6: Discussion (Novel Contribution - One)**

All the findings from the primary data collected in the Delphi study and the interviews were analysed and presented with discussion in this chapter. The outcomes derived from the empirical data analysis helped to develop a comprehensive framework for the selection process. This chapter describes the multi-stage framework for auto-ID selection process for warehouse management and concludes the findings.

- **Chapter 7: Conclusions, Contributions, Future Research and Limitations (Novel Contribution - Two)**

This chapter presents the conclusion of the study. Significant summaries and reflective conclusions bring together background, focal and data theory in tandem with critical empirical research findings. Thereafter, based upon the empirical data and research findings, the statement of the research contributions and implications are outlined. Finally, recommendations that can benefit decision-makers including research limitations as well as potential future research perspectives and endeavours are considered.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In this chapter, the literature on the warehouse roles and characterisations, automatic identification and data capture (auto-ID) technologies for locating warehouse resources are presented. A comparative analysis of different auto- ID technologies that have been used in a warehouse environment such as barcode, active RFID, passive RFID and semi-passive RFID systems, is provided. Moreover, this literature review has outlined and discussed the key models/theories of IT adoption especially, Diffusion of Innovation (DOI) theory, and the Technology–Organization–Environment (TOE) framework because they are the only ones that are at the organisation level. Details about the main factors and sub-factors relevant to the auto-ID selection decision in a warehouse environment are also reviewed. This chapter then focuses on the process of the selection decision and concludes that there is a lack of studies in the literature regarding the selection process framework of auto-ID technology in warehouse management. The chapter is divided into eight sections. In Section 1; the process of reviewing the literature is explained. A literature review of the role of the warehouse in logistics and supply chain management is presented in Section 2. Next, literature on warehouse characterisations has been reviewed in Section 3. In Section 4; current warehouse resource management tools are presented. Existing real-time location tracking technologies in a warehouse environment are shown in Section 5. In Section 6; Models of IT adoption are outlined and discussed. Factors relevant to auto-ID selection decisions in the warehouse environment are discussed in Section 7. Finally, Section 8 is devoted to a summary of this chapter.

2.2 The process of Reviewing the Literature

Reviewing the relevant literature is an essential part of any research project. In the management field, Tranfield et al. (2003) have suggested that researchers need to review the relevant literature before conducting any empirical research in order to formulate a research question, which leads to appropriate empirical work and enhances pre-existing knowledge. The literature relevant to warehouse, barcode, and RFID technologies has been reviewed. The main purpose of the review is to develop an effective overview, provide a comparative analysis and cover potential benefits and challenges related to different auto- ID technologies in a warehouse context. Also, to identify the key factors relevant to the auto-ID selection decision in the warehouse field. The literature has been analysed according to the following criteria: the warehouse roles and characterisations (resources and operations); the current warehouse resources management technologies (barcode and RFID) used to track warehouse resources location; key models of IT adoption and the factors relevant to auto-ID selection decision in the warehouse environment.

In order to fully map the prior research in the field of "auto-ID in warehouse management", a systematic literature review was conducted in this research. This systematic review followed the three stages outlined by Tranfield et al. (2003) as follows:

- **Stage I -Planning the review**
  - Phase 1 - Identifying the need for a review
  - Phase 2- Preparing a proposal for a review
  - Phase 3 - Developing a review protocol
- **Stage II- Conducting a review**
  - Phase 1 - Identification of research
  - Phase 2 - Selection of studies
  - Phase 3 - Study quality assessment
  - Phase 4 - Data extraction and monitoring progress

- Phase 5 - Data synthesis

❖ **Stage III- Reporting and dissemination**

- Phase 1 - The report and recommendations

- Phase 2 - Getting evidence into practice

These stages and phases are described in detail below.

2.2.1 Stage I: Planning the Review

According to Tranfield et al. (2003), prior to the beginning of the review, a review panel should be formed with experts in the areas of both methodology and theory. However, due to the nature of this research (PhD/doctoral research), only the researcher and the researcher's supervisors were involved in this systematic literature review. The researcher and the researcher's supervisors helped to direct the systematic literature review process through regular meetings and resolved upcoming disputes over the inclusion and exclusion of studies. Planning the review contains three phases (Tranfield et al., 2003) as follows:

2.2.1.1 Phase 1- Identifying the Need for a Review

At the beginning of the systematic literature review, it is important to identify the objectives and the need for a review. Therefore, the main purpose of the review was identified in the initial stages of the review, which is to fully map the prior research in the field of “auto-ID in warehouse management” and identify the critical factors relevant to auto-ID selection decision in the warehouse management.

2.2.1.2 Phase 2– Preparing a Proposal for a Review

Clarke and Oxman (2001) have stated that the initial stages of systematic literature review may be an iterative process of definition, clarification and refinement. Tranfield et al. (2003) have suggested that within management research, it is important to conduct scoping studies in order to evaluate the relevance and size of the literature and to specify the subject area or research topic. Therefore, in this research, it was necessary to consider cross-disciplinary perspectives and alternative ways in which a subject area has previously been tackled. Also, the scoping study included a brief summary of the theoretical, practical and methodological history debates surrounding the field of “auto-ID in warehouse management”.

2.2.1.3 Phase 3– Developing a Review Protocol

According to Tranfield et al. (2003), the protocol for any management literature review may include a conceptual discussion of the research problem and the problem significance rather than a defined research question. In addition, management reviews are usually considered as a process of exploration, discovery and development. Therefore, Tranfield et al. (2003) have stated that it is often considered unacceptable to plan the literature review activities closely and they have suggested that it is important to produce a protocol that does not compromise the researcher’s ability to be creative in the literature review process. However, it is necessary to ensure that the review is less open to researcher bias than is the more traditional narrative review (Tranfield et al., 2003). Thus, in this research, a flexible protocol was developed which enabled the researcher to state explicitly what changes have been made and the rationale for doing so (e.g., reasons for including/excluding articles).

2.2.2 Stage II: Conducting the Review Planning

According to Tranfield et al. (2003), this stage contains five phases as follows:

2.2.2.1 Phase 1– Identification of Research

The systematic literature review conducted in this research began with the identification of keywords and search terms (e.g. warehouse, warehousing, RFID, Barcode), which are built from the scoping study, the literature and discussion within the review team (the researcher and the researcher's supervisors). Then, the search string: "warehouse" OR "warehousing" AND "RFID" OR "Barcode" was considered to be the most appropriate for this research and employed in all search fields.

2.2.2.2 Phase 2– Selection of Studies

The literature was mainly collected from Google Scholar and five key bibliographical databases namely: Science Direct, EBSCO, Emerald, Scopus and Sage. The reason for selecting multiple data sources is that the majority of journals across disciplines are included within all these databases. Therefore, it is possible to search for and locate a significant proportion of the published material (Stuck et al., 1999).

2.2.2.3 Phase 3– Study Quality Assessment

The first search using this search string resulted in 31,438 (on 05/08/2011) articles which included research conference papers, articles, reviews, book chapters and many other categories of document. However, in order to retrieve relevant sources/literature for a more detailed evaluation of the full text, the scope of the literature review process have to be defined by other factors. In this regard, Tranfield et al. (2003) have stated that: "…management researchers usually rely on the implicit quality rating of a particular journal, rather than formally applying any quality assessment criteria to the articles they include in their reviews (i.e. refereed journals are 'better' than practitioner journals)…". Therefore, the initial assessment criteria for including studies into the literature review were: the focus on auto-ID in warehouse management, theoretical and empirical studies, quantitative and qualitative studies and studies which were published in high quality academic/leading journals.

The conducted search elicited 2250 hits. By restricting the search string to "Article Title, Abstract, Keyword", this substantially reduced the number of records to just 575 (on 05/08/2011). The research output has been further refined by discarding the articles published in languages other than English, which resulted in a final list of 236 articles published in 95 peer-reviewed journals between 1990 and 2011.

The selection process and total number of articles relevant to "auto-ID in warehouse management" are presented below in Table 2.1.

Date of Search	Database	Results/ All Fields	Results/ Journals Papers	Results/ Article Title, Abstract, Keywords	Results/ English Language	Related Results
05/08/2011	Google Scholar	28768	850	N/A	N/A	98
05/08/2011	ScinceDirect	715	500	21	15	5

Date of Search	Database	Results/ All Fields	Results/ Journals Papers	Results/ Article Title, Abstract, Keywords	Results/ English Language	Related Results
05/08/2011	EBSCO	600	50	101	95	2
05/08/2011	Emerald	155	100	0	0	0
05/08/2011	Scopus	1200	750	453	126	75
05/08/2011	Sage	0	0	0	0	0
05/08/2011	**Total**	**31438**	**2250**	**575**	**236**	**180**

Table 2.1 The process and total number of articles reviewed

However, in order to find as many articles as possible and to cross-check the search results, another search using the previous search string was conducted in each of the leading journals within the following areas: Supply Chain Management, Operations Research, Information Systems, and Production Economics, namely*: Research Journal of Applied Sciences, Engineering and Technology; International Journal of RF Technologies: Research and Applications; International Journal of Production Research; International Journal of Information Technology and Management (IJITM); Computers & Industrial Engineering; Expert Systems with Applications; Management Research Review; Information Systems Frontiers; Industrial Management and Data Systems; International Journal of Manufacturing Technology and Management; International Journal of Physical Distribution & Logistics Management; International Journal of Logistics Systems and Management; Journal of Cases on Information Technology; Packaging Technology and Science; European Journal of Information Systems; European Journal of Operational Research; International Journal of Logistics Research and Applications; International Journal of Value Chain Management; International Journal of Production Economics; Supply Chain Systems Magazine; Material Handling Engineering; and Computers and Industrial Engineering.* This additional search improved the numbers of articles found by 7 to 243 articles.

All 243 items were then examined in order to cross-check and confirm the relevance of the search results (Irani et al., 2010). As a result, 63 articles were rejected because they matched the search but did not focus on auto-ID research work for warehouse management (i.e. they only mentioned the warehouse as an example of RFID/barcode application, however they did not actually conduct research in the domain). This left only 180 articles to be analysed in this review. In order to keep up-to-date with the published literature, the same methodology was applied until this dissertation was completed.

The literature reviews are covered from 1990 up to 2014 because the role of warehousing in supply chain management has started to change since 1990s (Harmon, 1993). For example, warehouse operations are no longer confined to inventory storage and protection of materials, but they include different operations ranging from receiving, put away, order-picking, packaging of items and after sales services, to light assembly and inspection (Poon et al., 2011b).

2.2.2.4 Phase 4– Data Extraction and Monitoring Progress

Systematic reviews employ data-extraction forms in order to reduce human error and bias. These usually include general information (title, author, journal, and publication details), research features and specific information (details and methods), identification of emergent themes, key results and additional notes (Tranfield et al., 2003). Data-extraction can be paper based or computer based. The development of the data-extraction sheets may depend on the nature of the research (Tranfield et al., 2003). In this research, data-extraction was computer based (excel sheet) and included (title, author, journal, publication details, methods, emergent themes, key results, additional notes).

2.2.2.5 Phase 5– Data Synthesis

Research synthesis is the collective term for a family of approaches that seeks to summarise, integrate, and, where possible, accumulate the findings of different studies on a subject area or research question (Mulrow, 1994). According to Greenhalgh (1997), a narrative review is the simplest and best-known form of research synthesis that aims to identify what has been written on a subject area or topic. In this research, a narrative review (textual descriptions of studies, tabulation, content analysis) was used in order to identify, summarise and synthesis the existing literature review on " auto-ID technology in warehouse management".

2.2.3 Stage III: Reporting and Dissemination

According to Tranfield et al. (2003), this stage includes two phases as follows:

2.2.3.1 Phase 1– The Report and Recommendations

Tranfield et al. (2003) have mentioned that a full report (rough-cut and detailed) 'descriptive analysis' of the field may be produced within management research. This can be performed using a simple set of categories with the use of the extraction forms. In this research, analysis of the articles according to the year of publication, country of core contributions, journal, publication type, research methods and type of auto-ID technologies is reported below in the following sub-sections (Sub-Section 2.2.3.1.1– Sub-Section 2.2.3.1.6).

Moreover, Trenfield et al. (2003) have stated that researchers also need to report the key emerging themes and research question(s) from the synthesis and to link themes across the various core contributions. In this research, therefore, the key emerging themes have been reported, linked and presented (see Tables 2.8, 2.9, 2.12, and 3.1). Also, the research questions have been developed and presented in Chapter 1 (Sub-Section 1.6).

2.2.3.1.1 Auto-ID and Warehouse Management Studies According to Year of Publication

The research findings (illustrated in Table 2.2) reveal that the number of articles published on auto-ID and warehouse management has constantly increased from 1990 (C=0) to 2013 (C=16). To date, the largest number of articles (25) appeared in 2011, followed by 2012 with a total count of 23 articles.

Year	Count	% of Total	Year	Count	% of Total
2011	25	13.89	2003	8	4.44
2012	23	12.78	2007	7	3.89
2006	19	12.67	2002	5	2.78
2009	18	10	1999	3	1.67
2010	17	9.44	1996	1	0.56
2013	16	8.89	1995	1	0.56
2008	14	7.78	1994	1	0.56
2004	12	6.67	1990	0	0

2005	10	5.56	2014	0	0
			Total	**180**	**100**

Table 2.2 Auto-ID in warehouse management studies published between 1990 and 2014

Prior to 1990 no articles at all appeared in the search of the Scopus Database. It may be argued that the increasing number of publications appearing post 2002 illustrates increasing levels of interest and research activity in the subject area.

2.2.3.1.2 Auto-ID and Warehouse Management Studies According to Journals

A total of 95 journals published 180 articles on auto-ID in warehouse management. Table 2.3 presents the list of the search output according to the journals (only the top 16 journals with two or more articles) in which the articles on auto-ID and warehouse management appeared. Table 2.3 illustrates that the largest number of articles (9) on auto-ID and warehouse management appeared in the International Journal of RF Technologies: Research and Applications. This is followed by the Expert Systems with Applications (7), and then the four outlets namely International Journal of Production Economics, Supply Chain Systems Magazine, IEEE Transactions on Antennas and Propagation, and Industrial Management and Data Systems, with 3 publications each. The top 16 list also includes 10 journals with only two publications each such as International Journal of Logistics Research and Applications; International Arab Journal of Information Technology; International Journal of Electronics; Journal of Manufacturing Systems; International Journal of Production Research; Journal of Theoretical and; Applied Electronic Commerce Research; Packaging Technology and Science; Research Journal of Applied Sciences, Engineering and Technology; Wireless Personal Communications; and World Academy of Science, Engineering and Technology.

Source Title/Journal	**Count**	**% of total**
International Journal of RF Technologies: Research and Applications	9	5.1
Expert Systems with Applications	7	3.89
International Journal of Production Economics	3	1.67
Supply Chain Systems Magazine	3	1.67
IEEE Transactions on Antennas and Propagation	3	1.67
Industrial Management and Data Systems	3	1.67
International Journal of Logistics Research and Applications	2	1.11
International Arab Journal of Information Technology	2	1.11
International Journal of Electronics	2	1.11
Journal of Manufacturing Systems	2	1.11

Source Title/Journal	Count	% of total
International Journal of Production Research	2	1.11
Journal of Theoretical and Applied Electronic Commerce Research	2	1.11
Packaging Technology and Science	2	1.11
Research Journal of Applied Sciences, Engineering and Technology	2	1.11
Wireless Personal Communications	2	1.11
World Academy of Science, Engineering and Technology	2	1.11

Table 2.3 Auto-ID in warehouse management studies according to source titles/journals

The findings further show that of the journals publishing the highest numbers of articles on auto-ID in warehouse management, only few related with 'Operations and Management', 'Information Systems' and other business and management related areas, while all the publications mainly related with engineering and other technical disciplines. This might be due to the fact that a large number of early publications on auto-ID in warehouse management addressed technology development and engineering aspects of auto-ID technologies. Also, it could be the case that the journals from engineering and other technical disciplines are comparatively more sympathetic to such material.

2.2.3.1.3 Auto-ID and Warehouse Management Studies According to Country

The research findings (illustrated in Table 2.4) disclose that the research presented in the 180 publications we identified on "Auto-ID and warehouse management" was conducted in 26 countries. By far the largest number of contributors were located in the USA (52, 28.89%), which was followed by with a number of other countries such as Hong Kong (25, 13.89). The third largest category (18, 10%) was formed by the UK and China authors and then Taiwan (15, 8.33%) at fourth place. Table 2.4 illustrates the proportion of contributors from the 26 countries.

Country	Count	% of Total	Country	Count	% of Total
USA	52	28.89	Germany	2	1.11
Hong Kong	25	13.89	France	1	0.56
China	18	10	Iran	1	0.56
UK	18	10	Macau	1	0.56
Taiwan	15	8.33	Netherlands	1	0.56
Australia	10	5.56	Portugal	1	0.56
Italy	6	3.33	Romania	1	0.56
Japan	6	3.33	Slovakia	1	0.56
Malaysia	4	2.22	Spain	1	0.56

Country	Count	% of Total	Country	Count	% of Total
India	4	2.22	Turkey	1	0.56
Greece	3	1.67	Ireland	1	0.56
Canada	3	1.67	Austria	1	0.56
South Korea	2	1.11	Hungary	1	0.56
			Total	**180**	**100**

Table 2.4 Auto-ID in warehouse management studies according to country

2.2.3.1.4 Publication Type (According to Publisher Classification)

Findings presented in Table 2.5 illustrate that the largest number of published papers categorised as research paper (74, 41.11%) followed by case study (54, 30%), general review (28, 15.56%), technical paper (18, 10 %), conceptual paper (3, 1.67 %) and literature review (3, 1.67 %).

Publication Type	Count	% of total
Research Paper	74	41.11
Case Study	54	30
General Review	28	15.56
Technical Paper	18	10
Conceptual Paper	3	1.67
Literature Review	3	1.67
Total	**180**	**100**

Table 2.5 Auto-ID and warehouse management studies according to publication type

2.2.3.1.5 Research Methods

The findings illustrate that although a total of seven different research methods were recorded from our data analysis activities, the majority of studies (75, 41.67 %) within our results utilised multi-method research design which frequently combined design, simulation, and experimental test (see Table 2.6).

Research Methods	Count	% of total
Survey	10	5.56 %
Interview	10	5.56 %
Case Study	16	8.89 %
Experimental Test	25	13.89 %
Literature Review Analysis/Frameworks/ Conceptual/Design	30	16.67 %

Mathematical modelling/Simulation Modelling/ Algorithms	14	7.78 %
Multi-Method	75	41.67 %
Total	**180**	**100 %**

Table 2.6 Research methods employed in auto-ID and warehouse management research (Categories adapted from *Irani et al., 2010*)

The other major category employed was the literature review analysis/frameworks /conceptual model/design research, which was used in 30 articles. The other methods employed were experimental test (25), case study (16), mathematical modelling/simulation modelling/algorithms (14), survey (10) and interview (10).

2.2.3.1.6 Type of Auto-ID Technologies

Findings presented in Table 2.7 illustrate that the largest number of the studies (C= 170, 94.44 %) considered the integration of RFID technologies as substitution of current technologies such as, barcode. Only a few studies considered barcode technology in a warehouse management (C= 10, 5.56 %). However, no studies supported the notion of hybrid RFID-barcode systems.

Auto-ID Type	Count	% of total
Radio Frequency Identification (RFID)	170	94.44
Barcode	10	5.56
Total	**180**	**100**

Table 2.7 Types of auto-ID technologies adopted in warehouse management research

2.2.3.2 Phase 2– Getting Evidence into Practice

According to Tranfield et al. (2003), systematic literature review helps develop a reliable knowledge base by accumulating knowledge from a range of studies, which serves practitioners/managers. A very wide range of factors that may potentially affect warehouses in deciding to use auto-ID technologies has been found in this systematic literature review. The technology–organisation–environment (TOE) framework derived by Tornatzky and Fleischer (1990) has been used as a theoretical framework to categorise the identified factors and develop a conceptual framework that consists of six categories: (1) structural; (2) operational; (3) resources; (4) organisational; (5) technological; and (6) external environment category. The results of this literature review may have implications for practitioners/warehouse managers interested in auto-ID technologies. This is because the choice of auto-ID (barcode or RFID) is not straightforward, but a number of factors influence the selection decision (Poon et al., 2011a; Ilie-Zudor et al., 2011). Moreover, in order to understand the auto-ID technology selection decision in a warehouse context, it is important that warehouse managers and/or auto-ID project managers take heed of all key factors that affect this decision (Ilie-Zudor et al., 2011; Pero & Rossi 2013).

2.2.4 Literature Review Limitations

The literature review process conducted in this research is subject to a number of limitations. First of all, despite using five Databases and Google Scholar where the majority of journals across disciplines are included within these data sources, there is a possibility of some scientific articles on “auto-ID in warehouse management” not being covered. The second limitation is some of the articles may have been added at a later stage and backdated as they become available from the publishers. Therefore, we recognise that some articles might not have been included as they were not available on the databases at the time of searching. Finally, this research only focused on the research articles published in the English language. Despite these limitations, it is believed that this literature review has achieved reliable comprehensiveness and has implications for academics and practitioners in establishing new research directions of auto-ID technologies in the warehouse management.

2.3 Review of the Warehouse Roles in Logistics and Supply Chain Management

A warehouse or a distribution centre is a commercial building used for buffering goods and materials. Warehouses are a key aspect and play vital roles in modern supply chains and in the success, or failure, of businesses today (Frazelle, 2002a). Besides the traditional role of warehouses associated with the holding of inventory, they also have a critical impact on customer service levels and logistics costs (Higginson & Bookbinder, 2005). Therefore, it is crucial to the success of businesses that warehouse managers select the optimum auto-ID technology which may offer and sustain the competitive advantage of their company (Chow et al., 2006). However, every warehouse differs from the others in many ways, and the right auto-ID selection decision requires that warehouse contextual factors are taken into account (Karagiannaki et al., 2011). Consequently, the warehouse types, roles, objectives, operations and resources are reviewed in the following sub sections in order to identify the key warehouse contextual factors and sub-factors that may influence the auto-ID selection decision.

2.3.1 Types of Warehouses

It is possible to distinguish three main types of warehouses (Berg & Zijm, 1999):

- Production warehouses;
- Distribution warehouses; and
- Contract warehouses;

Production warehouses hold raw materials used in a manufacturing process, and also to store finished and semi-finished goods in the production facility. In *distribution warehouses* products storage is considered a very temporary measure. The main purpose of these warehouses is to receive products from many suppliers and quickly ship them out to customers. *Contract warehouses* include warehousing and logistics services that are provided to one or more customers.

2.3.2 Purpose of Warehouses

Warehouses contribute to a multitude of the company's missions, such as (Lambert et al. (1998),

- Achieving transportation economies (e.g. combine shipment, full-container load) (Klincewicz & Rosenwein, 1997)
- Accomplishing production economies (e.g. make-to-stock production policy) (Slack et al., 2007)
- Taking benefit of quality purchase discounts and forward buys (Slack et al., 2007)
- Supporting the company's customer service policies (Korpela & Tuominen, 1996)
- Meeting uncertainties and the changes in market conditions (e.g. seasonality, demand fluctuations, competition) (Ackerman, 1997; and Hill, 2005)
- Overcoming the differences of time and space that exist between manufacturers and customers (Slack et al., 2007)
- Attaining least total cost logistics comparable with a requested level of customer service

- Supporting the just-in-time programs of providers and customers
- Providing customers with a variety of products instead of a single product on each order (i.e. consolidation) (Hill, 2005)
- Providing temporary storage of goods and materials to be arranged or recycled (i.e. reverse logistics) (Slack et al., 2007)
- Providing a store place for trans-shipments (i.e. direct delivery, cross-docking) (Slack & Lewis, 2002)

These objectives show that warehouses are needed and play a critical role in the modern supply chains and in the companies' logistics success.

2.3.3 Roles of Warehouses

Warehouses can be classified according to their roles in the supply chain as follows (Ackerman, 1997; Frazelle, 2001; and Farzelle, 2002b):

- **Raw material and component warehouses:** These warehouses hold raw materials which are used in the firm's production operation and to supply them to a manufacturing or assembly process.
- **Work-in-process warehouses**: They hold materials that are uncompleted and still under process.
- **Finished goods warehouses:** They hold those products that are completed and ready for sale in order to balance the deviation between production schedules and demand. Its purpose is to loosen the sale function from the production function so that it is not important to finish the products before a sale can occur. In other words, finished goods warehouses store finished products to serve as a buffer to protect against uncertainties in customer demand. These warehouses are normally located near manufacturing locations.
- **Distribution warehouses and distribution centres:** Distribution warehouses collect products from different manufacturing points for combined shipment to the customer. Normally, these warehouses are situated central to either the manufacturing plants or the customer base (Rushton et al., 2010).

- **Fulfilment warehouses and fulfilment centres:** These warehouses receive, pick, and dispatch small orders for individual customers.

- **Local Warehouses:** The main purpose of these warehouses is to respond to the customer's needs. Often, single items are picked, and the same object is dispatched to the customer every day (Abrahamsson & Brege, 1997).

- **Value-added service warehouses:** In these warehouses important product customization activities occur like packaging, labelling, pricing, and returns objects processing (Van Den Berg, 2007).

In fact, warehouses are critical to the provision of high customer service levels. A big proportion of warehouses offer their customers a same-day or next-day lead-time from inventory (Baker, 2004) and they need to accomplish this reliably within tight tolerances of speed, accuracy and lack of damage.

2.3.4 Roles of Distribution Centres

Besides the traditional role of warehouses mentioned above which has been associated with holding of inventory, some new trends are emerging. For instance, Higginson & Bookbinder (2005) and Maltz & DeHoratious (2004) list the roles of distribution centres as follows:

• **Make-bulk/break-bulk consolidation centres,** where customer orders are consolidated together into one delivery in order to gain transport economies (Ackerman, 1997; and Van Den Berg, 2007).

• **Cross-dock points**, where products are transferred directly to the shipping docks without being put away into inventory. This means that customer orders only pass through the facility while they are fulfilled from another source (e.g. a manufacturing plant) (Baker, 2004).

• **Transhipment facilities**, they are used to change transport mode (e.g. from big line-haul vehicles to smaller delivery vehicles) (Maltz & DeHoratious, 2004).

• **Assembly facilities/production deferment centres**, where goods are configured or assembled particularly to customer requirements so that a small range of generic goods can be held in inventory (Ackerman, 1997; Van Den Berg, 2007).

• **Product-fulfilment centres**, which is used to respond directly to orders from the final customer (e.g. internet fulfilment operations) (Baker, 2007).

• **Returned goods points**, e.g. reverse logistics of packaging, damaged, faulty or end-of-life products.

• **Miscellaneous/mixed roles**, providing many other combined activities, such as customer support, installation and repair services.

Although warehouses are essential to a wide range of customer service activities, they are also critical from a cost perspective. According to a survey conducted by ELA European Logistics Association/AT Kearney in 2004, warehousing costs (e.g. rent, utilities and salaries) accounted for 25% of total logistics costs, whilst according to a survey conducted by Establish Inc. /Herbert W. Davis & Co., 2005 in USA, warehousing costs accounted for 22% of the total logistics costs. With this critical impact on customer service levels and logistics costs, it is thus imperative to the success of businesses that warehouse managers adopt efficient auto-identification technologies for locating the warehouse resources accurately and supporting the warehouse operations effectively and efficiently. This is particularly important as the warehouses will meet demands from suppliers as well as customers in a timely and cost-effective manner (Chow et al., 2006; Poon et al., 2008).

2.4 Review of Warehouse Characteristics

There are three different angles from which a warehouse may be viewed and which provides warehouse characteristics: operations, resources, and organisation. Products arriving at a warehouse are taken through a number of steps called processes or operations. Resources include all means, equipment and staff needed to operate a warehouse. Finally, "organisation" refers to all planning and control procedures used to run the system (Rouwenhorst et al., 2000).

2.4.1 Warehouse Operations

The main function of a warehouse is to receive a customer's orders, retrieve required items, and finally prepare and ship these orders. There are different ways to organise these operations but in general, most warehouses share the following common functions

(Tompkins & Smith, 1998; Rouwenhorst et al., 2000; Frazelle, 2002b; and Tompkins et al., 2003):

• **Receiving:** The process of the orderly receipt of all items, checking quality and quantity, and disbursing items for storage or to other organisational functions requiring them. Receiving is time consuming and subject to human error (Alexander et al., 2002).

• **Put away:** Includes materials handling, defining the suitable location for items, and transferring them to a specified storage place to wait for demand. The storage area may consist of two parts: the *reserve area*, where items are stored in the most economical way (bulk storage area) and the *forward area* where items are stored in smaller quantities so that storage units are retrieved and accessed easily by an order picker. For example, the reserve storage may comprise pallet racks while the forward storage may comprise shelves. The movement of items from the reserve area to the forward storage is called *replenishment* (Rouwenhorst et al., 2000).

• **Order picking:** retrieving items. This can be performed manually, or can be (partly) automated, from their storage places and transferring them either to the accumulation, sorting, and/or consolidation process or directly to the shipping area. Consolidation here refers to the grouping of items intended for the same customer. According to Alexander et al. (2002), the order picking function can employ up to half the workers in a distribution centre and requires many verifications. In addition, it represents 50-75% of the total operating costs in a typical warehouse (Coyle et al., 1996).

• **Shipping:** Orders checked and inspected, orders packed, palletised and loaded into trucks or trains for further delivery (Tompkins et al., 2003).

Figure 2.1 shows these typical warehouse operations, functional areas and flows within warehouses. Also, it shows the c*ross-docking* activity which is performed when the received items are transferred directly from the receiving docks to the shipping docks (short stays or services may be needed but little or no order picking is required).

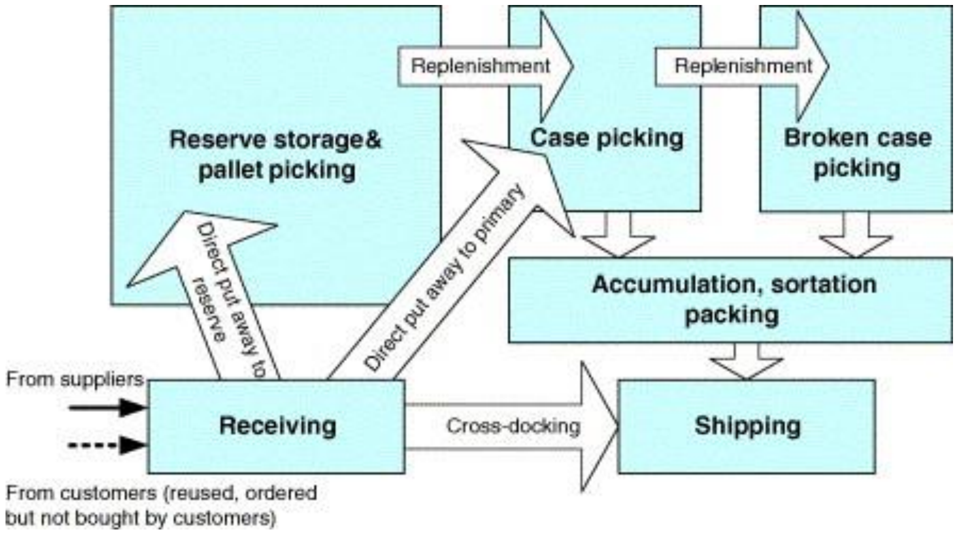


Figure 2.1 Typical warehouse operations and flow
(Tompkins et al., 2003)

2.4.2 Warehouse Resources

According to a classification by Tompkins et al. (1998) and Rouwenhorst et al. (2000), a number of warehouse resources can be distinguished:

- Storage units, which may be used for the storage of products e.g. pallets, cartons and plastic boxes, and trays.

- Storage systems, are very diverse and may consist of many subsystems in which different types of products may be stored. Storage systems may range from simple shelves up to automated cranes and conveyors.

- Material handling equipment, used for the retrieval of items from the storage system and preparing these items for the expedition e.g. standard forklifts, reach trucks, pallet trucks, sorter systems, and truck loaders.

- **Order pick Auxiliaries,** this equipment supports the order picker such as barcode scanners.

- Computer systems, which can be used to enable computer control of processes by a warehouse management system.

- **Personnel/Warehouse staff members,** are an important resource because they perform and control all of the pre-described resources.

Warehouse resources usually represent a sizeable capital investment. Nearly 50% of the costs in a typical warehouse are labour-intensive while facilities, machinery and storage equipment represent a smaller part of the capital investment (Aminoff et al., 2002). Therefore, decreasing the amount of labour or pursuing higher labour productivity can be seen as a means of cutting down the costs of warehouse operations. This is typically done by investing in costly warehouse technologies. However, to achieve an acceptable or positive rate of return on investments, the right technology must be selected and used properly (Angeles, 2005).

2.5 Current Warehouse Resource Management Tools

In today's complex supply chain network, warehouses focus on various essential logistics functions such as inventory management and location, receipts from suppliers, deliveries to customers, orders processing, labour management, equipment management and processes management to perform these activities and functions in the warehouse. Therefore, good warehouse resources management is the most important factor for handling warehouse operations effectively and efficiently which will lead to satisfying suppliers' and customers' demands (Poon et al., 2008). Hence, warehouse management systems (WMSs) are suggested for handling and monitoring the warehouse resources and operations as shown in Figure 2.2.

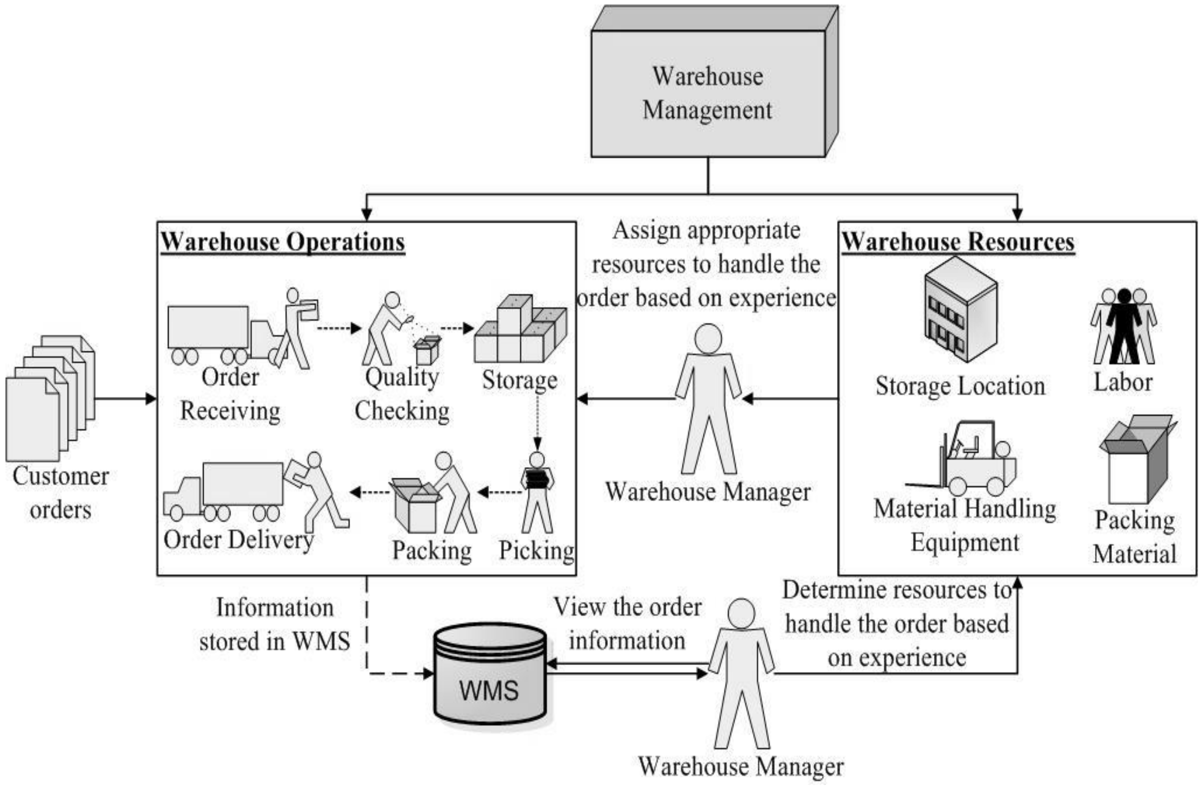


Figure 2.2 Current operation processes in warehouse
(Source: Lam et al., 2010)

The primary purpose of a warehouse management system is to provide the information necessary to manage and control the flow and storage of materials within a warehouse, from receiving to shipping (Faber et al, 2002). According to Faber et al. (2002), three types of warehouse management systems can be distinguished:

• **Basic WMSs:** supports stock and location control only. The products can be identified by using scanning systems. Also, the systems are mainly used to determine the location for storing the received products and to register this information. Moreover, storing and picking instructions are created by the system and potentially displayed on RF-terminals. The information for warehouse management is simple and it mainly focuses on throughput.

• **Advanced WMSs:** In addition to the functionality offered by basic WMSs, the advanced WMSs are capable of planning resources and activities to synchronize the flow of products in a warehouse. These systems focus on throughput, stock and capacity analysis.

• **Complex WMSs:** Warehouses can be optimized by using the complex WMSs. The systems are able to provide the information about the location of each product (e.g. tracking and tracing), and they also provide the information about where these products are going to and why (e.g. planning, execution and control). The complex WMSs are able to interface with different technical systems such as, automated storage and retrieval systems (AS/RS), sorter systems, radio frequency (RF), robots and data collection systems. Furthermore, the complex WMSs offer additional functionality like transportation planning, value added logistics planning, and occasionally simulation to optimize the parameter setting of the system and to improve the efficiency of the warehouse operations as a whole.

2.5.1 Automatic Identification and Data Capture (Auto-ID) Technologies

Warehouse management systems (WMSs) use different automatic identification and data capture (auto-ID) technologies such as barcode and radio frequency identification (RFID) technology (Waldner, 2008).

2.5.1.1 Barcode Technology

A barcode is an image of lines (bars) and spaces which store data for identifying and tracking products (Wyld, 2006). Barcodes have been developed for more than fifty years. Hundreds of different types of traditional one-dimensional barcodes are in existence in the market, while the most widely used is *Universal Product Code* (UPC) (Brown, 2007). A one-dimensional (1D) barcode includes typically up to 22 alpha numeric characters which are used to reference an external database. The 1D barcode contains no meaningful data (White et al., 2007) without reference to the database. Printing and reading the barcode is frequently performed with electronic devices, but specific conditions must be met. For instance, the scanning device must be carefully and precisely positioned near the barcode in order to read the data from it. Therefore, it was difficult to build a completely automated tracking system and there were no cost-effective alternatives (Brown, 2007).

A new innovation of barcodes is known as *2D barcode* or two-*dimensional barcode*. There are more than 20 different types of 2D barcodes nowadays containing, black and white and coloured versions. For instance, A PDF417 2D barcode can encode 1850 alphanumeric data (Shaked et al., 2001). Datastrip’s 2D barcodes may contain several kilobytes of data which enable them to store colour photographs, biometric data and text in a single magnetic stripe- sized barcode (White et al., 2007). The main difference from the traditional one-dimensional ID barcode is that data is extended to the second dimension which allows them to store actual information and not just data. However, use of the 2D barcode still requires proper reader positioning and light conditions. Figure 2.3 and Figure 2.4 show the one- and two-dimensional barcodes (Wyld, 2006).

Conventional 1D barcode (UPC)

Figure 2.3 Traditional one-dimensional barcode

Barcode (PDF417)2D

Figure 2.4 Two-dimensional barcode

Barcode-based warehouse management systems are unable to update daily inventory operations, locations of forklifts and stock keeping units (SKUs) in real-time or to provide timely and accurate data of warehouse operations (Shih et al., 2006). Also, incorrect data is inevitably input from time to time as the systems depend heavily on warehouse staff members to input operational data manually and human error is unavoidable (Sexton et al., 2000). Due to the shortcomings of barcode technology, RFID has become an alternative for tracking and monitoring warehouse resources and operations.

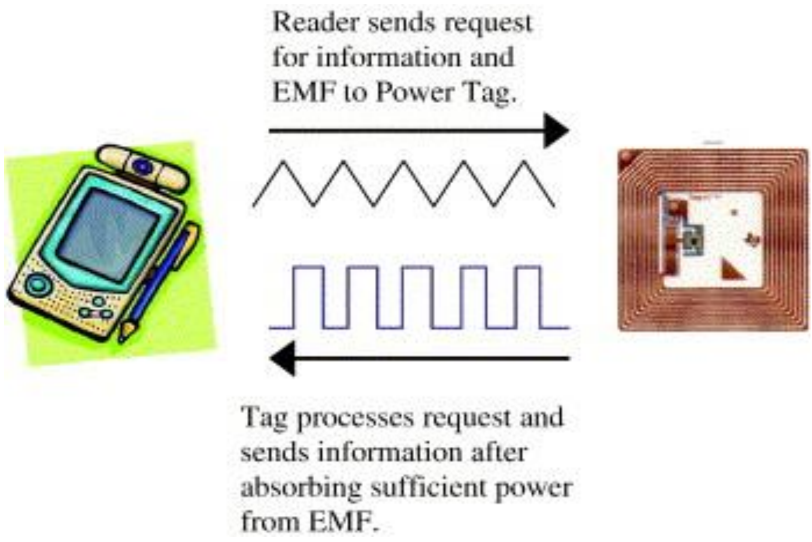
2.5.1.2 RFID Technology

RFID can be defined as “A generic technology concept that uses radio waves to identify, locate, and track objects” (Auto-ID Centre, 2002). RFID is a real-time information technique which can be used to facilitate the collection and sharing of data in a warehouse in order to accurately track the location and status of warehouse resources and to support warehouse operations effectively (Chow et al., 2006; and Poon et al., 2011a). RFID technology was first used over sixty years ago in Britain to identify friendly aircraft in the Second World War (Holloway, 2006). However, the technology took almost twenty years after the war to be considered as a business solution by the industry.

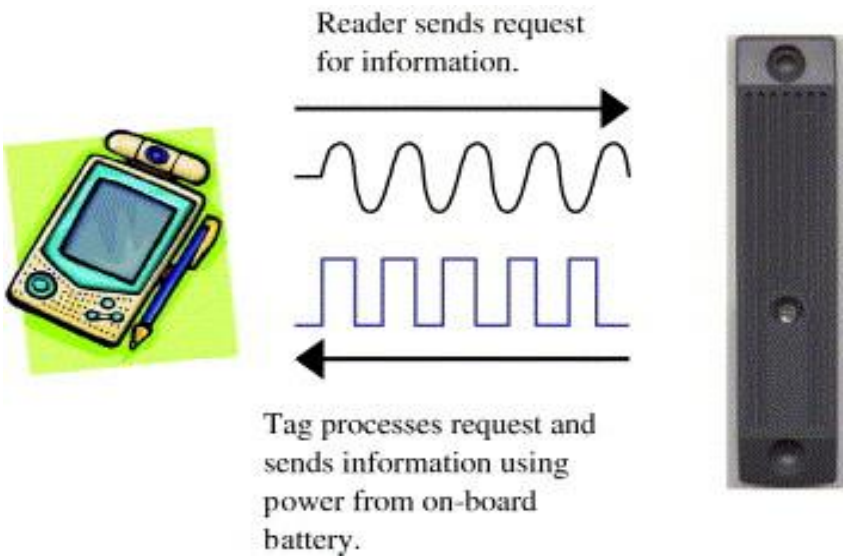
The commercial use of RFID technology began in the 1980s, mainly in the transportation industries of railroad and trucking (Landt, 2001). In its generic form, a RFID system is composed of three major components: (1) a tag/transponder, (2) a reader/interrogator, and (3) a host computer (Want, 2004). A small tag / transponder stores and retrieves data and this tag consists of an integrated circuit chip connected to an antenna, (Prater et al., 2005; Smith, 2005; Lahiri, 2005). The role of the antenna is to define the read range of the tag which is capable of responding to radio waves transmitted from the RFID reader. Also, certain types of tag are capable of sending, processing, and storing data (Wu et al., 2006). According to EPC-Global standards, the chip memory includes an Electronic Product Code (EPC) which enables the identification of each item in a unique way (Brock, 2001; Goel, 2007). There are different EPC formats such as, 64, 96, 128 bits (Lahiri, 2005). For instance, a 96-bits EPC can identify more than 268 million manufacturers, more than 16 million kinds of objects, and nearly 69 billion articles for each manufacturer (Brock, 2001). Through using radio waves, RFID systems provide real-time communication with multiple objects simultaneously at a distance, without contact or direct line of sight (Garcia et al., 2007).

On the other hand, the reader/ interrogator emits radio signs and receives in return answers from tags via antennas. Meanwhile, the host computer runs specialised RFID software or middleware to filter the data and route it to the correct application, to be processed into useful information (Want, 2004). There are three main types of RFID tags: (a) active-containing a small battery, (b) passive - draws energy from the transponder and (c) semi-passive - battery powered but requires signal from the transponder for activation (Angeles, 2005).

The following figures show the difference between passive and active RFID power scheme.



(A)



(B)

Figure 2.5 Passive RFID power scheme *(A)*, and Active RFID power scheme *(B)*
(Source: Goodrum et al., 2006)

The advantages and disadvantages of barcode and RFID systems are shown in Figure 2.6.

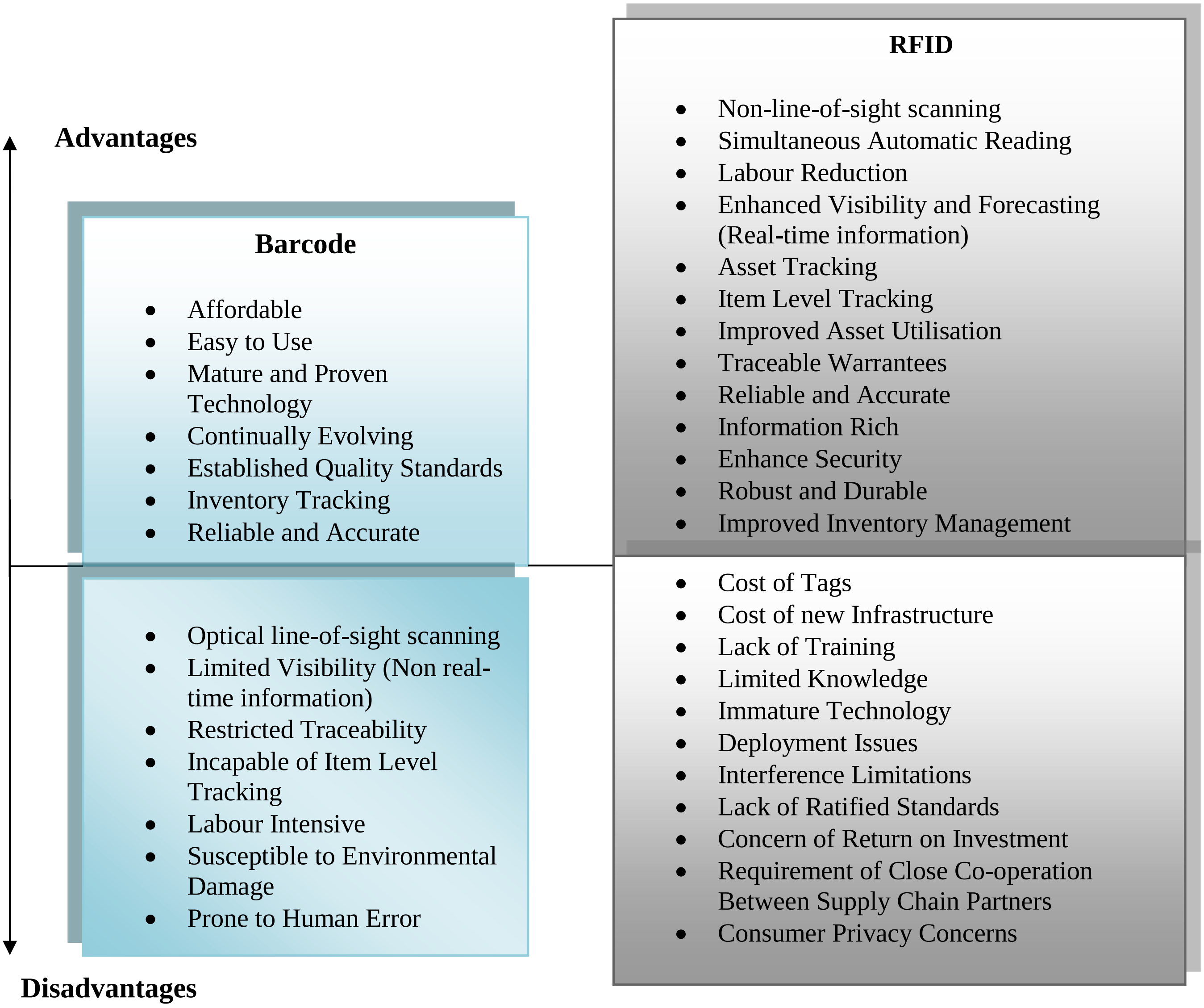


Figure 2.6 Dis (advantages) of Barcode and RFID
(Adapted from Huber et al., 2007)

Although RFID and barcode have emerged from the same technology family, auto identification, they are different in many ways such as line-of-sight, reliability and accuracy, tag and data characteristics, cost considerations, and deployment issues. Table 2.8 shows the differences between the two technologies.

Comparison of Characteristics	**Barcode**	**RFID**
Line-of-sight *(Finkenzeller,1999; Raza et al.,1999;Wyld, 2006; Song et al.,*	▪ Optical line-of-sight Scanning (It can only be read individually and with	▪ Automatic Non-line-of-sight Scanning (Multiple tags can be

Comparison of Characteristics	Barcode	RFID
2006; and Speakman & Sweeney, 2006)	the alignment)	read simultaneously)
Labour *(Speakman & Sweeney, 2006; Huber et al.,2007)*	▪ Labour Intensive: - Manual tracking; and - Prone to human error	▪ Labour Reduction: -Reducing operating costs; - Improving efficiency; -Reducing problems (e.g. out-of-stock occurrences); -Automatically tracked ; and - Removing human error
Visibility *(Raza et al., 1999; Wyld, 2006; Song et al., 2006)*	▪ Limited Visibility (Non-Real-Time data)	▪ Enhanced Visibility: (Real –Time data)
Accuracy and Reliability *(Raza et al.,1999; Speakman & Sweeney, 2006; Wyld, 2006; Huber et al., 2007)*	▪ Quite reliable and accurate, but they are subject to operator mistakes (e.g. forgetting/skipping to scan) and environmental obstacles	▪ Some initial read reliability and accuracy issues have been discovered through pilots, however these are being solved as the technology matures ▪ Removing operator mistakes and environmental obstacles
Item Level Tracking *(Raza et al., 1999; Wyld,2006; Song et al., 2006)*	▪ Incapable of Item Level tracking: - It can only identify the type of item	▪ Item Level Tracking: - Information on tags can also specify a product's expiry date
Traceability& Product Recalls *(Wyld,2006; Huber et al., 2007)*	▪ Restricted Traceability and Product Recalls across a supply chain	▪ Traceable Warranties and Product Recalls across a supply chain
Quality Control *(Wyld,2006; Huber et al., 2007*	▪ Quality Control cannot be very accurate because barcode has restricted traceability across a supply chain	▪ Quality control is accurate as RFID has traceable warrantees across a supply chain. Also RFID tags can monitor shock and temperature levels to

Comparison of Characteristics	Barcode	RFID
		ensure the quality of the end product
Tag and Data Characteristics *Finkenzeller,1999; Huber et al., 2007)* **Information Properties** *(Huber et al., 2007)*	▪ Traditional one-dimensional ID barcode (minimal amount of data) ▪ Two-dimensional (2D) and Reduced Space Symbology (RSS) (more information). ▪ Barcode information cannot be updated	▪ Active, Passive, and Semi-Passive. Tags can typically hold as little or as much information as required by users, although this is limited by cost ▪ Tags information can be updated
Inventory & Warehouse Management *(Speakman & Sweeney, 2006; Song et al. 2006; Chow et al., 2006; Huber et al., 2007; Poon et al., 2009; Poon et al., 2011a)*	▪ Incorrect information about inventory level, warehouse capacity, and storage location; limited visibility (non-real-time data); affecting warehouse productivity; and increasing the operational costs of warehouse	▪ Improving Inventory Management because it can provide an accurate picture of inventory levels in real-time; locating warehouse resources easily; enhanced visibility (real-time data); enhancing warehouse productivity; and reducing the operational costs of warehouse
Security *(Raza et al., 1999;* and *Huber et al., 2007)*	▪ limited or no security capabilities	▪ Information rich so, enhanced security
Environmental Issues *(Finkenzeller, 1999; Wyld, 2006; Huber et al., 2007)*	▪ Susceptible to Environmental Damage, cannot be read if damaged or dirty	▪ Robust and Durable, it can cope with harsh environments(e.g. a warehouse environment) with excessive dirt, dust, moisture, and in temperature extremes
Cost Considerations **Cost of Technology** ***(****Finkenzeller, 1999; Huber et al., 2007)* **Cost Savings**	 - Relatively cheap ($0.001)/tag - Improving inventory	 - Expensive ($0.40-10 / passive tag and $100 / Active tag) - Enhanced inventory

Comparison of Characteristics	Barcode	RFID
(Raza et al., 1999; Wyld, 2006; Huber et al., 2007; Poon et al., 2009)	management and efficiency, but it requires manual tracking and therefore they are prone to human error and a large labour component is required; and many problems in a warehouse; and limited security	management; improving efficiency; reducing operating costs, it can be automatically tracked removing human error and reducing required labour; reducing problems such as out-of-stock occurrences; and advanced security
Deployment Issues *(Michael & McCathie., 2005; Huber et al., 2007)*		
Deployment Costs *Michael and McCathie., 2005; Huber et al., 2007)*	- Inexpensive	- Cost of deployment (new infrastructure)
Interference& Reading *Michael & McCathie., 2005; Huber et al., 2007)*	- Not Available	- Radio interference which requires numerous pilots and testing
Ongoing Innovations *(Huber et al., 2007)*	- Mature and proven technology; and continually evolving	- Immature technology; and new applications are continually emerging
Ease of Use *(Huber et al., 2007)*	- Easy to use with little or no training required	- Training required for staff and users
Established Standards *(Finkenzeller,1999; Huber et al., 2007)*	- Barcodes are extremely developed and they are the standard in auto-ID supply chain management (SCM) Technology. It will be around for quite some time	- RFID has a limited number of deployments in SCM. In spite of this, recent mandates from leading organizations mean that in the near future the technology will be adopted extensively
Supplier and Retailer Cooperation *(Huber et al., 2007)*	- Not Available	- Requirement of close co-operation between supply chain partners

Comparison of Characteristics	Barcode	RFID
Privacy Concerns *(Huber et al., 2007)*	- The barcodes are unable to track individual items and this limits consumer privacy concerns	- Consumer privacy concerns (tags are rich information and quite durable)

Table 2.8 Comparison between Barcode and RFID systems

From the above table, we can see that RFID technology is much more expensive than barcode technology but, many people still want to implement it in their own business as it is able to identify products at the item level, can read without a line of sight to the reader, and it can operate in harsh environments such as in dirty, dusty and high moisture conditions which affect barcodes (Li et al., 2006). In addition, it can handle more complex information and it can be read even when it is embedded in an item (e.g. in the cardboard cover of a book or the packaging of a product) (Roberts, 2006; Wong et al., 2006). Furthermore, barcode still suffers from several problems and limitations that cannot be overcome easily (Kleist et al., 2004; Hunt et al., 2007). For instance, data are scanned and data input manually by operators so errors occur easily because human error is unavoidable and data cannot be shown in real-time (Hockey and Sauer, 1996; Sexton et al., 2000; Huang et al., 2007). Because of these problems and limitations, the collected data are not synchronised to reflect the real situation in the warehouse environment.

In other words, by using barcode systems, it is difficult to determine the real-time status and location of warehouse resources. Also, they cannot provide timely and accurate warehouse operations data (Shih et al., 2006). Thus, the warehouse operations and execution cannot be monitored and controlled in an effective way. Therefore, it is essential to adopt another data collection technology such as RFID for locating the warehouse resources accurately so as to support warehouse operations in a timely manner (Chow et al., 2006, Bottani & Rizzi, 2008; Poon et al., 2008; Poon et al., 2009; and Poon et al., 2011a).

2.5.1.3 Real-Time Data Management Techniques in Tracking Warehouse Resources Location

There are some real-time data management techniques implemented for smoothing data sharing in the existing supply chain and providing object location information. As far as the indoor environment is concerned, different technologies have been developed to locate objects in the buildings such as infrared, ultrasonic and radio frequency identification (RFID) technologies (Xu & Gang, 2006). Among these three technologies, RFID is an emerging technology that has been widely adopted in numerous areas in supply chain activities such as manufacturing, warehousing and retailing for object identification (Smaros & Holmstrom, 2000; Thevissen et al., 2006; Vijayaraman and Osyk, 2006). The RFID technology has made a significant contribution to the warehouse environment and many world-famous companies, such as Wal-Mart, Gillette, and Proctor & Gamble, have already implemented RFID technology for handling their warehouse resources (Chow et al., 2006; Poon et al., 2008; Sahin & Dallery, 2009; Poon et al., 2009; Poon et al., 2011a; Collins, 2004).

As we mentioned earlier, there are three types of RFID tags: (a) active- containing a small battery, (b) passive - draws energy from the transponder and (c) semi-passive - battery powered but requires signal from the transponder for activation (Angeles, 2005). Active, passive, and semi-passive RFID tags have many differences. Table 2.9 shows the differences among these tags.

Issues	**Active RFID tags**	**Passive RFID tags**	**Semi-passive RFID tags**
Tag power source	Internal to tag *(Juels & Pappu, 2003; Tajima, 2007; Domdouzis et al., 2007)*	Energy transferred from the reader *(Juels & Pappu, 2003; Tajima, 2007; Domdouzis et al., 2007)*	Internal power source *(Angeles, 2005; Jedermann et al., 2009)*
Availability of tag power	Continuous *(Juels & Pappu, 2003; Tajima, 2007; Domdouzis et al., 2007)*	Only when found in the field of the reader *(Juels & Pappu, 2003; Tajima, 2007; Domdouzis et al., 2007)*	Use their battery to power chip only, require a reader to interrogate them first *(Angeles, 2005; Jedermann et al., 2009)*

Issues	**Active RFID tags**	**Passive RFID tags**	**Semi-passive RFID tags**
Required signal strength from reader to tag	Low *(Juels & Pappu, 2003; Tajima, 2007; Domdouzis et al., 2007)*	High *(Juels & Pappu, 2003; Tajima, 2007; and Domdouzis et al., 2007)*	Low *(Angeles, 2005; and Jedermann et al., 2009)*
Available signal strength from tag to reader	High *(Juels & Pappu, 2003; Tajima, 2007; Domdouzis et al., 2007)*	Low *(Juels & Pappu, 2003; Tajima, 2007; Domdouzis et al., 2007)*	High *(Angeles, 2005; and Jedermann et al., 2009)*
Communication range	Long range (> 100 m) *(Tajima, 2007)*	Short range (Typically under 3 m) *(Tajima , 2007)*	Long range (> 100 m) *(Angeles, 2005; Jedermann et al., 2009)*
Multi-tag collection	Scanning of a thousand of tags from a single reader *(Domdouzis et al., 2007)*	Scanning of a hundred of tags within 3 meters from a single reader *(Domdouzis et al., 2007)*	Not available
Multi-tag collection	Scanning of up to 20 tags moving at more than 100 miles/hour *(Domdouzis et al., 2007)*	Scanning of 20 tags moving at 3 miles/hour or slower *(Domdouzis et al., 2007)*	Not available
Sensor capability	Ability to monitor continuously sensor input *(Domdouzis et al., 2007)*	Monitor sensor input when tag is powered from the reader *(Domdouzis et al., 2007)*	Not available
Data storage	Large *(Asif et al., 2005; Domdouzis et al., 2007)*	Small *(Asif et al., 2005; Domdouzis et al., 2007)*	Large *(Jedermann et al., 2009)*
Weight *(Juels & Pappu, 2003)*	120-130g	6-54g	30- 95g
Capabilities	Read/Write *(Tajima, 2007)*	Read only *(Tajima, 2007)*	Read/Write *(Jedermann et al., 2009)*
Operational life	5-10 years *(Tajima, 2007)*	Unlimited *(Tajima, 2007)*	Over than 5 years *(Jedermann et al., 2009)*
Memory *(Juels & Pappu, 2003)*	Up to 128 Kb	Up to 32 kb	Extended memory is able to store a significant amount of data on the tag (64 Kbit

Issues	**Active RFID tags**	**Passive RFID tags**	**Semi-passive RFID tags**
			total, 60 Kbit rewriteable)
Cost (in $)	100/tag *(Tajima, 2007)*	(0.40-10)/tag *(Tajima, 2007)*	(10-20)/tag (Fraction of actives and closer to passives) *(Jedermann et al., 2009)*
General applications	- Suitable for tracking high value items over long ranges; security / personnel access control; asset tracking *(Tajima, 2007)*	- Suitable for tracking low-value consumer goods; supply chain tracking *(Tajima, 2007)*	- Suitable for enhancing the control during cold transport chain of food products *(Angeles, 2005; and Jedermann et al., 2009)*
Performance in a Warehouse Environment *(Poon et al., 2009)*	- Higher data transmission rates; - Better noise immunity *(Tajima, 2007)*; - Less orientation; sensitivity - More tags can be read simultaneously; - Self-reporting capability; and - Suitable for RF-challenging environments such as, inside food pallets, or pharmaceutical containers, or around metals and liquids	- Lower data transmission rates; - Subject to noise *(Tajima, 2007)*; - Greater orientation sensitivity; - Fewer tags can be read simultaneously; - No self-reporting capability; and - Metals, and material of high water content decrease its reading range to less than (1) meter	Not available

Table 2.9 Differences among active, passive, and semi-passive RFID tags

From Table 2.9, it shows that, semi-passive tags may bridge the gap between passive and active RFID tags because they have a battery on board that enables them to be read from a longer range (Angeles, 2005) thereby delivering greater reading range and reading reliability than passive tags and offering much of the functionality found on active tags. Also, their prices are lower than active tags and closer to passive tags (Müller, 2008).

Selecting and implementing the right technology for the warehouse environment is a crucial decision factor for warehouse managers to gain the most out of the auto-ID technologies. Analysing a warehouse environment and defining their objectives, constraints, strengths, weaknesses, opportunities, and threats are as important as analysing and evaluating different auto-ID technologies in order to select and implement the most efficient technology (Roberti, 2003; Porter et al, 2004; Angeles, 2005; Poon et al, 2009; Sarac, et al, 2010; Poon et al., 2011a; Mercer et al., 2011; Poon et al., 2011b).

2.6 Models of IT Adoption

There are many theories about technology adoption used in IS research (Oliveira & Martins, 2011). The most adopted theories are the Technology Acceptance Model (TAM) (Davis, 1986, Davis, 1989; Davis et al., 1989), Theory of Planned Behaviour (TPB) (Ajzen, 1985; Ajzen, 1991), Unified Theory of Acceptance and Use of Technology (UTAUT) (Venkatesh et al., 2003), Diffusion of Innovation (DOI) (Rogers, 1995), and the Technology–Organisation–Environment **(**TOE) framework (Tornatzky & Fleischer, 1990). In this research, only the DOI and the TOE framework have been discussed, because they are the only ones that are used at the organisation level while the TAM, TPB and UTAUT are used at the individual level (Oliveira & Martins, 2011).

2.6.1 Diffusion of Innovation (DOI) Theory

Diffusion of Innovation is a theory that attempts to explain how, why, and at what rate new ideas and technology spread through cultures. DOI theory is a process by which an innovation is communicated through certain channels over time and within a specific social system (Rogers, 1995). The innovation process in organisations is much more complex. It usually involves a number of individuals, possibly including both supporters and opponents of the new idea, each of whom plays a role in the innovation-decision (Rogers, 1995).

Rogers' theory of innovation diffusion identifies five technological characteristics as drivers to any adoption decision: relative advantage, compatibility, complexity, trialability, and observability (Rogers, 2003). *Relative advantage* "is the degree to which an innovation is perceived as better than the idea it supersedes" (p. 229); *trialability* "is the degree to which an innovation may be experimented with on a limited basis" (p.16);

complexity is “the degree to which an innovation is perceived as difficult to understand and use” (p.15); *observability* “is the degree to which the results of an innovation are visible to others” (p. 16); and *compatibility* “is the degree to which an innovation is perceived as being consistent with the existing values, past experiences, and needs of potential adopters” (p. 15). In addition, Rogers, (1995) identifies three independent variables that influence the process by which the enterprise adopts a technological innovation: individual (leader) characteristics, internal characteristics of organisational structure, and external characteristics of the organisation. (a) *Individual characteristics* refers to the leader attitude toward change. (b) *Internal characteristics of organisational structure* consists of several factors: "centralisation is the degree to which power and control in a system are concentrated in the hands of a relatively few individuals" (pp. 379-380); "complexity is the degree to which an organisation's members possess a relatively high level of knowledge and expertise" (p. 380); "formalisation is the degree to which an organisation emphasises its members' following rules and procedures" (p. 380); "interconnectedness is the degree to which the units in a social system are linked by interpersonal networks" (p. 381); "organisational slack is the degree to which uncommitted resources are available to an organisation" (p. 381); "size is the number of employees of the organisation" (p. 381). (c) *External characteristics of the organisation* describes system openness.

2.6.2 The Technology–Organisation–Environment (TOE) Framework

The TOE theory is proposed by Tornatzky and Fleischer (1990), to study the adoption of technological innovations. They argue that the decision of a technological innovation adoption is based on factors in the technological, organisational, and environmental contexts (Figure 2.7). The technological context refers to both the internal and external technologies relevant to the organisation. This includes existing technologies and the equipment internal to the organisation (Starbuck, 1976), as well as the set of emerging technologies external to the firm (Thompson, 1967; Khandwalla, 1970; Hage, 1980). The organisational context refers to descriptive measures about the organisation such as the firm's structure and resources, scope (the horizontal extent of a firm's operations), size, and top management support and complexity of its managerial structure. The environmental context is the arena in which an organisation conducts its business. This arena includes the industry, competitors, and dealings with the government (Tornatzky & Fleischer, 1990).

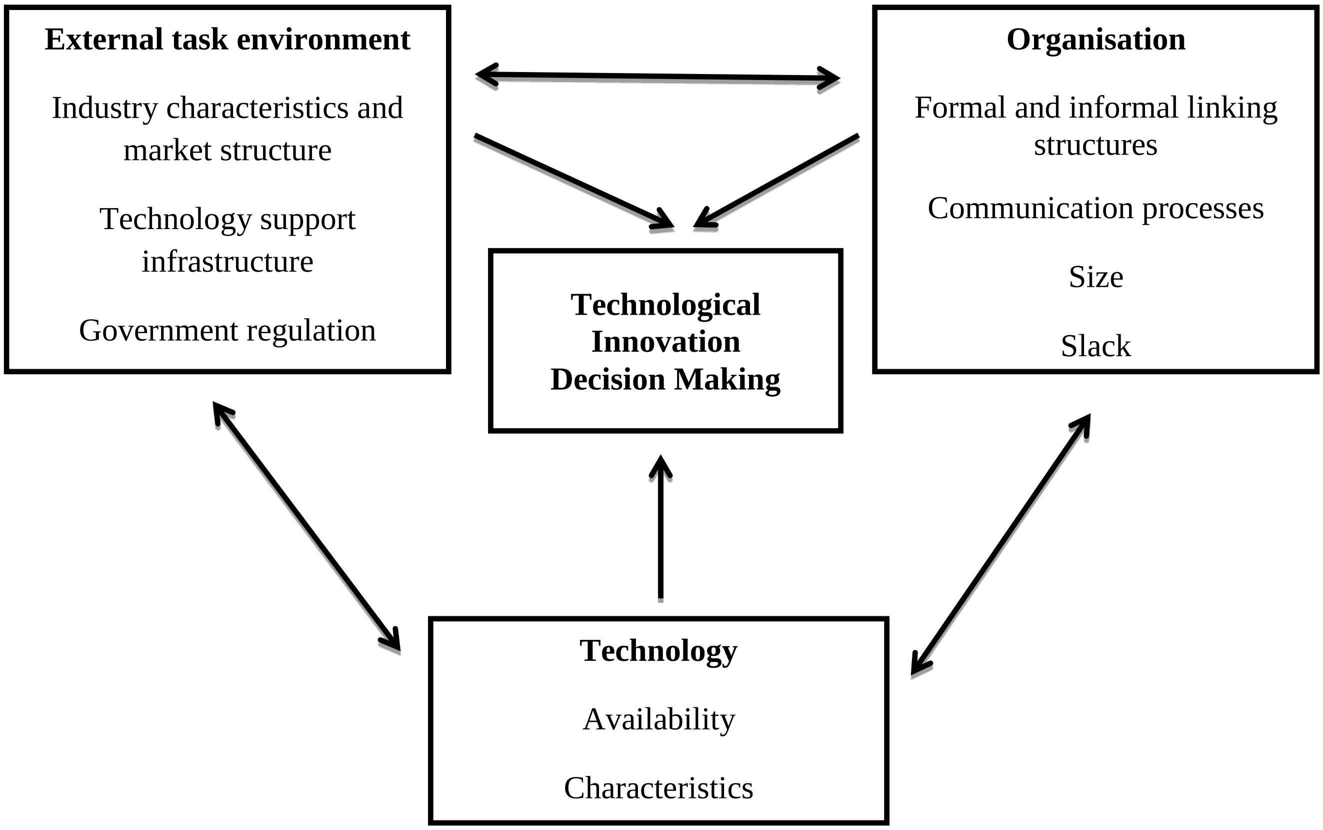


Figure 2.7 Technology, organisation, and environment (TOE) framework
(Tornatzky & Fleischer, 1990, p. 154)

The TOE framework as originally presented, and later adapted in IT implementation studies, can be used for studying the implementation of different types of IT innovation because it provides a useful analytical framework (Oliveira & Martins, 2011). The TOE framework has a solid theoretical basis and consistent empirical support and has been found useful in understanding the adoption of technological innovations. Many researchers applied only the TOE framework to understand different IT adoptions, such as: open systems (Chau & Tam, 1997); electronic data interchange (EDI) (Kuan & Chau, 2001); e-business (Zhu et al., 2003; Zhu and Kraemer, 2005; Zhu et al., 2006; Lin & Lin 2008; Oliveira & Martins 2010); web site (Oliveira & Martins, 2008); e-commerce (Liu, 2008; and Martins & Oliveira 2009); enterprise resource planning (ERP) (Pan & Jang, 2008); business to business (B2B) e-commerce (Teo et al., 2006); knowledge management systems (KMS) (Lee et al., 2009). Table 2.10 summarises the relevant studies based on the TOE framework.

Author(s)	IT Adoption	Variables
(Chau and Tam, 1997)	Open systems	• Characteristics of the "Open Systems Technology" Innovation: perceived benefits; perceived barriers; perceived importance of compliance to standards, interoperability, and interconnectivity. • Organisational technology: complexity of IT infrastructure; satisfaction with existing systems; formalisation of system development and management. • External environment: market uncertainly.
(Kuan and Chau, 2001)	EDI	• Technological context: perceived direct benefits; perceived indirect benefits. • Organisational context: perceived financial cost; perceived technical competence. • Environmental context: perceived industry pressure; perceived government pressure.
(Zhu et al., 2003)	E-business	• Technology competence: IT infrastructure; e-business know-how. • Organisational context: firm scope, firm size. • Environmental context: consumer readiness; competitive pressure; lack of trading partner readiness. • Controls (industry and country effect)
(Zhu and Kraemer 2005)	E-Business usage	• Technological context: technology competence. • Organisational context: size; international scope; financial commitment. • Environmental context: competitive pressure; regulatory support. • E-Business functionalities: front-end functionality; back-end integration.
(Zhu et al., 2006)	E-Business initiation E-Business adoption E-Business routinisation	• Technological context: technology readiness; technology integration. • Organisational context: firm size; global scopes; trading globalisation; managerial obstacles. • Environmental context: competition intensity; regulatory environment.
(Teo et al., 2006)	Deployment of B2B e-commerce: B2B firms versus non-B2B firms	• Technological inhibitors: unresolved technical issues; lack of IT expertise and infrastructure; lack of interoperability. • Organisational inhibitors: difficulties in organisational change; problems in project management; lack of top management support; lack of e-commerce strategy; difficulties in cost-benefit assessment. • Environmental inhibitors: unresolved legal issues; fear and uncertainty.
(Oliveira	Web site	• Technological context: technology readiness;

Author(s)	IT Adoption	Variables
and Martins, 2008)		technology integration; security applications. • Organisational context: perceived benefits of electronic correspondence; IT training programmes; access to the IT system of the firm; internet and e-mail norms. • Environmental context: web site competitive pressure. • Controls: services sector.
(Liu, 2008)	e-commerce development level (0-14)	• Technological: support from technology; human capital; potential support from technology. • Organisational: management level for information; firm size. • Environmental: user satisfaction; e-commerce security. • Controls: firm property.
(Pan and Jang, 2008)	ERP	• Technological context: IT infrastructure; technology readiness. • Organisational context: size; perceived barriers. • Environmental context: production and operations improvement; enhancement of products and services; competitive pressure; regulatory policy.
(Lin and Lin, 2008)	Internal integration of e-business External diffusion of use of e-business	• Technological context: IS infrastructure; IS expertise. • Organisational context: organisational compatibility; expected benefits of e-business. • Environmental context: competitive pressure; trading partner readiness.
(Lee et al., 2009)	KMS	• Technology aspect: organisational IT competence; KMS characteristics (compatibility, relative advantage and complexity). • Organisational aspect: top management commitment; hierarchical organisational structure. • Environmental aspect: With external vendors; among internal employees.
(Martins and Oliveira, 2009)	Internet Web site E-commerce	• Technological context: technology readiness; technology integration; security applications. • Organisational context: perceived benefits of electronic correspondence; IT training programmes; access to the IT system of the firm; internet and e-mail norms. • Environmental context: internet competitive pressure; web site competitive pressure; e-commerce competitive pressure. • Controls: services sector.
(Oliveira and Martins, 2010)	E-business	• Technological context: technology readiness; technology integration; security applications. • Organisational context: perceived benefits of electronic correspondence; IT training programmes; access to the IT system of the firm; internet and e-mail norms.

Author(s)	IT Adoption	Variables
		• Environmental context: web site competitive pressure. • Controls: services sector.

Table 2.10 Some studies using the TOE framework in investigation of the adoption of technological innovations
(Adapted from Wang et al., 2010c; and Oliveira & Martins, 2011)

The TOE framework is consistent with the Diffusion of Innovation (DOI) theory in which Rogers (1995) has emphasised technological characteristics, individual characteristics, and both the internal and external characteristics of the organisation, as antecedents to any adoption decision (Zhu et al., 2003; Zhu et al., 2006; Cooper & Zmud, 1990; Iacovou et al., 1995; Thong, 1999). These characteristics are similar to the technology and organisation context of the TOE framework, however the TOE framework also includes a new and important component which is environment context (Oliveira & Martins, 2011). The environment context includes both constraints and opportunities for IT innovations.

Therefore, the TOE framework makes the DOI theory better able to explain intra-firm innovation adoption (Hsu et al., 2006). For this reason, and drawing upon the empirical support, combined with the existing literature review and theoretical perspectives mentioned earlier, the TOE framework provides a good starting point for analysing and considering appropriate factors for understanding innovation decision-making (Wang et al., 2010c; and Oliveira & Martins, 2011). Thus, the TOE framework is an appropriate foundation for studying the selection process of auto-ID technologies in the warehouse environment. Auto-ID (RFID/barcode) has been enabled by technological developments in radio and automated identification, driven by organisational factors such as top management support, and affected by environmental factors related to business partners and competitors.

2.7 Factors Relevant to Auto-ID Selection Decision in a Warehouse Environment

In the auto-ID selection decision context, many researchers had explored the criteria/factors for the auto-ID selection decision in the supply chain (Brown & Bakhru., 2007; Kang & Koh, 2002; Fontanella, 2004; Lee et al., 2004; Fleisch & Tellkamp, 2005; Angeles, 2005; Lahiri, 2005; Rekik et al., 2006; Wyld, 2006; Lefebvre et al., 2006; Wamba et al. 2007; Goel, 2007; Huber et al., 2007; Lin & Lin, 2007; Miller, 2007; Lee and Ozer, 2007; Leung et al., 2007, White et al., 2008; Bottani & Rizzi, 2008; Sarac et al., 2010; Ilie-Zudor et al., 2011; Pfahl & Moxham 2012; Laosirihongthong et al., 2013). However, factors influencing auto-ID technology selection decisions in a warehouse are discussed by only a few researchers e.g. Porter et al., (2004); Vijayaraman & Osyk, (2006); Van De Wijngaert et al., (2008); Poon et al., (2009); Karagiannaki et al., (2011); Osyk et al., (2012); Lim et al., (2013). The summary of criteria and factors relevant to the auto-ID selection decision in a warehouse environment is shown in Table 2.11.

Cost is a key factor affecting the auto-ID selection decision in the supply chain (Fontanella, 2004; Murphy-Hoye et al., 2005; Bottani & Rizzi, 2008). Angeles (2005) has indicated that three factors have to be considered when choosing RFID technology in the supply chain: the needs of organisations, the needs of their partners, and the needs of the industry. Lahiri (2005) defines multiple-criteria and many factors such as benefits, costs, risks, complexity, and Return on Investment (ROI) to determine the potential of RFID technology in the supply chain. Lin and Lin (2007) identify the factors of RFID selection and implementation using such factors as quality, cost considerations, and system applicability. Miller (2007) discusses factors for evaluating RFID technology in the supply chain such as environment, cost, compliance, interface capability, and scalability. White et al. (2008) have mentioned that anticipated benefits, anticipated costs, ROI, and operational deployment are essential factors to consider when choosing RFID technology in supply chain.

A detailed study of the literature on the impact of RFID technologies on supply chain management was made by Sarac et al. (2010). In order to evaluate the benefits of different RFID technologies in the supply chain, they have investigated four main approaches: the analytical approach (Lee and Özer, 2007; Rekik et al., 2006), the simulation approach (Brown et al., 2001; and Leung et al., 2007), case studies and experiments (Lefebvre et al., 2006; Wamba et al., 2007; Bottani & Rizzi, 2008). Generally all of them are followed by a Return on Investment (ROI) study to quantify the economic impact of RFID in the supply chain (Kang and Koh, 2002; Lee et al., 2004; Leung et al., 2007; Goel, 2007). Fleisch and Tellkamp (2005) have mentioned that companies have to carefully analyse the economic impact of different RFID technologies in order to investigate the feasibility of RFID implementation and also to choose and integrate the most efficient technology in their supply chain processes.

Auto- ID characteristic is another key factor that should be taken into consideration when choosing auto-ID technology for the environment (Wyld, 2006; Huber et al., 2007). Ilie-Zudor et al. (2011) have stated that barcode and RFID have different characteristics and therefore have different effects on labour, costs, and supply chain issues. Thus, they have concluded that there must be interaction between the strategic analysis (supply chain network structure, supply chain business processes, and supply chain management components) and the technological analysis when considering the technology-selection process.

Literature Authors	Context	Auto-ID Technology	Methodology	Criteria
Porter et al., (2004)	Warehouse Environment	Active and Passive RFID	Experimental Study	Technical/Reading performance
Vijayaraman & Osyk, (2006)	Warehousing Industry	RFID	Survey	Return on investment (ROI), potential benefits, and costs
Van De Wijngaert et al., (2008)	logistics domain / Warehouse	RFID	Case Study	Business/IT-Alignment (business strategy; organisational infrastructure ; organisational readiness/ maturity; IT strategy and IT infrastructure and processes)
Poon et al., (2009)	Group Sense Limited (GSL) warehouse	Active and Passive RFID	Case Study/Experimental Design	Physical factors, internal environmental factors, technological factors (technical /reading performance & potential benefits)
Karagiannaki et al., (2011)	3PL Company with paper trading & Retail Distribution Centre	RFID	Case Study & Simulation Modelling	Warehouse contextual factors (structure; workflow; and resources)
Osyk et al.,	Retailers /	RFID	Online Survey	Return on

Literature Authors	Context	Auto-ID Technology	Methodology	Criteria
(2012)	Warehousing			investment (ROI), potential benefits, integration, costs, standards, and security
Lim et al., (2013)	Warehouse Management	RFID	Literature Analysis	RFID benefits (resource-related; operational; and informational) & RFID obstacles (internal obstacles; external obstacles; and application domain)

Table 2.11 Summary of criteria of auto-ID selection decision in the warehouse management

From Table 2.11, we can observe a list of the previous publications which discussed the factors affecting the auto-ID selection decision in a warehouse environment detailed in the following.

A test protocol has been developed by Porter et al. (2004). The main purpose of their study is to test the operational effectiveness of active and passive RFID systems for warehouse management operations. The major two categories of the test are: laboratory baseline performance tests and warehouse passive interference tests. The results of the study show that tag orientations and material types have a significant impact on the reading performance of RFID tags in a warehouse environment. Also, none of the active and passive RFID systems are able to meet all the operational requirements performance of a warehouse. Thus, they have concluded that the reading performance of RFID is an important factor when selecting the technology and it is advisable to evaluate the reading performance of RFID systems before they are selected for implementation to ensure they meet the operational performance requirements of the warehouse environment.

The findings of an empirical study conducted by Vijayaraman and Osyk (2006), show that a number of concerns still exist and scepticism remains about the potential for RFID to deliver cost savings or a positive ROI. Thus, return on investment (ROI), potential benefits, and costs are essential factors when considering RFID selection and implementation in the warehousing industry.

A case study has been conducted by Van De Wijngaert et al. (2008) in order to explore the selection decision of RFID in the logistics domain. This study compared thirteen organisations that operate one or more warehouses. Their results show that Business/IT-Alignment (BITA) such as business strategy, organisational infrastructure, organisational readiness (in terms of maturity), IT strategy, and IT infrastructure and processes are important factors influence managers and decision makers in companies to apply this type of new technology.

Another case study on RFID technology integration in the Group Sense Limited (GSL) warehouse has been performed by Poon et al. (2009). They have conducted numerous tests to evaluate the reading performance of different RFID technologies under different conditions. They have indicated that the most efficient RFID solution can be formulated by studying the actual environment of the warehouse first and then analysing various RFID technologies. This is because the interactions between warehouse contextual factors (physical and internal-environmental) and technological factors have a significant effect on RFID performance and accordingly on the warehouse performance. Therefore, physical factors, internal environmental factors, and technological factors are essential factors that may affect warehouse managers and decision makers when deciding on the type of auto-ID technology.

A framework for identifying the key warehouse contextual factors influencing the RFID selection decision has been provided by Karagiannaki et al. (2011). They have investigated two case studies that cover different types of warehouse in terms of product complexity, size, mechanisation level and other contextual factors and also two simulation models were developed based on the cases in order to identify important contextual factors that may moderate the impact of RFID on warehouse performance. They have observed that in a highly automated warehouse with well-defined processes, there is less need for RFID than in a warehouse where a large number of tasks are conducted manually. In other words, the less complex the warehouse is, the more benefit from the specific RFID there will be. Therefore, they have concluded that the warehouse contextual factors such as structure, operations' workflow, and resources are a major consideration in many RFID selection decisions in a warehouse. This is because every warehouse is different in several ways and the same RFID adoption may generate high productivity in one warehouse but not in another because one warehouse may have characteristics that affect the value of RFID.

An empirical study on factors affecting warehouses when selecting and adopting RFID technology have been conducted by Osyk et al. (2012). Their results show that there are a number of concerns still existing for a positive return on investment (ROI), potential benefits, integration, and other issues including costs, standards, security, and privacy.

A comprehensive analysis of the academic literature published from 1995 to 2010 pertaining to the application of RFID technology in warehouses has been performed by Lim et al. (2013). They have stated that there are several factors to consider during RFID selection and implementation in the warehouse such as RFID benefits (resource-related, operational, and informational), RFID obstacles (internal obstacles, external obstacles), application domains, and the type of warehouse operations.

In the review of the contemporary literature, Porter et al. (2004); and Poon et al. (2009) comment that the warehouse managers should follow several steps before any auto-ID technology is selected for implementation and identify many areas for further research. Technological perspectives have received considerable attention since the late 1950s, but less research attention have been undertaken from other perspectives such as an organisation and environment level when firms make an auto-ID selection decision (Sarac et al., 2010). Also, Sarac et al. (2010) comment that the warehouse managers should follow several steps before any auto-ID technology is selected for implementation and identify many areas for further research. In this regard, Ilie-Zudor et al. (2011) indicate that technological factors are more notable than strategic factors such as network structure, business processes and management components when firms decide to use auto-ID technology in their supply chain. In addition, Ilie-Zudor et al. (2011) have mentioned that the choice of barcode or RFID in the supply chain is not a single choice and they call for more investigation of a number of factors influencing auto-ID decision making to provide a step-by-step guide for choosing the right auto-ID system for a particular organisation's needs.

However, warehouse contextual factors such as structure, workflow and resources are major considerations in many RFID selection decisions (Karagiannaki et al., 2011). Consistent with this, Poon et al. (2009) have found that the most efficient RFID solution in a warehouse environment can be formulated by studying the actual physical and internal environment of a warehouse first and then analysing various RFID technologies. Moreover, Karagiannaki, (2011) and Kasiri et al. (2012) suggest more research regarding auto-ID technologies in a warehouse environment in order to help decision makers with the technology-selection process.

2.8 Summary

In this chapter, a review of the literature relevant to the research issues has been presented. The literature review covers the role of the warehouse in logistics and supply chain management, warehouse characterisations and provides a valuable comparative analysis of different auto- ID technologies that have been used in a warehouse environment such as barcode, active RFID, passive RFID, and semi-passive RFID systems. This literature survey shows that RFID and barcode technologies have different characteristics. Also, RFID technologies can provide several advantages over barcode systems in a warehouse environment. The main benefits of RFID technologies in a warehouse context are:

- Tracking easily the real-time location and status of warehouse resources
- Improving visibility of warehouse operations
- Enhancing warehouse productivity and
- Reducing the operation costs of the warehouse

In summary, a number of key research issues have been extracted from the discussion of the pre-existing literature review as shown below in Table 2.12.

Key Issues From Literature Review	Description	References
Warehouse Importance	- In a supply chain, a warehouse is an essential component linking all chain parties. The performance of the warehouse operations, which are either labour or capital-intensive, not only influences the productivity and operation costs of a warehouse, but also the whole supply chain.	Gu et al., 2007
Types/Roles of Warehouses	- In today's business environment, a warehouse can be as simple as a garage-like area at a self-storage facility or as complex as a massive facility that not only stores items, but also simultaneously supports different value-adding activities.	Karagiannaki et al., 2011

Key Issues From Literature Review	Description	References
	- Warehouse operations are no longer confined to inventory storage and protection of goods, but include various operations ranging from receiving, put away, order picking, packaging of items and after sales services, to light assembly and inspection.	Farzelle, 2002b; Higginson & Bookbinder, 2005; Maltz & DeHoratious, 2004; Van Den Berg, 2007; Poon et al., 2011b
	- Given such diversity, and despite some similarities, each warehouse differs from the others in many ways.	Poon et al., 2009; and Karagiannaki et al., 2011
Auto-ID Technology Importance	-Automatic identification (auto-ID) technologies such as barcode and radio frequency identification (RFID) are among the essential technologies in the 21st century knowledge-based economy.	Lim et al., 2013
	- Auto-ID technologies have been adopted to facilitate the collection and sharing of data in a warehouse environment.	Chow et al., 2006; Poon et al., 2008
	- An auto-ID technology is a long-term investment and it contributes to improving operational efficiency, achieving cost savings and creating opportunities for higher revenues.	Ilie-Zudor et al., 2011; and Lim et al., 2013
Auto-ID Selection/Adoption Decision	- Deciding on the type of auto-ID technology is a long term investment for warehousing companies or manufacturers operating large warehouses.	Karagiannaki et al., 2011; and Lim et al., 2013
	-Selecting an auto-ID technology is difficult and there is a very wide range of factors that may potentially affect warehouses in deciding to use auto-ID technologies.	Ilie-Zudor et al., 2011
	- Auto-ID selection decisions eventually face the barrier on what to consider for the economic impact/ (ROI) evaluation.	Fleisch & Tellkamp, 2005; Sarac et al., 2010
	- Choosing the right auto-ID technology for a warehouse environment is a key decision factor for warehouse managers in order to: ▪ locate warehouse resources efficiently; ▪ support warehouse operations effectively; ▪ achieve cost savings; ▪ create opportunities for higher revenues; ▪ achieve an acceptable/positive rate of return on investment (ROI); and ▪ sustain the competitive advantage of a warehouse.	Chow et al., 2006; Poon et al., 2009; Ilie-Zudor et al., 2011
Auto-ID Studies / Limitations in Warehouse Management	- The number of warehousing companies considering auto-ID technology continues to increase. However, there has been little work done on warehouse management motivations for using auto-ID technologies.	Sarac et al., 2010
	- The literature on the decision about auto-ID selection in the warehouse environment is limited, with few studies that discuss the factors affecting decisions in this context.	Porter et al., 2004; Vijayaraman & Osyk, 2006; Van De Wijngaert et al., 2008; Liviu et al., 2009; Poon et al., 2009; Karagiannaki et al., 2011; Osyk et al., 2012
	-The choice of barcode or RFID is not straightforward, but a number of issues/factors influence the selection that comprises a series of decisions. However, Previous studies have not considered the key factors affecting the process of making the selection of auto-ID in warehouse management as a whole. Also,	Poon et al., 2011a; Ilie-Zudor et al., 2011

Key Issues From Literature Review	Description	References
	they did not pay attention to problems in auto-ID selection decisions and recommendations to overcome them.	
	- Auto-ID technology can be more appropriate and efficient for one warehouse than another auto-ID technology and/or for another warehouse. In other words, different auto-ID technologies and warehouses have different characteristics and that might affect the value of auto-ID in the warehouse context.	Karagiannaki et al., 2011
	- To understand the auto-ID technology-selection process in a warehouse context, it is important to take heed of all key factors that influence this decision.	Ilie-Zudor et al., 2011; Pero & Rossi 2013
	- The importance of the various factors that influence the auto-ID selection decisions may change significantly over time. Determining the chronological order of those factors will help to arrange the key activities and understand the entire auto-ID selection process in warehouse management.	Adhiarna et al., 2011 Pettigrew, 1997; Aladwani, 2001; Robey et al., 2002
	- Warehouse managers and/or auto-ID project managers may find it difficult to consider the large number of factors that would affect the selection decision without understanding how the factors should be combined to produce a successful auto-ID selection process.	Porter et al., 2004; Poon et al., 2009; Sarac et al., 2010
	- Warehouse managers should follow several steps before any auto-ID technology is selected for implementation.	Pero and Rossi, 2013
	- The majority of existing studies use a factor research approach in investigating the auto-ID selection decision. Factor research is valuable for advancing understanding of the auto-ID selection process, but it adopts a static view, which limits its adequacy in explaining the dynamics of the selection decision process.	Aladwani, 2001
	- A process research approach or a combination of factor and process approaches have been suggested by some scholars in order to improve research in IS topics. Adopting a process approach, the auto-ID selection decision may be conceived of as a sequence of discrete activities that lead to outcomes of particular interest.	Aladwani, 2001; and Robey et al. , 2002 Pettigrew, 1997; Ilie-Zudor et al., 2011
	- A number of techniques have been advocated in the literature to aid auto-ID decision making in a supply chain such as the analytical approach; the simulation approach; experiment; case study and survey. However, those techniques cannot help in exploring/understanding the factors that affect auto-ID adoption decision OR understanding how the factors should be combined to produce a successful auto-ID selection process in the warehouse context.	Lee & Özer, 2007; Leung et al., 2007; Porter et al., 2004; Poon et al., 2009; Van De Wijngaert et al., 2008; Vijayaraman & Osyk, 2006; Osyk et al., 2012
Research Purpose	This research finds a great need to bridge a knowledge gap stemming from the absence of a holistic framework in the literature that comprehensively investigates the critical factors influencing the auto-ID selection decision and how the factors should be combined to produce a successful auto-ID selection process in warehouse management.	Consistent with recent studies (e.g. Ilie-Zudor et al., 2011; Pero & Rossi 2013) and based on the literature review analysis

Table 2.12 key research issues extracted from analysing the pre-existing literature review

Furthermore, this literature review has outlined and discussed the key models/theories of IT adoption especially, Diffusion of Innovation (DOI) theory, and the Technology–Organisation–Environment **(**TOE) framework because they are the only ones that are at the organisation level.

In the above chapter, there are diverse factors influencing auto-ID technology selection decisions for warehouse management that have been discussed. The discussion shows that selecting an auto-ID technology is difficult and there is a very wide range of factors that may potentially affect warehouses in deciding to use auto-ID technologies. The number of warehouses considering auto-ID technology continues to increase. A great deal of attention has been paid to critical factors influencing auto-ID decisions in a supply chain. Those factors have been examined separately in order to help decision makers to obtain optimum auto-ID technologies in the supply chain. However, the literature on auto-ID selection decisions in a warehouse environment is limited. Only a handful of research studies have attempted to set out the factors recognised in auto-ID selection decisions in a warehouse.

Auto-ID technology can be more appropriate and efficient for one warehouse than another auto-ID technology and/or for another warehouse. In other words, different auto-ID technologies and warehouses have different characteristics and that might affect the value of auto-ID in the warehouse context. Identifying key factors or issues in the early stages of the decision making process is crucial for warehouse management considerations. Most of the prior studies have separately investigated the key factors influencing auto-ID decisions in a warehouse environment. However, understanding the auto-ID technology-selection process in a warehouse field requires that all key factors that influence this decision are taken into account (Ilie-Zudor et al. 2011).

Moreover, the majority of existing studies use a factor research approach in investigating the auto-ID selection decision. Factor research is valuable for advancing understanding of the auto-ID selection process but, it adopts a static view (Aladwani, 2001), which limits its adequacy in explaining the dynamics of the selection decision process. Therefore, some scholars such as Aladwani (2001) and Robey et al. (2002) have suggested a process research approach or a combination of factor and process approaches in order to improve research in IS topics. Consequently, in this study, both factor research and process research have been adopted. The factor approach enabled the researcher to identify a comprehensive set of factors and sub-factors that may influence the auto-ID selection decision from synthesising and analysing the existing literature. The TOE framework of Tornatzky and Fleischer (1990) has been used as a lens to categorise the identified factors because it provides a good starting point when analysing appropriate factors for understanding the selection process of auto-ID technologies in a warehouse environment (Wang et al., 2010c; and Oliveira and Martins, 2011). Moreover, in adopting a process approach, the auto-ID selection decision may be conceived of as a sequence of discrete activities that lead to outcomes of particular interest (Ilie-Zudor et al., 2011).

Consistent with recent studies (e.g. Ilie-Zudor et al., 2011; Pero & Rossi 2013) and based on the literature review analysis, this study finds a great need to bridge a knowledge gap stemming from the absence of a comprehensive framework in which to understand how auto-ID technologies should be selected and the activities and issues that need to be considered in the selection process in a warehouse environment. This framework emphasises different stages of the selection and selection issues of auto-ID technology in warehouse management. In addition, the proposed framework makes the auto-ID selection process more tractable for practitioners by providing a holistic perspective of the issues involved in detail. The conceptual framework is described in detail in the following chapter.

CHAPTER 3

CONCEPTUAL FRAMEWORK

3.1 Introduction

It has been made evident by reviewing the literature in the previous chapter that the auto-ID selection/adoption decision for warehouse management is difficult. A very wide range of factors that may potentially affect warehouses in deciding to use auto-ID technologies has been found in the literature review. As discussed in Chapter 2, there are only a few studies in the existing literature that analyse the factors recognised in the auto-ID selection decisions in a warehouse. After reviewing the literature critically, this study identifies that auto-ID selection decision is an important research issue that needs to be carefully studied and understood (see Table 2.7). Therefore, this chapter proposes a conceptual framework to investigate and collectively understand key factors, and their relative importance, that may potentially influence the technology-selection process in warehouse management. The technology–organisation–environment (TOE) framework derived by Tornatzky and Fleischer (1990) was used as a theoretical framework to categorise the identified factors into six categories: structural, operational, resources, organisational, technological, and external environmental. For each category, the key factors that may affect auto-ID decision making were identified based on a comprehensive and systematic review of the literature on IS implementation, supply chain management, and warehouse management. The TOE framework provides a good starting point when analysing appropriate factors for understanding the selection process of auto-ID technologies in a warehouse environment (Wang et al., 2010c). Auto-ID technologies, for example RFID and barcodes, are enabled by technological developments and automated identification, driven by organisational factors such as top management support and affected by environmental factors related to business partners and competitors (Oliveira and Martins, 2011).

The proposed framework can be used by both practitioners and academics for understanding auto- ID selection in a warehouse environment. The framework will explain the critical issues within the decision making process of auto-ID technology in the warehouse management. The framework will also provide warehouses with assistance and an effective guide to better understand and prepare for the selection of auto-ID technologies. It will clarify the roles, activities, and responsibilities of all of the participants in the auto-ID selection process. The conceptual framework requires an empirical validation by the researcher, which will be reported in Chapters 5 and 6 of this dissertation.

3.2 Framework Build-up

Although auto-ID such as RFID may be treated as simply an input device to an Information System (IS) (Stair and Reynolds, 2008), deeper scrutiny of this technology has suggested that it is an IS in its own right. Auto-ID technology has the ability to collect and store data, process it into information, and disseminate that information to interested parties. Moreover, the technology offers its highest value to companies when it acts as an IS (Doerr et al., 2006). The review of the IS literature and also supply chain management and warehouse management theories has led to a strong conceptual framework of the factors affecting auto-ID selection being proposed.

Warehouses are a key aspect and play vital roles in modern supply chains and in the success, or failure, of businesses today (Frazelle, 2002a). Besides the traditional role of warehouses associated with the holding of inventory, they also have a critical impact on customer service levels and logistics costs (Farzelle, 2002b; Higginson & Bookbinder, 2005; Maltz & DeHoratious, 2004; Van Den Berg, 2007; Poon et al., 2011b). With this critical impact on customer service levels and logistics costs, it is thus imperative to the success of businesses that warehouse managers adopt efficient auto-identification technologies for locating the warehouse resources accurately and supporting the warehouse operations effectively and efficiently. This is particularly important as the warehouses will meet demands from suppliers as well as customers in a timely and cost-effective manner (Chow et al., 2006; Poon et al., 2008).

Therefore, it is crucial to the success of businesses that warehouse managers select and adopt the optimum auto-ID technology for locating the warehouse resources accurately and supporting the warehouse operations effectively and efficiently. This is particularly important as the warehouses will meet demands from suppliers as well as customers in a timely and cost-effective manner, which may offer and sustain the competitive advantage (Chow et al., 2006; Sarac et al., 2010; and Poon et al., 2008). However, every warehouse differs from the others in many ways, and the right auto-ID selection decision requires that warehouse contextual factors are taken into account (Karagiannaki et al., 2011). Consequently, the warehouse types, roles, objectives, operations and resources are reviewed in this research (Chapter 2) in order to identify the key warehouse contextual (structural, operational, resources-related) factors and sub-factors that may influence the auto-ID selection decision.

On the other hand, automatic identification (auto-ID) technologies such as barcode and radio frequency identification (RFID) are among the essential technologies in the 21st century knowledge-based economy (Lim et al., 2013). Auto-ID technologies have been used to facilitate the collection and sharing of data in a warehouse context. According to Sarac et al. (2010), the number of warehouses considering auto-ID technology continues to increase. Deciding on the type of auto-identification (auto-ID) technology is a key aspect of strategic decision-making for warehousing companies or manufacturers operating large warehouses (Karagiannaki et al., 2011; Lim et al., 2013). Auto-ID selection decisions eventually face the barrier on what to consider for ROI evaluation (Fleisch & Tellkamp, 2005; Sarac et al. 2010). Choosing the efficient auto-ID technology for a warehouse environment is a key decision factor for warehouse managers in order to (Poon et al., 2009; Ilie-Zudor et al., 2011; Lim et al., 2013):

- locate warehouse resources efficiently;
- support warehouse operations effectively;
- achieve cost savings;
- create opportunities for higher revenues;
- achieve an acceptable/positive rate of return on investment (ROI); and
- sustain the competitive advantage of a warehouse.

Auto-ID technology can be more appropriate and efficient for one warehouse than another auto-ID technology and/or for another warehouse. In other words, different auto-ID technologies have different characteristics and that might affect the value of auto-ID in the warehouse context. In this research, therefore, a comparative analysis of different auto- ID technologies that have been used in a warehouse environment (i.g. barcode, active RFID, passive RFID and semi-passive RFID) has been conducted in order to identify the key technological factors that may affect the auto-ID selection decision.

Due to its well-perceived capability and popularity in the business world, there has been a rapid growth of interest in auto-ID in the academic community across different disciplines. However, it can also be seen that the interest in auto-ID research for warehouse management has been less prominent than in other application domains such as transport, logistics and supply chain (Sarac et al., 2010; Poon et al., 2011a; Karagiannaki et al., 2011; and Lim et al., 2013). To understand the auto-ID technology-selection decision in a warehouse environment, it is important to take heed of all key factors that may potentially influence this decision (Ilie-Zudor et al., 2011; and Pero & Rossi 2013). Although there are some papers that explored the criteria of the auto-ID selection decision in a warehouse (Porter et al. 2004, Vijayaraman and Osyk 2006, Van De Wijngaert et al. 2008, Poon et al. 2009, Osyk et al. 2012, Karagiannaki et al. 2011), those factors have been examined separately. The choice of barcode or RFID is not a single choice, but a number of issues influence the selection that comprises a series of decisions (Ilie-Zudor et al. 2011). Warehouse managers should follow several steps before any auto-ID technology is selected for implementation (Poon et al., 2009; Pero and Rossi 2013).

Accordingly, this research defines a conceptual framework, which draws on the TOE framework of Tornatzky and Fleischer, (1990), to examine and collectively understand the key factors that may potentially influence the technology-selection decision in a warehouse environment, because it is a long term investment contributing to cost savings and affecting service levels.

The TOE framework is consistent with the DOI theory where technological characteristics, individual characteristics, and both the internal and external characteristics of the organisation are antecedents to any adoption decision (Zhu et al., 2006). These are similar to the technology and organisation context of the TOE framework; however, the TOE framework also has the environment context that includes constraints and opportunities for IT innovations (Oliveira & Martins, 2011). Therefore, the TOE framework makes the DOI theory better able to explain intra-firm innovation adoption (Hsu et al., 2006). For this reason and drawing upon the existing literature review and theoretical perspectives mentioned earlier in Chapter 2, the TOE framework provides a good starting point when analysing and considering appropriate factors for understanding technology adoption (Wang et al., 2010c). Auto-ID technologies are enabled by technological developments and automated identification, driven by organisational factors such as top management support and affected by environmental factors related to business partners and competitors (Oliveira & Martins, 2011).

3.3 Conceptual Framework of Key Factors Influencing Auto-ID Selection Decision in Warehouse Management

Most of the past IS/IT implementation research can be categorised either into factor or process research (Sambamurthy & Kirsch, 2000; and Newman & Robey, 1992). The factor approach involves survey research methods to identify the factors or variables that are critical for selecting and implementing the systems successfully (Aladwani, 2001, p. 267). Under the factor approach, in this research, a comprehensive set of factors and sub-factors that may affect auto-ID selection decisions is identified from synthesising and analysing the pre-existing literature. These factors are presented in detail in Table 3.1.

However, the focus of IS/IT implementation studies under the process approach is on the sequence of discrete and collective activities and events that lead to outcomes of particular interest (Pettigrew, 1997). For example, some studies under the process approach have investigated the selection process of auto-ID technology in the supply chain and found that the interaction between the strategic analysis (e.g. network structure, business processes and management component) and the technological analysis is crucial in the technology selection process (Ilie-Zudor et al., 2011).

Although factor research is valuable for advancing understanding of the auto-ID selection process, it adopts a static view (Aladwani, 2001), which limits its adequacy in explaining the dynamics of the technology selection process. Warehouse managers and/or auto-ID project managers may find it difficult to focus on the large number of factors that would affect the selection decision. Also, warehouse managers will find that identifying the factors will not be enough without understanding how the factors should be combined to produce a successful auto-ID selection process (Poon et al., 2009; Ilie-Zudor et al., 2011; Pero & Rossi, 2013). Aladwani (2001) and Robey et al. (2002) suggest a process research approach or a combination of factor and process approaches in order to improve research in IS topics.

Therefore, this research employs both factor and process approaches to narrate the entire auto-ID selection process in the warehouse environment. This research does that by first using the factor approach to identify, from synthesising and analysing the existing literature, a comprehensive set of factors and sub-factors that may affect auto-ID selection decisions. Building on the technology–organisation–environment (TOE) framework of

Tornatzky and Fleischer (1990, this research develops a conceptual framework that categorises the identified factors into six categories: (1) structural; (2) operational; (3) resources; (4) organisational; (5) technological; and (6) external environmental factors. On the other hand, using the process approach, this research identifies all the key steps and activities in the auto-ID selection process.

The conceptual framework investigates and understands collectively the key factors and sub-factors in order to find the most important factors influencing the technology selection decision (Adhiarna et al., 2011). As a result, the chronological order of the key activities in the auto-ID selection process would be determined (Ilie-Zudor et al., 2011). The arrangement of the activities according to their chronological order would form the entire auto-ID selection process for warehouse management from its inception to its end. The conceptual framework is presented in Figure 3.1 and discussed in detail below.

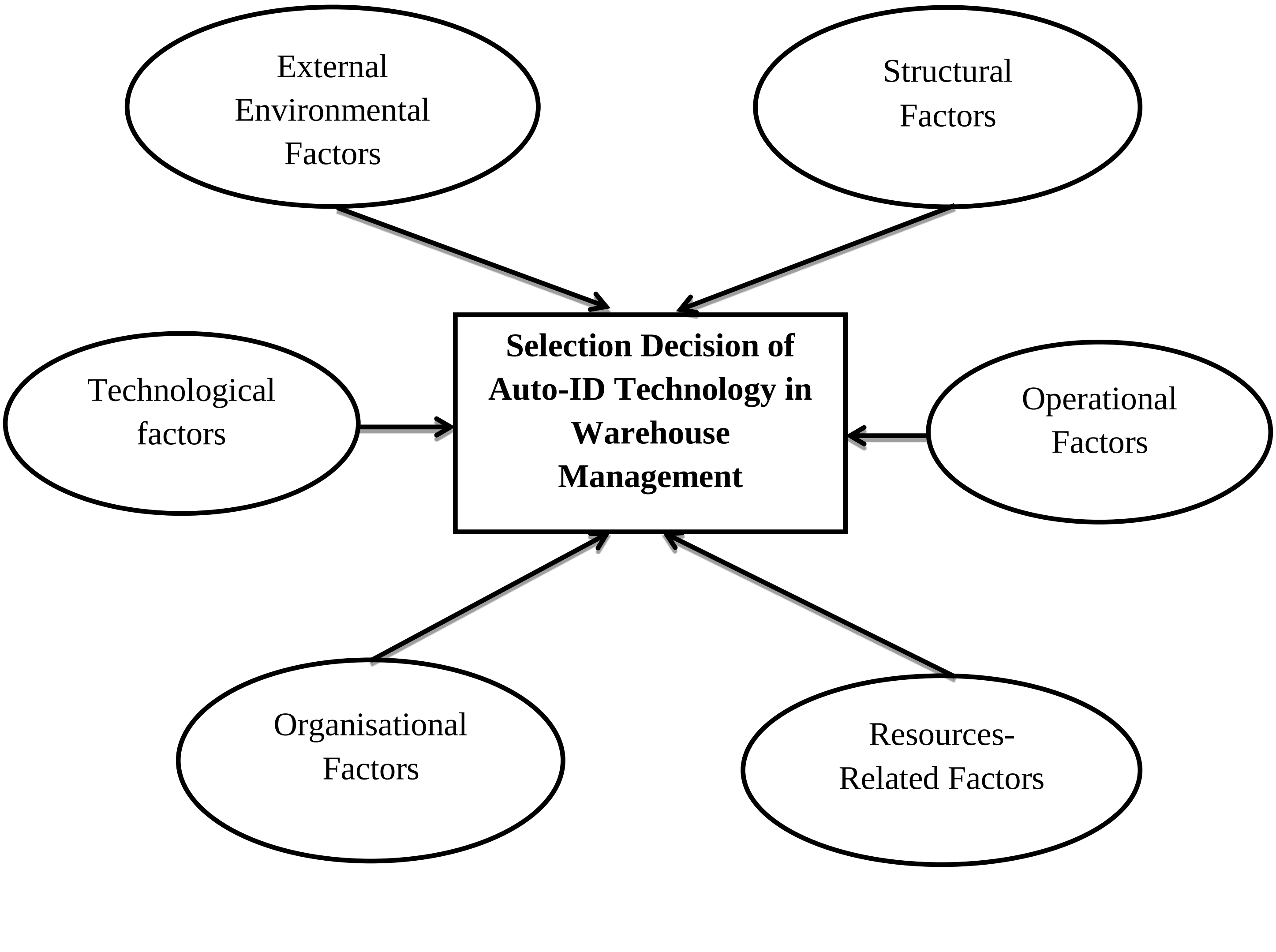


Figure 3.1 Conceptual framework of key factors influencing auto-ID selection decision in the warehouse management
(Adapted from Tornatzky & Fleischer, 1990)

For each category of the conceptual framework, the key sub-factors that may affect auto-ID decision making were identified based on synthesising and analysing the literature on IS implementation, warehouse management, and supply chain management (see Table 3.1).

Major Factors	**Sub-Factors**	**Considered by**
Structural factors	Warehouse size; number of aisles; number of racks; mechanisation level; departments layout; product carrier of the stock keeping unit (pallet, case, or item); product type; temperature; humidity; noise; dust and dirt; pressure; E-Plane (electric field); H-Plane (magnetic field)	Berg & Zijm, 1999; Tompkins et al., 2003; McGinnis et al., 2005; De Koster et al., 2007; Gu et al., 2007; Arooj et al., 2011; Bhuptani & Moradpour 2005; Karagiannaki et al., 2011
Operational factors	Receiving; put away; forward reserve allocation; order-picking; order accumulation and sorting; zoning; batching; routing; shipping; storage assignment policy	Rouwenhorst et al., 2000; Karagiannaki et al., 2011
Resources-related factors	Storage units; storage systems; warehouse management system (WMS); material handling equipment; warehouse staff members (labour); storage space capacity	Ackerman,1997; Rouwenhorst et al., 2000; Tompkins et al., 2003; Karagiannaki et al., 2011
Organisational factors	Top management support; IT knowledge capability; warehouse internal needs	Hwang et al., 2004; Angeles, 2005; Lee & Kim, 2007; Liviu, et al., 2009; Laosirihongthong et al., 2013

Major Factors	Sub-Factors	Considered by
Technological factors	Technology costs; deployment costs; line-of-sight; labour; visibility; accuracy; reliability; item level tracking; traceable warranty; product recalls; quality control; tag data storage; information properties; tag weight; tag read/write capabilities; operational life; memory; communication range; multi-tag collection; security; privacy; environmental sensitivity; interference; ongoing innovations; ease of use; established standards; performance; Return on Investment (ROI)	Wyld, 2006; Huber et al., 2007; Tajima et al., 2007; Sarac et al., 2010; Poon et al. 2011a; Piramuthu et al., 2013; FossoWamba & Ngai, 2013; Piramuthu & Zhou, 2013
External environmental factors	Government pressure; competitors pressure; customer pressure; supplier support	Hwang et al., 2004; Wang et al., 2010c; Quetti et al., 2012

Table 3.1 Identified factors and sub-factors arranged under the TOE framework
Of Tornatzky and Fleischer (1990)

3.3.1 Structural Factors

The warehouse structural factors can be considered as a set of factors that are mainly concerned when starting-up a new warehouse or renewing/adding to an older one (Karagiannaki et al., 2011). Warehouses need to determine their warehouse structure and study their actual environment thoroughly before making auto-ID decisions. This is because the warehouse layout design and structure (physical and internal-environmental factors) vary among different warehousing companies (Bhuptani & Moradpour, 2005). According to Berg and Zijm (1999), Tompkins et al. (2003), McGinnis et al. (2005), De Koster et al. (2007), Gu et al. (2007), Arooj et al. (2011), Bhuptani and Moradpour (2005), Karagiannaki et al. (2011) and on the basis of the literature review, warehouse size, number of aisles, number of racks, mechanisation level, departments layout, product carrier of the stock keeping unit (SKU) (pallet, case, or item), product type, temperature, humidity, noise, dust and dirt, pressure, E-Plane (electric field), and H-Plane (magnetic field) are considered as the key sub-factors that constitute structural factors in warehouse management. These sub-factors are described in detail below.

3.3.1.1 Warehouse Size

In today's business environment, a warehouse can be as small and simple as a garage-like area at a self-storage facility or as large and complex as a massive facility that not only stores items, but also simultaneously supports different value-adding activities (Karagiannaki et al, 2011). In large-sized warehouses, with more than one entrance and several containers are placed at farther locations, the status of the containers changes quickly in a day because large number of customer orders are received every day. Thus, it is burdensome to manage the data of containers at every instant manually (Arooj et al., 2011). In addition, there will be greater chance of incorrect data entry and work delay. Therefore, in order to avoid this situation, Arooj et al. (2011) have suggested that auto-ID technology (RFID system with active tags) can be used to keep the pace of the work fast and correct.

Accordingly, in this research, warehouse size is considered as a key component of structural factors that may influence auto-ID decision-making in the warehouse field.

3.3.1.2 Number of Aisles

In a warehouse, aisles consist of storage pallets which may be used for the storage of products. Many problems may occur if warehouses (e.g., a warehouse with a large number of aisles, storage pallets and products) adopt manual-based warehouse management (Huang et al., 2007; Sexton et al., 2000). For example, it will be difficult to define the actual inventory level in the warehouse, or, to locate and deliver products on time. In order to solve these problems, Poon et al. (2009) have proposed that auto-ID technology (RFID) can be adopted.

In this research, therefore, number of aisles is considered as another key structural sub-factor that may influence the selection decision of auto-ID in warehouse management.

3.3.1.3 Number of Racks

Racks are used in warehouses to keep aisles clear, safe and provide better organisation of products. Racks reduce the amount of damage to the product and the time for storing and retrieving items (Ackerman, 1997). Warehouses can use plastic, wood or metal racks. Different warehouses have different number of racks and products. Hence, in large-sized warehouses, where the number of racks is big, it is important to use auto-ID (RFID) technology for tracking the real-time location and status of racks and products which will enhance the operational efficiency of a warehouse (Poon et al., 2009; 2011a). Moreover, warehouse managers should know the number of racks in their warehouses in order to know the amount of products, metal, wood, or plastic in their warehouse environment, which will help them to choose the most suitable auto-ID/RFID tags for their warehouse (Bhuptani & Moradpour, 2005; Poon et al., 2011b).

Consequently, in this research, number of racks is also considered as a key structural sub-factor that may affect auto-ID decision-making in a warehouse environment.

3.3.1.4 Mechanisation Level

Mechanisation level is the degree of automation of warehouse tasks and operations (manual, semi-automated, or automated) (Karagiannaki et al., 2011). Level of mechanisation/automation of warehouse tasks may affect the impact of auto-ID technology on warehouse performance. This is because in a highly automated warehouse there is less need for auto-ID/RFID than in a warehouse where a large number of tasks are performed manually (Karagiannaki et al., 2011).

Therefore, in this research, the mechanisation level of warehouse (manual, semi-automated, or automated) is considered as a critical structural sub-factor that may influence the selection decision of auto-ID technology in a warehouse context.

3.3.1.5 Departments Layout

Departments' layout and design vary among different warehousing companies (Bhuptani & Moradpou, 2005; Gu et al., 2010). The more complex the warehouse, the more beneficial is the specific auto-ID implementation in terms of reduction in labour, increase in utilisation and time savings (Karagiannaki et al., 2011).

Hence, in this research, departments' layout is considered as a key structural sub-factor that may affect the auto-ID adoption decision in a warehouse field.

3.3.1.6 Product Carrier of the Stock Keeping Unit (Pallet, Case, or Item)

In a warehouse, product carrier of the stock keeping units (SKUs) can be either pallet, case, or item. Stock keeping unit (SKU) is defined as a code that consists of letter, numbers, symbols or any combination thereof that uniquely identifies the price, product options and manufacturer of the item (Tompkins et al., 1998). Different auto-ID technologies have different tracking capabilities (pallet-level, case-level, or item-level) (Raza et al., 1999; Karagiannaki et al., 2011). For example, RFID tags are suitable for item-level tracking (tracking individual items) which will enhance the inventor control and visibility. On the other hand, barcode systems are incapable of item-level tracking (e.g., they can only identify the type of item, they can not specify a product's expiry date) (Wyld, 2006; Song et al., 2006). Therefore, warehouse managers should choose the most appropriate auto-ID technology that works in their warehouse environment. As a result, the warehouse resources will be easily tracked and accurately located which will enhance the visibility of warehouse operations, improve the warehouse productivity and reduce the operational costs of the warehouse (Chow et al., 2006).

Accordingly, product carrier of the stock keeping unit (pallet, case, or item) is considered in this research as an important structural sub-factor that may affect the auto-ID selection decision in warehouse management.

3.3.1.7 Product Type

Many products in a warehouse environment include metal and/or water, such as canned food, detergents and drinks. Water and metal are considered as the two most common and difficult materials in a warehouse because metal reflects and water absorbs and/or reflects the radio waves (Porter et al., 2004). In other words, liquid and metallic objects in warehouse environment have a strong effect on the reading performance of auto-ID technology (active and passive RFID tags) (Poon et al., 2009). However, different auto-ID technologies have different capabilities and warehouse managers should select the right technology in order to gain the most out of the auto-ID technology. For example, active RFID tags are suitable for radio frequency (RF) challenging environments (e.g., inside food pallets, pharmaceutical containers, around metals and liquids), while metals and material of high water content decrease the reading range of passive RFID tags to less than (1) meter (Mercer et al., 2011). Moreover, active RFID tags are suitable for tracking high-value products over long ranges, while passive RFID tags are suitable for tracking low-value consumer products (Tajima, 2007).

Therefore, in this research, product type has been considered as an important structural sub-factor that may affect the auto-ID decision-making in warehouse context.

3.3.1.8 Temperature

According to Huber et al. (2007); and Wyld (2006), some auto-ID technologies such as barcode cannot operate in harsh environment (e.g., a warehouse environment) with excessive temperature because high temperature affects its performance. On the other hand, all RFID tags are robust and can cope with excessive temperature in a warehouse (Finkenzeller, 1999; Huber et al., 2007; Wyld, 2006). However, the temperature extremes have a significant effect on the reading performance of RFID tag and thus it is essential to select the RFID tags which can operate within those extremes.

Consequently, in this research, temperature is regarded as a significant structural sub-factor that might influence the auto-ID adoption decision in warehouse management.

3.3.1.9 Humidity

Humidity is an important component of the warehouse structural factors (Bhuptani & Moradpour, 2005). High humidity and moisture conditions in warehouse environment affect the performance of auto-ID/barcode systems (Li et al., 2006). On the other hand, RFID tags are robust, durable and can cope with high humidity in a warehouse. However, the humidity and moisture extremes have a strong effect on the reading performance of RFID tag and therefore it is necessary to choose the RFID tags which can operate within these extremes.

Consequently, in this research, humidity is considered as a key structural sub-factor that may affect the auto-ID selection decision in warehouse environment.

3.3.1.10 Noise

According to Bhuptani and Moradpour (2005), noise is a key component of the warehouse structural factors and different warehouses have different levels of noise. Noise in the warehouse environment has negative effect on the reading performance of auto-ID technology. For example, passive RFID tags are subject to noise, while active RFID tags are better noise immunity (Tajima, 2007). Hence, warehouse managers should assess the noise level in their environment and select the auto-ID technology that can cope with this noise.

In this research, therefore, noise has been considered as a key structural sub-factor that may influence the selection decision of auto-ID technology in a warehouse field.

3.3.1.11 Dust and Dirt

RFID technology is much more expensive than barcode technology, but many people still want to implement it in their own business as it can operate in harsh environments such as in dust and dirty conditions which affect barcodes (Li et al., 2006). Barcodes are susceptible to environmental damage and they cannot be read if damaged or dirty, while RFID tags are robust, durable and can cope with excessive dirt and dust (Finkenzeller, 1999; Huber et al., 2007; Wyld, 2006). Thus, it is essential that warehouse managers select the auto-ID technology that can operate in their environment.

Accordingly, dust and dirt have been considered as key structural sub-factors that might affect the auto-ID decision-making in a warehouse environment.

3.3.1.12 Pressure

Pressure is an important component of the warehouse structural factors (Bhuptani & Moradpour, 2005). Pressure has a significant effect on the performance of auto-ID technology. However, the performance of RFID technologies is better than barcode systems in harsh environment (e.g., a warehouse environment) with high level of pressure (Huber et al., 2007; Wyld, 2006). Thus, warehouse managers should evaluate the pressure level in their environment in order to choose the most appropriate auto-ID technology (Huber et al., 2007; Wyld, 2006).

In this research, therefore, pressure is regarded as a key structural sub-factor that may influence the selection decision of auto-ID technology in a warehouse context.

3.3.1.13 E-Plane (Electric-Field)

E-Plane (electric-field) is defined as “the plane containing the electric-field vector and the direction of maximum radiation,” (Balanis 2011). E-Plane has been found to have a significant influence on the reliability and accuracy of the reading performance of auto-ID/RFID technology (Porter et al., 2004; Clarke et al., 2006; Mercer et al., 2011; Poon et al., 2011a). According to Michael and McCathie (2005); and Huber et al. (2007), RFID technology requires many pilot tests in order to check if there is any interference with other devices (e.g., electronic devices).

Consequently, in this research, E-Plane (electric-field) is considered as a critical structural sub-factor that may affect the auto-ID selection decision in warehouse field.

3.3.1.14 H-Plane (Magnetic-Field)

Balanis (2011) has defined H-plane (magnetic-field) as, “the plane containing the magnetic-field vector and the direction of maximum radiation”. H-Plane has a strong impact on the reliability and accuracy of the reading performance of auto-ID/RFID technology (Mercer et al., 2011; Poon et al., 2011a). In order to select the right auto-ID technology, warehouse managers should check the magnetic-field in their environment (Poon et al., 2011a).

In this research, therefore, H-Plane (magnetic-field) has been considered as a key structural sub-factor that may influence the auto-ID adoption decision in warehouse context.

3.3.2 Operational Factors

Operational factors can be considered as a set of factors that are mainly concerned at the operating stage (Karagiannaki et al., 2011). Products arriving at a warehouse afterwards are taken through a number of steps called “operations” or “processes” (Rouwenhorst et al., 2000). The performance of warehouse operations not only affects the productivity and operation costs of a warehouse, but also the entire supply chain (Gu et al., 2007; Chow et al., 2006; Poon et at., 2011a). According to Tompkins and Smith (1998); Rouwenhorst et al. (2000); Frazelle (2002b); Tompkins et al. (2003): and on the basis of the literature review, receiving, put away, forward reserve allocation, order-picking, order accumulation and sorting, zoning, batching, routing, shipping, and storage assignment policy are categorised as critical sub-factors that constitute operational factors in warehouse management. These sub-factors are described in detail below.

3.3.2.1 Receiving

Receiving is the process of the orderly receipt of all items from suppliers, checking quality and quantity, and disbursing items for storage or to other organisational functions requiring them (Frazelle, 2002b). Some warehouses are more complex with well-designed receiving workflow than other warehouses (Karagiannaki et al., 2011). Therefore, receiving operation is extremely labour-intensive and prone to human error because warehouse workers need to check and count manually the precise number of items inside each case or pallet (Alexander et al., 2002). Also, theft is very common in receiving operation. Thus, many warehouses seek to adopt auto-ID technology to effectively automate the inspection and checking operations, avoid human error, educe theft and enhance the performance of receiving operation.

The importance of receiving operation in auto-ID selection decision has been demonstrated in previous literature review. For example, Chow et al. (2006); and Poon et al. (2011a) have suggested that warehouse managers should analyse their receiving operation and identify points to be improved before considering an auto-ID technology in order to select the technology that matches the warehouse’s needs.

Therefore, based on previous literature and the arguments presented above, receiving is considered as a key operational sub-factor that may affect the selection decision of auto-ID technology in a warehouse management.

3.3.2.2 Put away

In a warehouse, put away includes materials handling, defining the suitable location for items, and transferring them to a specified storage place to wait for demand (Frazelle, 2002b). Put away is a critical operation in any warehouse and it is labour intensive and time consuming, especially, in large-sized and medium-sized warehouses (Karagiannaki et al., 2011). Therefore, if warehouses have problems in put away operation (e.g., high labour costs, human error), then they should start to look at auto-ID/RFID technology in order to increase the efficiency of the put away operation (Chow et al., 2006).

In this research, put away is regarded as an important operational sub-factor that might influence the auto-ID adoption decision in a warehouse field.

3.3.2.3 Forward Reserve Allocation

Many warehouses store some goods in storage area which consists of two parts: a *reserve area*, where items are stored in the most economical way (it is used for efficient storage and replenishing the forward area, bulk storage area), and a *forward area*, where items are stored in smaller quantities so that storage units are retrieved and accessed easily by an order picker (it is used for efficient order-picking) (Rouwenhorst et al., 2000). The reserve storage may comprise pallet racks while the forward storage may comprise shelves (Rouwenhorst et al., 2000). The forward-reserve allocation determines the set of Stock-Keeping Units (SKUs) and their space allocations in the forward and reserve areas. Many warehouses have problems in the forward-reserve allocation operation (e.g., high amount of labour, human error), particularly, in a large-sized and medium-sized warehouses (Tompkins & Smith, 1998). Hence, auto-ID/RFID technology can be implemented to save time and avoid human errors in forward reserve allocation (Karagiannaki et al., 2011; Chow et al., 2006).

In this research, therefore, forward reserve allocation is considered as key operational sub-factor that may influence the auto-ID selection decision in a warehouse context.

3.3.2.4 Order-Picking

Order-picking is a key component of the operational factors. Picking is retrieving items- which can be performed manually or can be (partly) automated- from their storage places and transferring them either to the accumulation, sorting, and/or consolidation process or directly to the shipping area (Rouwenhorst et al., 2000). According to Alexander et al. (2002), the order-picking function can employ up to half the workers in a warehouse/distribution centre and requires much verification. In addition, it represents 50-75% of the total operating costs in a typical warehouse (Coyle et al., 1996). If warehouses have problems in order-picking operation (e.g., high labour costs, human error), then they should implement auto-ID/RFID technology in order to enhance the performance of picking operation (Chow et al., 2006).

Accordingly, based on previous literature and the arguments presented above, order-picking is regarded as an important operational sub-factor that might influence the auto-ID decision-making in a warehouse environment.

3.3.2.5 Order Accumulation and Sorting

Accumulation and sorting of picked orders into individual (customer) orders are essential activities, especially, if the orders have been picked in batches (Tompkins et al., 2003; De Koster et al., 2007). The accumulation and sorting operation is also time consuming, labour intensive and subject to human error. Usually, warehouses seek to use auto-ID technology/RFID in order to solve the problems in the accumulation and sorting of picked orders (e.g. high labour costs) (Karagiannaki et al., 2011).

In this research, the accumulation and sorting is considered as a critical operational sub-factor that may affect the auto-ID selection decision in a warehouse management.

3.3.2.6 Zoning

According to De Koster et al. (2007), zoning means that a storage area (a pallet storage area or the entire warehouse) is split in many parts, each with different order pickers. Zoning might be further classified into two different types: *progressive zoning* (orders picked in a zone are passed to other zones for completion) and *synchronised zoning* (orders picked in parallel) (De Koster et al., 2007). Zoning type may moderate the impact of auto-ID/RFID technology on warehouse performance (Karagiannaki et al., 2011).

In this research, therefore, zoning is regarded as a significant operational sub-factor that might influence the auto-ID adoption decision in a warehouse area.

3.3.2.7 Batching

Batching is grouping the customer orders into picking orders (Rouwenhorst et al., 2000). Order batching has been proven to be fundamental for the efficiency of order-picking operations (De Koster et al., 2007). Order batching can be distinguished into *static batching* (e.g., the corresponding order lines for each customer order are known) and *dynamic batching* (e.g., customer orders arrive at many points in time while the picking is already being executed) (De Koster et al., 2007). In large-sized and medium-sized warehouses, batching function demands a large amount of manual labour. Batching function may moderate the effect of auto-ID/RFID technology on warehouse performance (Karagiannaki et al., 2011).

In this research, batching is considered as a significant operational sub-factor that might affect the auto-ID selection decision in a warehouse context.

3.3.2.8 Routing

Routing function is defined as the determination of the sequences in which the items have to be picked and the identification of the corresponding paths (shortest tour for the order picker) in the warehouse environment (De Koster et al., 2007). According to Karagiannaki et al. (2011), routing may moderate the impact of auto-ID/RFID technology on warehouse performance.

In this research, routing is regarded as a key operational sub-factor that may influence the auto-ID adoption decision in a warehouse field.

3.3.2.9 Shipping

Shipping has been described as orders checked and inspected, orders packed, palletised and loaded into trucks or trains for further delivery (Tompkins et al., 2003). Shipping operation is necessary to deliver products to markets (customers) as quickly and reliably as possible, enabling warehouses to reduce total cycle time effectively (Chow et al., 2006; Poon et al., 2009). Warehouses want a fast and efficient way to ship the right items to their customers. Therefore, many warehouses seek to adopt auto-ID/RFID technology in order to enhance shipping operation and improve quality of customer service and satisfaction (e.g., increasing the speed of delivery, delivering the right quantity and quality at the right time, reducing missed shipments) (Chow et al., 2006).

In this research, shipping is considered as a critical operational sub-factor that may influence the auto-ID adoption decision in a warehouse field

3.3.2.10 Storage Assignment Policy

Storage assignment is described as putting products into storage locations before picking them to fulfil customer orders. According to De Koster et al. (2007), there are five ways of storage assignment as follows:

- Random storage: every incoming pallet of similar products is assigned to a storage location in the warehouse that is chosen randomly from all eligible empty locations;
- Closest open location storage: order pickers can select the location for storage themselves;
- Dedicated storage: to store each item at a fixed storage location;
- Full turnover storage: this policy distributes items over the storage area according to their turnover/sales rates; and
- Class- based storage: it combines some of the four ways mentioned above.

The importance of storage assignment policy has been demonstrated in empirical research. For instance, Karagiannaki et al. (2011) have observed that the warehouse using closest open location storage obtain more benefits from the RFID implementation (in terms of reduction in labour utilisation and time savings) than the warehouse using dedicated storage assignment policy.

Therefore, in this research, storage assignment policy is considered as a critical operational sub-factor that may affect the auto-ID selection decision in a warehouse management.

3.3.3 Resources-Related Factors

Warehouse resources include all means, equipment and staff needed to operate the warehouse (Rouwenhorst et al, 2000). Warehouse resources usually represent a sizeable capital investment. Nearly 50% of the costs in a typical warehouse are labour-intensive while facilities, machinery and storage equipment represent a smaller part of the capital investment (Aminoff et al., 2002). In this research, the resources–related factors were identified based on synthesising the works proposed by Ackerman (1997), Rouwenhorst et al. (2000), Tompkins et al. (2003) and Karagiannaki et al. (2011) as follows:

- storage units;
- storage systems;
- warehouse management system (WMS);
- material handling equipment;
- warehouse staff members (labour); and
- storage space capacity.

These sub-factors are described in detail below.

3.3.3.1 Storage Units

Storage units include pallets, cartons and plastic boxes, and trays which may be used for the storage of products (Rouwenhorst et al., 2000). In today's business environment, many warehouse managers struggle to maintain accurate data about the location and status of products in their warehouses (Poon et al., 2009; Sarac et al., 2010). As a result, products go missing and it usually takes a long time to find them (Chow et al., 2006). Moreover, in any warehouse, effective inventory control (e.g., the precise quantity of products) and stock location management (e.g., precise storage location of the items) are crucial in order enhance the operational efficiency of a warehouse. An auto-ID/RFID technology helps warehouses to track and trace storage units (products) accurately and in real-time, and thus it improves the warehouse visibility (e.g., what is in the warehouse and where at any time) (Vijayaraman & Osyk, 2006; Poon et al., 2011a).

According to Angeles (2005), warehouse managers should use auto-ID technology after examining their storage units and checking if they have any problems (such as the above mentioned problems).

Hence, in this research, storage unit is considered as an essential resources-related sub-factor that may influence the auto-ID selection decision in a warehouse management.

3.3.3.2 Storage Systems

Storage systems are very diverse and may consist of many subsystems in which different types of products may be stored. Storage systems may range from simple shelves up to automated cranes and conveyors (Rouwenhorst et al., 2000). Storage systems moderate the impact of auto-ID (RFID) technology on warehouse performance and thus warehouse managers should analyse their storage systems before deciding to use the technology. For example, Karagiannaki et al. (2011) have found that in a warehouse where a large number of tasks are performed manually, there is more need for auto-ID (RFID) than in a highly automated warehouse (Karagiannaki et al., 2011). In other words, large-sized or medium-sized warehouses that have complex storage systems (e.g., many shelves) will benefit more from adopting auto-ID/RFID technology in terms of reduction in labour utilisation and time savings than small-sized warehouses with simple storage systems (garage-like, few shelves) (Karagiannaki et al., 2011).

Accordingly, based on previous literature and the arguments presented above, storage system is considered as a critical resources-related sub-factor that might affect the selection decision of auto-ID technology in a warehouse context.

3.3.3.3 Warehouse Management System (WMS)

In a warehouse environment, warehouse management system (WMS) provides the information necessary to manage and control the flow and storage of materials within a warehouse, from receiving to shipping (Faber et al., 2002). WMS is an essential component of resources-related factors and it should not be ignored when investigating auto-ID decisions for warehouse management (Chow et al., 2006). According to Vijayaraman and Osyk (2006), WMS is one of the top concerns of warehouses implementing auto-ID (RFID) technology due to the integration complexity of RFID with WMS. Adopting of RFID within the warehouse will generate a large amount of data that needs to be stored, processed and used in real-time. Therefore, RFID technology will need to be combined with the existing warehouse management system (Vijayaraman & Osyk, 2006). Hence, it is crucial to evaluate the overall warehouse management system (WMS) design/re-design and ability of RFID to integrate into the existing WMS in order to obtain the expected results (Karagiannaki et al., 2011).

Consequently, in this research, warehouse management system (WMS) is regarded as a critical resources-related sub-factor that may influence auto-ID decision-making in the warehouse field.

3.3.3.4 Material Handling Equipment

Material handling equipment such as standard forklifts, reach trucks, pallet trucks, sorter systems and truck loaders are used for the retrieval of items from the storage system and preparing these items for the expedition (Rouwenhorst et al., 2000). Different types of material handling equipment have different impact on the reading performance and accuracy of auto ID (RFID tags). Warehouse managers should examine the material handling equipment in their warehouse when considering auto-ID (RFID) technology in order to select the optimum technology. For example, passive large-sized RFID tag is not suitable to be adopted in tracking the forklifts, because the reader is unable to detect the tags which are stuck on the metal (Poon et al., 2009).

In this research, material handling equipment is recognised as a key resources-related sub-factor that might affect the auto-ID selection decision in a warehouse management.

3.3.3.5 Warehouse Staff Members (Labour)

Warehouse staff members (labour) are an important component of the resources-related factors because they perform and control all of the resources-related factors (e.g., storage units, storage systems warehouse management system (WMS), material handling equipment, storage space capacity) (De Koster et al., 2007). Auto-ID/RFID technology can be used to save time and increase the productivity of the warehouse staff members, especially in large and medium warehouses (e.g., it eliminates the need for labour-intensive stock counts and inspections when products are received) (Poon et al., 2009; Karagiannaki et al., 2011).

In this research, warehouse staff member (labour) is considered as a key resources-related sub-factor that may influence the auto-ID adoption decision in a warehouse environment.

3.3.3.6 Storage Space Capacity

Storage space is a storage area, facility or zone in a warehouse that can be used for buffering goods and materials (Tompkins et al., 2003). Owing to seasonal demand patterns, different proportions of occupied storage space are observed in any warehouse (Karagiannaki et al., 2011). Storage space capacity of a warehouse is a critical issue when considering auto-ID technology because it moderates the impact of RFID on warehouse performance (Karagiannaki et al., 2011). Auto-ID (RFID) technology can be effectively adopted to improve the utilisation of the storage space capacity in a warehouse environment (Wang et al., 2010a; Karagiannaki et al., 2011).

Therefore, in this research, storage space capacity is regarded as a critical resources-related sub-factor that may affect the auto-ID selection decision in a warehouse field.

3.3.4 Organisational Factors

The need and success of auto-ID technology is based on key organisational factors (Tornatzky & Fleischer, 1990). According to Hwang et al. (2004), Angeles (2005), Lee and Kim (2007), Liviu et al. (2009), Laosirihongthong et al. (2013) and on the basis of the literature review, top management support, IT knowledge capability, and warehouse internal needs are categorised as critical sub-factors that constitute organisational factors in warehouse management. These sub-factors are described in detail below.

3.3.4.1 Top Management Support

Without support from top management, the project team will not be able to execute the auto-ID selection decision, and will be unable to ensure that the technology selection and adoption aligns with the strategic direction of the warehouse (Lee & Kim, 2007). It is important to gain support from senior management because top management can provide a vision, support and commitment to create a positive environment for IT innovation (Lee & Kim, 2007; Wang et al., 2010a). Top management support is more critical for RFID technologies since the RFID adoption requires sufficient resources, process reengineering and user coordination (Hwang et al., 2004). Management support will help ensure that an RFID project receives the necessary resources for the success of selection and implementation (Irani et al., 2010).

Therefore, in this research, top management support is considered as a critical organisational sub-factor that might influence the auto-ID decision-making in a warehouse environment.

3.3.4.2 IT Knowledge Capability

IT knowledge capability refers to possessing the knowledge and skills to select and implement RFID-related IT applications (Wang et al., 2010c). In general, the development of an RFID technology is still relatively new to many companies and adopting RFID applications requires new IT knowledge and skills (Ngai et al., 2007). One of the most difficult problems in making an auto-ID selection decision is the limit of IT knowledge capabilities (Ngai et al., 2007; Attaran, 2012). Therefore, warehouse managers must possess the knowledge and skills on auto-ID technology in order to choose and adopt the appropriate technology for their warehouses and applications (Wang et al., 2010c).

In this research, top management support is considered as a key organisational sub-factor that may affect the auto-ID decision-making in a warehouse management.

3.3.4.3 Warehouse Internal Needs

According to Liviu et al. (2009); and Chan and Chang (2011), identifying any existing needs and potential problems are crucial for warehouse management before approaching auto-ID technology. There are many problems that may occur at the warehouse such as a high level of theft, high labour costs, reduced productivity, high level of inventories and shipping inaccuracies (Sarac et al., 2010; Poon et al., 2011a). Warehouse managers should determine whether to deploy auto-ID to solve one problem or multiple problems. Moreover, they should determine what types of problem can be solved by using RFID and/or barcode systems. Hybrid RFID-barcode systems would employ a particular technology in a warehouse environment in order to take advantage of its relative cost effectiveness or robustness (White et al., 2007). Warehouse managers therefore must first focus on their business problems and needs and then select the technology matches those needs and requirements (Angeles, 2005).

Hence, in this research, warehouse internal need is recognised as an important organisational sub-factor that might influence the auto-ID selection decision in a warehouse area.

3.3.5 Technological Factors

Based on the Technology-Organisation-Environment (TOE) framework of Tornatzky and Fleischer (1990), the technological context constituted both the internal and external technologies relevant to the organisation. According to Ilie-Zudor et al. (2011), it is essential to conduct a technological analysis before approaching auto-ID technology as barcode and RFID have different characteristics and therefore have different effects on labour, costs and supply chain issues. In this regard, Poon et al. (2009) and Poon et al. (2011b) have indicated that the technological factors have a significant effect on RFID performance and accordingly on warehouse performance.

A comprehensive set of technological factors have been identified based on a synthesis of the works proposed by Finkenzeller (1999), Raza et al. (1999), Juels & Pappu (2003), Wyld (2006), Song et al. (2006), Speakman & Sweeney (2006), Huber et al. (2007), Tajima et al. (2007), Domdouzis et al. (2007), Jedermann et al. (2009), Poon et al. (2009), Sarac et al. (2010), Poon et al. (2011a), Piramuthu et al. (2013), FossoWamba and Ngai (2013), and Piramuthu and Zhou (2013). The technological factors were categorised with twenty eight (28) sub-technological factors as follows:

technology costs (1); deployment costs (2); line-of-sight (3); labour (4); visibility (5); accuracy (6); reliability (7); item level tracking (8); traceable warranty (9); product recalls (10); quality control (11); tag data storage (12); information properties (13); tag weight (14); tag read/write capabilities (15); operational life (16); memory (17); communication range (18); multi-tag collection (19); security (20); privacy (21); environmental sensitivity (22); interference (23); ongoing innovations (24); ease of use (25); established standards (26); performance (27); and Return on Investment (ROI) (28).

These technological sub-factors are described in detail below.

3.3.5.1 Technology Costs

Technology cost has been widely considered as a key obstacle to auto-ID (RFID) widespread deployment in supply chain management (Angeles, 2005; Huber et al., 2007; Sarac et al., 2010). Technology costs consist of hardware cost (e.g., RFID readers, RFID tags, RFID antennas, cabling and connectors, computers Network witches) and software costs (middleware system, database system, interface system) (Banks et al., 2007).

Different auto-ID technologies have different costs. For example, RFID technology is much more expensive than barcode technology (e.g., passive RFID $0.40-10/tag, active RFID $100/ tag, semi-passive $10-20/tag, barcode $0.001/tag) (Tajima, 2007; Jedermann et al., 2009).

Thus, in this research, technology cost is recognised as a crucial technological sub-factor that may affect the auto-ID selection decision in a warehouse.

3.3.5.2 Deployment Costs

Deployment costs of auto-ID technology include system integration costs, installation service costs, personnel costs and business process reengineering costs (Banks et al., 2007). Barcode technology is relatively cheap, while RFID technology is expensive and requires new infrastructure (Michael & McCathie, 2005; Huber et al., 2007).

In this research, deployment cost is considered as a key technological sub-factor that might influence the auto-ID adoption decision in a warehouse field.

3.3.5.3 Line-of-Sight

Line-of-sight may refer to the straight line that goes directly from the reader to the object without interruption (Song et al., 2006). The big difference between RFID and barcode is that barcode is line-of-sight technology, which means that a scanner has to see the barcode in order to read it. In other words, barcode is an optical line-of-sight scanning and it can only be read individually and with the alignment of the barcode toward a scanner (Raza et al., 1999; Wyld, 2006). On the other hand, RFID technology does not require line of sight and RFID tag can be read as long as it is within the reader range. So, RFID technology is an automatic non-line-of-sight scanning and multiple tags can be read simultaneously (Raza et al., 1999; Wyld, 2006; Speakman & Sweeney, 2006).

Hence, in this research, line-of-sight is regarded as an important technological sub-factor that may affect the auto-ID decision-making in a warehouse context.

3.3.5.4 Labour

Labour has been recognised as a key technological factor influencing the widespread usage of auto-ID (RFID) technology (Kleist et al., 2004; Hunt et al., 2007). Barcode technology is labour-intensive because operators have to scan data and then input this data manually (manual tracking) and thus errors occur easily as human error is unavoidable (Sexton et al., 2000; Speakman & Sweeney, 2006; Huber et al., 2007). However, RFID helps to automate the supply chain, leading to labour reduction throughout the process such as reducing problems (e.g., out-of-stock occurrences), improving efficiency and removing human error (automatic tracking) (Speakman & Sweeney , 2006; Huber et al., 2007).

Thus, based on previous literature and the arguments presented above, labour is considered as a key technological sub-factor that might influence the auto-ID decision-making in a warehouse field.

3.3.5.5 Visibility

In a warehouse environment, RFID technologies enhance visibility by providing an accurate picture of inventory levels in real-time and locating warehouse resources easily, and therefore enhancing warehouse productivity and reducing the labour and operational costs of the warehouse (Poon et al., 2009; 2011a). On the other hand, barcode systems provide limited visibility because they are unable to update daily operations of inventory level, locations of forklifts and SKUs in real-time, or, to provide timely and accurate data of warehouse operations, resulting in high operational costs for the warehouse (Raza et al.,1999; Wyld, 2006; Song et al., 2006).

Hence, visibility is recognised as a critical technological sub-factor that may influence the auto-ID selection decision in a warehouse environment.

3.3.5.6 Accuracy

Accuracy of auto-ID technology refers to the probability that a tag will be read correctly for a specific operating environment (Wolstenholme, 1999). Barcode systems are accurate, but they are subject to operator mistakes (e.g. forgetting/skipping to scan) and environmental obstacles which affect their reading accuracy (Raza et al., 1999; Wyld, 2006; Huber et al., 2007). However, RFID is more accurate than barcode and it can be used to improve the inventory management because it can provide an accurate picture of inventory levels in real-time (Poon et al., 2011a). Moreover, RFID technology can remove operator mistakes and cope with the environmental obstacles (Speakman & Sweeney, 2006; Chow et al., 2006).

Therefore, based on previous literature and the arguments presented above, accuracy is considered as a key technological sub-factor that might influence the auto-ID adoption decision in a warehouse management.

3.3.5.7 Reliability

According Wolstenholme (1999), reliability is described as the probability that a component or system will operate satisfactorily, either at any specific instant at which it is required, or for a particular length of time. The reliability of auto-ID (RFID tags) is an important issue that may affect the technology's ultimate success (Michael, 2005). Barcode systems are quite reliable, but they cannot be read correctly in a harsh environment (e.g., prone to environmental damage, they cannot be read if damaged or dirty) (Wyld, 2006; Huber et al., 2007). However, RFID tags are more reliable and they can cope with harsh environments (e.g. a warehouse environment with dirt, moisture, temperature extremes) (Speakman & Sweeney, 2006; Huber et al., 2007).

3.3.5.8 Item-Level Tracking

Item-level tracking means to use item-level tagging for tracking individual items in order to better visibility and control of inventory throughout the supply chain (Li et al., 2006). Barcode is incapable of item-level tracking (e.g., it can only identify the type of item), while RFID is item-level tracking (e.g., it is able to identify products at the item level, identify the type of item, specify a product's expiry date), which will enhance safety and reduce theft (Raza et al., 1999; Wyld, 2006; Song et al., 2006).

In this research, item-level tracking is recognised as a key technological sub-factor that may affect the auto-ID selection decision in a warehouse filed.

3.3.5.9 Traceable Warranty

Traceability is described as the ability to trace the origin, movement and destination of items throughout the supply chain (Huber et al., 2007). RFID technologies have traceable warranties across a supply chain which will enhance safety, reduce operating expenses and improve efficiency, while barcode has restricted traceability across a supply chain (Huber et al., 2007).

In this research, traceable warranty is considered as a critical technological sub-factor that might influence the auto-ID decision-making in a warehouse environment.

3.3.5.10 Product Recalls

A product recall is defined as a request to return product after the discovery of product defects or safety issues that may threaten the consumer or put the seller at risk of legal action (Wyld, 2006). Michael (2005) has stated that the product recalls can be attributed as a costly source of loss in the supply chain. RFID technology can uniquely identify every single product in the supply chain, allowing manufacturers to get instant access to data that enables them to issue recalls of only defective products, unlike barcode systems (Michael, 2005; Huber et al., 2007).

In this research, product recall is considered as a key technological sub-factor that may affect the auto-ID decision-making in a warehouse context.

3.3.5.11 Quality Control

Quality control cannot be very accurate by using a barcode as it has restricted traceability and product recalls across a supply chain (Huber et al., 2007). However, RFID technology allows organisations to control and monitor the quality of products internally (e.g., within their manufacturing process) as well as when the goods move throughout the supply chain (Michael, 2005). RFID technologies provide an accurate quality control because they permit the collection of real-time data in the manufacturing process. As a result, the chance of customers receiving poor quality products will be reduced and the time spent for monitoring and reworking orders will be decreased (Michael, 2005). RFID tags can also monitor shock and temperature levels to ensure the quality of the end product (Wyld, 2006).

Therefore, based on previous literature and the arguments presented above, quality control is considered as a critical technological sub-factor that may influence the auto-ID adoption decision in a warehouse field.

3.3.5.12 Tag data Storage Accuracy

Different auto-ID technologies have different capabilities regarding tag data storage. For example, one-dimensional ID barcode can hold only minimal amount of data, while two-dimensional (2D) and Reduced Space Symbology (RSS) can hold more data (Finkenzeller, 1999; and Huber et al., 2007). In contrast, active, passive and semi-passive tags can typically hold as little or as much data as required by users, although this is limited by cost (Asif et al., 2005; Domdouzis et al., 2007; Jedermann et al., 2009).

In this research, tag data storage is recognised as a key technological sub-factor that might affect the auto-ID selection decision in a warehouse field.

3.3.5.13 Information Properties

The information properties of tags vary among different auto-ID technologies. Unlike a barcode, RFID tag contains information that can be updated dynamically, storing new information from RFID readers as they move along the supply chain, resulting in many advantages (e.g., reduce labour costs, reduce disruption to business) (Michael, 2005; Tajima, 2007).

In this research, information property is considered as a key technological sub-factor that may affect the auto-ID adoption decision in a warehouse context.

3.3.5.14 Tag Weight

Some researchers have claimed that tag weight has a significant effect on the reading performance of auto-ID/RFID tags (Poon et al., 2009). The weight of active RFID tag is 120-130g as it has a battery on board and thus it is suitable for tracking vehicles, large assets and containers (Juels & Pappu, 2003; Tajima, 2007; Domdouzis et al., 2007). However, the weight of passive RFID tag is 6-54g and therefore it is suitable for tracking small assets and containers (Juels & Pappu, 2003; Tajima, 2007; Domdouzis et al., 2007).

In this research, therefore, tag weight is regarded as an important technological sub-factor that might influence the auto-ID decision-making in a warehouse environment.

3.3.5.15 Tag Read/Write Capabilities

Barcode has no read/write capabilities and therefore no new information can be added to the information written on a printed barcode. RFID, however, can be read/write tags, allowing the RFID reader to communicate with the tag and alter as much of the information as the tag design will permit (Tajima, 2007). For instance, active and semi-passive RFID tags have read/write capabilities, while passive RFID tag is read only (Tajima, 2007; Jedermann et al., 2009). Tag read/write capability is a very important feature of RFID because users using read/write tags can comply with the new requirements with minimal cost or disruption to business by writing the new information to their existing tags (Tajima, 2007).

Therefore, in this research, tag read/write capability is considered as a key technological sub-factor that may affect the auto-ID selection decision in a warehouse management.

3.3.5.16 Operational Life

Operational life of some auto-ID/RFID tags is limited by the battery life. For example, the operational life of active RFID tags is limited (5-10 years) as they possess an internal battery, while passive RFID tags have unlimited operational life as they do not have any battery (Tajima, 2007). This is a critical issue because most active RFID tags are more expensive than passive RFID tags **(**Finkenzeller, 1999; Huber et al., 2007).

Thus, in this research, operational life is recognised as a key technological sub-factor that may affect the auto-ID adoption decision in a warehouse area.

3.3.5.17 Memory

Memory is a key feature of auto-ID/RFID tags. Some RFID tags have an extended memory (e.g. active RFID tag up to 128 kb), which allows them to store a significant amount of data on the tag (Juels & Pappu, 2003). Passive RFID tags, however, have low memory (up to 32 kb) (Juels & Pappu, 2003). High memory tag is critical issue, especially, for situations where an asset does not have guaranteed access to a network or does not want to share information across organisations. There are many advantages that can be obtained by integrating high memory RFID tags into an application such as maintenance and asset management. For example, high memory RFID tags enable users to add, edit and recall records; enhance security; ensure availability of information at all times; provide simplification of deployment without the need for complex IT integration and reduce the need for contact with network (Juels & Pappu, 2003).

Accordingly, in this research, memory is considered as an important technological sub-factor that may influence the auto-ID selection decision in a warehouse environment.

3.3.5.18 Communication Range

Different auto-ID/RFID tags have different communication ranges. For instance, active and semi-passive RFID tags have a long communication range (> 100 m) because they possess an internal battery (own power source), while passive RFID tags have short communication range (typically under 3m) as they do not have their own power source (Angeles, 2005; Jedermann et al., 2009). The long communication range of active RFID tags makes them suitable for many industries where asset location and other improvements in logistics are essential (Tajima, 2007).

In this research, communication range is considered as key technological sub-factor that might affect the auto-ID decision-making in a warehouse field.

3.3.5.19 Multi-Tag Collection

Multi-tag collection is a key component of the technological factors. Some RFID systems can scan a thousand tags from a single reader (e.g., active RFID), while passive RFID systems can only scan a hundred tags within 3 meters from a single reader (Domdouzis et al., 2007). This means that active RFID tags can be read much faster than passive tags, which can help businesses save more time and increase the operational efficiency (Poon et al., 2009).

In this research, multi-tag collection is regarded as a key technological sub-factor that may influence the auto-ID selection decision in a warehouse environment.

3.3.5.20 Security

The main purpose of security is to minimise the effect of any type of threats within the supply chain such as theft, counterfeit, terrorism, loss of reputation sabotage, extortion, accidents, etc (Huber et al., 2007). Barcode has limited or no security capabilities as it is incapable of item-level tracking (e.g., it can only identify the type of item). In contrast, RFID enhance the security as the information stored in RFID tags is rich (Raza et al., 1999; Huber et al., 2007). RFID is able to identify products at the item level, identify the type of item and also specify a product's expiry date, which will eliminate counterfeiting and achieve patient safety and wellbeing (e.g., pharmaceutical industry) (Raza et al., 1999; Song et al., 2006; Wyld & Jones, 2007).

Hence, based on previous literature and the arguments presented above, security is recognised as a critical technological sub-factor that might influence the auto-ID adoption decision in a warehouse management.

3.3.5.21 Privacy

Privacy issues are considered as one of the biggest threats to the success of auto-ID/RFID technology. RFID tags are rich information and quite durable and therefore consumers have privacy concerns (e.g., retailers may use data of RFID tag to profile consumers by linking their purchases with other personal information such as credit cards or driver licenses, lack of information about how the tags could be turned off once an item is purchased) (Michael, 2005). On the other hand, barcodes are unable to track individual items and this limits consumer privacy concerns (Huber et al., 2007).

Consequently, in this research privacy is considered as a key technological sub-factor that may affect the auto-ID selection decision in a warehouse environment.

3.3.5.22 Environmental Sensitivity

Warehouse managers should analyse their environment in order to select the suitable auto-ID technology that works in their warehouse environment. RFID tags are robust and durable and they can cope with harsh environments (e.g. a warehouse environment) with excessive dirt, dust, moisture, and in temperature extremes, which affect barcodes (Li et al., 2006). However, barcodes are susceptible to environmental damage and they cannot be read if damaged or dirty (Finkenzeller, 1999; Wyld, 2006; Huber et al., 2007).

In this research, therefore, environmental sensitivity is considered as a critical technological sub-factor that may influence the auto-ID adoption decision in a warehouse filed.

3.3.5.23 Interference

The interference commonly experienced with RFID technologies results from internal environmental factors such as metal, liquids or other devices (electronic devices) in the workplace. According to Michael and McCathie (2005); and Huber et al, (2007), RFID technology requires many pilot tests in order to check if there is any interference with other devices. Active RFID technologies, where transmission from tags occurs continuously, have more risk of interference than passive or semi-passive technologies where transmission only occurs at the time of reading (Domdouzis et al., 2007).

Thus, in this research, interference is regarded as a key technological sub-factor that might affect the auto-ID decision-making in a warehouse filed.

3.3.5.24 Ongoing Innovations

Barcode is mature and proven auto-ID technology and it continues to evolve, allowing businesses to solve different problems and challenges (Huber et al., 2007). RFID, however, is an immature technology and there are new applications and devices are continually emerging at the moment. Therefore, it is essential for warehouse managers to keep up-to-date with those applications and devices, since any one of them could be ideally suited to the requirements of their environment 9 Huber et al., 2007).

Hence, in this research, ongoing innovation is considered as a critical technological sub-factor that may influence the auto-ID decision-making in a warehouse context.

3.3.5.25 Ease of Use

Ease of use of the barcode technology is a significant technological factor in its success. Barcode labels can easily be used and printed on items (with little or no training required) (Wyld & Jones, 2007). However, RFID technology requires training for staff and users in order to use it properly and to be able to adapt themselves to the new processes and responsibilities created by RFID (Huber et al., 2007).

Thus, based on previous literature and the arguments presented above, ease of use is recognised as a critical technological sub-factor that might influence the auto-ID adoption decision in a warehouse management.

3.3.5.26 Established Standards

In a supply chain, it is crucial to adopt a standard auto-ID (RFID) technology in order to be able to communicate with your partners, not only on the RFID level but also on the Information Technology (IT) level (Angeles, 2005). Barcodes are extremely developed and they are the standard in supply chain management and it will be around for quite some time (Finkenzeller, 1999; Huber et al., 2007). However, RFID has a limited number of deployments in supply chain management because there is still no standard supported by all stakeholders that meets the needs of all users. In spite of this, recent mandates from leading companies mean that in the near future RFID technology will be adopted extensively.

Therefore, in this research, established standard is considered as a key technological sub-factor that may affect the auto-ID selection decision in a warehouse environment.

3.3.5.27 Performance

Different auto-ID technologies have different performance. For example, the performance of active RFID tags is better than passive tags (e.g., higher data transmission rate, better noise immunity, less orientation sensitivity, more tags can be read simultaneously, self-reporting capability, suitable for RF-challenging environments such as inside food pallets or pharmaceutical containers, or around metals and liquids) (Tajima, 2007; Poon et al., 2009).

According to Porter et al. (2004), tag orientations and material types have a significant impact on the reading performance of RFID tags in a warehouse environment. Moreover, none of the active and passive RFID systems are able to meet all the operational requirements performance of a warehouse (Porter et al., 2004). Thus, it is advisable to evaluate the reading performance of RFID systems before they are selected for implementation to ensure they meet the operational performance requirements of the warehouse environment (Porter et al., 2004; Poon et al., 2009).

Hence, in this research, performance is recognised as a critical technological sub-factor that may influence the auto-ID selection decision in a warehouse field.

3.3.5.28 Return on Investment

Return on Investment (ROI) analysis is crucial for companies to determine whether an investment is profitable over a period of time (Banks et al., 2007). Fleisch and Tellkamp (2005) have mentioned that companies have to carefully analyse the economic impact (ROI) of different RFID technologies in order to investigate the feasibility of RFID implementation and also to choose and integrate the most efficient technology in their supply chain processes. Angeles (2005) reports that choosing the right technology is very important for positive ROI. A number of concerns still exist and scepticism remains about the potential for RFID to deliver cost savings or a positive ROI (Vijayaraman & Osyk, 2006; Osyk et al., 2012).

Consequently, return on investment (ROI), is an essential technological sub-factor that may influence the auto-ID selection decision in the warehousing industry.

3.3.6 External Environmental Factors

The external environmental context is the arena in which an organisation conducts its business-its industry, competitors, and dealings with the government (Tornatzky and Fleischer, 1990). The key external environmental sub-factors that may influence auto-ID selection decision in a warehouse management were identified based on analysing the relevant literature review and synthesising the works proposed by Hwang et al. (2004), Brown and Russell (2007), Lin and Ho (2009), White et al. (2008), Li et al. (2010), Wang et al. (2010c), and Quetti et al. (2012) as follows:

- Government pressure;
- Competitors pressure;
- Customer pressure; and
- Supplier support

These sub-factors are described in detail below.

3.3.6.1 Government Pressure

Government pressure is an important component of external environmental factors for technological innovation. Tornatzky and Fleischer (1990) have mentioned that the government through regulations mad discourage the adoption of innovation. For example, governmental officials do not provide financial incentives, pilot projects or tax incentives (tax breaks) to promote technological innovation. Also, the set of spectrum frequency allocated for RFID technology varies in each country due to government policy and regulations (Lin & Ho, 2009).

Therefore, in this research, government pressure is considered as a critical external environmental sub-factor that might influence the selection decision of auto-Id technology in a warehouse context.

3.3.6.2 Competitors Pressure

Competitors' pressure has been recognised as a major external power for driving the technological innovation adoption (Tornatzky and Fleischer, 1990; Zhu et al., 2003; Wang et al., 2010c). For instance, if the main competitors have adopted auto-ID/RFID technology, the organisation will feel great pressure to adopt it (Zhu et al., 2003).

Thus, in this research, competitor's pressure is regarded as a key external environmental sub-factor that may affect the selection decision of auto-Id technology in a warehouse environment.

3.3.6.3 Customer Pressure

Customer pressure is also a key component of the external environmental factors and plays an important role for auto-ID (RFID) adoption in organisations. For example, many powerful companies such as Wal-Mart, the US Department of Defence, Metro and Tesco, have recently exerted strong pressure on their suppliers to implement RFID technology (Wu et al., 2006, Ngai et al., 2008).

In this research, customer pressure is considered as a critical external environmental sub-factor that might influence the auto-ID adoption decision in a warehouse environment.

3.3.6.4 Supplier Support

Before making auto-ID (RFID) adoption decision, warehouse managers should check the support and cooperation of their suppliers (e.g., sharing the cost of auto-ID). According to Lee and Shim (2007), it takes a relatively long time for organisations to make the RFID adoption decision because it requires them to conduct a fundamental strategic review of their relationships with suppliers before adopting RFID (Lee and Shim, 2007). Huber et al. (2007) have stated that RFID adoption requires close co-operation between supply chain partners (e.g., customers and suppliers).

In this research, supplier support is considered as a key external environmental sub-factor that may affect the auto-Id selection decision in a warehouse field.

3.4 Summary

The conceptual framework chapter covers the wide range of the factors that may affect auto-ID selection decisions in warehouse management. The technology–organisation–environment (TOE) framework proposed by Tornatzky and Fleischer (1990) was used as a theoretical framework to categorise the identified factors into six categories: structural, operational, resources, organisational, technological, and external environmental category. For each category, the key factors that may affect auto-ID decision making were identified based on a comprehensive and systematic review of the existing literature on IS implementation, supply chain management, and warehouse management.

Although a number of key factors that may influence the auto-ID selection decision in a warehouse field have been identified, an understanding of the auto-ID technology-selection process in a warehouse context requires that all the key factors that influence this decision are taken into account (Ilie-Zudor et al., 2011). Also, the importance of the various factors that influence auto-ID decisions may change significantly over time and between different countries (Adhiarna et al., 2011). In addition, a description of the whole auto-ID selection process in a warehouse environment is still lacking. The choice of auto-ID is not straightforward, but a number of issues influence the selection that comprises a series of decisions (Poon et al., 2011b; and Ilie-Zudor et al., 2011). Warehouse managers should follow several steps before any auto-ID technology is selected for implementation (Pero & Rossi, 2013). Furthermore, warehouse managers will find that identifying the factors will not be enough without understanding how the factors should be combined to produce a successful auto-ID selection process (Poon et al., 2009; Ilie-Zudor et al., 2011).

Consequently, the factor approach was chosen for its ability to investigate collectively key factors and sub-factors, and their relative importance in order to determine the most important factors influencing the technology selection decision. As a result, the chronological order of the key issues and activities in the auto-ID selection process would be determined. Moreover, in this research, in order to arrange the activities according to their chronological order and understand the entire selection process of auto-ID technologies in a warehouse context, a decision was made to investigate the auto-ID selection from its inception to its completion by using the process approach.

To effectively investigate the critical factors affecting the auto-ID selection process in a warehouse, an appropriate methodology of research is required. A number of techniques have been advocated in the literature to aid auto-ID decision making in a supply chain: the analytical approach (Lee & Özer, 2007); the simulation approach (Leung et al., 2007); experiment (Porter et al., 2004; and Poon et al., 2009); case study (Van De Wijngaert et al., 2008) and survey (Vijayaraman & Osyk, 2006; and Osyk et al., 2012). However, this study focuses more generally on understanding the factors that are motivating and influencing decisions about different auto-ID technologies as well as understanding how the factors should be combined to produce a successful auto-ID selection process in the warehouse context. Therefore, a Delphi study is an appropriate tool to address the research problem because it is ideal for exploring and understanding the factors that affect decision-making on a specific issue, topic or problem area (Lummus et al., 2005; and Wang et al., 2010c) allowing for gathering richer knowledge on the auto-ID selection decision in a warehouse.

Given the undeveloped level of auto-ID research in warehouse management, the Delphi method is also well suited for research in this area where theory is not yet well-developed (Skulmoski et al., 2007) and thus enhances the external validity of this research design. Moreover, compared with surveys or case studies, which usually depart from a certain perspective, a Delphi technique offers a much wider perspective because it can use an open question as a starting point, which can be then developed into a set of issues (Seuring & Müller, 2008). Furthermore, compared with the traditional surveys, where participants are always anonymous to each other and to the researcher, participants in the Delphi study are always anonymous to each other, but never anonymous to the researcher. This gives researchers more opportunity to conduct a follow-up study for clarification and verification of the Delphi results (Okoli & Pawlowski, 2004). This approach is described in detail in the following chapter.

CHAPTER 4

RESEARCH METHODOLOGY

4.1 Introduction

In the previous chapter the researcher developed a conceptual framework for this research. This chapter aims to justify the research paradigm, describe the design/strategy employed and the research methods/approaches utilised in the pursuit of the research aim and objective(s). In this chapter, the researcher discusses the empirical research methodology including data collection and analysis in order to validate the conceptual framework of this research presented in Chapter 3. It will be shown that this study adopted different research methods to meet its aim and measurable objectives. The justification for selecting the positivist research stance in this thesis is provided. Moreover, this chapter justifies the combination of a two-phase research design e.g. the first phase was a combination of exploratory and descriptive research design in which a modified mixed-method Delphi study was used, while the second phase was a follow-up verification study consisting of interviews, both face-to-face and telephone in order to refine and verify the Delphi results.

Understanding the underlying philosophy of the study is very important because it opens the researcher’s mind to other possibilities such as enriching research skills and enhancing confidence to select the appropriate methodology (Holden & Lynch, 2004).

Different disciplines use different research approaches. The purpose of this chapter is to:

- Discuss the research philosophy in relation to other philosophies;
- Explain the approaches including the research methods adopted; and
- Introduce the research design or strategy.

4.2 Philosophical Underpinnings of the Study

For this study, selecting an overall research philosophical paradigm is the choice between two primary alternatives: a positivist or an interpretivist philosophy. A number of authors (Guba, 1990; Easterby-Smith et al., 1991; Collis and Hussey, 2009; Saunders et al., 2000; Bryman & Bell, 2003) have highlighted the main elements of this choice of research philosophy. In particular, Guba (1990:17-27) has highlighted that the philosophical paradigms can be characterised through their: **ontology** (What is reality?), **epistemology** (How do you know something? What is the relationship between the researcher and that being researched?) and **methodology** (How do you go about finding out? What is your strategic approach?) These characteristics create a holistic view of how we see knowledge: how we view ourselves in relation to this knowledge and the methodological strategies we use to un/discover it. The key features of the two philosophy paradigm alternatives are shown in Table 4.1.

Paradigm Assumption	Positivism	Interpretivism
Ontology	Realist-Reality is objective and singular as seen by the researcher (knowledge governed by the laws of nature)	Relativist- Reality is subjective and multiple, as seen by participants in the study (knowledge is normative, socially constructed and interpreted by individuals)
Epistemology	Objectivist- Researcher is independent and becomes invisible to the study	Subjectivist-Researcher collaborates and spends time in field with participants, and becomes an "insider"
Methodology	Experimental/manipulative- questions and/or hypotheses are stated in advance in propositional form and subject to empirical tests	Hermeneutic, dialectic- individual constructions are elicited and refined hermeneutically, and compared and contrasted dialectically, with the aim of generating one (or a few) constructions on which there is substantial consensus
	Researcher uses deduction and attempts to position the research to a generalizable state and uses a predetermined research design	Researcher uses inductive logic, studies in the topic within its context and uses an emerging design

Table 4.1 Research philosophical paradigms
(Source: Guba, 1990:17-27)

Given the research problem as outlined in Chapter 1, the underlying philosophy of this study has been based upon the positivist philosophical paradigm (Guba, 1990). This is because the research focuses on the theories, concepts, and practices involved in the auto-ID selection process in warehouse environment, and not the actors involved in the process. In other words, the aim is to evaluate the components and characteristics of the conceptual framework and not how warehouse managers, or any other users execute it.

The positivist‘s emphasis on evidence of formal propositions, quantifiable measures of variables, hypothesis testing and/or question addressing, and drawing of predictions about a phenomenon from the previously observed and explained realities and their inter-relationships (Orlikowski & Baroudi, 1991), is suitable for this research. It is because there are diverse factors affecting the selection decision-making of different auto-ID technologies in the warehouse environment. All these factors can be classified either as structural, operational, resources-related, organisational, technological, or external environmental factors. Therefore, adopting a positivist stance would help this study to investigate these critical factors, and their relative importance, to develop a comprehensive conceptual framework. This framework will address the nature of the decision making process concerning the selection of auto-ID technologies in a warehouse environment.

4.3 Research Approaches

Research can have elements which are based on a non-empirical approach, an empirical approach, or a combination of the both approaches (Alavi & Carlson, 1992; Chen & Hirschheim, 2004; Avison et al., 2008). For the empirical approach, there are two primary dimensions which can be evaluated for use (Collis & Hussey, 2009; Myers, 1997):

- Quantitative/Qualitative
- Deductive/Inductive

4.3.1 Non-Empirical/Empirical Research

Non-empirical research is the research that is not based on specific data and emphasises ideas and concepts, and it is more abstract and intangible. In other words, it is the process of generating knowledge through conceptual or quantitative analytical reasoning (Alavi and Carlson, 1992; Avison et al., 2008). According to Alavi et al. (1992), non-empirical studies may be divided into three categories: conceptual, illustrative, and applied concepts. Conceptual studies describe frameworks, models, or theories and provide explanations and reasons. These studies try to develop frameworks and arguments that primarily serve as a basis for research by synthesizing pre-existing knowledge, categorising unstructured thoughts and concepts that circumscribe the phenomenon under research. In contrast, illustrative studies are intended to give advice and guidelines for practice, often in the form of rules and recommendations for action, steps and procedures to be followed in given circumstances, hints and warnings. These studies emphasise “what” or “how” rather than “why”. Applied concepts studies are those that have an approximately equal stress on conceptual and illustrative elements.

The pre-existing body of knowledge that exists in a particular field is one of the first considerations to be faced by a researcher. Searching and reviewing the existing literature is a research method which should be used to provide the sources for the theories which pertain to the selected subject area, as well as the references for the studies previously conducted in the chosen field of enquiry (Saunders et al., 2000, p.46). A systematic literature review was used in this research. Systematic reviews have been defined as ‘concise summaries of the best available evidence that address sharply defined clinical questions’ (Mulrowet al., 1998). One of the main features of a systematic review is that reviewers follow a strict protocol and utilise exacting research strategies to ensure that the maximum extent of relevant research and academic theories have been considered. The reviews use explicit and rigorous methods to identify, critically appraise, and synthesise relevant studies in order to answer a predefined question (Mulrowet al., 1998).The methodology of this systematic literature review has been presented in Chapter 2.

On the other hand, empirical research is the research that utilises data including archival data (quantitative, qualitative, or mixed) (Alavi & Carlson, 1992; and Avison et al., 2008). According to Easterby-Smith et al. (1991), empirical data are data gathered and produced by observation or experiment.

This research was designed to take into account both the non-empirical and empirical research approaches.

4.3.2 Quantitative/Qualitative Approach

Another choice was whether to adopt a quantitative or qualitative approach, or some mix of the two.

Quantitative research is derived from the natural sciences (Huff et al., 1998), where the research emphasises quantification and research data is normally in the form of precise numbers that have been collected in clearly defined steps (Neuman, 1997). Also, the researcher tests or verifies a theory by examining hypotheses or questions derived from it (Creswell, 2009, p.55). Quantitative research questions inquire about the relationships between variables that the researcher seeks to know (Creswell, 2009, p.132).

Quantitative research methods include:

- Survey methods (Huff et al., 1998)
- Laboratory experiments (Galliers & Land, 1987)
- Formal methods (e.g. econometrics) (Myers, 2009)
- Numerical methods (e.g. mathematical modelling)

The above list is adapted from Myers (1997).

Qualitative research, on the other hand, has a history from the social sciences, and it has been found particularly useful for studying social and cultural phenomena. In qualitative research, a number of different research methods are available (Bryman & Bell, 2003).

Qualitative research methods are classified as:

- Action research (Mumford, 2001)
- Ethnographic research (Klein & Myers, 1999)
- Grounded theory (Jarvinen, 1999)
- Case study research (Yin, 1994)

The above list is taken from Myers (1997).

Qualitative data sources include "observation and participant observation (fieldwork), interviews and questionnaires, documents and texts, and the researcher's impressions and reactions" (Myers, 2009, p.8).

Within the positivist paradigm, as the study‘s philosophical underpinning, both the quantitative and the qualitative research strategies can be used (Mertens, 2005, p. 12). Under the methods associated with the mixed–methods strategy, a Delphi Technique (Creswell, 2003) was adopted followed by both face-to-face and telephone interviews in order to verify the Delphi results (Skulmoski et al., 2007). The Delphi Technique was developed in a fashion similar to the mixed-methods research. Creswell indicates that mixed-methods research was developed to create “understandable designs out of complex data and analyses” (Creswell, 2003, p. 208). This corresponds to the development of the Delphi Technique which was developed in response to the need for understanding the multiple factors required to understand the objectives of the original RAND Corporation study (Dalkey, 1968). The similarity of their origins is echoed in their methods; both consider the use of qualitative and quantitative data to achieve their objectives (Creswell, 2003). Thus, the Delphi technique was used for qualitative data gathering by sending open-ended questions to the experts, and also was used as a quantitative Likert-scale Delphi method to confirm the criteria identified in the qualitative phase (MacCarthy & Atthirawong, 2003; Skulmoski et al., 2007).

The Delphi process is explained in detailed in the Sub-Section 4.4.10.

4.3.3 Deductive/Inductive

The choice between the deductive and inductive research approach has been discussed by many authors (Hussey & Hussey, 1997; Bryman & Bell, 2003; and Creswell, 2003). Deductive research (theory-testing) is a study in which theory is tested by empirical observation (Hussey and Hussey, 1997; and Bryman & Bell, 2003). Deduction is the process of reasoning by which logical conclusions (output propositions) are deduced and drawn from a set of input propositions (premises) and the information given. The premises might be assumptions that the reasoner is investigating or propositions that the reasoner believes (Bryman & Bell, 2007). Deductive reasoning works from the more general to the more specific. Sometimes this is informally called a “top-down” approach or waterfall. Arguments based on laws, rules, and accepted principles are usually used for deductive reasoning. The process of deductive research is as following (Creswell, 2003).

Theory (Literature Review) ⟶ Hypothesis /Questions ⟶ Observations/ Findings ⟶ Confirmation

Deductive reasoning implies testing already existing theory in the framework of a certain case (Saunders et al, 2007, p. 146; Bryman & Bell, 2007, p. 11). Also, it is associated with positivism and natural science models of social research, and quantitative research (Bryman & Bell, 2003).

On the other hand, inductive research (theory-building), which contrasts with deductive research, is a study in which theory is developed from the observation of empirical evidence (Hussey and Hussey, 1997, p.13). The truth of the premises would not guarantee the truth of the conclusion (Bryman & Bell, 2003). Inductive reasoning works the way of deductive reasoning, moving from specific observations to broader generalisations and theories. Informally, it is sometimes called a “bottom-up” approach or “hill climbing”. Qualitative research is based on inductive reasoning (Bryman & Bell, 2003). The process of inductive research is as follows (Creswell, 2003).

Observations/ Findings ⟶ Patterns ⟶ Tentative Hypotheses ⟶ Theory

In this research the deductive approach has been used because the modified Delphi technique has been adopted in this research. The modified Delphi process is similar to the deductive research process which starts from the literature review/theory (see Figure 4.2). The modified Delphi process is explained in detailed in the Sub-Section 4.4.10. In addition, the inductive approach has been used as the follow-up interviews have been conducted in this research. The interviews process, Sub-Section 4.4.18, started from discussing the Delphi findings and this is similar to the inductive approach.

4.4 Empirical Research Methodology

The general empirical methodology of this research is presented to achieve its aim, objectives, and research questions. The empirical methodology in this research was based on three stages: (a) Research Design, (b) Data Collection, and (c) Data Analysis. The three stages/parts will be discussed in detail in the following sub-sections.

4.4.1 Research Design

The research design (Figure 4.1) was structured in such a way as to answer the research questions and achieve its aim and objectives. The first stage of the empirical research methodology is the research design which was used to guide the research process. According to Yin (2009), research design is the logical sequence of an action plan to collect, analyse and interpret data for getting from the questions to the conclusions.

Research designs can be categorised into three main types: exploratory, descriptive, or explanatory (causal) research or combination of these (Pizam, 1994; and Saunders et al., 2012). Exploratory research may involve a literature search or conducting focus group interviews. The objective of exploratory research is to identify critical issues and key variables, to identify a problem and clarify the nature of it, to develop propositions and hypotheses for further research and to obtain a greater understanding of an issue (Pizam, 1994). Descriptive research seeks to provide an accurate description of observations of phenomena. On the other hand, explanatory (causal) research looks for explanations and provides an understanding of the nature of certain relationships that exist between variables (Saunders et al., 2012).

The choice of the modified Delphi technique required a combination of exploratory and descriptive research design (Cunliffe & Australia, 2002). The exploratory first stage identified, after reviewing and analysing the existing literature review, key issues relevant to the auto-ID selection decision in warehouse management and that formed the basis of the first round Delphi questionnaire. The first round of the Delphi study was a combination of exploratory and descriptive research design using open-ended and closed-ended questions (Cunliffe & Australia, 2002; Skulmoski et al., 2007). In the first round, both quantitative content analysis and descriptive statistics (Bryman, 2004) were adopted to identify major factors and sub-factors, and their relative importance that influence auto-ID selection decision in warehouse management. This was followed by one more round of a refined and redrafted questionnaire incorporating a summary of responses from the previous round. The second round of the Delphi study was also a combination of exploratory and descriptive research using closed-ended questions in order to get feedback, comments and to come to a consensus regarding the results.

Most researchers recommended further/follow-up study to refine and verify their results (Keil et al., 2002; Nambisan et al., 1999; Wynekoop & Walz, 2000). Follow-up verification studies can enhance, expand and refine the research findings as well as provide rich research opportunities for new researchers (Powell, 2003; Kennedy, 2004; Skulmoski et al., 2007; Hasson & Keeney, 2011). Therefore, the exploratory/descriptive Delphi study was followed by a verification study carried out with face-to-face and telephone interviews to discuss in-depth, verify and refine the findings of the Delphi study.

The first three parts of the research: problem definition, research questions, and conceptual framework were explained in Chapters 1, 2, and 3 respectively. This leads to a specific research area and identifies a research need. Then, a conceptual framework is developed to represent the intended empirical research which will need to be investigated through empirical studies. The intended empirical investigation passes through three primary stages: research strategy, research methods, and analysis techniques. It was found necessary for this research to use a mixed-method Delphi study strategy through the employment of the quantitative and qualitative research methods due to the needs of an empirical study. The epistemological stance, positivist, is determined and justified based on the data required to validate the proposed framework. The justification for choosing a modified (mixed-method) Delphi study strategy is provided in the Sub-Sections 4.4.5, and 4.4.6**.** Then, in-depth interviews, both face-to-face and by telephone were conducted to verify the Delphi results. The justification for using these types of interview is detailed in the Sub-Section 4.4.16.

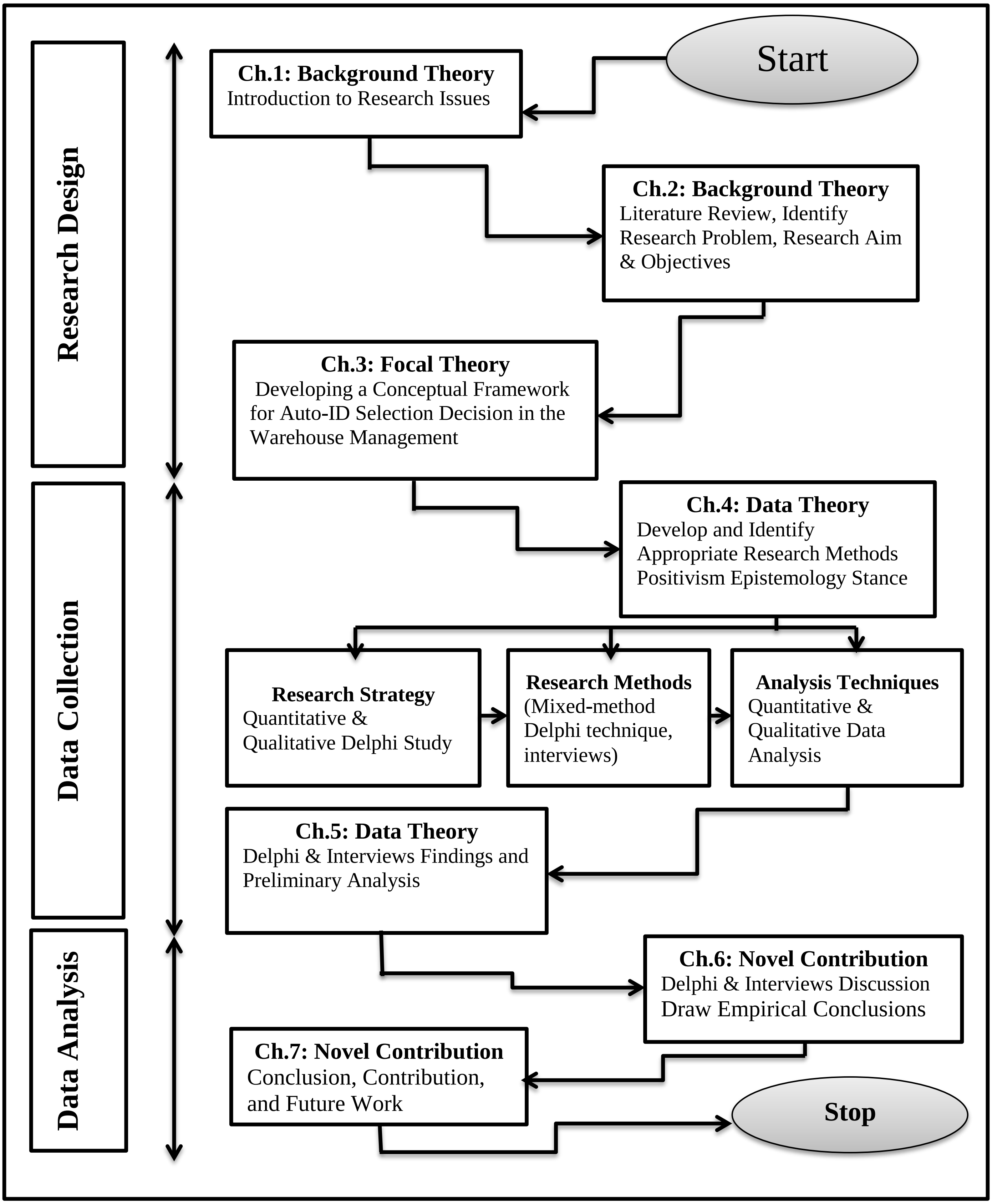


Figure 4.1 Empirical Research Methodology

4.4.2 Data Collection

In this research, data were collected by conducting first a modified (mixed-method) two-round Delphi study with a worldwide panel of experts (107) including academics, industry practitioners and consultants in auto-ID technologies. The results of the Delphi study were then verified via follow-up interviews, both face-to-face and telephone, carried out with 19 experts across the world.

4.4.3 Delphi Study

A Delphi study is a systematic, iterative process, with controlled anonymous judgments and systematic refinement, to extract a consensus view from a carefully selected panel of experts within a particular field of study backgrounds (Hasson et al., 2000; Linstone & Turoff, 2002). The Delphi technique is used as a survey research method to structure group opinion and discussion (Bowling, 1997). Delphi uses a representative group of experts to produce, by a series of intensive questionnaires interspersed with controlled opinion feedback, the most reliable consensus of opinion and a more accurate and more informed judgement than is obtainable from one individual (Dalkey & Helmer, 1963 p.458).

In the early 1950's, the Delphi technique was popularised by the United States Air Force RAND (Research And Development) Corporation, with 'Project Delphi' being employed as an instrument using military experts to estimate the likelihood of Russian nuclear bomb strikes (Linstone & Turoff, 1975; Benson et al., 1982). Since then, its usefulness has been demonstrated in a range of areas outside defence applications including business research related to uncertainties in the performance of new projects and investments (Daniel & White, 2005) and exploratory studies in operations management (Malhotra et al., 1994; Akkermans et al., 2003; MacCarthy & Atthirawong, 2003; Ogden et al., 2005). Malhotra et al. (1994) have conducted a Delphi study to identify and rank major manufacturing issues in the 1990s. Akkermans et al. (2003) have looked into how Enterprise Resource Planning (ERP) systems can affect operations in supply chain management. MacCarthy and Atthirawong (2003) have used a Delphi study to identified key factors influencing location decisions in international operations. Ogden et al. (2005), using the Delphi method, have identified future factors influencing the supply chain. Such usage is indicative of its potential and ability to gather a spread of judgements, in response to current problems, from a group of informed experts.

For this very reason, Bowles (1999) has indicated that there have been more than 1,000 research projects, which have used the Delphi technique, particularly when looking to examine practitioners' views, surrounding issues of topical interest. Baxter et al. (1978) have mentioned that the term 'Delphi' is now applied to the complete range of group communications, from the more structured, right through to face-to-face discussions. Coates et al. (1986) have asserted that Delphi *"has become the most popular forecasting technique generally used in the United States by public and private institutions"* (p.71). Linstone and Turoff, (1975) have suggested that it is a response to *"a demand for improved communication among large and/or geographically dispersed groups which cannot be satisfied by other available techniques"* (p.11).

It is conceded that since the time of writing of Linstone and Turoff (1975), there are now many other comparable methods of group communications, especially the advent of Web2.0, use of social media and netnography. However, it is debated that the rationale behind these new methods and many of the techniques applied still follow the ethos of Delphi. Thus, what Delphi offers is a paradigm and structured mind-set.

4.4.4 Characteristics of the Delphi Technique

The Delphi method should comprise a panel of experts who must be selected carefully, and who have experience and/or knowledge of the subject being studied. The expert panel is not intended to be representative of the population for statistical purposes (Powell, 2003). Benson et al. (1982) and Tavana et al. (1996) note that the Delphi method comprises three particular features:

(1) Anonymity among the panel of experts;
(2) Obtaining a statistical group response from a well-designed questionnaire; and
(3) Controlled feedback.

On the other hand, Linstone & Turoff, (2002) indicates that the panel size and the qualifications of the experts are two issues in a Delphi study. A literature review by Reid (1988) shows that the sizes of the panels in the studies reviewed varied from 10 to 1585, and there is no recommendation for a specific sample size. Murphy et al (1998) have shown that as the number of experts increases, the reliability of the panel's judgments increases as well. However, they have indicated that there is no evidence about the relationship between the reliability and validity of the final consensus and the panel size.

While some of the older studies used conventional mail (Cramer, 1991; and Silverman, 1981), some researchers (Cabaniss, 2001; Richards, 2000) used online surveys to collect their data. The online data collection process, through e-mail and Web-based surveys, has become an increasingly popular and widespread research methodology (Granello and Wheaton, 2004). There are many methods for collecting data online but the two most common are e-mail surveys and Web-based surveys methods (Granello & Wheaton, 2004). With e-mail surveys, the respondents receive an e-mail with a survey embedded in it, click on the "reply" button, and click on the "send" button when they have completed the survey. The researcher then transfers the raw data into a database or spreadsheet. Web-based surveys, on the other hand, need the instrument to be available on a Web site, and participants are solicited either by conventional mail, e-mail, telephone, or through other Web sites-to participate in the survey. Respondents are given access information to enter the survey Web site, they fill out the form online, and then click on a "submit" button when they have completed it (Granello & Wheaton, 2004). The advantages of these methods are as following:

- Reduced response time and rapid collation of feedback (Lazar & Preece, 1999; and Gill et al., 2013);
- Decreased cost (Schleyer & Forrest, 2000);
- Ease of data entry (Granello & Wheaton, 2004);
- High quality data collection (Gill et al., 2013);
- Flexibility and control over format (Wyatt, 2000);
- Ease and speed of survey administration (Gill et al., 2013)
- Advances in technology (Solomon, 2001);
- Recipient acceptance of the format (Joinson, 1999; Moon, 2000; Conboy et al., 2001);
- Obtain additional response-set information (Winzelberg, 1997; Bosnjak & Tuten, 2001); and

- Direct communication with the panel (Gill et al., 2013).

Despite the several advantages of online data collection especially, web-based surveys, concerns about their use have been raised by researchers in many fields in which this methodology has been adopted. These concerns focus on the following limitations/ disadvantages: representativeness of the sample (Dillman et al., 1998), response rates (Bachmann et al., 1996; Couper et al., 1999; Crawford et al., 2001), measurement errors (Wyatt, 2000), and technical difficulties (Nichols & Sedivi, 1998).

Accordingly, in this research, a web- based survey method has been adopted using Google Form. Numerous advantages have been obtained using this web application including high quality data collection, ease and speed of the survey administration, reduced cost, and quick collation of feedback allowing data collection for each round of the Delphi to be undertaken in 4 weeks.

4.4.5 Delphi's Suitability for Doctoral Studies

Particularly within doctoral studies, Skulmoski, Hartman and Krahn (2007) have suggested that,

> *"The Delphi method is well suited as a research instrument when there is incomplete knowledge about a problem or phenomenon"* (p.1). Moreover, it *"works especially well when the goal is to improve our understanding of problems, opportunities, solutions, or to develop forecasts"* (p.1).

Their study makes reference to 34 identified doctoral theses that adopted the Delphi technique, during the period of 1981-2006, within the social sciences.

A further area of consideration is the time that the Delphi takes to collect data. Delbecq et al. (1975) have found that the minimum time required between rounds is 45 days. As a full-time doctoral student, the researcher paid special attention to this point– as it was an area of concern. With such a diverse panel, hailing from various organisations and based in different countries, being asked to provide a significant amount of information, the researcher was acutely aware that adopting 'soft power' methods was crucial. The soft power is "the ability to get what you want through attraction rather than coercion or payment" (Nye, 2004, p. 11). Using these methods was embraced as positive aspect of this research for two reasons. Firstly, the researcher was able to demonstrate mastery over complicated research methods, through being able to motivate and extract responses from the panellists, whom the researcher had few incentives to offer and limited resources to manage. Secondly, the extended time taken when collecting data enabled the panellists greater time in which to reflect upon and revise their responses.

4.4.6 Applicability of the Delphi Technique for the Research Questions

As mentioned before, much of the previous studies so far have addressed separately the critical factors influencing auto-ID decisions in a supply chain. Hence, a wider research focus was chosen here, so a panel study of experts in the field seemed a good choice. The Delphi method is often used as a qualitative forecasting technique, but it is also used to examine and understand the factors that affect or may affect decision-making on a specific issue, topic or problem area (McCarthy & Atthirawong, 2003; Lummus et al., 2005; Wang et al., 2010c). Thus, a Delphi study is the most appropriate approach to address the research questions because it relies upon expert opinions to identify and deepen the understanding of a number of key factors that are separately discussed in the previous literature on auto-ID decisions in the warehouse field. On the other hand, other group judgment techniques, such as brainstorming, do not seem to be appropriate for this study because they do not follow a particular and systematic procedure, or opinion polls, and also the responses are not treated as judgments but as self-reporting. In other words, a Delphi method is different from brainstorming in that it avoids group interactions of individuals, which may result in induced responses. Therefore, a Delphi approach helps to reduce the effect of dominant individuals and to generate a consensus of expert opinion on subjective issues (Ray & Sahu, 1990; Azani & Khorramshahgol, 1990; Klassen & Whybark, 1994; Green & Price, 2000).

Other well-known decision-making techniques such as analytical hierarchical process (AHP), which was developed by Thomas L. Saaty in the 1970s, has been extensively studied and refined since then for analysing complicated decision problems based on mathematics and psychology (Saaty, 1980). There have been many studies conducted on applying the AHP technique to the technology selection. In those studies, the process of AHP approach has been employed as follow (Gerdsri & Kocoglu, 2007):

1. Three levels (objective, criteria, and technology alternatives) or four levels (objective, criteria, sub-criteria, and technology alternatives) have been used to

construct the hierarchical model for the evaluation and assessment of technologies.

2. In order to determine the relative impact of technologies on the objective, the series of comparative judgments is analysed.
3. Then, the results are represented as a relative value indicating how many times one technology is better than the other alternatives.

However, this research focuses more generally on investigating and understanding the motivations/reasons of warehouses in seeking to use auto-ID technologies, the challenges in making an auto-ID decision, the recommendations to address the challenges, the key factors and their relative importance that influence auto-ID selection decision and how the factors should be combined to produce a successful auto-ID selection process in warehouse management. Therefore, a Delphi technique is the most appropriate tool to address the research problem because it is ideal for exploring and understanding the factors that affect decision-making on a specific issue, topic or problem area (Lummus et al., 2005; and Wang et al., 2010c) allowing for gathering richer knowledge on the auto-ID selection decision in a warehouse. Given the undeveloped level of auto-ID research in warehouse management, the Delphi method is also well suited for research in this area where theory is not yet well-developed (Skulmoski et al., 2007) and thus enhances the external validity of this research design.

Moreover, compared with surveys or case studies, which usually depart from a certain perspective, a Delphi Technique offers a much wider perspective because it can use an open question as a starting point, which can be then developed into a set of issues (Seuring and Müller, 2008). Also, compared with the traditional surveys, where participants are always anonymous to each other and to the researcher, participants in the Delphi study are always anonymous to each other, but never anonymous to the researcher. This gives researchers more opportunity to conduct a follow-up study for clarification and verification of the Delphi results (Okoli & Pawlowski, 2004). Therefore, the power of a Delphi approach is that it provides more understanding of complicated problems than other techniques (Linstone & Turoff, 1975; Skulmoski et al., 2007).

4.4.7 Types of Delphi Design

Since its inception, the Delphi technique has evolved into a number of adaptations. Keeney, (2009) has identified ten main categories of Delphi, including classical, modified, decision, policy, real time, e-Delphi, technological, online, argument and disaggregative policy (see Table 4.2). There are hundreds and potentially thousands of studies in the previous literature reporting on studies using these different manifestations, and this is tribute to the flexibility of the Delphi approach (Landeta, 2006; Skulmoski et al., 2007; Keeney et al., 2011). The reason for these modifications is based on the fact that there are no formal, universally accepted guidelines on the use of the Delphi technique (Hasson & Keeney, 2011).

Design type	Aim	Target panellists	Administration	Number of rounds	Round 1 design
Classical (Dalkey & Helmer, 1963)	To elicit opinion and gain consensus	Experts selected based on aims of research	Traditionally postal	Employs three or more rounds	Open qualitative first round, to allow panellists to record responses
Modified (McKenna, 1994)	Aim varies according to project design, from predicting future events to achieving consensus	Experts selected based on aims of research	Varies, postal, online etc.	May employ fewer than 3 rounds	Panellists provided with pre-selected items, drawn from various sources, within which they are asked to consider their responses
Decision (Rauch, 1979)	To structure decision-making and create the future in reality rather than predicting it	Decision makers, selected according to hierarchical position and level of expertise	Varies	Varies	Can adopt similar process to classical Delphi
Policy (Turoff, 1970)	To generate opposing views on policy and potential resolutions.	Policy makers selected to obtain divergent opinions	Can adopt a number of formats including bringing participants	Varies	Can adopt similar process to classical Delphi

Design type	Aim	Target panellists	Administration	Number of rounds	Round 1 design
			together in a group meeting		
Real time/consensus conference (Turoff, 1972)	To elicit opinion and gain consensus	Experts selected based on aims of research	Use of computer technology that panellists use in the same room to achieve consensus in real time	Varies	Can adopt similar process to classical Delphi
e-Delphi (Chou, 2002)	Aim can vary depending on the nature of the research	Expert selection can vary depending on the aim of the research	Administration of Delphi via email or online web survey	Varies	Can adopt similar process to classical Delphi
Technological	Aim varies according to project design, from predicting future events to achieving consensus	Experts selected based on aims of research	Use of hand-held keypads allowing responses to be recorded and instant feedback provided	Varies	Can adopt similar process to classical Delphi
Online (Edwards, 2003)	Aim varies according to project design, from predicting future events to achieving consensus	Experts selected based on aims of research	Implementation of the technique on any online instrument such as a chat room, or forum.	Varies	Can adopt similar process to classical Delphi
Argument (Kuusi, 1999)	To develop relevant arguments and expose underlying reasons for different opinions on a specific single issue	Panellists should represent the research issue from different perspectives	Varies	Varies	Can adopt similar process to modified Delphi i.e. first round involves expert interviews
Disaggregative policy (Tapio, 2003)	Constructs future scenarios in which panellists are asked about their probable and the preferable future	Expert selection can vary depending on the aim of the research	Varies	Varies	Adoption of modified format using cluster analysis

Table 4.2 Types of Delphi design
(Source: Keeney et al., 2011; Hasson & Keeney, 2011)

Within each Delphi type, the characteristics of the Delphi can also differ, for instance, the rounds number, the anonymity level and feedback given, as well as the inclusion criteria, sampling approach or analysis method (Skulmoski et al., 2007; Hasson & Keeney, 2011). Personal bias can also influence the accuracy of a Delphi application (Woudenberg, 1991; Kahneman et al., 1982). For example, experts' judgements can be affected by a number of personal factors such as level of experience, qualification and exposure to the problem being examined, which can affect the reliability of reporting and confidence placed in the results.

Whilst the flexibility of the Delphi is viewed as a key strength of the technique, this has implications, leading Kastein et al. (1993, p. 322) to state even "*when reliable results are encountered in a particular Delphi application, generalizing this finding to the 'ideal Delphi' is never justified"*. In addition, the various modifications of the Delphi approach have led to considerable criticism with some claiming that it threatens the ability to determine the reliability and validity of the approach (McKenna & Keeney, 2008). The reliability and validity and also the trustworthiness of this research are discussed in detail in Sections 4.5 and 4.6 respectively.

4.4.8 Advantages of the Delphi

There are a number of advantages associated with the Delphi process, in addition to those mentioned earlier that relate to response anonymity, which have been suggested by Dalkey et al. (1969):

- It is a quick and relatively efficient manner in which to obtain expert opinions.
- If well designed, the procedure requires less effort of participants than a conference.
- It can be a highly motivating environment.
- Feedback can be novel and interesting.
- The systematic procedure gives the appearance of objectivity to the results.
- There is a sense of shared responsibility because of anonymity, which decreases social inhibitions.

- Data can be acquired from a large group of experts who are geographically widely dispersed, and who may be of diverse backgrounds or live in remote locations (Strauss & Zeigler, 1975).
- The researcher has an enhanced ability to focus the group's attention on the topic of interest (Weatherman & Sevenson, 1974).
- It increases rational input (Skutsch & Hall, 1973).
- It is relatively inexpensive means of extracting group opinions (Barnett et al., 1978).

As the Delphi technique depends on the experimental knowledge of a panel of experts (Powell, 2003), it is a process for making the best use of data, ranging from scientific information to collective wisdom (Black et al., 1999). It offers concepts imbedded in quantitative and qualitative techniques– such as attitudinal measurements and open-ended questions (Bowles, 1999). Also, it provides more understanding of complicated problems than other survey techniques. In other words, the power of a Delphi technique is that it is able to minimise the limitations whilst maximising the benefits of surveys and consultative processes (Jairath & Weinstein, 1993).

4.4.9 Disadvantages of the Delphi

In a critical review of the Delphi technique, Weaver (1972) has cited several studies (Campbell, 1966; Weaver, 1969; and Waldron, 1970) investigating factors influencing Delphi forecasting outcomes. Weaver (1972) has found evidence for questioning the accuracy of Delphi forecasts, and he has suggested that its utility would be improved, instead, by a shift in focus to the plausibility of forecasts. Other criticisms of the Delphi approach include:

- The inductive analysis of responses to the initial questionnaire may lead to problems in interpretation (Bernstein, 1969).
- The unprovable nature of a Delphi makes its usefulness subject to the effects of unforeseen events, such as scientific discoveries, politics, and events in nature (Linstone & Simmonds, 1977).
- Lack of assurance of consensual agreement by panel members (Bernstein, 1969).

- Motivating panellists to participate in the Delphi, and maintaining their interests in each subsequent round (Tersine & Riggs, 1976).
- Time investment in preparation and execution of the rounds when using traditional (i.e., regular mail) methods of questionnaire delivery, and computer programming challenges when adopting electronic (i.e., e-mail surveys/Web-based surveys) delivery of the Delphi.

4.4.10 Delphi Process

The Delphi process, Figure 4.2, began by reviewing the existing literature review on auto-ID technologies, supply chain management, and warehouse management in order to determine if a theoretical gap exists and to identify the research aim and objectives, which have been presented in Chapters 1, 2, and 3. Then, it was followed by identifying a panel of experts for possible inclusion in the study. The panel selection was an extremely rigorous process which commenced in July 2012 and was not completed until December 2012. According to Story et al. 2000, the panel selection process, if not conducted properly, can be the source of many problems. The panel selection process is shown in the Sub-Section 4.4.11.

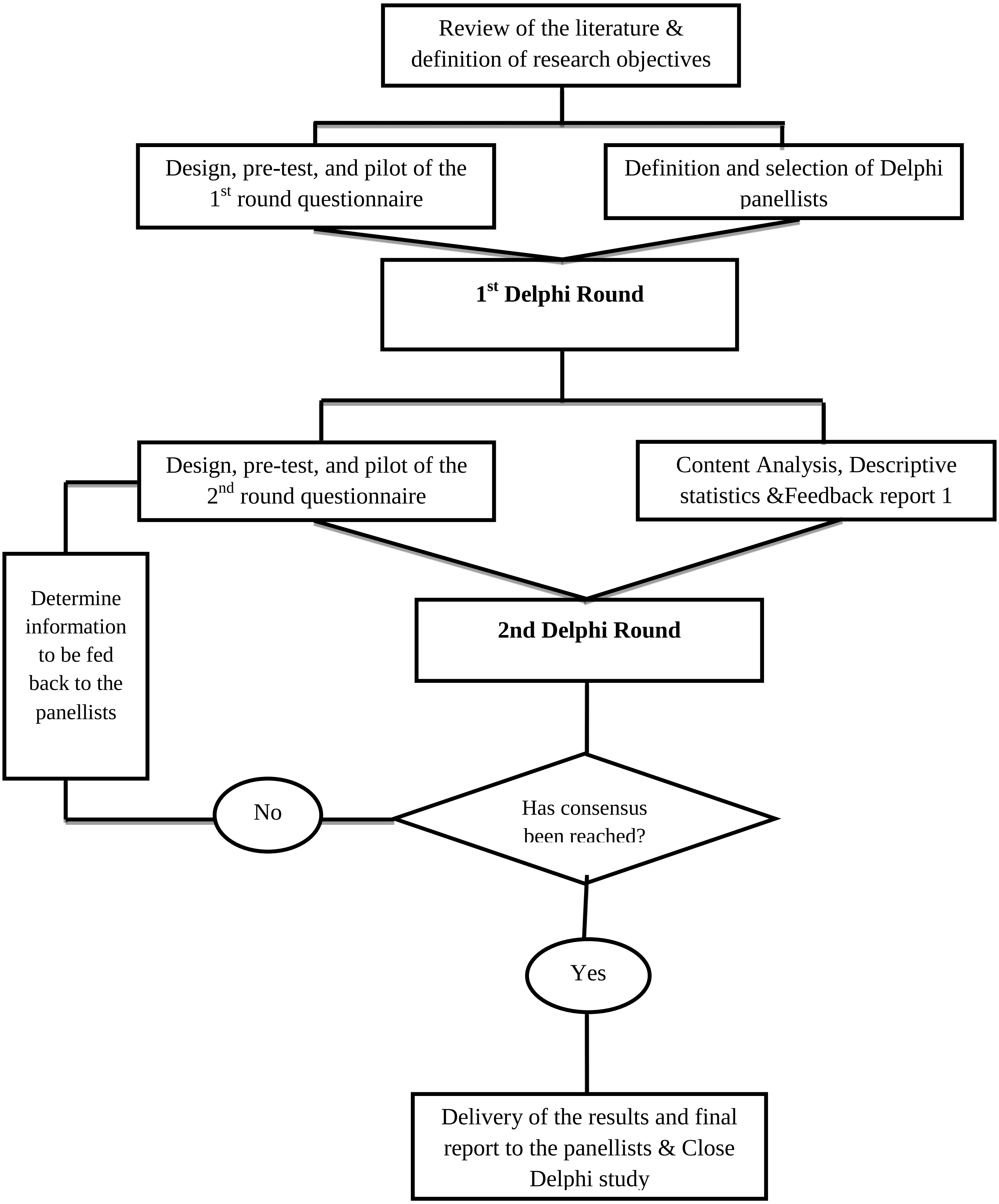


Figure 4.2 Delphi Process
(Adapted from Skulmoski et al., 2007)

After definition and selection of the Delphi panellists, the design and pilot of the first round questionnaire was conducted. Then, the actual first round Delphi study was conducted. The first round data concerning the key factors affecting auto-ID technology selection in a warehouse was then gathered and analysed using content analysis and descriptive statistics explained in the Sub-Section 4.4.19. After that, design, pre-testing, and pilot of the second round questionnaire was conducted. The pilot Delphi study for the first and second round is presented in the Sub-Sections 4.4.12 and 4.4.14 respectively. Afterwards, the first feedback report was sent to the panellists combined with the second round questionnaire. The aim of the second questionnaire was to get feedback and comments and also to come to a consensus regarding the results. The responses from the second round demonstrated strong agreement on the broad results. Overall, it was felt that a third round of the study would not add to the understanding provided by the first and second round. Thus, at this stage, the Delphi study was concluded and then the follow-up interviews, explained in the Sub-Sections 4.4.16, 4.4.17 and 4.4.18 were begun. The Delphi study was completed over a period of 4 months.

4.4.11 Panel Selection Process

In this research, the experts have been selected from different fields to obtain a variety of insights from researchers with both theory-based and practice-based backgrounds. The invited experts, with a theory-based background, were all first or second authors on high quality papers in the field of auto-ID technology in supply chain management and warehouse management published between 2000 and 2012. Database searches in ScienceDirect, Sage, Scopus, and Emerald was performed to identify experts and to examine reference lists from relevant papers, book chapters, review studies, and conference abstracts. The experts with a practice-based background were selected on the basis of their publications, but also by using the Snowball Sampling Approach (Goodman, 1961) where each member of the responding experts was asked to nominate names of important experts in the field.

This resulted in an initial list of 135 experts who were invited by email to participate in the Delphi survey, 8 respondents refused to participate, 7 did not respond. So, the total number of experts who agreed to participate was 120 (88% response rate). However, the actual number of experts who participated in this research was 107 (79% response rate) because there were 13 experts who agreed at first but did not participate.

The largest group of panellists (40.1%) were from the field of automatic identification and data capture (auto-ID) technology (RFID and/or Barcode), followed by supply chain management (24.5%), warehouse management (14.4 %), logistics (13.6 %), and operations management (7.4%). The panellists were based in Western Europe (UK, Italy, France, Germany and Portugal; 49.4%), North America (US and Canada; 42%), Asia (China and India; 5.6%), Australia (1.9%), and South America (Brazil; 0.9%). The panel members consisted of 39 academics, 36 industry practitioners and 32 auto-ID (Barcode/RFID) consultants. Eighty eight of the panel members were male and 19 were female. The majority (105) held a Ph.D. or a Master's degree. Table.4.3, reports the demographic data of the Delphi panel.

Characteristics	**Frequency (N= 107)**	**Percentage (%)**
Age		
Below 25 years	0	0
26-35	5	5
36-45	33	31
46-55	58	54
56-65	11	10
Above 65 years	0	0
Gender		
Male	88	82
Female	19	18
Highest Qualifications		
PhD	101	94
DBA	4	4
MBA	2	2
Occupation		
Academics	39	36
Industry practitioners	36	34
Auto-ID consultants	32	30

Table 4.3 Demographic characteristics of the Delphi panel members

Asking respondents to complete a "self-assessment" of their level of expertise is a method of validating the suitability of the participants (Dalkey et al., 1972; and Rowe & Wright, 1999). In this research the respondents were asked to rank their knowledge of auto-ID technologies (RFID/barcode) and warehouse management using a set of guidelines (Figure 4.3). The findings from this section of the survey, illustrated in Figure 4 .3, show that 29 (27%) of the respondents said that they have a rare practical skill or knowledge with regards to the topic area, 105 (98%) of the participants have published papers, books, or articles in this area of expertise, 101 (94%) of them hold high-level educational degrees

(PhD, Masters, etc.), 22 (24%) of the respondents have testified in a court on this area of expertise, 105 (98%) have been recognised by peers as being an expert, and 38 (36%) of the respondents have extensive (15+ years) industry experience of this particular area. The participants have been asked to select more than one checkbox/ criteria and hence the percentages exceeded 107 (100%).

Figure 4.3 Level of expertise of respondents

The fact that (98%) of the respondents rated themselves as being experts in the area or (36 %) having extensive (15+ years) industry experience of this particular area was a strong indicator that the panel selection criteria have been successful.

4.4.12 Pilot Delphi Study – Round 1

A first round questionnaire was developed based around the factors and sub-factors presented earlier in Table 3.2, in Chapter 3. It was first pre-tested with 10 postgraduate colleagues to check for clarity and consistency and appropriate changes were made. Then a proper pilot study of the questionnaire was conducted on 10th December, 2012, with 12 people (10% of the expert sample size) as suggested by Baker and Risley (1994). Four academics, six industrialists, and two auto-ID consultants participating in the Delphi study were selected and participated in the pilot study in order to receive comments and feedback. The pilot study was closed on 24th December, 2012. Through the pilot study, participants made valuable contributions to the development and improvement of the questionnaire. The pilot study allowed ambiguities to be highlighted and some sub-factors to be grouped, rearranged or removed. Six major factors and 65 sub-factors were identified for consideration in the actual first round of the Delphi study.

4.4.13 Actual Delphi Study – Round 1

The initial round of the Delphi study, Appendix.2, was sent out to the panellists on the 6th of January 2013 and the round was not closed until the 10th of February 2013. The email included detailed information on the study aim and procedure, as well as a link referring them directly to the first-round questionnaire. Non-responders received a reminder email after the 3-week response period had expired. As a result, 21 additional responses were received after the reminder.

The first round of the Delphi study was a combination of exploratory and descriptive research design using open-ended and closed-ended questions (Cunliffe & Australia, 2002). The first round questionnaire consisted of two parts. The specific issues addressed in Part A of the questionnaire were:

- The motivations of warehouses that seek to use auto-ID technology;
- The key steps in the selection process of auto- ID technology in a warehouse environment;
- The most difficult problem in making an auto-ID decision; and
- The ways to overcome the problem.

Part A consisted of 4 open-ended questions which allowed respondents to express their opinions or add information freely and independently.

On the other hand, Part B of the questionnaire focused on the relative importance of major factors and sub-factors affecting auto-ID selection decisions in the warehouse field and this importance was measured using a five-point Likert scale. The qualitative data were analysed manually using the content analysis approach presented in the Sub-Section 4.4.19. The results of the content analysis were presented quantitatively and converted into frequencies because it offers easy comparison with other studies undertaken within a similar framework (Bryman, 2004). Also, descriptive statistics were used to analyse the quantitative data using SPSS (Statistical Package for Social Sciences) version 18.0. Later a second round of the study was conducted to get feedback, comments, and to come to a consensus regarding the results of the first round of the Delphi. The level of response to this round was quite strong with 107 out of the panel of 120 completing round 1, a 79% response rate.

4.4.14 Pilot Delphi Study – Round 2

After the first round responses were gathered and analysed, the second round questionnaire was developed and pre-tested with 8 postgraduate colleagues to check for clarity and consistency and suitable changes were made. Then, a pilot study of the questionnaire was conducted on the 25th February 2013 and ran until the 9th March 2013 with 10 experts (10% of the experts sample size) as suggested by Baker and Risley (1994) in order to receive comments and feedback. The respondents were three academics, four industrialists, and three auto-ID consultants who made valuable contributions to the development and improvement of the questionnaire and some ambiguities have been highlighted.

4.4.15 Actual Delphi Study – Round 2

The second round of the Delphi study was also a combination of exploratory and descriptive research using closed-ended questions. The actual second round and an interim report, Appendix 3, were sent back to the first round participants on 10th March, 2013, in order to get feedback and comments and also to come to a consensus regarding the results. The second round was closed on the 10th April 2013. The interim findings were presented mainly in tabular form. Participants were invited to make comments on any aspect of the interim findings, to record their agreement or disagreement, to suggest revisions, clarifications or to add further information. A reminder letter was sent to all panellists who had not replied, after the 2-week response period had expired and this produced 17 additional responses. The evaluation of the second round responses was conducted by using SPSS software version 18.0 to represent group opinion and consensus. A total of 102 panellists replied to the second round, yielding a response rate of 75% for the second round.

The responses from the second round demonstrated strong agreement on the broad results. Most feedback was concerned with the priorities of the factors and sub-factors from the first round. A number of specific items, comments, and additional factors relevant to particular contexts have been added by the panellists. Overall, it was felt that a third round of the study would not add to the understanding provided by the first and second round. Thus, at this stage, the Delphi study has been concluded and the follow-up interviews have been started.

4.4.16 Interviews

Interviews are usually used in survey designs as well as in exploratory and descriptive studies (Mathers et al., 1998). There are three main types of interviews: structured, semi-structured and unstructured (In-depth) (Bryman & Bell, 2003). Structured interviews allow the interviewer to ask each participant the same questions in the same way. The questions and the possible choice of answers in many structured interviews are set in advance. Semi-structured interviews are similar to structured interviews in that the interviewer prepares in advance a list of questions about the main ideas that will be covered, but instead of using closed-ended questions, the interviewer uses open-ended questions. In the semi-structured interview, the interviewees answer freely and give their point of view with any relevant issues. On the other hand, unstructured or in-depth interviews have very little structure at all and it is an intensive approach for gathering data. In-depth interviews are appropriate when there is a clear and well-defined research interest and there are constraints on time for the research (Taylor & Bogdan, 1984).

Interviews can be conducted using different methods: individual, group interviews, face-to-face, telephone and web interviews (Mathers et al., 1998). Individual interviews are suitable where researcher may expect a variety of different stories to be told concerning an incident or context. According to Morgan (1998), group interviews (focus groups) are only appropriate for qualitative approaches, and can be utilised where there is some benefit in getting a ‘group story’ about a setting. A face-to-face or personal interview involves collection of data whereby the participant and research administrator sit together while a telephone interview involves calling the respondent and the answers are obtained over the phone. Finally, Web interviews can be conducted using the internet through chat rooms for interviewing.

A Face-to-face interview can be the best way of collecting high quality data, however is considered more expensive than telephone interview given that the researcher may be required to travel and also this process may be time consuming (Fowler, 2009). Therefore, the results of the Delphi study were discussed in-depth with the experts in the second phase of the study through two face-to-face and 17 telephone interviews in order to verify and validate the results of the Delphi study on the factors affecting the auto-ID selection for warehouse management (Skulmoski et al., 2007; Hasson & Keeney 2011).

4.4.17 Selection of Participants for the Interviews

Participants of the interviews were 19 experts across the world. The largest group of panellists (42.12%) were experts in the field of Automatic Identification and Data Capture (Auto-ID) technology (RFID/or Barcode), followed by supply chain management (26.34%), warehouse management (15.79%), operations management (10.53%) and logistics (5.26%). Interview participants were based in Western Europe (UK, Italy and Germany; 52.63%), North America (US and Canada; 26.34%), Asia (India; 5.26 %), Australia (5.26%), and the Middle East (Egypt and Lebanon; 10.53%). The participant group consisted of seven academics, eight industry practitioners and four auto-ID (RFID or Barcode) consultants. Sixteen of the panel members were male and three were female. The majority (15) held a PhD or a Master's degree. Similar to the first phase of the research, the experts were selected through purposive and snowball sampling (Goodman, 1961). Consequently, 19 experts, nine of whom were among the Delphi panellists, accepted to participate in the interviews.

4.4.18 Interview Process

The preparation of the interviews started on 25th March, 2013, and the interviews have been conducted between 28th April - 29th May 2013. The panellists were given detailed information about the purpose of the study via e-mail. The interviews were recorded using an audiotape and transcribed so that the data could be analysed later. In addition, the researcher took notes during the interviews. Interviews followed the protocol shown in Appendix.5. Face-to-face interviews lasted about an hour, and telephone interviews lasted about 20 - 40 minutes. Creswell (2008) has suggested that the researcher reads the data several times after transcribing the records in order to get a general sense of the material, and code them. The data were coded according to the questions posed in the interviews, as well as the codes used in the Delphi study. Then, the data were explained and interpreted.

4.4.19 Data Analysis

The final part of the empirical research methodology is the data analysis. The data analysis method used in the Delphi study may change according to the research aim, rounds structure, types of research questions and number of participants, and consensus can be defined in a variety of ways (Powell, 2003). In most Delphi studies, consensus on a topic is achieved when a certain percentage of the given responses fall within a prescribed range (Scheibe et al., 2002). Determination of the consensus level depends on the research topic; for example in a topic related with health, having 100% consensus may be required (Keeney et al., 2006). However, Williams and Webb (1994) have stated that some researchers accepted the consensus level as 55% in the studies they conducted. In addition, measures of central tendency (e.g. mean, mode, median) and dispersion (e.g. standard deviation, interquartile range) have been used to measure the consensus in Delphi studies. Mitchell (1991) has asserted that the median is a robust measure of central tendency because it is not strongly influenced by outlying data points while; the mean is very sensitive to data in the tails of a distribution. However, according to Budruk and Phillips, (2011), the mean is workable and the score mean score of 3.50 should be adopted as a cut-off point for the consensus. In this sense, Keeney et al., (2011) have mentioned that mean and standard deviation can be used to define the consensus level.

Therefore, descriptive statistics were used to analyse the quantitative data using SPSS (Statistical Package for Social Sciences) version 18.0. For example, mean and standard deviation were calculated by using SPSS software version 18.0 to represent group opinion and consensus. A mean score of 3.50 or greater showed overall agreement (*agree* to strongly *agree)* within the panel members on a certain item (Budruk & Phillips, 2011). The standard deviation for each item was also calculated – this measure shows how much variation there is within the panel – and thus showed the level of consensus or shared opinion. A standard deviation of 1 or less shows that the panel has a strong consensus while a standard deviation of more than 1 shows that there is a wide range of opinion, and therefore a low consensus, amongst the panel members.

The data collected in this research is qualitative and quantitative in nature. Usually, the analysis methods of qualitative data are often not well formulated (Lubbe, 2004; Miles & Huberman, 1994). Although the process of qualitative data analysis may take many forms, it is non-mathematical in nature. According to Bogdan & Biklen 2003, in order to find out what is important, qualitative data should be divided into manageable units for synthesising and searching for patterns. The qualitative data of the Delphi study obtained from the open-ended questions were analysed manually using a content analysis approach (Bryman, 2004). According to Stemler (2001, p.1) content analysis is defined as "a systematic, replicable technique for compressing many words in text into fewer content categories based on explicit rules of coding". Bryman (2004, p.181) has a broader definition: "Content analysis is an approach to the analysis of documents and texts (which may be printed or visual), that seeks to quantify content in terms of predetermined categories and in a systematic and replicable manner". Both these definitions view content analysis as fundamentally a quantitative method since all the data are finally converted into frequencies (Pope et al., 2007). In order to undertake quantitative content analysis, the themes (categories) of interest have to be defined sufficiently precisely in advance and then counting how often each theme occurs (Bryman, 2004; and Pope et al., 2007). Quantitative content analysis measures frequencies and this distinguishes this approach from 'thematic analysis' and qualitative forms of content analysis which can be adopted to analyse and group concepts, however, does not attempt to count them (Pope et al., 2007). Accordingly, in this research, the results of the content analysis were presented quantitatively and converted into frequencies because this method offers easy comparison with other studies undertaken within a similar framework (Bryman, 2004).

The qualitative data obtained from the interviews were analysed manually using a thematic content analysis approach (Hasson et al., 2000). In this study, on average, 80 pages of interview transcripts were collected. Thematic analysis was chosen because it offers an accessible and theoretically flexible method for analysing qualitative data (Braun & Clarke, 2006). In the process of the thematic analysis process, repeated patterns of meaning and similar factors were grouped together; where several different terms are used for what appears to be the same factor, in order to provide one universal description (Hasson et al., 2000; and Braun & Clarke, 2006). Joffe and Yardley (2004) have indicated that there are few published guides regarding how to carry out thematic analysis and it is often applied in published research without clear report of the specific techniques that were involved. Braun and Clarke (2006) have rectified this lack of guidelines by providing a comprehensive discussion of the rationale, philosophy and process of applying the thematic analysis approach in psychology research. These guidelines involve 6 basic steps of thematic analysis. These steps are similar to many other qualitative analysis approaches suggested by other researchers such as Smith (1995) and Creswell (2007). In this study, the 6 steps/phases were followed as shown below:

- ***Phase 1: Familiarising self with data***

Braun and Clarke (2006) have suggested that the researchers immerse themselves in the data. This includes repeated reading of the data and reading in an 'active way', which means searching across a data set to find repeated patterns of meaning. Braun and Clarke (2006) and Smith (1995) have also recommended that it is a good idea to start taking notes or mark ideas for coding at this phase.

- ***Phase 2: Generating initial codes***

Braun and Clarke (2006) have stated that codes identify a feature of the data (semantic or latent) that seems to be interesting to the analyst. Coding can be done either manually or through a software programme (Braun and Clarke, 2006). Due to the manageable amount of qualitative data, it was decided to code this data manually, to ensure full immersion and connection with the data. The data in this study was coded by writing notes in the text to indicate potential patterns. Once the codes were identified, a 'cut and paste technique' on the word document was performed in order to organise the codes with their associated data extracts (Miles & Huberman, 1994).

- ***Phase 3: Searching for themes***

In this phase, the codes were collated into potential themes and all data relevant to each potential theme was gathered.

- ***Phase 4: Reviewing themes***

After sorting the codes into potential themes that best represented each code, the themes were reviewed and refined until it was decided that the data within themes cohered together significantly and that there were clear and recognisable distinctions among themes.

- ***Phase 5: Defining and naming themes***

This phase involved ongoing analyses to refine the specifics and identify the essence of each theme and also, to generate clear definitions and names for each theme.

- ***Phase 6: Producing the report***

This phase started when a set of fully worked-out themes was produced. This phase involved writing-up the final and a detailed analysis of each theme and ensuring that the themes are not too complicated. Appropriate quotations from participants were presented in the results section to demonstrate suitable themes. Some participants' quotations were the most suitable for reflecting the focus of the particular theme therefore; these quotations have been used more than others.

4.5 Reliability and Validity of Delphi Study

Traditional techniques used for determining validity and reliability are not easily applicable to Delphi studies (Fish & Busby, 2005). However, several different approaches are adopted to determine whether Delphi studies are reliable and valid or not. The reliability and validity of this research is discussed below.

4.5.1 Reliability

The term reliability refers to "the consistency of measurement within a study" (Gerrish Lacey, 2010, p.28) and it has been sub-divided into three distinct types which include: "(1) the degree to which a measurement given repeatedly remains the same (2) the stability of a measurement over time and (3) the similarity of measurements within a given time period" (Kirk and Miller, 1986, pp. 41–42). In other words, reliability refers to whether replication of a study will yield the same results under constant conditions on all occasions (Yin, 1994). Reliability can be increased by standardisation of research procedures (Van Zolingen & Klaassen, 2003).

A number of researchers claim that the Delphi approach enhances reliability (Gordon, 1992; Ziglio, 1996; Clayton, 1997). This belief is based on two main principles, firstly, the claim that the interactive nature of the approach, combined with the avoidance of respondents' bias and the occurrence of respondents' thought scenarios, enhances the reliability of the outcome. Secondly, as the size of the panel increases, the reliability of the respondent group also increases, based on the belief that a larger sample will reflect the judgement of the population, providing a smaller confidence interval. Others, also, including Jillson (1975), has established guidelines in order to increase the reliability of the Delphi approach and to test the quality of Delphi research. As part of the guidelines, the following aspects can be referred to when assessing the reliability of a Delphi approach:

a) the applicability of the approach to a specific problem;
b) the selection of the respondents and their expertise (the panel);
c) the design and administration of the questionnaire;
d) the feedback;
e) the consensus; and
f) the group meeting

Whilst laudable, the application of how such guidelines can enhance reliability is uncertain, given the huge differences in application, design, administration and analysis, hindering reliability and validity (Hardy et al., 2004). Also, the reliability claims have been widely questioned (Woudenberg, 1991; Rowe et al., 1991; Sackman, 1975; Williams and Webb, 1994; and Yousuf, 2007) because the larger the group the more variation can occur, diminishing the degree of accuracy and level of generalisability. Such scenarios can lead to a false consensus being attained, as it forces participants to achieve a consensus without any opportunity to debate the issues (Mullen, 2003; and Morgan et al., 2007), leading Loo (2002) to claim that the use of an (open-ended) first round makes the assessment of reliability problematic.

In the literature, it is accepted that the Delphi technique is as reliable as the other techniques for forecasting, creating consensus of opinion, making decisions, etc. (Clayton, 1997). According to Waltz et al. (2005), there are four main approaches for estimating reliability: firstly, test-retest which includes administering a test on two different occasions to the same sample; secondly internal consistency, which evaluates the consistency of results across items within a test; thirdly, inter-observer which requires rating of the same information and recording of the consistent estimates by different observers; finally, parallel form, also referred to as “alternate” (Patton, 2001), which is undertaken when two different versions of an assessment tool are designed to test the same information and produce the same results.

- **Test re-Test Reliability**

There are a number of studies that have applied reliability measures to assess the stability and consistency of Delphi research over time. A number of authors have applied the test re-test reliability measure (Uhl, 1975; Quintana et al., 2000; Berra et al., 2010; and Diana et al., 2010). The application of the test re-test measure is based upon the assumption that no substantial changes to the construct, being measured, have taken place between two different occasions. However, as researchers expect Delphi participants to revise their responses, Okoli and Pawlowski (2004) have argued that test-re-test reliability is not relevant. In addition, a Delphi merely represents a snapshot of expert opinion for that group, at that moment in time (Stevenson, 1990; Maceviciute & Wilson, 2009; Thompson, 2009). As such the application of the test–retest approach for Delphi research is invalid.

Okoli and Pawlowski, (2004) have suggested that pre-testing the questionnaire is an important reliability assurance for Delphi studies. Pre-tests are useful to evaluate the questions and determine whether they form a cohesive, smoothly flowing questionnaire (Oksenberg et al., 1991, P.349). Particularly, pre-tests have to be considered essential in Delphi studies, since the design of the statement is very demanding and the clarity of the statements will directly affect the reliability of the outcomes (Mitchell, 1991, p. 343). In this sense, Skulmoski et al. (2007) have indicated that the Delphi pilot study should be conducted with the goals of pre- testing and adjusting the Delphi questionnaire in order to enhance comprehension, and to work out any procedural problems. In this research, therefore, the questionnaire has been pre-tested and the Delphi pilot study has been conducted to ensure common understanding of the questions and assure the reliability of the results.

- **Internal Consistency Reliability**

Internal consistency reliability can accurately reflect the consistency of results within a test or whatever an instrument measures (Graziano & Raulin, 2006). It focuses on the degree to which measured items are correlated with each other. In this context, researchers usually apply the split-half reliability, which correlates one half of the items with the other half (Von der Gracht, 2008). Correlation is usually measured by the Pearson product-moment correlation coefficient or internal correlation coefficient (Cronbach's alpha) (Kumar, 2005; and Saunders et al., 2007). Perhaps the Cronbach's α (1951) is the most widely used measure of the reliability of scale. The reason for this are that it is the only reliability index that does not require two administrations of the scale, or two or more examiners, and therefore, it can be measured with much less effort than test re-test or inter-rater reliability (Streiner, 2003). According to Nunnally's (1978) suggestion, α value should be 0.70 or above in order to be considered as a sufficient condition.

A number of Delphi studies have applied the Cronbach's alpha (α) reliability measure to assess the internal consistency reliability (Arke & Primack, 2009; Tomasik, 2010; and Bhattacharya et al., 2011). In this study, internal consistency reliability (Cronbach's Alpha or α coefficient) was chosen to establish inter-item reliability for the constructs and measures that have been adapted and amalgamated from previous studies. Cronbach's Alpha was computed independently for both rounds of the Delphi process. According to Nunnally's (1978) suggestion, α value should be 0.70 or above in order to be considered as a sufficient condition. In this study, Cronbach's alpha was high for both rounds as shown in Table 4.4.

Category	**Cronbach's α Round 1 (# of items)**	**Cronbach's α Round 2 (# of items)**
Organisational sub-factors	0. 789 (3)	0.842 (3)
Operational sub-factors	0.777 (10)	0.943 (10)
Structural sub-factors	0.851 (14)	0.933 (9)
Resources-related sub-factors	0.773 (6)	0.877 (6)
External environmental sub-factors	0.750 (3)	0.870 (3)
Technological sub-factors	0.758 (28)	0.951 (23)

Table 4.4 Cronbach's Alpha for both rounds of the Delphi study

- **Inter-Observer/ Inter-Rater Reliability**

A number of studies have estimated the reliability of the Delphi by applying inter-observer/ Inter-rater measure that have compared panel's outcomes from studies that have started with the same information and involved experts with similar characteristics (Welty, 1972; Duffield, 1993; Quintana et al., 2000; Claeys et al., 2012). Howell et al. (2009) have cited that if a study involves behavioural ratings or ratings based on judgment, Inter-rater reliability simply means that the study should be conducted by at least two researchers. In a scenario where there were two researchers, both researchers should conduct the study oblivious to the other's judgement. Thus, Inter-rater reliability depends heavily on the consistency of the researchers involved (Howell et al., 2009). This type of reliability was not considered applicable in this study due to the nature and manner of the data being collected.

- **Parallel-form Reliability**

Reliability can also be measured by applying parallel/alternate forms, for instance, changing the order of the questions or adjusting the wording of the question in round one of the Delphi process. If the participants answered in the same way at both times, this possibly points towards reliability indicated by positive correlation (Polit & Beck, 2004), at least 0.80 (Brink & Wood, 1998). Parallel form measures are commonly applied in psychometric and educational research (Brennan, 2001; and DeVon et al., 2007). However, these measures are rarely reported in Delphi studies due to the practical constraints of creating a second parallel test (Hasson & Keeney, 2011). Therefore, this type of reliability has been ignored in this research.

4.5.2 Validity

Many researchers claim that the Delphi is a valid instrument (Murry & Hammons, 1995; and De Meyrick, 2003). However, this can sometimes be a sweeping statement, with little detail provided in the types of validity achieved (Hasson & Keeney, 2011). In evaluating Delphi validity, a distinction should be made between external and internal validity. The external validity of the Delphi approach refers to the similarity between a judgement about the future and its real value (Woudenberg, 1991). On the other hand, the internal validity of the Delphi approach is concerned with the question whether the approach itself leads to desired results and forecasts (Woudenberg, 1991). There are different ways in which validity can be measured including content, construct and criterion (Mason & Bramble, 1989; Keeney et al., 2011) each way highlights different aspects of rigour testing as following.

- **Content Validity**

Content validity, similar to face validity, normally refers to the extent to which a research instrument provides adequate coverage of a topic under investigation (Mason & Bramble, 1989; Leedy & Ormrod, 2004; and Huck, 2007). Numerous authors have claimed that the Delphi approach provides evidence of content and face validity (Reid, 1988; Morgan, 2007; Goodman, 1986; Caves, 1988; Walker & Selfe, 1996; Sharkey & Sharples, 2001; and Huang et al., 2008). This belief is based on three key assumptions. Firstly the results arise from group judgement, which is supposed to be more valid than a decision made by a single person. Secondly, the process is based on expert judgement from the 'real world' providing confirmative opinions on the subject (Spencer-Cooke, 1989; and Cross, 1999). Finally, the process of a classical Delphi, combining an open first qualitative round enables experts to produce scale items. Moreover, the continual succession of rounds provides the opportunity to review and judge the suitability of the scale. In reality however, a Delphi sample may have certain features that affect findings; for instance, Rowe et al. (1991) have believed that the Delphi validity is influenced by: experts number, their level of expertise, and the agreement which the experts possess. In addition, a traditional first round may generate ambiguous, broad statements, which could lead to bias from the outset as well as biased results thereafter (Marchant, 1988). Therefore, the use of a modified (close-ended) Delphi has been recommended in order to verify the content and face validity (Hsu & Sandford, 2007). In this research, the Delphi process will be modified to best answer the research questions and to verify the content and face validity. For example, different types of questions (closed/open) and analysis (qualitative/quantitative) have been used in each round of the Delphi process (Skulmoski et al., 2007).

According to Morgan (2007), content validity is sought, which is usually identified according to the related literature and expert judgment. Thus, in order to provide content validity in this research, the researcher carried out a comprehensive literature review and benefited from the views of some other experts throughout the study. In addition, as the content in Delphi studies is created by the panel members, the validity is directly related to the selection of the experts panel (Fish & Busby, 2005). So, it is crucial to define clearly the qualifications that the panellists should have and then to select the experts according to those determined qualifications (Clayton, 1997). Therefore, in the study, the required qualifications were defined clearly, and the panel members were selected among the ones having those qualifications.

- **Construct Validity**

Construct validity, is often cited as being the most significant form of validity (Neill, 2004). Construct validity assesses the theoretical foundations of a particular scale or measurement and the adequacy of the test in measuring the construct (Mason & Bramble, 1989). The Delphi approach is assumed to attain construct validity, as the parameters are defined and approved by the items given by the experts (Okoli & Pawlowski, 2004; Schmidt, 1997). Both Schmidt (1997) and Okoli and Pawlowski (2004) have suggested that a researcher's interpretation and categorisation of round one findings should be fed back to the experts for checks to be undertaken. Thus, in this research, the construct validity will be assured by careful questionnaire design and by pretesting, and also by asking experts to validate the researcher's interpretation and categorization of the variables. The fact that the respondents in a Delphi are not anonymous to the researcher permits this validation step, unlike many surveys. Doing this ensures that the experts' definitions are correct and increase the likelihood that the results can be generalisable to different settings (Okoli & Pawlowski, 2004).

- **Criterion-Related Validity**

Criterion-related validity is used to measure the accuracy of one criterion within a research instrument by comparing it to a pre-existing "validated" instrument (Leedy & Ormrod, 2004). Criterion-related validity is established when a test is demonstrated to be effective in predicting criteria or indicators of a construct (McIntire & Miller, 2005). There are two different types of criterion-related validity, concurrent and predictive, and the difference lies in the timing. Concurrent validity can be shown when a test administered at the same time is correlated well with a measure that has been previously validated. Predictive validity, on the other hand, is where one measurement occurs earlier and is meant to predict some later measurement (McIntire & Miller, 2005). It is assumed that the Delphi approach contributes to concurrent validity (Williams & Webb, 1994; Goodman, 1986; Walker & Selfe, 1996; and Sharkey & Sharples, 2001) due to the successive rounds (Hasson et al., 2000) and because the panellists have identified and agreed the components (Williams & Webb, 1994). Criterion-related validity is very much optional depending on the nature of the study (Hashim et al., 2007). Therefore, concurrent validity has been examined in this study by conducting successive rounds and achieving components' agreement while predictive validity, which is about forecasting accuracy, is not relevant to this type of study so it was not examined.

4.6 Trustworthiness of the Delphi Study

A number of authors believe the term "trustworthiness" is more appropriate than reliability and validity to determine the effectiveness and appropriateness of the Delphi study (Holloway & Wheeler, 1996; Day & Bobeva, 2005; Cornick, 2006). There are four main strategies to establish trustworthiness: credibility, dependability, confirmability and transferability (Lincoln, 1985; Polit et al., 2001). Engles and Kennedy (2007) have suggested that credibility of the Delphi study can be improved by ongoing iteration and feedback given to panellists. Cornick, (2006) has proposed that dependability can be obtained by including a range and representative sample of experts in the Delphi study. Confirmability can be determined by maintaining a detailed description of the Delphi data collection and analysis process, while transferability can be established through the verification and confirmation of Delphi findings (Powell, 2003; and Kennedy, 2004). For the verification of the Delphi results, Skulmoski et al. (2007) have suggested conducting a follow-up study after Delphi, such as interviews or survey. Thus, the trustworthiness of this study has been established through the ongoing, iteration, and feedback given to the panellists; involving a range and representative sample of panel of experts in the Delphi study; maintaining a detailed description of the Delphi data collection and analysis process; and by discussing the Delphi results in-depth via both face-to-face and telephone interviews.

4.7 Ethics in the Research

Ethics in the empirical research is very important. Researchers should protect the rights of respondents and inform them about the research procedures and risks before collecting data. The participants should know that the collected data is going to be used for the benefit of the research only and will remain confidential. Also, they should be informed that their identity will remain anonymous throughout the research. In addition, the respondents should voluntarily participate in the research and no data should be used without their agreement.

There are standards of ethics that must be met in order to protect the participants' privacy. The rights of the respondents should not be infringed in any way during the study. In addition, the participants should be informed that they can end the interview at any time or not to answer any question. In this research, before collecting the data and interviewing the participants, an approval to conduct the Delphi study and the interviews was received from the top management of Brunel University.

4.8 Summary

The purpose of Chapter 4 is to justify the use of an appropriate methodology for this thesis. This chapter outlined what can be broadly grouped concerning the research design, data collection, and data analysis. Underpinning these, the following points were addressed:

- Philosophical underpinning adopted (positivist epistemological stance)
- Research design (Phase 1: exploratory/descriptive Delphi study; Phase 2: Follow-up verification interviews)
- Research strategy employed (mixed- method strategy)
- Rationale and justifications for research approaches (quantitative and qualitative)
- Expertise of the researcher
- Appraisal of the Delphi suitability for doctoral studies
- Methods of data collection and analysis

The reasons behind this methodology are based on the aim and objectives of this research that deals with developing a framework for the selection process of auto-ID technology in warehouse management. The justification to use the modified (mixed-method) Delphi study was explained in the Sub-Sections 4.4.5 and 4.4.6. The researcher conducted two-round Delphi study with a worldwide panel of experts comprising a total of 107 academics, industries practitioners, and consultants in auto-identification (ID) technologies. In fact, the Delphi study was used within this research because it relies upon expert opinions to identify and deepen the understanding of a number of key factors, and their relative importance, that affecting the auto-ID selection process in the warehouse environment. Both face- to-face and telephone interviews, on the other hand, have been conducted with a total of 19 experts across the world in order to verify and refine the Delphi findings. The researcher acknowledges that by including academics and practitioner experts as an integral part of the research process, there is a likelihood of obtaining a greater level and of insight to address the research problem.

The Delphi study and the follow-up interviews provided sufficient information for this research. The work presented in this thesis will provide a broader understanding of the phenomenon of the auto-ID selection process in warehouse management. The Delphi study findings as well as the interview findings along with preliminary analysis and discussions are presented in detail in Chapter 5.

CHAPTER 5

FINDINGS AND EMPIRICAL DATA

5.1 Introduction

This chapter's aim is to present the analysis and descriptions of the empirical data collected from both the modified two-round Delphi study and the follow-up interviews answering the research questions. As discussed in Chapters 2 and 3 of this dissertation, there is an absence of a theoretical framework that focuses on the auto-ID technology selection-process in warehouse management. This study contributes to knowledge through conducting two phases of research design. In the first phase, a modified (mixed-method) two-round Delphi study with a worldwide panel of 107 experts including academics, industry practitioners and consultants in auto-ID technologies was conducted. This was a combination of exploratory and descriptive research design. The objective was to identify the motivations/reasons for warehouses to seek to use auto-ID technologies; the challenges in making an auto-ID decision; the recommendations to address the challenges; the key steps that should be followed in making auto-ID selection decision; the key factors and their relative importance that influence the auto-ID selection decision in warehouse management.

On the other hand, the second phase incorporated follow-up interviews, both face-to-face and by telephone, using 19 experts across the world. This was a follow-up verification study. The objective was to discuss in-depth, verify and refine the results of the Delphi study.

Pulling together the insights obtained from the Delphi study and the interviews, the researcher developed a comprehensive framework for the auto-ID selection process that consists of seven stages: organisational analysis, operational analysis, structural analysis, resources analysis, external environmental analysis, technological analysis, and decision-making.

The chapter begins with the findings of the Delphi study based on the two rounds. Then, the interviews findings have been presented. Finally, stages that the auto-ID selection process goes through have also been demonstrated.

The international two-round Delphi study and the follow-up interviews conducted by the researcher are sufficient for providing enough data to understand and reach the aim and objectives of this research.

5.2 Findings from the Delphi Study

In this study, data were collected through a two-round Delphi study using a worldwide panel of experts comprised of a total of 107 academics, industries practitioners, and consultants in auto-identification (ID) technologies.

The first round questionnaire consisted of two parts (A and B). The specific issues addressed in Part A of the questionnaire were:

1) The motivations of warehouses that seek to use auto-ID technology;
2) The key steps in the selection process of auto- ID technology in warehouse environment;
3) The most difficult problem in making an auto-ID decision; and
4) The ways to overcome the problem.

Part B of the questionnaire, on the other hand, focused on the relative importance of the main factors and sub-factors influencing the auto-ID selection decision for warehouse management and the relative importance was measured using a five-point Likert scale. The qualitative data were analysed manually using a quantitative content analysis approach (Bryman, 2004). Also, descriptive statistics (frequencies, mean, and standard deviation), using SPSS (Statistical Package for Social Sciences) version 18.0, were calculated to analyse the quantitative data and to represent group opinion and consensus.

The findings were presented separately for each of the four questions of Part A mentioned above. The corresponding tables summarise the frequencies (F) of the responses in the first round of the Delphi, as well as their means and standard deviations (SD) in the second Delphi round.

5.2.1 Part A of the Questionnaire

Part A consisted of 4 open-ended questions which allowed respondents to provide and express their opinions or add information freely and independently. The findings of Part A questionnaire are shown in the following Sub-Sections.

5.2.1.1 Motivations of Warehouses that Seek to Use Auto-ID Technology

The results and the frequencies of the responses from the first round and the agreement obtained from the second round are presented in Table 5.1

Motivations	Round 1 (N = 107)	Round 2 (N = 102)			
	Frequency N (%)	Consensus Mean	SD	Agreement Level (%)	
				Agree	Disagree
1- Operational performance optimisation	100 (93.46)	4.95	0.217	102 (100)	0
2- Enhanced customer service	67(62.62)	4.79	0.430	101 (99)	0
3- Improved resource management	64 (59.81)	4.89	0.312	102 (100)	0
4- Improved security	25 (23.36)	4.73	0.491	100 (98)	0
5- Increase and sustain competitive position and advantage	19 (17.76)	4.80	0.423	101 (99)	0

Table 5.1 Warehouse management motivations for using auto-ID technology

This finding shown in Table 5.1, reveals that the largest number of the panellists identified the major motivation/reason for warehouses to use auto-ID technology was for **operational performance optimisation (F=100)** (e.g. efficiency and effectiveness gains in receiving, put-away, picking and shipping; improving productivity; higher throughput; speed; high quality; improve and maintain processes reliability, visibility and accuracy; reduce errors related to manual processes; real time operations; reduced overall costs; improving the level of automatic processes and reducing the level of manual steps; effectively automate inspection and checking processes; and simpler stock-taking process).

Other important reasons highlighted were **the ability to achieve enhanced customer service (F= 67)** (e.g. customer responsiveness; Customer Relationship Management (CRM); enhanced level of customer satisfaction and customer 'self-service'), **improved**

resource management (F= 64) (e.g. maximise the effective use of space/vertical space, equipment and labour; real-time visibility; improved inventory visibility and accuracy; cycle counting and annual inventory audit effectiveness; improved inventory planning; minimising the shrinkage and out of stock; enhanced tracking and tracing of items; strong WMS to support the operations; optimising asset utilisation), **improved security (F= 25)** (e.g. enhancing physical control and security of people and objectives; prevent or decrease the level of theft in the storage area especially at night; strengthen security against product loss, and counterfeiting)**,** and finally to **increase and sustain competitive position and advantage (F=19).**

In the second round the panellists tended to agree with the above findings. For example, operational performance optimisation was highly estimated as the most important motivation of warehouses to use auto-ID technology **(Mean= 4.95; SD= 0.217; agreement level= 100%)** which already had a top placement in the first round. Also, the second ranking category from the first round remains among the largely agreed categories, i.e. enhanced customer service **(Mean= 4.79; SD= 0.430; agreement level= 99%)** but, it is topped by improved resource management (**Mean=4.89; SD= 0.312; agreement level= 100%)** and also by increased and sustained competitive position and advantage **(Mean= 4.80; SD= 0.423; agreement level= 99%).** Again, improved security received the lowest ratings both in the first and in the second round **(Mean= 4.73; SD= 0.491; agreement level= 98%)** and thus it is the lowest important motivation of warehouses that seek to use auto-ID technology.

Nevertheless, some panellists indicated that the motivations depend on the type of warehouse needs and problems, type of business, and the nature of the business environment. In addition, two experts stated that some warehouses use auto-ID technologies because they are mandated from customer(s) downstream in the supply chain.

The above motivations and the comments obtained from the second round are discussed in detail in Chapter 6.

5.2.1.2 Key Steps in the Selection Process of Auto- ID Technology in Warehouse Environment

There was strong consensus on the steps identified in the technology selection process over the two rounds of the study. The following steps presented in Table 5.2 are a summary of the preferred or expected procedure in making the auto-ID selection decision for warehouse management obtained from the first round and the agreement obtained from the second round:

Step	Consensus Mean	SD	Agreement Level (%)	
			Agree	Disagree
1. Organisational issues				
1.1 Secure top management support for the initiative	4.84	0.392	101 (99)	0
1.2 Absolute clarity of the internal problems, needs and requirements	4.96	0.195	102 (100)	0
1.3 Make clear the objectives for the overall business both in the short and long term	4.95	0.217	102 (100)	0
1.4 Setting reasonable expectations and understanding the warehouse manager's perceptions of auto-ID's capabilities	4.86	0.346	102 (100)	0
1.5 Educate workers as to why the company is moving to the new system	4.83	0.375	102 (100)	0
1.6 Train those workers in new system operations	4.52	0.656	97 (95.1)	0
2. Warehouse environment specifications				
2.1 Understanding key operations and processes of the warehouse and determining points to be improved	4.94	0.236	102 (100)	0
2.2 Evaluate the overall business process design/re-design	4.89	0.312	102 (100)	0
2.3 Defining company's preferred process flow and the system requirements necessary to implement that process	4.75	0.460	101 (99)	0
2.4 Evaluate the overall Warehouse Management System design/re-design	4.95	0.217	102 (100)	0
2.5 Overall definition of the IT infrastructure	4.83	0.400	101 (99)	0
2.6 Overall evaluation of warehouse resources	4.88	0.353	101 (99)	0
2.7 Check the amount of metal and liquid in your warehouse	4.76	0.530	99 (97.1)	0
2.8 Check other types of RF devices in the area	4.69	0.545	98 (96)	0
3. External environment study				
3.1 Consider your customer	4.88	0.380	100 (98)	0
3.2 Check provider/supplier support	4.95	0.259	101 (99)	0

Step	Consensus Mean	SD	Agreement Level (%)	
			Agree	Disagree
3.3 Define the industry competitors	4.64	0.577	97 (95.1)	0
3.4 In-country service support	4.91	0.285	102 (100)	0
4. Technological analysis				
4.1 Requirements definition for the technology (necessary and optional)	4.73	0.470	101 (99)	0
4.2 Analysis of the different auto-ID solutions (possibilities, and limitations)	4.93	0.254	102 (100)	0
4.3 Think about adopting a hybrid and/or integrating various auto-ID technologies	4.92	0.336	100 (98)	0
4.4 Initial cost-benefit analysis/Return On Investment (ROI) analysis/feasibility	4.93	0.290	101 (99)	0
4.5 Pilot test part of the system in the actual warehouse environment	4.95	0.259	101 (99)	0
4.6 Review the pilot test to identify strengths, weakness and as well as additional opportunities to deploy the system	4.80	0.423	101 (99)	0
4.7 Final cost-benefits analysis/ROI including both quantitative and qualitative factors	4.96	0.195	102 (100)	0
5. Decision–Making				
5.1 Select and get buy in from all the relevant people involved in the process	4.91	0.375	101(99)	0

Table 5.2 Key steps in the auto- ID selection process obtained from round 1 (N=107) and the agreement obtained from round 2 (N=102)

Some specific and relevant comments emerged in the second round. One comment was that these steps are appropriate only for large warehouses, because small- and medium-sized warehouses may not have sufficient resources or budgets to follow the steps when considering auto-ID choices. It was also noted that the step “requirements definition for the technology” especially, RFID, is linked to process flows that warehouse managers want to improve. Specific comments indicated that the steps to“ educate workers as to why the company is moving to the new system” and “train those workers in new system operations” are very important in succeeding the implementation of RFID technology in a warehouse, but they are not important for the selection process of auto- ID technology; unless the step “training those workers in new system operations” is aiming to educate the people on the technology so they can be more knowledgeable in the selection process.

In Chapter 6, the researcher discussed the above key steps in the auto- ID selection process and the relevant comments emerged in the second round.

5.2.1.3 The Most Difficult Problem in Making an Auto-ID Decision in Warehouse Environment

This question generated a variety of opinions in the first round. The panellists identified many problems that may arise in the auto-ID selection decision process as shown in Table 5.3.

Problem	Round 1 (N = 107)	Round 2 (N = 102)			
	Frequency (%)	Consensus Mean	SD	Agreement Level (%)	
				Agree	Disagree
1.Technological issues	**73 (68.2)**				
1.1 Cost-benefit analysis/ROI analysis	30 (28.04)	4.96	0.195	102 (100)	0
1.2 Changing the practices and processes to suit auto-ID technology, or, adapt the technology to facilitate practices	20 (18.69)	4.89	0.312	102 (100)	0
1.3 Evaluation of the technology without assistance from others	10 (9.35)	4.93	0.352	101 (99)	0
1.4 Integration complexity with existing systems (WMS/ERP)	4 (3.74)	4.93	0.290	101 (99)	0
1.5 How to leverage the system across internal processes and external partners	3 (2.80)	4.78	0.459	100 (98)	0
1.6 Missing standardisation	2 (1.87)	4.62	0.527	100 (98)	0
1.7 Competing with other internal projects	2 (1.87)	4.65	0.591	96 (94.1)	
1.8 Stability/low maintenance costs	1 (0.93)	4.50	0.625	97 (95.1)	0
1.9 Planning for 99% read accuracy	1 (0.93)	4.30	0.715	89 (87.2)	0
2. Decision process	**17 (15.9)**				
2.1 Decision process is complex and many factors are involved in it, e.g. benefits, costs, expected risks, ROI, complexity, social needs	17 (15.9)	4.90	0.330	101 (99)	0
3. Information	**15 (14.00)**				
3.1 Quality of information about a system integrator, hardware, and software providers	5 (4.67)	4.93	0.290	101 (99)	0

Problem	Round 1 (N = 107)	Round 2 (N = 102)			
	Frequency (%)	Consensus Mean	SD	Agreement Level (%)	
				Agree	Disagree
3.2 Missing overview of a technology provider(s)	4 (3.74)	4.52	0.656	97 (95.1)	0
3.3 Comparison of alternatives	3 (2.80)	4.60	0.618	99 (97.1)	0
3.4 Missing best practices	3 (2.80)	4.55	0.623	99 (97.1)	0
4. Management Issues	**13 (12.1)**				
4.1 Limited knowledge capabilities on auto-ID technology	7 (6.54)	4.91	0.375	99 (97)	0
4.2 Lack of skills to address the underlying problem	3 (2.80)	4.83	0.489	97 (95.1)	0
4.3 Diversion of warehouses' managers from the evaluation process by the 'shiny objects' of technology that does not meet its objectives	2 (1.87)	4.70	0.559	97 (95.1)	0
4.4 Warehouse managers and IT managers are not geared for evaluating the multi-faceted aspects of auto-ID technology	1 (0.93)	4.38	0.718	90 (88.3)	0
5. People	**7 (6.5)**				
5.1 Ability and/or rationality of decision maker	4 (3.74)	4.80	0.488	100 (98)	0
5.2 Experience of the analyst	2 (1.87)	4.83	0.424	100 (98)	0
5.3 Available time	1 (0.93)	4.84	0.392	101 (99)	0
6. Customer	**3 (2.8)**				
6.1 Understanding the customer needs and ensuring that they are the real issues	3 (2.8)	4.74	0.486	100 (98)	0

Table 5.3 The most difficult problem in selecting an auto-ID technology

The results in Table 5.3 show that the largest number of the panellists **(73)** identified the most difficult problem in making an auto-ID decision in warehouse environment was **the technological issues.** Other difficult problems highlighted were the **decision process** is complex and many factors involved in it **(F=17),** quality of **information (F=15), management issues (F=13), people (F=7)** and understanding the **customer** needs and ensuring that they are the real issues **(F=3).**

In the second round, the panellists did not argue with these findings but some valuable comments were provided. For instance, one panellist noted, from some projects he participated in, that the "Planning for 99% read accuracy" means 100 miss-reads per day and he suggested that the planning should be for 100% read accuracy. Specific comments indicated that the issue "Warehouse managers and IT managers are not geared for evaluating the multi-faceted aspects of auto-ID technology" is correct if they are alone while, they are good when they work together particularly, in a multidisciplinary team. Three panellists noted that the "quality of information, experience of the analyst, and available time" are very important and could lead to major problems in the selection process. Also, it was argued that combinations of qualitative and quantitative factors affect significantly the selection decision process and make the process of decision-making complicated.

5.2.1.4 Recommendations on the Ways to Overcome the Problem

The panellists recommended a variety of ways to overcome the different types of problems mentioned above in Table 5.3. These recommendations may be summarised as shown in Table 5.4.

Recommendation	**Round 1 (N = 107)**	**Round 2 (N = 102)**			
	Frequency (%)	**Consensus Mean**	**SD**	**Agreement Level (%)**	
				Agree	**Disagree**
1. Prudent evaluation process	**67 (62.62)**				
1.1 Empower cross-functional team(s) to serve on the project in a warehouse and to work with supply chain partners	18 (16.82)	4.99	0.99	102 (100)	0
1.2 Building a thorough and rigorous business case methodology	15 (14.02)	4.97	0.170	102 (100)	0
1.3 Comprehensive and accurate information	10 (9.35)	4.98	0.139	102 (100)	0
1.4 Careful analysis of all impacts of the technology, including overall SCM	5 (4.67)	4.94	0.236	102 (100)	0
1.5 Good planning and screening of the market	5 (4.67)	4.94	0.275	101 (99)	0

Recommendation	Round 1 (N = 107)	Round 2 (N = 102)			
	Frequency (%)	Consensus Mean	SD	Agreement Level (%)	
				Agree	Disagree
1.6 Technology selection and deployment must be strictly based on need alone	3 (2.80)	4.92	0.390	100 (98)	0
1.7 Process of reviewing the best practices of class warehouses	3 (2.80)	4.88	0.405	101 (99)	0
1.8 Visit to conference and exhibition on auto-ID	3 (2.80)	4.91	0.348	100 (98)	0
1.9 Continuous decision process based on good involvement of warehouse's executives	2 (1.87)	4.93	0.290	101 (99)	0
1.10 Requirement for a demonstration	1 (0.93)	4.77	0.443	101 (99)	0
1.11 Install an experimental setup/mini pilot	1 (0.93)	4.89	0.342	101 (99)	0
1.12 Visit similar installations	1 (0.93)	4.93	0.254	102 (100)	0
2. Specialist advice/expertise	**35 (32.71)**				
2.1 Employ qualified consultants and/or professional advisors to investigate and pull all stakeholders together at the beginning of the auto-ID selection process	24 (22.43)	4.74	0.506	99 (97.1)	0
2.2 Strong understanding of auto-ID physics by having physics experts who can support and recommend the best hardware and configuration	11 (10.28)	4.38	0.845	87 (85.3)	2 (1.96)
3. Techniques/Tools	**30 (28.04)**				
3.1 Advanced numerical models for cost-benefit analysis	11 (10.28)	4.65	0.591	98 (96.1)	0
3.2 Comprehensive and robust ROI calculations including quantitative and qualitative factors	9 (8.41)	4.94	0.236	102 (100)	0
3.3 Multi analysis tools	6 (5.61)	4.64	0.559	100 (98)	1(0.98)
3.4 Multiple testing stages	4 (3.74)	4.82	0.432	100 (98)	0
4. Incentives	**4 (3.74)**				
4.1 Develop appropriate incentives scheme and relevant organisational structures to improve the quality of information and help in decision-making process	4 (3.74)	4.73	0.529	100 (980	0

Recommendation	Round 1 (N = 107)	Round 2 (N = 102)			
	Frequency (%)	Consensus Mean	SD	Agreement Level (%)	
				Agree	Disagree
5. Standardisation	**3 (2.80)**				
5.1 Movement towards international standards for the technology, especially, RFID products	4 (3.74)	4.78	0.500	100 (98)	1 (0.98)

Table 5.4 Recommendations to overcome problems in auto-ID technology selection

This finding presented in Table 5.4, reveals that the largest number of the panellists identified the way to overcome the difficult problem in making an auto-ID decision for warehouse management was by conducting **prudent evaluation process_(F=67).** Other important recommendations highlighted were to have **specialist advice/expertise (F= 35),** adopting advanced **techniques/tools (F= 30),** developing appropriate **incentives** scheme and relevant organisational structures **(F= 4),** and movement towards s**tandardisation (F=3).**

Some specific and relevant comments emerged in the second round. One comment was that these issues reflected a large warehouse's perspective. Another believed that "educating a team and training of IT and operations people on the Auto-ID technology so they can participate in the selection process vs. rely on consultants" could help to overcome problems. It was also highlighted that "physics experts" are not the only ones that will recommend the best hardware and configuration; they may help in designing the solution/configuration but not the hardware. Four panellists were not in agreement on these issues, indicating that the approach would depend on the warehouse motivations.

The discussion of the most difficult problem in selecting an auto-ID technology and the recommendations to overcome the problems are presented in detail in Chapter 6.

5.2.2 Part B of the Questionnaire

In Part B of the questionnaire, panel members were asked to rate the importance of the major factors and their sub-factors generally in auto-ID selection decision, using a five-point Likert scale (1 – not at all important to 5 – extremely important). Then, descriptive statistics (mean, and standard deviation), using SPSS (Statistical Package for Social Sciences) version 18.0, were calculated to analyse the quantitative data, represent the importance of these factors obtained from round 1, and to present the group opinion and agreement obtained from round 2 (Skulmoski et al., 2007; Budruk & Phillips, 2011). The results for the major factors from the first round of the Delphi study are presented first. The results for the most important sub-factors are then presented.

5.2.2.1 The Importance of Major Factors Influencing Auto-ID Selection Decision in a Warehouse

In the first round, the panellists were asked to rate the importance of 6 major factors for the auto-ID selection decision. The importance of the mean ratings of these factors obtained from round 1 and the agreement obtained from round 2 are presented in Table 5.5.

Major Factors	**Round 1 (N= 107)**		**Round 2 (N= 102)**		
	Importance Mean (SD)	**Rank**	**Consensus Mean (SD)**	**Agreement Level (%)**	
				Agree	**Disagree**
Organisational Factors	4.72 (0.453)	1	4.92 (0.305)	101 (99)	0
Operational Factors	4.52 (0.556)	2	4.95 (0.259)	101 (99)	0
Structural Factors	4.43 (0.798)	3	4.73 (0.600)	96 (94.1)	1 (0.98)
Resources-Related Factors	4.40 (0.645)	4	4.74 (0.596)	98 (96.1)	2 (1.96)
External Environmental Factors	4.34 (0.578)	5	4.80 (0.468)	99 (97)	0
Technological Factors	4.27 (0.567)	6	4.83 (0.582)	98 (96.1)	3 (2.94)

Table 5.5 The importance of the major factors influencing auto-ID decision

Organisational Factors are ranked highest among all major factors **(Mean= 4.72; S.D. = 0.453)**. Operational **(Mean= 4.52; S.D. = 0.556)**, structural **(Mean= 4.43; S.D. = 0.798)**, resources- related **(Mean= 4.40; S.D. = 0.645)**, external environmental **(Mean= 4.34; S.D. = 0.578)** and technological **(Mean= 4.27; S.D. = 0.567)** factors are also significant factors highlighted, in decreasing order. It is also apparent that the ratings for all these factors are very close to one another and all are rated relatively highly.

In the second round, very few comments were made on the relative rankings of the 6 factors. For example, three panellists suggested that the importance of each factor may vary from one situation to another and would depend on sectors or market types. In addition, it was noted by two panellists that “technological factors” should rank more highly.

5.2.2.2 The Importance of the Sub-Factors

The relative importance of the sub-factors was also investigated in Part B of the questionnaire for each of the major factors mentioned above. In this research, mean score of 3.50 was adopted as a cut-off point (Budruk & Phillips, 2011). Only the factors that had a score 3.50 or above were fed back to panellists in the second round for the re-evaluation and comments. Fifty Four (54), out of (65), sub-factors had an importance mean score exceeding 3.50.

The results for each sub-factor are summarised below. In each case (Tables 5.6 - 5.11) the sub-factors are ranked in decreasing order of mean scores. In the second round, panellists were asked to comment on the importance of the rankings of each of these sets of sub-factors. In general, there was wide agreement across the panel members on the ranking order of sub-factors; however, a number of comments, interpretations and reflections were added.

5.2.2.2.1 Organisational Sub-Factors

Table 5.6 shows the relative importance of the organisational sub-factors factors obtained from the first round and the agreement from the second round.

Sub- Factors	**Round 1 (N=107)**		**Round 2 (N=102)**		
	Importance Mean (SD)	**Rank**	**Consensus Mean (SD)**	**Agreement Level (%)**	
				Agree	**Disagree**
Warehouse internal needs	4.93 (0.344)	1	4.93 (0.352)	101 (99)	0
Top management support	4.62 (0.526)	2	4.81 (0.593)	98 (96)	0
IT Knowledge capability	4.62 (0.488)	3	4.82 (0.534)	99 (97.1)	0

Table 5.6 The relative importance of the organisational sub-factors

From Table 5.6, we can see that the warehouse internal needs was highly considered as the most important organisational sub-factor that affects the technology selection decision in a warehouse **(Mean= 4.93; SD= 0.344).** Followed by top management support **(Mean= 4.62; SD=0.526)** and IT knowledge capability **(Mean= 4.62; SD= 0.488),** in decreasing order.

The results from the second round revealed that the majority of the panellists agreed with the importance order of the organisational sub-factors and no valuable additional comments were made.

5.2.2.2.2 Operational Sub-Factors

Table 5.7 shows the relative importance of the operational sub-factors obtained from the first round and the consensus level achieved in the second round. Operational factors are regarded as one of the most important factors in dealing with the selection decision of auto-ID technology in warehouse management.

Sub- Factors	**Round 1 (N= 107)**		**Round 2 (N= 102)**		
	Importance Mean (SD)	**Rank**	**Consensus Mean (SD)**	**Agreement Level (%)**	
				Agree	**Disagree**
Shipping	4.76 (0.431)	1	4.86 (0.468)	97 (95.1)	0
Receiving	4.75 (0.478)	2	4.88 (0.380)	100 (98)	0
Storage assignment policy	4.72 (0.491)	3	4.78 (0.538)	96 (94.1)	0
Picking	4.57 (0.616)	4	4.63 (0.561)	98 (96.1)	0
Zoning	4.49 (0.572)	5	4. 54 (0.640)	94 (92.2)	0
Routing	4.48 (0.555)	6	4.47 (0.640)	93 (91.2)	0
Put away	4.44 (0.586)	7	4.33 (0.708)	92 (90.2)	0
Batching	4.37 (0.607)	8	4.42 (0.696)	92 (90.2)	0
Order accumulation and sorting	4.30 (0.633)	9	4.42 (0.710)	91 (89.2)	0
Forward reserve allocation	4.30 (0.586)	10	4.44 (0.654)	93 (91.1)	0

Table 5.7 The relative importance of the operational sub-factors

From Table 5.7, it is clear that shipping was highly estimated as the most important operational sub-factor that influences the auto-ID selection decision in a warehouse environment **(Mean= 4.76; SD= 0.431)**. Followed by, in decreasing order, receiving

(Mean= 4.75; SD= 0.478), storage assignment policy **(Mean=4.72; SD= 0.491),** picking **(Mean= 4.57; SD= 0.616),** zoning **(Mean=4.49; SD= 0.572),** routing **(Mean= 4.48; SD= 0.555),** put away **(Mean= 4.44; SD= 0.586),** batching **(Mean= 4.37; SD= 0.607)**; order accumulation and sorting **(Mean=4.30; SD= 0.633)**, and forward reserve allocation **(Mean= 4.30; SD= 0.586)**.

Most of the panellists, in the second round, tended to agree with importance ranking of the operational sub-factors. However, a small number of panellists argued against that importance ranking, with reasons such as "the ranking order and importance depend on the products if they have already arrived tagged at the warehouse".

5.2.2.2.3 Structural Sub-Factors

The relative importance of the structural sub-factors obtained after round 1 and the consensus level obtained from round 2 are displayed in Table 5.8. It is apparent that product type was ranked highest among all the structural sub-factors **(Mean = 4.76; Std. Deviation = 0.596),** mechanisation level **(Mean = 4.64; S.D. = 0.650)**, E-Plane (electric field) (Mean = 4.48; S.D. = 0.781), departments layout (Mean = 4.41; S.D. = 0.921), warehouse size **(Mean = 4.38; S.D. = 0.809)**, number of racks **(Mean = 4.34; S.D. = 0.951)**, H-Plane (magnetic field) **(Mean = 4.23; S.D. = 0. 808)**, product carrier of the stock keeping unit (SKU) (pallet, case, or item) **(Mean = 4.16; S.D.= 0.716)**, and number of aisles **(Mean = 3.97; S.D. = 0.946)** are also significant structural sub- factors highlighted, in decreasing order.

Sub-Factors	**Round 1 (N= 107)**		**Round 2 (N= 102)**		
	Importance Mean (SD)	**Rank**	**Consensus Mean (SD)**	**Agreement Level (%)**	
				Agree	**Disagree**
Product/Material type	4.76 (0.596)	1	4.88 (0.380)	100 (98)	0
Mechanisation level	4.64 (0.650)	2	4.86 (0.468)	99 (97.1)	0
E-Plane (electric field)	4.48 (0.781)	3	4.76 (0.632)	95 (93.1)	0
Departments layout	4.41(0.921)	4	4.59 (0.603)	96 (94.2)	0
Warehouse size	4.38 (0.809)	5	4.33 (0.680)	94 (92.2)	2 (1.96)
Number of racks	4.34 (0.951)	6	4.34 (0.605)	95 (93.1)	0
H-Plane (magnetic field)	4.23 (0.808)	7	4.32 (0.720)	91 (89.2)	2 (1.96)
product carrier of the stock keeping unit (SKU) (pallet, case, or item)	4.16 (0.716)	8	4.29 (0.623)	93 (91.1)	0
Number of aisles	3.97 (0.946)	9	4.26 (0.659)	90 (88.2)	1(0.98)
Humidity	**2.65 (0. 790)**	**Not considered as they are below the threshold.**			

Sub-Factors	Round 1 (N= 107)		Round 2 (N= 102)		
	Importance Mean (SD)	Rank	Consensus Mean (SD)	Agreement Level (%)	
				Agree	Disagree
Temperature	**2.45 (0.717)**				
Dust and dirt	**2.10 (0.900)**				
Pressure	**2.08 (0.837)**				
Noise	**2.07 (0.918)**				

Table 5.8 The relative importance of the structure sub-factors

It is also apparent, from Table 5.8, that the ratings for all these sub-factors are very close to one another and all are rated relatively highly. However, the structural sub-factors that had a mean score below 3.50 such as, humidity **(Mean = 2.65; S.D. = 0. 790)**, temperature **(Mean = 2.45; S.D. = 0.717)**, dust and dirt **(Mean = 2.10; S.D. = 0.900)**, pressure **(Mean = 2.08; S.D. = 0.837)**, and noise **(Mean = 2.07; S.D. = 0.918)**, were not fed back to the panel members in the second round for comments.

There was a high degree of consensus on these findings in the second round of the study. However, it was argued that the importance of "warehouse size and number of aisles" should be ranked more highly. Importantly, it was noted that in addition to the E-Plane (electric field), "H-Plane (magnetic field)" is also a critical issue in auto-ID selection decisions in a warehouse and should rank more highly, as it directly affects the operational performance of the technology.

5.2.2.2.4 Resources-Related Sub-Factors

Table 5.9 presents the relative importance of the sub-factors of resources-related factors obtained after the first round and the consensus level obtained from the second round.

Sub- Factors	Round 1 (N=107)		Round 2 (N= 102)		
	Importance Mean (SD)	Rank	Consensus Mean (SD)	Agreement Level (%)	
				Agree	Disagree
Material handling equipment	4.77 (0.524)	1	4.83 (0.564)	97 (95.2)	2 (1.96)
Warehouse Management System (WMS)	4.74 (0.634)	2	4.87 (0.460)	99 (97.1)	1 (0.98)
Warehouse staff members (labour)	4.48 (0.781)	3	4.67 (0.635)	97 (95.1)	2 (1.96)
Storage systems	4.30 (0.703)	4	4.34 (0.638)	94 (92.1)	2 (1.96)

Sub- Factors	Round 1 (N=107)		Round 2 (N= 102)		
	Importance Mean (SD)	Rank	Consensus Mean (SD)	Agreement Level (%)	
				Agree	Disagree
Storage units	4.13 (0.616)	5	4.45 (0.623)	95 (93.2)	2 (1.96)
Storage space capacity	4.00 (0).614	6	4.84 (0.685)	91 (89.2)	0

Table 5.9 The relative importance of the resources-related sub-factors

It is clear from the above table, that material handling equipment was ranked highest among all the resources-related sub-factors **(Mean = 4.77; SD = 0.524),** followed directly by the warehouse management system (WMS) **(Mean = 4.74; S.D. = 0.634).** Also, warehouse staff members (labour) **(Mean = 4.48; S.D. = 0.781)**, storage systems **(Mean = 4.30; S.D. = 0.703)**, storage units **(Mean = 4.30; S.D. = 0.616)**, and storage space capacity **(Mean = 4.34; S.D. = 0.951)** are also significant resources-related sub- factors highlighted, in decreasing order.

In the second round of the study, most panellists agreed with the rankings of these sub-factors. However, it was felt by four panellists that the "storage systems and storage units" should rank more highly. In addition, it was argued by two panellists that "Warehouse management system (WMS)" should be the most important issue among all the components and should rank in the top position.

5.2.2.2.5 External Environmental Sub-Factors

The relative importance of the external environmental sub-factors obtained from the first round and the consensus level achieved in the second round are shown in Table 5.10.

Sub- Factors	Round 1 (N=107)		Round 2 (N=102)		
	Importance Mean (SD)	Rank	Consensus Mean (SD)	Agreement Level (%)	
				Agree	Disagree
Customer pressure	4.91 (0.292)	1	4.96 (0.195)	(100)	0
Supplier support	4.87 (0.366)	2	4.91 (0.401)	98 (96.1)	0
Competitive pressure	4.35 (0.551)	3	4.77 (0.579)	96 (94.1)	1 (0.98)
Government pressure	3.80 (0.818)	4	4.74 (0.644)	95 (93.2)	2 (1.96)

Table 5.10 The relative importance of the external environmental sub-factors

In the second round the panellists tended to agree with the above results. For example, customer pressure was highly estimated as the most important external environmental sub-factor **(Mean= 4.96; SD= 0.195; agreement level= 100%)** which had already a top placement in the first round **(Mean= 4.91; SD=0.292).** Also, the second ranking external environmental sub-factor from the first round, i.e. supplier support **(Mean=4.87; SD=0.366)** remains among the largely agreed external environmental sub-factors **(Mean= 4.91; SD= 0.401; agreement level= 96.1).** In addition, competitive pressure has been ranked as the third most important external environmental sub-factor in the second round **(Mean= 4.77; SD= 0.579; agreement level= 94.1)** which had already the third placement in the first round **(Mean= 4.35; SD= 0.551).** Again, government pressure get the lowest ratings both in the first round **(Mean= 3.80; SD= 0.818)** as well as in the second round **(Mean= 4.73; SD= 0.491; agreement level= 98%)** and thus it is the lowest important external environmental sub-factor influencing auto-ID selection decision in warehouse management.

Although, the results from the second round revealed that most of the panellists clearly agreed with the external environmental sub-factors and their relative importance ranking, two panellists noted that the "government pressure" is more important than the "competitive pressure" in some countries or sectors.

5.2.2.2.6 Technological Sub-Factors

Table 5.11 displays the relative importance of the technological sub-factors obtained from the first round and their consensus level obtained from the second round. The findings show that there are many technological sub-factors that had an importance mean score above 3.50. For example, Return on Investment (ROI) **(Mean= 4.97; SD= 0.166)** was ranked highest among all the technological sub-factors. Deployment costs **(Mean= 4.83; SD= 0.376)**, reliability **(Mean= 4.82; SD= 0.384)**, performance **(Mean= 4.81; SD= 0.392),** technology costs **(Mean= 4.79; SD= 0.413)**, accuracy **(Mean= 4.75; SD= 0.436)**, visibility **(Mean= 4.64; SD= 0.664)**, security **(Mean= 4.56; SD= 0.703)** are also significant technological sub- factors highlighted, in decreasing order.

Sub-Factors	Round 1 (N= 107)	Round 2 (N= 102)

	Importance Mean (SD)	Rank	Consensus Mean (SD)	Agreement Level (%)	
				Agree	Disagree
Return on Investment (ROI)	4.97 (0.166)	1	4.93 (0.290)	101 (99)	0
Deployment costs	4.83 (0.376)	2	4.89 (0.370)	100 (98)	0
Reliability	4.82 (0.384)	3	4.87 (0.363)	101 (99)	0
Performance	4.81 (0.392)	4	4.66 (0.497)	101 (99)	0
Technology costs	4.79 (0.413)	5	4.51 (0.558)	99 (97)	0
Accuracy	4.75 (0.436)	6	4.31 (0.563)	97 (95.1)	0
Visibility	4.64 (0.664)	7	4.21 (0.569)	94 (92.2)	0
Security	4.56 (0.703)	8	4.24 (0.583)	94 (92.2)	0
Privacy	4.36 (0.745)	9	4.19 (0.609)	93 (91.1)	1 (0.98)
Quality control	4.35 (0.646)	10	4.22 (0.574)	93 (92.1)	0
Product recalls	4.27 (0.667)	11	4.18 (0.636)	91 (89.2)	1 (0.98)
Multi-tag collection	4.17 (0.707)	12	4.32 (0.616)	94 (92.2)	0
Labour	4.15 (0.611)	13	3.80 (0.664)	75 (73.5)	5 (4.90)
Ease of use	4.12 (0.544)	14	3.84 (0.689)	77 (75.5)	4 (3.92)
Item level tracking	4.11 (0.555)	15	3.98 (0.660)	81 (79.4)	2 (1.96)
Traceable warranty	4.03 (0.574)	16	3.98 (0.645)	82 (80.4)	1 (0.98)
Interference	4.00 (0.644)	17	4.20 (0.564)	94 (92.2)	0
Established standards	3.94 (0.580)	18	4.09 (0.599)	88 (86.3)	0
Communication range	3.94 (0.529)	19	4.07 (0.618)	86 (84.3)	0
Tag read/ write capabilities	3.74 (0.619)	20	4.32 (0.616)	94 (92.2)	0
Environmental sensitivity	3.72 (0.595)	21	4.23 (0.628)	91 (89.2)	0
Line-of-sight	3.57 (0.754)	22	4.23 (0.612)	92 (90.2)	0
Information properties	3.51 (0.732)	23	4.23 (0.612)	92 (90.2)	0
Ongoing innovations	3.03 (0.746)	**Not considered as they are below the threshold.**			
Operational life	2.78 (0.744)				
Tag data storage	2.51(0.781)				
Memory	2.40 (0.781)				
Tag weight	2.20 (0.693)				

Table 5.11 The relative importance of the technological sub-factors

It is apparent that the ratings for these technological sub-factors are very close to one another and all are rated relatively highly. Moreover, privacy **(Mean= 4.36; SD= 0.745)**, quality control **(Mean= 4.35; SD= 0.646)**, product recalls **(Mean= 4.27; SD= 0.667)**, multi-tag collection **(Mean= 4.17; SD= 0.707)**, labour **(Mean= 4.15; SD= 0.611)**, ease of use **(Mean= 4.12; SD= 0.544)**, item level tracking **(Mean= 4.11; SD= 0.555)**, traceable warranty **(Mean= 4.03; SD= 0.574)**, interference **(Mean= 4.00; SD= 0.644)**, established standards **(Mean= 3.94; SD= 0.580)**, communication range **(Mean= 3.94; SD= 0.529)**, tag read/write capabilities **(Mean= 3.74; SD= 0.619)**, environmental sensitivity **(Mean= 3.72; SD= 0.595)**, line-of-sight **(Mean= 3.57 SD= 0.754)**, information properties **(Mean= 3.51; SD= 0.732)** are important technological sub-factors highlighted, in decreasing order.

On the other hand, there are some technological sub-factors that had an importance mean score below 3.50 such as ongoing innovations **(Mean = 3.03; S.D. = 0. 746)**, operational life **(Mean = 2.78; S.D. = 0.744)**, tag data storage **(Mean = 2.51; S.D. = 0.781)**, memory **(Mean = 2.40; S.D. = 0.781)**, and tag weight **(Mean = 2.20; S.D. = 0.693)**, which were not fed back to the panel members in the second round for comments.

In the second round, all the mean scores for all 23 technological sub-factors were greater than 3 indicating agreement or neutrality (i.e. none of the mean scores showed disagreement amongst the panel about any of each other's opinions). Overall, the panellists agreed with the rankings of these sub-factors because all the mean scores were greater than 3.50.

Also, it can be seen from Table 5.11 that all 23 technological sub-factors had a standard deviation less than 1 (100%). This means that the panel agreed with each other and had a very high level of consensus amongst them. However, It was argued by a panellist that "Return on Investment (ROI), deployment costs, reliability, performance, technology costs, accuracy" are all equally at a high level and they should be ranked at the same level rather than in order. Four panellists suggested that the "Labour, Ease of Use, item level tracking, and established standards" should be ranked more highly. Furthermore, it was commented by some of the panellists that the relative importance of these issues would depend on the type of the business and also on the objectives and strategic motivations of the warehouse e.g. "security, privacy, and item level tracking" are critical issues in some applications while, they are not important in others.

In Chapter 6, the researcher discussed in detail the findings of the two-round Delphi study including the motivations/reasons of warehouses in seeking to use auto-ID technologies, the challenges in making an auto-ID decision, the recommendations to address the challenges, the key steps that should be followed in making the auto-ID selection decision, the key factors and their relative importance that influence the auto-ID selection decision in warehouse management.

5.3 Findings from the Interviews

Following the Delphi study, the results of the study were discussed in-depth in both face-to face and telephone interviews by the researcher. Participants in the interviews were 19 experts across the world and the interviews were recorded and transcribed. After each interview, the researcher reviewed notes and transcripts to identify potential difficulties or problems. Only in two cases was it necessary to contact the respondents for clarification.

To avoid bias, the analysis of the interview results was conducted after all interviews had been completed. Then, due to the manageable amount of qualitative data, the researcher analysed the data manually using thematic content analyses approach (Hasson et al., 2000; and Braun & Clarke, 2006). Data were coded according to the questions posed in the interviews and following open and axial coding methods, as well as according to the codes used in the Delphi study (Braun & Clarke, 2006). Then, the data were explained and interpreted.

At the start of each interview, participants were asked to describe the motivations of warehouses that seek to use auto-ID technology. Then, panel members were asked about the key steps in the auto-ID selection process in warehouse management. Finally, panel members were also asked about the problems involved in auto-ID decisions in a warehouse and the recommendations they expected to overcome these problems. The results of the interviews with quotes from the panel members are summarised and presented in the Sub-Sections below.

5.3.1 Motivations of Warehouses that Seek to Use Auto-ID Technology

At the beginning of each interview, respondents were asked to describe the motivations of warehouses that seek to use auto-ID technologies. Motivations of warehouses included: mandate and/or compliance, improved operational performance, improved warehouse visibility, enhanced customer responsiveness, and enhanced security. Table 5.12 shows the motivations of warehouses with quotes from the panel members.

Motivations	Quotes from interviews
Mandate/Compliance	"Nowadays, RFID is driven by mandate compliance such as, mandate from buyers, government departments (the food and drugs administration), mandate from department of defence. For example, the warehouse of the retail store…so, the retailer who puts the mandate on the suppliers but, not the other way round and this is what exactly Wal-Mart did." *[Professor in Information Systems and Operations Management & RFID Consultant]*
	"Even today even if we are… there are still some employers in the industry making mandate…so; company / warehouse do not think because of mandate but, not all of them." *[Professor in Operations Management & RFID consultant]*
Improved operational performance	"I would say that the main reason behind auto-ID technology is to increase the efficiency of the warehouse operations (i.e., reduction in operating and labour costs, increase the speed of delivery; quality; higher productivity, higher performance, save time, reduce human errors, reduce waste and higher throughput. For instance, RFID helps warehouses to automatically record data about objects received into computer systems and this automation enhances efficiency and improves performance provided if it is used prudently. The higher cost of technology will be easily compensated by high productivity." *[Professor in Logistics and Supply chain Management & RFID consultant]*
	"The most important factor in a workhouse environment is accuracy of despatches leading to stock integrity. As a warehouse, you will decide by yourself if you will use RFID or not, there were two surveys 2009, the first by auto-ID Research and the second by RFID Journal showing that in 2008-2009 there was like a turning point and most of the companies are adopting RFID because of business processes improvement but, not because of mandate." *[Professor in Operations Management & RFID consultant]*
Improved warehouse visibility	"All companies struggle to maintain accurate data about what is in their warehouses and where it is located. As a result, items go missing and it often takes a long time to find items. RFID helps you to track and trace your resources accurately and in real-time, so it provides the visibility into what is in the warehouse, and where." *[Founder & editor of RFID Journal, RFID Consultant]*
	"In any warehouse, effective inventory control and stock location management are very important because both the precise quantity and the precise storage location of the items are crucial to a warehouse to be operated efficiently." *[Professor in Operations Management and Supply chain Management]*

Motivations	Quotes from interviews
	“Need for part-level visibility in the supply chain, RFID is justified only in cases where visibility is important. Installing RFID for warehouse operations alone may not be a prudent decision. For e.g. in case an *original equipment manufacturer* (OEM) is keen to track a part from the warehouse till it is sold to the consumer, and then RFID is the only answer.” *[Chief Operating Officer, Logistics and Supply Chain Management]*
Enhanced customer responsiveness	"Warehouses want a fast, efficient way to find items stored, pick the right items and ship the right items to their customers. RFID can be used to confirm pick accuracy, reducing missed shipments.” *[Assistant Professor in Supply Chain Management]*
	“I think one of the reasons for using auto-ID technologies is to improve quality of customer service and satisfaction through more accurate and time delivery of goods, and better tracking information that provides customers with visibility as to movements of those goods.” *[Assistant Professor in Logistics, Operations Management]*
Enhanced security	“In a warehouse environment, theft in the storage area is very common but, this can be avoided by item level tagging with readers installed on racks which will allow 24 hours security control. However, objects can be stolen by truck drivers and this is “in-transit theft” which can only be prevented or decreased by careful counting of the number of items in the receiving process. Actually, this process is extremely labour intensive and prone to human error because pallets have to be broken down and cases have to be opened in order to count manually the precise number of items inside each case. Therefore, RFID technology can be implemented to replace manual counting and effectively automate the inspection and checking processes and to avoid human errors both in receiving and as well as in shipping processes where theft can also be existed.” *[Chair of Materials Handling and Warehousing, Managing Director of Operations & RFID Consultant]*

Table 5.12 Motivations of warehouses that seek to use auto-ID technology, quotes from interviews

From **Error! Reference source not found.**.12, motivations mentioned in the interviews are imilar to those found in the Delphi study; however, mandate compliance, such as mandate from buyers, government departments (the food and drug administration), and from the department of defence has received more emphasis as a motivation for warehouses to use auto-ID technologies.

5.3.2 Key Steps in the Auto- ID Selection Process in Warehouse Environment

Panel members were asked about the key steps in the auto–ID selection process in warehouse management. Table 5.13 gives a summary of the expected procedure in making the auto-ID selection decision in warehouse management.

Step	Quotes from interviews
1. Organisational analysis	"If your warehouse is running pretty well, then you have no interest in RFID. However, if there is a high level of theft, high labour costs, or shipping inaccuracies, then you start to look at auto-ID technologies to solve these problems. You might also see an opportunity to add value for customers by providing data on location of products or inventory levels. Thus, you must not be blinded by the technology; you must first focus on the business problems and objectives." *[Warehouse Manager & RFID Consultant]*
	"Training and education of the team that will be involved in the project is essential and not only relying on consultants and vendors. Unfortunately, few budgets are available for this portion of the project and the training usually costs are planned once a solution has been implemented. The team will serve on the project and identify how their work units (processes) could utilise the technology system. Then the team members need to identify and work with supply chain partners who can take advantage of the new technology system. Here you want collaborative partners who you are going to share information with." *[Professor in Operations Management & RFID consultant]*
2. Warehouse characteristics analysis	**"**It is very important to do a site survey which is to have a look at the physical infrastructure and understand the processes/operations, and then you try to see if there are any interferences and physical problems such as metal, engine. For instance, warehouses that deals with liquid/metallic objects may not be as receptive to auto-ID implementation vs. a warehouses that deals with other types of objects since liquid/metal may necessitate additional expenses or result in high read-rate errors. Also, you have to check how easy is it to revamp (any/necessary changes to) the processes? Since auto-ID may eliminate some, add some, as well as shuffle some processes. After that, then you justify if there is a big problem or not. Today, 2013 we can say that the technology has been improved so much and physical problems are not a big issue anymore." *[Professor in Information Systems and Operations Management, RFID Consultant]*
3. External environmental analysis	"Defining the set of spectrum frequency allocated for RFID is very important because this varies in each country (government problem). For example, in the USA 900 MHz, in Europe is 842 MHz so, depending on that the reader can be decided and selected and also the wireless line infrastructure, the tags… etc. can be created." *[Industrial Engineer and RFID consultant]*

Step	Quotes from interviews
4. Technological analysis	"Warehouses should consider and examine different auto-ID systems available from different vendors and then compare the hardware capabilities to match their objectives and requirements. Warehouses should also think about adopting a hybrid solution (RFID and barcode) which is very common in supply chain (e.g. sometimes, the actual barcode solution cannot resolve your problem or RFID is not able to get a good spectrum to catch and read because of the location of the warehouse). Then properly check the feasibility/ROI/cost-benefit analysis of the technology. After that, pilot test part of the system, by using real-world scenarios, in your actual warehouse environment and if the pilot is successful then go select and roll out the technology." *[Industrial Engineer and RFID consultant]*
5. Decision – Making	"Selection decision of the technology should be based on joint effort and collaboration among IT team, warehouse managers (top management & functional managers), experts, stockholders, and vendors (technology providers), because selecting and implementing a solution that based on one person's views always fails. Actually, it is very important to determine the openness of all stakeholders to consider / implement auto-ID and to check if there is any resistance. Also, it is important to investigate the synergies across other divisions/groups of the firm e.g. auto-ID implemented at warehouse may be beneficial at the manufacturing shop floor or supply chain…!" *[Managing Director & RFID Consultant]*

Table 5.13 Key steps in the auto- ID selection process in warehouse environment, quotes from interviews

From the above table, it is clear that the technology selection process is similar to that which has been identified in the Delphi study. Five stages/aspects are crucial in the selection process of auto-ID technology in a warehouse environment. The organisational, warehouse characteristics analysis, external environmental analysis and technological analysis are part of this decision process. Once the organisational analysis has been conducted, an analysis for warehouse characteristics should be started in order to have a look at the physical infrastructure and understand the processes/operations and resources as well as to see if there are any interferences or physical problems. External environmental analysis should be started after conducting the organisational and warehouse characteristics (operational, structural, resources) analysis. For example, the set of spectrum frequency allocated for RFID should be defined because this varies in each country. After that, warehouses should consider different auto-ID systems available from different vendors, think about adopting a hybrid solution (RFID and barcode together), check the feasibility/ROI/cost-benefit analysis of the technology, and do a pilot test for part of the system in their actual warehouse environment. After conducting all the above activities and if the final cost-benefits analysis/ROI analysis is successful, then warehouse managers should select and roll out the technology.

5.3.3 The Most Difficult Problem in Making an Auto-ID Decision in Warehouse Environment and Recommendations to Overcome the Problem

Finally, panel members were also asked about the problems involved in the auto-ID selection decision in a warehouse and the recommendations they expected to overcome these problems. Some problems relevant to the information, technology, and management have been highlighted. Warehouses should employ a variety of ways to overcome these problems including prudent analysis, standardisation, advanced techniques and tools, and consulting and training. Table 5.14 gives a summary of representative responses to this question.

Problems/Recommendations	Quotes from interviews
Information/Prudent analysis	"One of the big problems with auto-ID systems in general is the vendors. Let us say that you have two big choices of the vendors: e.g. Motorola & Alien, they have very good solutions but, they are more expensive than some training companies that have very good solutions but, no reputation. As a buyer do I go to the choice with a good reader and technology and have a risk of that company is not reliable! OR just I pay more! So this is a kind of questions that warehouses asking themselves today: What kind of these choices we need to choose! So, what they do, a lot of them go to RFID Journal Life OR RFID World but, RFID Journal Life has the main conferences and exhibition centres. So, for three days instead, of travelling a lot and making extra costs, you can go to this conference and you will have the opportunity to meet all the vendors in the industry. And, this is part of the process of selecting and buying the technology right now and which is very important." *[Professor in Operations Management & RFID consultant]*

Problems/Recommendations	Quotes from interviews
Technology/Standardisation	"Standards issues were very important back 2007 but, they are not important now. Most of the vendors toady what they did is, they did a lots of standards solutions. For example, if you buy the technology for receiving or shipping. Few years ago, 2003-2006 and 2007, there were no unified standards so, the same tags you are using in Canada you cannot use them in the UK but, right now tags can be used at the same frequencies in different countries and the same for the readers….. They are able to read tags at different frequencies so they can command the whole supply chain without any problems." *[Professor in Operations Management & RFID consultant]*
	"You are a warehouse and you have suppliers and different customers. You have different ways to do the business. For example, you can order products pre-tagged by the suppliers and you may require that the supplier attach specific tags to specific products. For instance, attach tags starting with numbers XXX000 to XXX125 to the products A (1 to 125), model X, size C, etc. A pre-tagged product means that the solution of the technology needs to be decided gently with your supplier. The supplier uses specific technology and you only can have a reader that would be able to read the tags. This means that you can just have the same technology (standard technology) in order to be able to communicate with your supplier. In other words, within the supply chain (you as a warehouse, your suppliers, and your customers) there is no way to implement the technology alone." *[Professor in Supply Chain Management & auto-ID consultant]*

Problems/Recommendations	Quotes from interviews
	''Actually, the selection of the technology would be basically the IT… whatever the model is you adopted in supply chain. So you need to adopt a standard technology and you need to have a technology that can talk together, not only on the RFID level but, on the Information Technology (IT) level. There are different ways to order the tags from your suppliers. When you buy tags or smart labels (RFID + bar code) they are available already encoded with unique ID numbers (i.e., pre-encoded) or you can encode them yourself. - **Pre-encoded tags:** If you want pre-encoded tags you have to provide your tag supplier with a list of numbers that they shall use to encode the tags. Once you receive the tags you will attach them to specific products and then make the match. Sometimes, the numbers are not important as long as they are unique – and that you properly make the match between a specific tag and a specific product. - **"Conditioning the tags":** Happens in situation like - when a client buys products from a supplier that does not uses RFID but, bar codes. Upon the receiving of the product, an RFID tag is encoded with a unique number (linked to the product ID) – so you can start to automate the following processes (e.g. put away, picking…etc.)" *[Professor in Operations Management & RFID consultant]*
Technology/Techniques and tools	"The most difficult part is estimating the impact of the technology and translating that impact into measurable value. In fact, it can be hard to prove a clear ROI, especially if workers will not be let go if labour time is decreased. So, warehouses need to determine the overall costs… whether such costs justify the benefits envisaged! Therefore, advanced numerical models for the technology analysis (cost-benefit/ROI) and comprehensive information about the technology will assist estimating its impact on the business processes and good ROI proving." *[Assistant Professor of Supply Chain Management]*

Problems/Recommendations	Quotes from interviews
Management/Consulting and training	"The most important thing is the project you are managing because different products will require different tags. When defining the solution, you have multiple choices and each technology design is important because the customers who buy the solution are not aware of that. One of the problems is that the warehouses managers especially, the managers of small companies are not familiar with the technology and they are ready to pay… let us say 10,000 dollars just to implement the technology… so, they lose a lot of money in order to have anything and they are much more difficult than big companies. So, what we suggest as an RFID Academia is that the warehouses have consultants who will not just provide you with a solution but, provide you with training and then when you are educated you start to go and join the decision with any vendor of the technology." *[Professor in Operations Management & RFID consultant]*
	"There are a lot of companies who go in many directions and cannot make the technology decision because they are not educated on the technology. If you do not know what to do you will rely on the consultants and that is why the training is essential in order to make your own requirements. Thus, you have to be educated on the technology so, you can gently decide what type of the technology is the best for your warehouse environment." *[Technology Engineer and RFID consultant]*

Table 5.14 Problems in auto-ID selection decisions and recommendations to overcome, quotes from interviews

One of the big problems with auto-ID systems in general is the information about vendors. However, warehouses can overcome this problem by conducting prudent analysis of the vendors in the industry, e.g. by attending conferences and exhibition centres that will help them select the best technology vendors. Another difficult problem that has been highlighted by the panellists was estimating the impact of the technology and proving a clear Return on Investment (ROI). Adopting advanced techniques and tools for the technology analysis (cost-benefit/ROI) and comprehensive information about the technology will assist in estimating its impact on the business processes and good ROI. The final important problem in making an auto-ID decision was that the warehouse managers, especially the managers of small companies, are not familiar with the technology. Therefore, the warehouses should have consultants who will not just provide them with a solution, but also provide them with training as well. As a result, they can join the decision with any vendor of the technology and can decide what type of technology is best for their environment.

In summary, the data from the interviews presented a similar trend to that found in the Delphi study: the selection process of auto-ID is crucial and warehouses must do it before implementing the technology. Pulling together the insights obtained in the Delphi study and the interviews, it has been found that the selection process of auto-ID technologies for warehouse management is complicated and there are many issues involved in it. Also, all the relevant people should be involved in this process. In addition, warehouses should do this process before adopting the technology in order to reduce the high risks involved and achieve successful implementation. Accordingly, a comprehensive framework for auto-ID selection process for warehouse management has been developed (see Figure 6.1, Chapter 6). There are seven key stages involved in this framework:

(1) organisational analysis;

(2) operational analysis;

(3) structural analysis;

(4) resources analysis;

(5) external environmental analysis;

(6) technological analysis; and

(7) decision-making.

The selection decision of auto-ID technology for warehouse management consisted of seven stages/aspects. The first important aspect is the decision process itself. The choice for barcode and/or RFID for warehouse management is not a simple choice. The organisational, operational, structural, resources, external environmental and technological analysis are part of this decision process and several decisions have to be taken during those stages. Therefore, the selection process of auto-ID technology is complex and needs support and closer collaboration between all stakeholders involved in the process such as the IT team, top management, warehouse manager, functional managers, experts, stockholders and vendors (technology providers). Therefore, warehouses must have this process before adopting the technology in order to reduce the high risks involved and achieve successful implementation.

5.4 Challenges and Lessons Learned From the Empirical Research

In this section, some of the most significant challenges that the researcher faced while conducting this research (the Delphi Study and the interviews) and the lesson learned have been articulated.

First, one of the most significant challenges of conducting the Delphi study was the “time” (time for selecting experts and collecting data). According to Story et al. (2000), the panel selection process, if not conducted properly, can be the source of many problems. Therefore, in this research, the panel selection was an extremely rigorous process which commenced in July 2012 and was not completed until December 2012 (nearly six months). Also, the Delphi study and the follow-up verification study (conducted in-depth interviews to refine and verify the Delphi results) were completed within six months. As a full-time doctoral student, the researcher paid special attention to this point– as it was an area of concern.

Second challenge faced the research was "motivating the experts/panellists". With such a diverse panel, hailing from various organisations and based in different countries, being asked to provide a significant amount of information, the researcher was acutely aware that adopting ‘soft power’ methods was crucial. The soft power is “the ability to get what you want through attraction rather than coercion or payment” (Nye, 2004, p. 11). For example, the researcher promised the experts to provide each of them with a copy of the results after completing the research. Using this method was embraced as positive aspect of this research because the researcher was able to motivate and extract responses from the panellists. However, one of the panellists, who have already agreed to participate in the interviews, refused to continue his participation after he took a copy/summary of the findings of Delphi study. Therefore, researchers should be very careful when conducting Delphi studies and they should not provide experts/participants with detailed results.

Thirdly, it is imperative for researchers to be in close contact with the experts/panels and to keep all the emails correspondence in order to keep the relationships and communications alive. This is because, in this research, there was one of the panellists who agreed to participate in the beginning, but he refused later to continue, claiming that he did not receive any email that asking him for his consent (it could be because he forgot that he agreed to participate OR he changed his mind as he was busy!).

Finally, the challenge that worth mentioning in this research is "the use and understanding of terminology". This is because the understanding of different terms may differ among practitioners (e.g., collaboration and coordination were sometimes used as synonyms). Thus, the researcher decided to pay great attention to simplify terms and define each term clearly.

5.5 Summary

This chapter has presented the motivations/factors/reasons of warehouses in seeking to use auto-ID technologies, the challenges in making an auto-ID decision, the recommendations to address the challenges, the key steps that should be followed in making auto-ID selection decision, the key factors and their relative importance influencing decision makers when selecting auto-ID system in warehouse environment. There were six major factors identified in the Delphi study that influence the auto-ID selection decision in warehouse management: organisational, operational, structural, resources, external environmental and technological factors (in decreasing order of importance). In addition, there are 54 key sub-factors have been identified from the list of each of the major factors and ranked in decreasing order of the importance mean scores. However, the importance of these factors depends on objectives and strategic motivations of warehouse; size of warehouse; type of business; nature of business environment; sectors; market types; products and countries.

In order to discuss in-depth and verify the Delphi results, follow-up interviews, both face-to-face and telephone, were conducted. Based on the empirical data derived from a two-round Delphi study and follow-up interviews, this chapter has provided a comprehensive framework for the selection process of auto-ID technology in warehouse field.

The findings from the empirical study illustrated that the auto-ID selection process is complex and there are many factors affecting this process in warehouse management.

Also, the empirical findings revealed that auto-ID selection process has gone through seven stages/phases: organisational analysis, operational analysis, structural analysis, resources analysis, external environmental analysis, technological analysis, and decision-making phases. As a result, the selection phases need support and closer collaboration from various stakeholders and all the relevant people.

The international two-round Delphi study and follow-up interviews conducted by the researcher were sufficient for providing enough information to understand and reach the aim and objectives of this research.

Discussion of the Delphi study findings and the interview results as well as the framework of the selection process of auto-ID technology is carried out in Chapter 6.

CHAPTER 6

DISCUSSION AND REFLECTION

6.1 Introduction

This chapter will discuss the data collected from the empirical study, mainly Delphi study and interviews, to understand the motivations/reasons of warehouses in seeking to use auto-ID technologies, the challenges in making an auto-ID decision, the recommendations to address the challenges, the relative importance of the key factors and sub-factors that influence auto-ID selection decision in a warehouse and the key steps of the auto-ID technology-selection process in warehouse management. This research presented and discussed the conceptual framework proposed in Chapter 3 for key factors influencing the auto-ID selection decision in warehouse management. The framework consisted of six categories: (1) structural, (2) operational, (3) resources. (4) organisational, (5) technological, and (6) external environmental factors. For that purpose, empirical data collected from a two–round Delphi study and the interviews were presented and analysed in Chapter 5. To meet the aim and objectives of this research, this chapter aim is to (i) discuss the findings of the Delphi study; (ii) discuss in-depth, verify and validate the Delphi study results through interviews; and (ii) understand how the critical factors influencing the auto-ID selection decision should be combined to produce a successful auto-ID selection process in warehouse management. The auto-ID selection process serves as a frame of reference that can be used as a guiding tool for warehouse management practice and a research background for researchers in auto-ID technologies and warehouse management.

The following is a discussion of the main findings of the Delphi study and the interviews reported in this thesis.

6.2 Discussion of Delphi Findings

The two–round modified Delphi study has been conducted to explore the dominant motivations for, factors, and their relative importance, affecting warehouses in deciding to make auto-ID technology decisions as well as the key steps of the auto-ID technology-selection process in warehouse management. The significance of the findings is discussed below.

6.2.1 Motivations for Auto-ID Technology in Warehouse Management

The findings lend support to other studies which suggest that warehouses are driven by a variety of motives when they decide to use auto-ID technologies. For instance, the ability to improve and optimise the overall performance of warehouse operations and processes, the ability to improve the level of customer service and satisfaction, to handle and manage warehouse resources effectively, the ability to enhance physical control and security of people and objectives, and to increase and sustain competitive position and advantage (e.g. Chow et al., 2006; Bhattacharya et al., 2007; Poon et al., 2009; Wang et al., 2010c). An important issue highlighted by the panellists is that some warehouses use auto-ID technologies because they are mandated from the customer(s) downstream in the supply chain. Southall et al. (2010) supports this view, noting that many industries focused exclusively on RFID technology through retailer mandates rather than the business benefits. In addition, some panellists stated that the motivations depend on the type of warehouse needs and problems, the type of business, and the nature of the business environment. In this sense, Banks et al. (2007) have indicated that the ability to achieve improved security (e.g. enhancing physical control and security of people and objectives; prevent or decrease the level of theft in the storage area especially at night) is a key reason for the auto-ID decision in finished goods warehouses because the availability of finished goods makes it a prime area for theft. Moreover, Wyld (2008) noted that the ability to strengthen security against products being counterfeited (eg. counterfeit drugs) with RFID is vital in the pharmaceutical industry for protecting public health.

6.2.2 Key Steps for Auto-ID Selection Decision Process

The study has highlighted five key stages in the decision-making process for the auto-ID selection choice in warehouse management. The stages identified develop and extend those noted in other studies (Poon et al., 2009; Ilie-Zudor et al., 2011). Decision-makers should start with gathering information relevant to different auto-ID solutions (possibilities and limitations) with regards to the internal problems, needs, requirements and objectives of the warehouse. Such information may be both tangible and intangible. Because of the differences between barcode and RFID, it is essential that separate scenarios should be made for analysing both auto-ID systems. An analysis can be made about how the existing barcode technology works and if and how it can be changed to meet the new requirements. New and different possible solutions should be created with a complete new auto-ID system or some kind of hybrid system where various auto-ID technologies (barcode and RFID) are used together. Several methods are suggested to analyse different solutions, such as cost-benefit analysis or Return on Investment (ROI) analysis, in order to find a preliminary best solution. However, decision-makers should ensure that all factors (qualitative and quantitative) are evaluated for each auto-ID solution in order to select an appropriate system.

Consistent with other studies (i.e. Angeles, 2005; Sarac et al., 2010), the findings have emphasised the importance of conducting the pilot test part of the system in the actual warehouse environment to discover problems in an early phase. However, this study has also highlighted the importance of reviewing the pilot test in order to identify strengths and weakness as well as additional opportunities to deploy the system. Weaknesses and problems might include accuracy and interference problems of RFID, organisational problems like people/workers, and the complexity of integration with existing systems (WMS/ERP). Therefore, this study suggested that educating and training those workers in the new system operations are very important as they can be more knowledgeable in the selection process and also in enabling the implementation process.

Although it seems that the decision-making process is the last step, it is actually an ongoing process in order to reach the final decision. Auto-ID systems are of strategic importance in warehouse management, because high risks are involved and as well as them being relatively expensive to implement. It was argued by some panellists that the key steps identified in this study are suitable only for large warehouses, because small and medium-sized warehouses may not have sufficient resources or budgets to follow the recommended steps when considering auto-ID choices. However, this study has also found that the selection decision process is complex and requires a whole series of decisions over a long period and also all the relevant people should be involved in the process. Nixon, (1995) and Ilie-Zudor et al. (2011) support this view, indicating that the more complex a decision becomes, the less financial influences there will be in the decision. Moreover, they have mentioned that top management should be directly involved in the decision process where a series of decisions have to be made.

6.2.3 The Most Difficult Problem in Making an Auto-ID Decision in a Warehouse

According to the panellists, the most difficult problem in making an auto-ID selection decision in a warehouse lies in the technological issues. Other difficult problems highlighted were the decision process, information, management issues, people and customers. The issues are noted in a number of studies (Angeles, 2005; Spekman & Sweeney, 2006; Sarac et al., 2010; Kim & Garrison, 2011; and Poon et al., 2011a). It was suggested by some of the panellists and has been noted by others (Bendavid & Cassivi, 2010) that warehouse managers and IT managers are not geared to evaluating the multi-faceted aspects of auto-ID technology if they work separately, however, they are good when they work together, particularly in a multidisciplinary team. The quality of information, experience of the analyst, and available time are very important and if they are deficient could lead to major problems in the decision process. It was also noted in this study that combinations of qualitative and quantitative factors influence significantly the decision-making process and make the selection process complex. It was argued that the planning for 99% read accuracy means hundreds of miss reads per day and it was suggested that the planning should be for 100% read accuracy (Schuster et al., 2004; Tu & Piramuthu, 2011; Tu et al., 2009).

6.2.4 Recommendations on the Ways to Overcome the Problem

The study has highlighted five recommendations on the ways to overcome the problems in the auto-ID selection decision in warehouse management, for example, a prudent evaluation process, specialist advice/expertise, techniques/tools, development of an appropriate incentives scheme and relevant organisational structures, and movement towards international standards. However, it was argued that these issues reflected a large warehouse's perspective. It was also highlighted that educating a team and training of IT and operations people on the auto-ID technology so they can participate in the selection process may be better than relying on specialist advice and/or consultants. In addition, physics experts are not the only ones that will recommend the best hardware and configuration; they may help in designing the solution/configuration but not the hardware (Attaran, 2012).

6.2.5 Major Factors and Sub-Factors Influencing Auto-ID Selection Decision in Warehouse Management

6.2.5.1 Organisational Factors

Overall, organisational factors are the most important factors highlighted in this study. Deciding on the type of auto-ID technology (barcode and/or RFID) is a key aspect of strategic and logistical decision-making for warehouses. Sarac et al. (2010) noted that the auto-ID decision is a fundamental factor for warehouses to improve and sustain the competitive advantage. The significance of organisational factors is noted in a number of studies (Hwang et al., 2004; Lin, 2009; Robert, 2009; Wang et al., 2010c). This study has highlighted the relative importance of organisational sub-factors and the majority of the panellists agreed with the importance ranking. Warehouse internal needs were ranked in the top of the organisational sub-factors in this study and were suggested by others (Angeles, 2005) to be the first issue in making an auto - ID technology choice for the business environment.

6.2.5.2 Operational Factors

Operational factors are also of major concern in auto-ID selection decisions. The intensive competition in today's business environment results in pressure to reduce the time to bring products to markets as well as demands by customers for improved levels of service and enhanced delivery reliability (Soroor & Tarokh, 2006). In addition, a warehouse is an essential component for linking all supply chain partners and the performance of the warehouse operations not only influences the productivity and operation costs of a warehouse, but also the whole supply chain (Gu et al., 2007). Operational factors have, therefore, become crucial in auto- ID decision making (Chow et al., 2006; and Poon et al., 2011b). Shipping, receiving, storage assignment policy, picking, zoning, routing, put away, batching, order accumulation and sorting, and forward reserve allocation have been highlighted in the study. Shipping and receiving operations are necessary to bring products from suppliers to warehouses and to deliver products to markets as quickly and reliably as possible, enabling warehouses to reduce total cycle time effectively. Therefore, many warehouses seek to apply auto-ID systems for achieving superior customer responsiveness. However, this study found that the importance of the operational sub-factors depends on the products if they have already arrived tagged at the warehouse. For instance, receiving operations were suggested to be the most important issue, particularly for pre-tagged products by the supplier. This means that only the warehouse has a reader that would be able to read those tags, enabling swift and more flexible communication with the supplier.

6.2.5.3 Structural Factors

Auto-ID choices are also influenced by warehouse structural factors. The product type (liquid/metallic objects) is an increasingly critical issue and is found to be significant in many studies (e.g. Porter et al., 2004; Clarke et al., 2006; and Mercer et al., 2011), as it affects the reliability and accuracy of the reading performance of the technology. In deciding to use auto-ID, it is also necessary to investigate the warehouse mechanisation level (manual, semi-automated, and automated) because in a highly automated warehouse, there is less need for auto-ID/RFID than in a warehouse where a large number of tasks are performed manually (Karagiannaki et al., 2011). Not only must warehouses consider the product type and the warehouse mechanisation level, they must also consider the E-Plane (electric-field) and H-Plane (magnetic-field) as they have a negative effect on the reading performance of auto-ID/RFID tags (Poon et al., 2011a). E-plane is “the plane containing the electric-field vector and the direction of maximum radiation,” and H-plane is, “the plane containing the magnetic-field vector and the direction of maximum radiation” (Balanis, 2011, p. 33).

Moreover, this study has noted that warehouse size, departments’ layout, number of racks, number of aisles, and product carrier of SKU (pallet, case, or item) are increasingly important when considering the auto-ID in warehouse management. Karagiannaki et al. (2011) support this views, indicating that the more complex the warehouse, the more beneficial from the specific auto-ID (RFID) implementation in terms of reduction in labour utilisation and time savings. In practice, warehouses need to study their actual environment thoroughly and determine their specifications before making auto-ID decisions (Bhuptani & Moradpour, 2005). This is because the warehouse layout design and structure (physical and internal-environmental factors) vary between different companies.

6.2.5.4 Resources-Related Factors

This study has highlighted the general importance of resources-related factors and their sub-factors that should not be ignored when investigating auto-ID decisions for warehouse management (Chow et at., 2006). Not surprisingly, there was a significant emphasis by some panellists that warehouse management system (WMS) should be ranked in the top position of all components because integration complexity with existing systems (WMS/ERP) is one of the top concerns of warehouses implementing RFID (Vijayaraman & Osyk, 2006). In addition, it was argued that the storage systems, storage units, and storage space capacity should be ranked highly. Wang et al. (2010a) and Karagiannaki et al. (2011) agree that the storage space capacity is a critical issue when considering auto-ID decisions in a warehouse environment and they demonstrate that RFID technology can be effectively applied to enhance the utilisation of the space capacity in a warehouse.

6.2.5.5 External Environmental Factors

Auto-ID decisions in the warehousing industry are also inspired by external environmental factors. Not surprisingly, the customer pressure/mandate was found to be the most significant factor that affects decision makers when deciding on auto-ID technology in a warehouse (Li et al., 2010). Wu et al. (2006) and Ngai et al. (2008) have mentioned that many powerful companies, such as Wal-Mart, the US Department of Defence, Metro, and Tesco, have recently exerted strong pressure on their suppliers to implement RFID. This study has also noted that supplier support, competitive pressure and government pressure are critical when considering the auto-ID in the warehouse environment and were found to be significant in many studies (Brown & Russell, 2007; Lin & Ho, 2009; White et al., 2008; Li et al., 2010). However, it was argued by some panellists that government pressure is more important than competitive pressure in some countries or sectors (Wang et al., 2010a).

6.2.5.6 Technological Factors

Technological factors such as, Return on Investment (ROI), deployment costs, reliability, performance, technology costs and accuracy have received more emphasis in auto-ID choices and the study has suggested that these factors are all equally at a high level and they should be ranked at the same level rather than in ascending order. Also, some panellists suggested that labour, ease of use, item level tracking and established standards should be ranked more highly. Moreover, it was commented that the rankings of technological sub-factors would depend on the type of the business and also on the objectives and strategic motivations of the warehouse. For example, security, privacy and item level tracking are critical issues in some applications/industries, while they are not important in other industries. Symonds and Parry (2008) have stated that medical healthcare devices are often high value products manufactured in low volumes and it is vital that the medical device manufacturers label every product individually in order to achieve full traceability in the healthcare supply chain. In this regard, Wyld and Jones (2007) noted that the key difference in RFID adoption between the pharmaceutical industry and other industries is that in pharmaceutical industry tagging at the item level is crucial to eliminate counterfeiting and achieve patient safety and wellbeing.

Technological factors such as accuracy, visibility, quality control, traceable warranty, product recalls and labour have also been highlighted in this study as key factors in the decision making process. For instance, RFID systems enhance visibility by providing an accurate picture of inventory levels in real-time and locating warehouse resources easily and therefore, enhancing warehouse productivity and reducing the labour and operational costs of the warehouse (Poon et al., 2009). On the other hand, barcodes are manual systems and thus they are labour-intensive. Barcode systems provide limited visibility because they are unable to update daily inventory operations, locations of forklifts and stock keeping units (SKUs) in real-time or to provide timely and accurate data of warehouse operations, resulting in high operational costs of the warehouse (Poon et al., 2009). Moreover, the quality control cannot be very accurate by using barcode as it has restricted traceability and product recalls across a supply chain, while RFID technologies provide an accurate quality control because they have traceable warranties and product (Huber et al., 2007). RFID tags can also monitor shock and temperature levels to ensure the quality of the end product (Wyld, 2006).

Other key technological factors including multi-tag collection interference, communication range, tag read/write capabilities, environmental sensitivity, line-of-sight, and information properties have been highlighted in this study. Domdouzis et al. (2007) agree that multi-tag collection is a key technological factor because some RFID systems can scan a thousand tags from a single reader i.e. active RFID, while passive RFID systems can only scan hundreds of tags within 3 meters from a single reader. That is because different RFID tags have different communication ranges and different read/write capabilities. For instance, active RFID tags have a long communication range (> 100 m) with read/ write capabilities, while passive RFID tags have short communication range (typically under 3 m) with read capabilities only (Tajima, 2007). RFID systems are automatic non-line-of-sight scanning (multiple tags can be read simultaneously) and tags information can be updated. Barcode systems, by contrast, have optical line-of-sight scanning (it can only be read individually and with the alignment) and the barcode information cannot be updated (Wyld, 2006; and Huber et al., 2007). In addition, RFID can operate in harsh environments such as in dirty, dusty and high moisture conditions which affect barcodes (Li et al., 2006). Therefore, warehouse managers should consider all these technological factors in order to select the most appropriate auto-ID technology which will enhance the operational efficiency of their warehouses (Poon et al., 2009; and Poon et al., 2011a).

6.3 Verification of the Delphi Study Results through Interviews

The main aim of this research was to investigate empirically the auto-ID technology-selection process and to determine the factors that influence decision makers when selecting an auto-ID system in warehouse management. Following the Delphi study, the results of the study were verified and discussed in-depth in both face-to face and telephone interviews by the researcher. Using the modified (mixed-methods) Delphi method and follow-up interviews, the knowledge and experience of a worldwide panel of experts who were actively involved in auto-ID technologies and their applications for warehouse management have been leveraged. Motivations, factors, and reasons of decision makers in seeking to use auto-ID technologies have been studied. Also, the key steps that should be followed in making the auto-ID selection decision have been examined.

The motivations of warehouses from the interviews included: mandate and/or compliance, improved operational performance, improved warehouse visibility, enhanced customer responsiveness, and enhanced security. It is clear that these motivations are similar to those found in the Delphi study, however; mandate compliance such as mandate from buyers, government departments (the food and drug administration), and mandate from department of defence has received more emphasis as a motivation for warehouses to use auto-ID technologies (RFID) (Li et al., 2010). One of the big problems with auto-ID systems in general is the information about vendors. However, warehouses can overcome this problem by conducting prudent analysis of the vendors in the industry (e.g. attending conferences and exhibition centres) which will help them select the best technology vendors. Another difficult problem that has been highlighted by the panellists was estimating the impact of the technology and proving a clear Return on Investment (ROI). However, adopting advanced techniques and tools for the technology analysis (cost-benefit/ROI) and comprehensive information about the technology will assist in estimating its impact on the business processes and good ROI (Sarac et al., 2010). The final important problem in making an auto-ID decision was that the warehouse managers, especially the managers of small companies are not familiar with the technology or they are not educated in the technology. Therefore, the warehouses should have consultants who will not just provide them with a solution but provide them with training as well. As a result, they can join the decision with any vendor of the technology and can gently decide what type of technology is the best for their environment.

Pulling together the insights obtained in the Delphi study and interviews, we found that the selection decision of auto-ID technologies for warehouse management is complicated and there are many activities involved in it and also all the relevant people should be involved in this process. Therefore, warehouses must have this process before implementing the technology in order to reduce the high risks involved and achieve successful implementation. This conclusion strongly supports the view of the auto-ID selection process as a sequence of stages, in which related steps and activities occur (Ilie-Zudor et al., 2011). Also, the more complex a decision becomes, the less financial influences there will be in the decision (Nixon, 1995).

In short, both of the two rounds of the Delphi study and follow-up interviews conducted in this research were sufficient for providing enough information to collectively investigate the critical factors influencing the auto-ID selection decision and understand how the factors should be combined to develop a comprehensive framework for the auto-ID selection process in warehouse management. The framework for auto-ID selection process has been proposed as shown in Figure 6.1. The framework consists of seven stages: organisational analysis, operational analysis, structural analysis, resources analysis, external environmental analysis, technological analysis, and decision-making. The proposed framework provides a complete and holistic view of the many issues involved in the process which can be viewed as a multi-stage process. Details about the developed framework are discussed in the following sub-sections.

6.4 Framework for Auto-ID Selection Process in Warehouse Management

Seven stages/ aspects are crucial for a framework for selecting an auto-ID technology in warehouse management. The first important aspect is the decision process itself. The choice of barcode and/or RFID for warehouse management is not a single choice. The organisational, operational, structural, resources, external environmental and technological analysis are part of this decision process and several decisions have to be taken during those stages. These stages and sub-stages are discussed in detail below.

6.4.1 Stage 1: Organisational Analysis

The typical tasks in this stage consist of identifying the warehouse internal problems, needs and requirements; defining the business objectives and scope; checking IT knowledge capability, training and education; and securing top management support. These are all important in the organisational analysis stage. These tasks/activities are discussed as follow.

6.4.1.1 Identify the Warehouse Internal Problems, Needs and Requirements

Absolute clarity about the internal problems, needs and requirements is crucial for warehouse management (Angeles, 2005; Liviu et al., 2009; Chan & Chang, 2011). Warehouse managers must start by identifying any existing needs and potential problems in their business processes/operations through empowering a cross-functional team in order to understand the key operations/processes of the warehouse, determine points to be improved, serve on the project in a warehouse, and to work with supply chain partners. There are many problems that may occur at the warehouse such as a high level of theft, high labour costs, reduced productivity, high level of inventories and shipping inaccuracies. Warehouse managers should determine whether to deploy auto-ID as a point solution to solve one problem, or as an infrastructure approach to solve multiple problems. Also, they should determine what types of problem can be solved by using RFID and/or barcode systems. Hybrid RFID-barcode systems would employ a particular

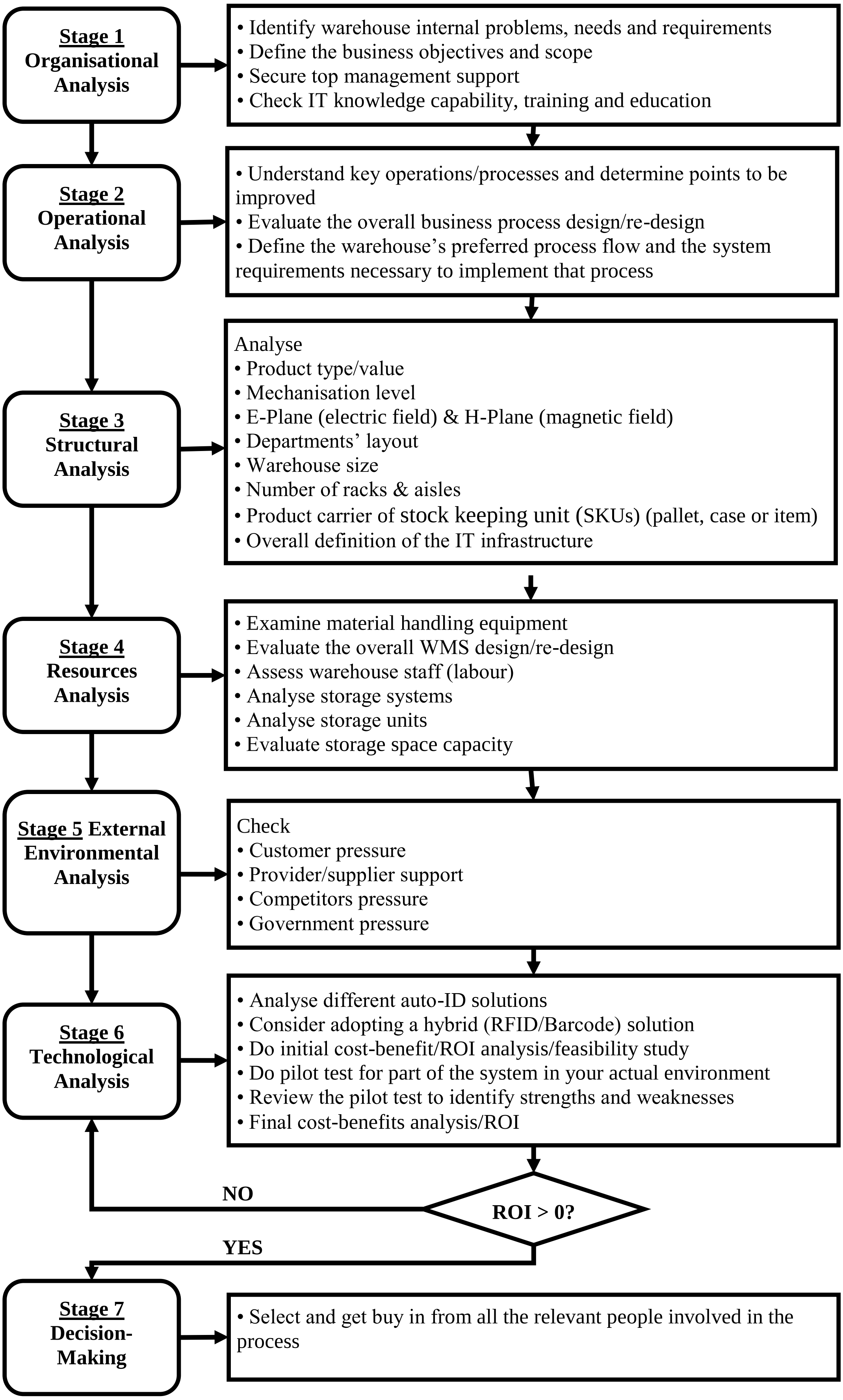

Stage 1 Organisational Analysis
• Identify warehouse internal problems, needs and requirements
• Define the business objectives and scope
• Secure top management support
• Check IT knowledge capability, training and education
Stage 2 Operational Analysis
• Understand key operations/processes and determine points to be improved
• Evaluate the overall business process design/re-design
• Define the warehouse's preferred process flow and the system requirements necessary to implement that process
Stage 3 Structural Analysis
Analyse
• Product type/value
• Mechanisation level
• E-Plane (electric field) & H-Plane (magnetic field)
• Departments' layout
• Warehouse size
• Number of racks & aisles
• Product carrier of stock keeping unit (SKUs) (pallet, case or item)
• Overall definition of the IT infrastructure
Stage 4 Resources Analysis
• Examine material handling equipment
• Evaluate the overall WMS design/re-design
• Assess warehouse staff (labour)
• Analyse storage systems
• Analyse storage units
• Evaluate storage space capacity
Stage 5 External Environmental Analysis
Check
• Customer pressure
• Provider/supplier support
• Competitors pressure
• Government pressure
Stage 6 Technological Analysis
• Analyse different auto-ID solutions
• Consider adopting a hybrid (RFID/Barcode) solution
• Do initial cost-benefit/ROI analysis/feasibility study
• Do pilot test for part of the system in your actual environment
• Review the pilot test to identify strengths and weaknesses
• Final cost-benefits analysis/ROI
ROI > 0?
NO
YES
Stage 7 Decision-Making
• Select and get buy in from all the relevant people involved in the process

Figure 6.1 Developed framework for auto-ID selection process in warehouse management

technology in a warehouse area in order to take advantage of its relative cost effectiveness or robustness (White et al., 2007). Warehouse managers therefore must not be blinded by the technology, but they must first focus on the business problems and needs and then the technology selection and deployment must be strictly based on those needs and requirements alone.

6.4.1.2 Define the Business Objectives and Scope

Warehouses should define and make clear the objectives for the overall business both in the short and long term. For example, warehouse managers should build a thorough and rigorous business case methodology including the background of the project, the expected business benefits, the expected costs, the expected risks, the warehouse's strategy and so on. Auto-ID selection without any clear definition of the objective and scope will become directionless and difficult to manage (Ilie-Zudor et al., 2011). The clarity of the problems and the assurance that the bottom line business objectives are clearly articulated up front will significantly simplify the technology selection task and help to generate a productive programme.

6.4.1.3 Secure Top Management Support

Without approval and support from top management, the project team will not be able to enforce the selection process, and will be unable to ensure that the system selection and adoption aligns with the strategic direction of the warehouse (Lee & Kim, 2007). It is important to gain support from senior management, as this will be essential for the success of the selection process. Top management can show their support and commitment in the technology selection by developing appropriate incentive schemes and relevant organisational structures to improve the quality of information and help in the decision-making process. In addition, top management support is important to convince line and unit managers that the technology can help the warehouse. High management support will also help ensure that an auto-ID project receives the necessary resources for successful selection and implementation (Hwang et al., 2004; Irani et al., 2010).

6.4.1.4 Check IT Knowledge Capability, Training and Education

Setting reasonable expectations and understanding the warehouse manager's perceptions of auto-ID capabilities are key steps that must be achieved at the initial stage of the technology selection process. One of the most difficult problems in making an auto-ID selection decision for the warehouse environment is the limit of IT knowledge capabilities (Ngai et al., 2007; Wang et al., 2010c). Therefore, warehouse managers must possess the knowledge and skills on auto-ID technology in order to select and implement the appropriate technology for their warehouses and applications.

There are many warehouses that go in many directions and cannot make the technology decision because they are not educated on the technology. So, if they do not know what to do, they will rely on the consultants and thus training is essential in order to help warehouse managers identify their own requirements (Attaran, 2012). Warehouses should employ qualified consultants and/or professional advisors who will not just provide them with a best solution, but provide them with training and education. Then, when warehouse managers are educated in the technology, they can decide what type of technology is the best for their warehouse environment. Therefore, training is crucial at the initial stage of the technology selection process. As a result, warehouse managers will be able to identify their own requirements and join the decision with any vendor of the technology.

6.4.2 Stage 2: Operational Analysis

Once the organisational analysis has been conducted, an operational analysis should be started. The operational analysis encompasses three steps: understanding key operations/processes and determining points to be improved; evaluating the overall business process design/re-design; and defining warehouse's preferred process flow and the system requirements necessary to implement that process. These key steps can be done through empowering a cross-functional team who will leverage the system across internal processes and external partners. In this research, ten key operations/processes have been identified as following: shipping, receiving, storage assignment policy, picking, zoning, routing, putting away, batching, order accumulation and sorting, and forward reserve allocation. However, some warehouses are more complex with well-designed operations/processes workflow than other warehouses (Karagiannaki et al., 2011). Also, auto-ID may eliminate some, add some, as well as shuffle some processes and therefore warehouses have to check how easy it is to revamp the processes. Accordingly, operational analysis is crucial and must be conducted before considering an auto-ID technology in order to select the technology that matches the warehouse's needs. This will lead to optimised operational performance and superior customer responsiveness (Chow et al., 2006; and Poon et al., 2011a).

6.4.3 Stage 3: Structural Analysis

After the organisational analysis and the operational analysis are conducted, a structural analysis should be done. Structural analysis involves considering the following issues:

- Product type/value.
- Mechanisation level.
- E-Plane (electric field) & H-Plane (magnetic field).
- Departments' layout.
- Warehouse size.
- Number of racks and aisles.
- Product carrier of stock keeping unit (SKUs) (pallet, case, or item).
- Overall definition of the IT infrastructure.

It is very important that warehouse managers conduct a survey of the site which is to employ RFID and physics experts, to examine the physical infrastructure and look for any interference or physical problems (e.g. metal, engine), and to support and recommend the best hardware and configuration. This is because the warehouse layout design and structure (physical and internal-environmental factors) vary between different companies (Bhuptani & Moradpour, 2005; Gu et al., 2010; Arooj et al., 2011; Karagiannaki et al., 2011). For instance, warehouses that deal with liquid/metallic objects may not be as receptive to auto-ID implementation as warehouses that deal with other types of object since liquid/metal may necessitate additional expense or result in high read-rate errors (Porter et al., 2004; Clarke et al., 2006; Poon et al., 2009; Mercer et al., 2011). However, today, the technology has been improved so much and physical problems are not a big issue anymore. In addition, in a highly automated warehouse, there is less need for auto-ID/RFID than in a warehouse where a large number of tasks are performed manually (Karagiannaki et al., 2011). Therefore, warehouses need to study their actual environment thoroughly and determine their characteristics before making an auto-ID decision.

6.4.4 Stage 4: Resources Analysis

Resources analysis involves studying and examining all means and equipment needed to operate the warehouse such as material handling equipment; evaluate the overall WMS design/re-design; assess warehouse staff members (labour); analyse storage systems; analyse storage units; and evaluate storage space capacity. An overall evaluation of warehouse resources should be conducted by warehouse managers when investigating auto-ID decisions as follows:

- Prioritise the benefits of tracking and monitoring the objects/resources on their list.
- Determine which objects and/or people that they would like to track and trace.
- Determine how large is their asset.
- Determine if the application needs to detect the labelled items online or just by keeping a checkpoint on the gate of the warehouse if any item passes by.
- Determine how important it is to collect real-time data such as the location of the items, the status of the movable assets or resources (trucks, forklifts, and other material handling equipment, stock keeping unit (SKUs), containers, pallets, operators…etc.).

Warehouse managers should consider the material handling equipment in their warehouse when considering auto-ID technology because different types of material handling equipment have different effect on the readable range and accuracy of auto ID/RFID tags. For example, passive large-sized tag is not suitable to be adopted in tracking the forklifts, because the reader is unable to detect the tags which are stuck on the metal (Poon et al., 2009). Also, warehouse management system (WMS) is one of the top concerns of warehouses adopting RFID technology. Implementation of RFID within the warehouse and supply chain will generate a large amount of data that needs to be stored, processed, and used in real-time. RFID systems will, therefore, need to be combined with the existing warehouse management and other enterprise systems (ERP) (Vijayaraman & Osyk, 2006). Thus, it is essential to evaluate the overall warehouse management system design/ re-design and how easily the auto-ID technology can be integrated into the existing WMS and ability to interface with the ERP to obtain the expected results. In addition, owing to seasonal demand patterns, different proportions of occupied storage space are observed in any warehouse. RFID technology can be effectively applied to improve the utilisation of the storage space capacity in a warehouse environment (Karagiannaki et al., 2011). In general, warehouse resources should not be ignored when investigating auto-ID decisions for warehouse management (Chow et al., 2006).

6.4.5 Stage 5: External Environmental Analysis

External environmental analysis should be started after conducting the organisational and warehouse characteristics (operational, structural, resources) analysis. The following aspects should be included in the external environmental analysis:

- **Customers' pressure:** Checking mandate/compliance from retailer; and understanding the customer needs and ensuring that they are the real issues.
- **Provider/Supplier support:** Check suppliers support; overview of a technology providers and research potential vendors (hardware (HW), software (SW), integration, Request for Proposal (RFP), Request for Quotation (RFQ), Bid evaluations, Vendor meetings); visit to conference and exhibition on auto-ID; and comprehensive and accurate information about a system integrator, hardware and software providers.
- **Competitors' pressure:** Define the industry competitors.
- **Government pressure:** Define the set of spectrum frequency allocated for RFID because this varies in each country due to government pressure; check the mandate compliance from government departments (e.g. the food and drug administration); and check in-country service support.

The above mentioned external environmental factors were also found to be significant in many studies when considering auto-ID technology for the environment (Hwang et al., 2004; Brown & Russell, 2007; Lin & Ho, 2009; White et al., 2008; Li et al., 2010; Wang et al., 2010c).

6.4.6 Stage 6: Technological Analysis

Warehouses should consider and examine different auto-ID systems (possibilities, and limitations) available from different vendors and then check the hardware capabilities for matching their internal problems, needs, requirements and objectives. Because of the differences between barcode and RFID technologies, it is vital that separate scenarios should be made for analysing both auto-ID systems (Ilie-Zudor et al., 2011). An analysis can be made about how the existing barcode technology works and if and how it can be changed to meet the new requirements. New and different possible solutions should be created with a complete new auto-ID system or some kind of hybrid system where various auto-ID technologies (barcode and RFID) are used together. Warehouse managers should think about adopting a hybrid solution, which is very common in the supply chain, because sometimes the actual barcode solution cannot resolve their problems or RFID is not able to get a good spectrum to catch and read because of the location of the warehouse. Hybrid RFID-barcode systems help to take advantage of its relative cost effectiveness or robustness (White et al., 2007). Several methods are suggested to analyse and check the feasibility of different auto-ID solutions, such as cost-benefit analysis/Return on Investment (ROI) analysis (Sarac et al., 2010). However, Decision-makers should ensure that all factors (qualitative and quantitative) are evaluated for each auto-ID solution in order to find a preliminary best solution (Ilie-Zudor et al., 2011).

After conducting this initial analysis, warehouses should pilot test part of the system, by using real-world scenarios, in the actual warehouse environment (Angeles, 2005; Sarac et al., 2010; and Ilie-Zudor et al., 2011). Afterwards, in this research, it has been found that warehouses should review the pilot test to identify the strengths and weakness of the system. Finally, a final cost- benefits analysis/ROI analysis should be conducted and if it is successful, then they select and roll out the technology.

6.4.7 Stage 7: Decision-Making

Although it seems that the decision making process is the last step, it is actually an ongoing process in order to get to the final and the appropriate decision (Ilie-Zudor et al., 2011). Auto-ID technologies for warehouse management are of strategic importance because high risks are involved and also they are relatively expensive to adopt. In this research, it has been found that the selection decision process is complicated and requires a whole series of activities and decisions over a long period. In addition, selection decision of the technology should be based on joint effort and collaboration among all the relevant people involved in the process, such as the IT team, top management, warehouse managers, functional managers, experts, stockholders, and vendors (technology providers), because selecting and implementing a solution that is based on one person's views is highly likely to fail. As a result, the openness/resistance of all stakeholders to consider/implement auto-ID technology can be determined. Also, the synergies across other divisions/groups of the company will be investigated.

6.5 Summary

This chapter presented a comprehensive discussion of the key findings in this research. It has focused on the discussion of the findings of the Delphi study in order to understand the motivations/reasons for warehouses in seeking to use auto-ID technologies, the problems in making an auto-ID decision, the recommendations to overcome the challenges, the relative importance of the key factors and sub-factors that influence the auto-ID selection decision for a warehouse and also the key steps of auto-ID technology-selection process in warehouse management. Moreover, this chapter has focused on the discussion of the verification and validation of the Delphi study through in-depth interviews, both face-to-face and by telephone. Finally, this chapter has focused on how the Delphi study findings and the interview results should be combined to produce a successful auto-ID selection process in warehouse management.

Empirical evidence derived from the analysis of the international two-round Delphi study and the follow-up interviews, confirmed the importance of the auto-ID selection decision process. This process serves as a frame of reference framework as a guiding tool for warehouse management practice and a research background for researchers in auto-ID technologies and warehouse management. The decision making process of barcode and/or RFID for warehouse management is not straightforward. There are seven key stages involved in this process: (1) organisational analysis; (2) operational analysis; (3) structural analysis; (4) resources analysis; (5) external environmental analysis; (6) technological analysis; and (7) decision-making. For each stage, there are several activities and decisions have to be taken during the selection process of auto-ID technology.

The aim of this research was to understand the key factors and their relative importance in influencing the auto-ID selection decision and investigate the selection process of auto-ID technologies for a warehouse management. The framework of the auto-ID selection process presented in this chapter focuses on the following:

- This framework is the first to explore and understand the key factors influencing auto-ID selection decision in warehouse management.
- The framework incorporates seven key stages. Empirical findings illustrate that the joint effort and collaboration among all the relevant people during these stages are critically important for its success.
- Researchers can use this framework as a research background to understand and analyse the auto-ID selection process in warehouse management.
- Warehouse managers can use the framework as a process guiding tool to better understanding of how auto-ID selection process should be carried out in warehouse management.

In the following chapter, the conclusions, contributions, and implications of this research will be outlined. The next chapter will also consider the study's recommendations that can benefit decision-makers including research limitations as well as potential future research perspectives and endeavours.

CHAPTER 7

CONCLUSIONS

7.1 Introduction

This study has focused on the critical factors affecting the auto-ID selection decision process in warehouse management. This research attempted to address the voids in the existing literature by using the factor approach and proposing a conceptual framework that investigates collectively key factors and sub-factors, and their relative importance, affecting the auto-ID selection decision in a warehouse field. The proposed conceptual framework is based on the technology–organisation–environment (TOE) framework developed by Tornatzky and Fleischer (1990). Moreover, in this research, in order to arrange the critical factors/activities according to their relative importance and understand the entire selection process of auto-ID technologies in a warehouse context, a decision was made to investigate the auto-ID selection process from its inception to its termination by adopting the process approach.

The empirical data were collected by conducting first a modified (mixed-method) two-round Delphi study with a worldwide panel of experts (107) including academics, industry practitioners and consultants in auto-ID technologies. The results of the Delphi study were then verified via follow-up interviews, both face-to-face and telephone, carried out with 19 experts across the world. Based on the Delphi study and the interviews findings, a comprehensive multi-stage framework for the auto-ID technology selection process has been developed.

The researcher claims and empirically verifies through the modified two-round Delphi study and the follow-up interviews that the developed framework can be used as a frame of reference to support warehouse managers for understanding and managing the entire auto-ID selection process. Also, it allows researchers to comprehend and analyse the auto-ID selection process for warehouse management.

This chapter gives a summary of the thesis and draws conclusions derived from the literature review and empirical findings. Afterwards, the contributions, implications and limitations claimed in this dissertation will be summarised. Finally, this chapter concludes with the recommendations and directions for future research in the area of the auto-ID selection decision in warehouse management.

7.2 Key Findings

This research was conceived in order to investigate empirically the auto-ID technology-selection process and to determine the critical factors that influence decision makers when selecting auto-ID technologies in the warehouse environment. To achieve the research aim and objectives, the research design relied on two phases. In the first phase, the modified (mixed-method) Delphi approach (Dalkey & Helmer, 1963; and McKenna, 1994) was adopted to capture and consolidate expert knowledge and opinion. The choice of the modified Delphi method required a combination of exploratory and descriptive research design (Cunliffe & Australia, 2002). The exploratory first stage identified, after reviewing and analysing the pre-existing literature review, key factors relevant to the auto-ID selection decision for warehouse management and that formed the basis of the first round Delphi questionnaire. The first round of the Delphi study was a combination of exploratory and descriptive research design using open-ended and closed-ended questions (Cunliffe & Australia, 2002; and Skulmoski et al., 2007). Both quantitative content analysis and descriptive statistics (Bryman, 2004) were used in the first round in order to identify major factors and sub-factors, and their relative importance, affecting the auto-ID selection decision in warehouse management. This was followed by one more round of a refined and redrafted questionnaire incorporating a summary of responses from the first round. The second round of the Delphi study was also a combination of exploratory and descriptive research using closed-ended questions in order to obtain feedback, comments and to come to a consensus regarding the results.

On the other hand, in the second phase of this research, a follow-up verification study (Powell, 2003; Kennedy, 2004; Skulmoski et al., 2007; and Hasson & Keeney, 2011) was carried out with face-to-face and telephone interviews to discuss in-depth, verify and refine the findings of the Delphi study.

The key findings of this research are discussed in the context of the research questions.

RQ1. What are the motivations/reasons of warehouses that seek to use auto-ID technologies?

1. Optimising the overall performance of warehouse operations and processes: efficiency and effectiveness gains in receiving, put-away, picking and shipping;

improving productivity; higher throughput; speed; high quality; improve and maintain processes reliability, visibility and accuracy; reduce errors related to manual processes; real time operations; reduced overall costs; improving the level of automatic processes and reducing the level of manual steps; effectively automate inspection and checking processes; and simpler stock-taking process.

2. Improving the level of customer service and satisfaction: customer responsiveness; Customer Relationship Management (CRM); enhanced level of customer satisfaction and customer 'self-service'.
3. Handling and managing warehouse resources effectively: maximise the effective use of space/vertical space, equipment and labour; real-time visibility; improved inventory visibility and accuracy; cycle counting and annual inventory audit effectiveness; improved inventory planning; minimising the shrinkage and out of stock; enhanced tracking and tracing of items; strong WMS to support the operations; optimising asset utilisation.
4. Enhancing physical control and security of people and objectives: enhancing physical control and security of people and objectives; prevent or decrease the level of theft in the storage area especially at night; strengthen security against product loss, and counterfeiting.
5. Increase and sustain competitive position and advantage.

RQ2. What are the challenges in making an auto-ID decision and the recommendations to address the challenges?

The challenges are as follows:

1) Technological issues: Cost-benefit analysis/ ROI analysis; changing the practices and processes to suit auto ID technology or adapt the technology to facilitate practices; evaluation of the technology by yourself; integration complexity with existing systems (WMS/ERP); how to leverage the system across internal processes and external partners; missing standardisation; competing with other internal projects; stability/ low maintenance costs; and planning for 99% read accuracy.

2) Decision process: Decision process is complex and many factors are involved in it e.g. benefits, costs, expected risks, ROI, complexity, social needs.

3) Information: Quality of information about a system integrator, hardware, and software providers; missing overview of technology providers; comparison of alternatives; and missing best practices.

4) Management issues: Limit of knowledge capabilities on auto-ID technology; failing to address the underlying problem; diversion of warehouse managers from the evaluation process by the 'shiny objects' of technology that do not meet its objectives; and warehouse managers and IT managers who are not geared for evaluating the multi-faceted aspects of auto-ID technology.

5) People: Ability and/or rationality of the decision maker; experience of the analyst; and time available.

6) Customer: Understanding the customer needs and ensuring that they are the real issues.

The recommendations that should be followed to overcome these challenges during the auto-ID selection for warehouse management included:

1. Prudent evaluation process: Empower a cross-functional team to serve on the project in a warehouse and to work with supply chain partners; building a thorough and rigorous business case methodology; comprehensive and accurate information; careful analysis of all impacts of the technology including the overall supply chain management (SCM); good planning and screening of the market; technology selection and deployment must be strictly based on need alone; process of reviewing the best practices of class warehouses; visit to conference and exhibition on the auto-ID; continuous decision process based on the involvement of the warehouse’s executives; requirement for a demonstration; install an experimental setup/mini-pilot; and visit similar installations.

2. Specialist advice/expertise: Employ qualified consultants and/or professional advisors to investigate and pull all stakeholders together at the beginning of the auto-ID selection process; and strong understanding of auto-ID physics by having physics experts who can support and recommend the best hardware and configuration.

3. **3.** Techniques/Tools: Advanced numerical models for cost-benefit analysis; comprehensive and robust ROI calculations including quantitative and qualitative factors; multi analysis tools; and multiple testing and stages.

4. **4.** Incentives: Develop an appropriate incentive scheme and relevant organisational structures to improve the quality of information and help in the decision- making process.

5. **5.** Standardisation: Movement towards international standards for the technology, especially, RFID products.

RQ4. What are the key steps in the selection process of the auto- ID technologies for a warehouse environment?

1) Organisational issues: Secure top management support for the initiative; absolute clarity of the internal problems, needs and requirements; make clear the objectives for the overall business both in the short and long term; setting reasonable expectations and understanding the warehouse manager's perceptions of the auto-ID's capabilities; and educate workers as to why the company is moving to the new system.

2) Comprehensive warehouse study: Understanding key operations and processes of the warehouse and determining points to be improved; evaluate the overall business process design/re-design; defining company's preferred process flow and the system requirements necessary to implement that process; evaluate the overall Warehouse Management System design/re-design; overall definition of the IT infrastructure; overall evaluation of warehouse resources; check amount of metal and liquid; and check other types of RF devices in the area.

3) External environment study: Consider your customer; check providers support; define the industry competitors; and check in-country service support.

4) Technological analysis: Requirements definition for the technology (necessary and optional); analysis of the different auto-ID solutions (possibilities, and limitations); think about adopting a hybrid and/ or integrating various auto-ID technologies; initial cost-benefit analysis/Return On Investment (ROI) analysis/feasibility; pilot test part of the system in the actual warehouse environment; review the pilot test to identify strengths, weakness and as well as additional opportunities to deploy the system; and final cost- benefits analysis/ ROI including both quantitative and qualitative factors.

5) Decision–Making: Select and get buy-in from all the relevant people involved in the process.

RQ3. What is the relative importance of major factors and sub-factors affecting auto-ID selection decisions in a warehouse field?

The results of the Delphi study show that the six major factors affecting the auto-ID selection decision for warehouse management are, in decreasing order of importance: organisational, operational, structural, resources, external environmental and technological factors. In addition, there are 54 key sub-factors that have been identified from the list of each of the major factors and ranked in decreasing order of their importance mean scores.

The above findings were obtained from the first round of the Delphi study. In the second round of the Delphi study, this study tried to come to a consensus regarding the results obtained in the first round. A very high level of consensus on the findings has been obtained in round 2. However, some comments have been obtained in the second round e.g. the importance of the key factors depends on objectives and strategic motivations of the warehouse; size of the warehouse; type of business; nature of business environment; sectors; market types; products and countries.

The data from the interviews presented a similar trend to that found in the Delphi study: the selection process of auto-ID is crucial and warehouses must do it before implementing the technology based on the Delphi results and the interviews findings, a comprehensive framework for the auto-ID selection process that can be viewed as a multi-stage process has been developed (see Figure 7.1).

7.3 Contributions of the Research

7.3.1 Contribution 1: Theoretical Contribution

The most significant contribution of this research is its auto-ID selection process framework in warehouse management. This research contributes to the body of auto-ID

(RFID and barcode) and warehouse management literature by synthesising the literature that shows the key factors and sub-factors which influence the auto-ID selection decision (Chapter 3, Table 3.1). The major factors that have emerged from this study are, in decreasing order of importance: organisational, operational, structural, resources, external environmental and technological factors. These major factors were merged with their sub-factors (54) to form the framework of the auto-ID selection process. This study extends previous literature through investigating the auto-ID technologies in warehouse management. This research also contributes by providing a theoretical basis upon which future research on auto-ID selection and implementation could be built.

A review of the literature on the auto-ID selection decision in chapter 2 has revealed the research problem. The research problem pertains to the lack of literature on auto-ID selection decision in warehouse management, especially the selection process, while a great deal of attention has been paid to critical factors influencing auto-ID decisions in a supply chain. This lack of literature has some implications. For example, there is an absence of a comprehensive framework in the literature that collectively investigates the critical factors influencing the auto-ID selection decision and how the factors should be combined to produce a successful auto-ID selection process for warehouse management.

Furthermore, this research has referred to the Technology-Organisation-Environment (TOE) framework of Tornatzky and Fleischer (1990) in investigating IS implementation and its usefulness for developing an auto-ID selection framework for warehouse management. The use of the framework in Chapters three, five and six has enabled this study to categorise the factors affecting the auto-ID selection decision within six categories, namely, organisational, operational, structural, resources, external environment and technological category. In addition, it enabled this research, after determining the relative importance of the major factors and sub-factors, to arrange the key activities according to their chronological order and frame the auto-ID selection process into seven stages: organisational analysis, operational analysis, structural analysis, resources analysis, external environmental analysis, technological analysis, and decision-making. Each stage contributes differently to the selection process.

7.3.2 Contribution 2: Practical Contribution

It is anticipated that the framework of the auto-ID selection process will help practitioners with auto- ID selection in the warehouse environment. This framework serves as a frame of reference that will provide warehouse managers with assistance to better understand and prepare for the selection process of auto-ID technologies. The power of this framework provides a simple step-by-step approach that can be leveraged to define, present and manage auto-ID selection activities by all of the participants in the selection process. The key activities are divided into seven stages as shown in (see Figure 6.1). In addition, the framework identifies and explains the key activities and decisions that have to be taken during the selection process. The summary of the framework (the seven stages) is presented below.

- During the organisational analysis stage, the key activities that have been found to be crucial to the selection processes' success: identifying the warehouse internal problems, needs and requirements (1); defining the business objectives and scope (2); securing top management support (3); and checking IT knowledge capability, training and education (4). These are all important in the organisational analysis stage. Warehouse managers must start by identifying any existing needs, requirements and potential problems in their business processes/operations through empowering a cross-functional team to serve on the project in a warehouse and to work with supply chain partners. These requirements and needs should then be translated into objectives for the overall business as either short or long term objectives. The clarity of the problems and the business objectives will significantly simplify the technology selection task and help to generate a productive programme.

  Once the internal needs and requirements have been identified and the business objectives and scope have been defined, they will be incorporated into the business case that will be presented to the organisation‘s top management. The senior management will investigate the business case providing the justification for the selection of the technology. Most business cases justified the selection and implementation through cost savings and user satisfaction. These reasons, along with the availability of the necessary resources and funds will lead senior management to grant their approval for the selection and implementation.

IT knowledge capability includes setting reasonable expectations and possessing the knowledge and skills on auto-ID technology. This can be achieved through employing qualified consultants and/or professional advisors who will provide warehouse managers and workers with training and education. Then when warehouse managers are educated on the technology, they will be able to make their own requirements and join the decision with any vendor of the technology.

- During the operational analysis stage, the following key activities were found to be crucial to the technology selection‘s success: understanding key operations/processes and determining points to be improved (1); evaluating the overall business process design/re-design (2); and defining the warehouse's preferred process flow and the system requirements necessary to implement that process (3). These sub-steps can be done through empowering a cross-functional team who will leverage the system across internal processes and external partners. There are ten key operations which have been highlighted in this study: shipping, receiving, storage assignment policy, picking, zoning, routing, put away, batching, order accumulation and sorting and forward reserve allocation. However, some warehouses are more complicated with well-designed operations workflow than other warehouses. Moreover, auto-ID may eliminate some, add some, or shuffle some operations. Thus, warehouses have to check how easy it is to revamp any changes to the processes and select the technology that matches their needs.

- During the structural analysis stage, considering the product type/value; mechanisation level; E-Plane (electric field) and H-Plane (magnetic field); departments' layout; warehouse size; number of racks and aisles; product carrier of stock keeping units (SKU) (pallet, case or item); and overall definition of the IT infrastructure were found to be the key activities. An on- site survey should be conducted through employing RFID and physics experts to have a look at the physical infrastructure, interferences, and recommend the best hardware and configuration.

- The resources analysis stage involved studying all means and equipment needed to operate the warehouse such as material handling equipment (1); evaluate the overall WMS design/re-design (2); assess warehouse staff members (labour) (3); analyse storage systems (4); analyse storage units (5); and evaluate storage space capacity (6).

- Within the external environmental analysis stage, customer pressure (1), provider/supplier support (2), competitors' pressure (3), and government pressure (4) have been determined to be the key activities. Customer pressure consisted of sub-activities such as checking the mandate/compliance from the retailer, understanding the customer needs and ensuring that they are the real issues. The provider/supplier support sub-activities consisted of: (1) checking suppliers support ; (2) overview of a technology providers and research potential vendors (hardware (HW), software (SW), integration, Request for Proposal (RFP), Request for Quotation (RFQ), Bid evaluations, Vendor meetings); (3) visit to conference and exhibition on auto-ID ; and (4) comprehensive and accurate information about a system integrator, hardware and software providers. Competitors' pressure involved defining the industry competitors. Government pressure was to define the set of spectrum frequency allocated for RFID because this varies in each country due to (1) government pressure; (2) to check the mandate compliance from government departments (e.g. In the US, the food and drugs administration); and (3) to check in-country service support.

- During the technological analysis stage, the following six key activities were found to be crucial to the selection‘s success: (1) analyse different auto-ID solutions; (2) think about adopting a hybrid (RFID/Barcode); (3) initial cost-benefit analysis/ROI analysis/feasibility; (4) pilot test part of the system; (5) review the pilot test to identify strengths and weaknesses; and (6) final cost-benefits analysis/ROI.

- After conducting the all those sub-activities and if the final cost-benefits analysis/ROI analysis is successful, then warehouse managers select and roll out the technology. It seems that the decision-making is the last step in the selection process, however, it is an ongoing process in order to get to the final and the appropriate decision. The selection decision process is complicated and requires a joint effort and collaboration among all the relevant people involved in the process (e.g.IT team, top management, warehouse manager, functional managers, experts, stockholders and vendors) because selecting and implementing a solution that is based on one person's views always fails.

7.3.3 Contribution 3: Methodological Contribution

To the best knowledge of the researcher, this is the first time such a Delphi study has been conducted as a modified/mixed method where data were collected from most of the active and interested experts across the world in order to investigate the auto-ID selection decision for warehouse management. The two-round Delphi study questionnaire was developed based on the factors and sub-factors presented in Table 3.2, in Chapter 3 (see Appendices 4 and 5). This research contributes to Delphi technique research by establishing and enhancing the measures of rigour for both qualitative and the quantitative methodological trinity of reliability, validity and trustworthiness have been applied in this research. In addition, the Delphi study findings have been refined and verified by conducting additional research, that is, follow-up interviews both face-to-face and by telephone. The reflection of the TOE framework in the Delphi study and the interviews may help in analysing and exploring a similar phenomenon. The Delphi study was validated which is a helpful guideline for future researchers. Therefore, the Delphi study is considered to be a methodological contribution that may guide researchers in following the same methodology because it demonstrated how future research can be conducted to build on Delphi studies.

7.4 Limitations of the Research

This research has some limitations. First, the results and general conclusion from this research must be interpreted and generalised with care. The Delphi study provides broad and subjective views on critical factors influencing the auto-ID decision making process for warehouse management. It is not designed for advanced statistical analysis and does not, in itself, present relationships and interactions among factors. For example, the results from this research are applicable to only barcode and/or RFID because they are pretty much the only auto-ID technologies that are widely used in warehouse management applications. In addition, the objectives and strategic motivations of warehouse, size of warehouse, location, type of business, nature of business environment, sectors; market types, countries and characteristics of items (e.g., cold chain) in the warehouse would alter the results because they affect the relative importance of the identified major factors and sub-factors in the auto-ID selection decision.

Regarding the warehouse size, it was argued by some panellists that the key steps in the auto-ID selection process identified in this study are suitable only for large warehouses, because small and medium-sized warehouses may not have sufficient resources or budgets to follow the recommended steps when considering auto-ID choices. However, this research has also found that the selection process of auto-ID is crucial and all warehouses (small, medium, or large) should do it before implementing the technology. In other words, the technology selection process is found to be complex and it requires a whole series of decisions over a long period and also all the relevant people should be involved in the process. On the other hand, characteristics of items in the warehouse alter the results. For instance, the technological sub-factors such as item level tracking is critical issue in some applications/industries (e.g., pharmaceutical industry; perishables products in cold chain) because tagging at the item level is crucial to eliminate counterfeiting and achieve patient/people safety and wellbeing, while it is not important in other industries (e.g. paper trading).

Second limitation of this research is the Delphi technique is considered a useful method to obtain consensus of opinion and stability of results as well as to produce new ideas. However, most of the problems involve imprecise and incomplete data. Also the decisions made by the experts rely on their individual competence and are subjective. Hence, in this research, the panel members were not chosen randomly, but their selection was based on their experience and knowledge concerning the topic being surveyed, and on their willingness to participate. Moreover, additional research (follow-up interviews) has been conducted in order to refine and verify the Delphi results. The Delphi study was methodologically sufficient and rigorous, however the size of the experts panel in the interviews was small (a total of 19 experts across the world).

Thirdly, the experts have been selected from different fields to obtain a variety of insights from researchers with both theory-based and practice-based backgrounds. However, the heterogeneity of panel members (demographic attributes, intellectual backgrounds, professional experience and geographical exposures) should have been considered when analysing the findings.

Finally, conducting the Delphi study and follow-up interviews were time consuming and labour intensive due to the number of rounds (pilot and actual) and volume of data gathered, which make its replication problematic. Whilst it is acknowledged that such methodological rigour of the Delphi research technique required considerable resources, it demonstrated how future research can be utilised to build on Delphi studies.

7.5 Recommendations and Future Research Directions

Promising avenues for future studies of the auto-ID selection for warehouse management are hereby proposed. First, future studies may want to replicate this study using fuzzy Delphi method or two step fuzzy Delphi and the fuzzy multi attribute decision making (MADM) method. The fuzzy Delphi method, which is an integration of the fuzzy concept and the Delphi approach, requires only a small survey sample to achieve objective and reasonable results. With this method, the time and costs of collecting questionnaires and gathering data can be reduced, the data to be presented by fuzzy numbers instead of crisp numbers, and the opinions of the experts' panel can be kept as they are without being twisted (Maskeliūnaite et al., 2009).

Second, the findings reported in this research should provide a useful basis for other studies seeking to improve understanding of factors influencing the auto-ID selection decisions in the warehouse environment. Further research using other methodologies such as detailed case studies, is advocated to take the subject forward. Currently, the researcher is preparing a proposal for Mark & Spencer in order to have access to one OR two of their warehouses/stores and conduct a case study. This case study aims to evaluate the usefulness of the proposed framework of the auto-ID selection process in a real world warehouse. Also, to find out: ***How do different warehouses, in terms of size and products, go about the auto-ID selection process?***

7.6 Summary

This chapter has presented a summary of the thesis. Conclusions, contributions, implications and limitations claimed in this dissertation have been discussed. Finally, this chapter concluded with the recommendations and directions for future research in the area of the auto-ID selection decision for warehouse management.

This study was conceived in order to investigate empirically the auto-ID technology-selection process and to determine the key factors that influence decision makers when selecting the auto-ID technology for warehouse environment. The modified Delphi method was employed to capture and consolidate expert knowledge and opinion. The power of the Delphi technique is that it provides more understanding of complex problems than other survey methods. Also, follow-up interviews, both face-to-face and by telephone were conducted in order to discuss in-depth and verify the Delphi results. By consolidating the insights obtained from the Delphi study and the interviews, a comprehensive framework for auto-ID selection process has been developed.

The findings of this study may be of benefit to warehouses by bringing more understanding and a broader view of what the critical factors are in dealing with auto-ID selection choices. The key steps in making auto-ID decisions may assist warehouses in conducting, analysing and evaluating auto-ID choices. The findings may also provide guidelines for warehouse management to ensure that appropriate and relevant factors are taken into consideration in the early stages of the decision making process. In addition, the findings should provide a useful basis for other studies seeking to improve understanding of critical factors affecting the auto-ID selection decisions for warehouse management.

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Appendices

Appendix 1: E-Mail Invitation to Delphi Participants

Dear Prof. Ygal Bendavid,

Hopefully you are great!

I am Mayadah Hassan, Ph.D Student at Brunel University /London.

I am really interested in your experience and publications such as: **"Bridging the gap between RFID/EPC concepts, technological requirements and supply chain e-business processes".**

At present, I am conducting a research to investigate the critical factors, and their relative importance, affecting decisions makers when choosing an auto-ID technology (barcode & RFID) for a warehouse environment.

I will conduct a Delphi Study where open-ended and closed questions will be sent by email to experts. So I am looking for experts in auto-ID Technology, Warehouse Management, and Supply Chain Management in order to join me in this study.

A Delphi study is a systematic, iterative process, with controlled anonymous judgments and systematic refinement, to extract a consensus view from a carefully selected panel of experts within a particular field of study backgrounds. The Delphi panel will be comprised of people who will be carefully selected based on their theory-based and / or practice-based backgrounds. The invited experts, with a theory-based background, are all first or second authors on high quality papers in the field of Automatic Identification and Data Capture (auto-ID) technologies such as, RFID and barcode, in general, and the applications of these technologies in warehouse management in particular published between 2000 and 2012. On the other hand, the experts with a practice-based background have been selected on the basis of their publications, but also by using Snowball Sampling Approach where each member of the responding experts will be asked to nominate names of important experts in the field. A Delphi Study does not require face-to-face participation. It employs a series of highly structured and well-designed questionnaires interspersed with information summary and feedback report from preceding responses.

Moreover, I am aiming to conduct an in-depth interview in order to verify the Delphi results.

I would be greatly appreciated if you could join me in this study and complete my questionnaire later on. A background of my research will be provided as well as a copy of my results will be provided later.

If not, would you kindly suggest some experts in this area you might know!

Looking forward to hearing from you shortly.

Kind Regards,
Mayadah Hassan
PHD Candidate in Logistics & Global Supply Chain Management
Brunel Business School, Eastern Gateway Building 201
Brunel University
Kingston Lane,
Uxbridge, Middlesex UB8 3PH
United Kingdom
Tel: +44 (0)1895 267 927
E-mail: mayadah.hassan@brunel.ac.uk

Appendix 2: Participant Information Sheet

Brunel Business School

Research Ethics

Participant Information Sheet

1. Title of Research: [A developed Conceptual Framework of Factors Affecting Decisions of Automatic Identification Technologies in a Warehouse Environment: A Delphi Study]

2. Researcher: Student [Mayadah Hassan] on [Management Studies Research, PHD Degree], Brunel Business School, Brunel University.

3. Contact Email: E-mail: [mayadah.hassan@brunel.ac.uk]

4. Purpose of the research*:* [The main aim of this research is to investigate empirically the auto-ID technology-selection process and to determine the factors and sub-factors that affect decision makers when choosing auto-ID system in a warehouse environment].

5. What is involved: [The main tasks that the participants (experts) will be asked to undertake are completing a well-designed questionnaire (open-ended and closed questions)].

6. Voluntary nature of participation and confidentiality. I adhere and undertake your participation is completely voluntary and you may stop and leave at any time. Data collected will be kept securely. The data will only be used in an aggregated form in the project report with no reference to you as an individual.

Appendix 3: Participant Consent Form

Brunel University London

Brunel Business School

Research Ethics

Participant Consent Form

Thank you very much for agreeing to participate in my research project. The project has to be completed in part fulfilment of my degree programme and so your assistance is greatly appreciated.

Consent:

I wish to be identified in the report YES ☐ NO ☐

I have read the Participation Information Sheet and I agree to participate in this study (Please Tick) ☐

Name of participant: …………………………………………………

Signature: ………………………… Date: ……………………………..

Name of the researcher: …………………………………………......

Signature: ………………………… Date: ……………………………..

Appendix 4: Delphi Study – Round 1 Questionnaire

Delphi Study

Auto-Identification Technologies in Warehouse Environment

Round One Questionnaire

Mayadah Hassan

Brunel Business School, Brunel University, London

Background

To begin with let me take this opportunity to thank you very much for agreeing to participate in this piece of research. I believe that the benefits gained from your participation will far outweigh the time and effort taken to participate in it. The Delphi panel, of which you are a member, is consisted of 120 participants whom have been carefully selected based on their extensive knowledge of auto-identification technologies such as, RFID and barcode, in general, and the applications of these technologies in warehouse management in particular. By design, the panellists will remain anonymous until the completion of the Delphi study to help reduce the effect of dominant individual and prevent the opinion of any member having an undue influence on the responses of the others.

The entire Delphi study is an iterative process consisting of a series of two consecutive questionnaires. This first questionnaire is composed primarily of open-ended and closed questions. The main aim of this questionnaire is to determine the motivations of warehouses that seek to use auto-ID technologies and the process of making the technology-selection decision. Also, to rate the importance of the main factors and their sub-factors generally affecting auto-ID decisions in warehouse environment, using a five-point Likert scale.

I would be greatly appreciated if could complete my questionnaire by using the following web:

https://docs.google.com/spreadsheet/viewform?formkey=dFBvOGVRdzlhZEJDdzFNa3ZqTTZUTVE6MQ#gid=0

Please respond to each question in longhand and feel free to explain your ideas in as much detail as you wish. Once you have completed the questionnaire, the data will be collated and a feedback report will be circulated to the panellists for further comments. This feedback report will be accompanied by a second questionnaire and the aim is to help consolidate the consensus.

Questions.

1. What are the reasons and motivations of warehouses that seek to use auto-ID technologies (barcode and /or RFID)?

2. What are the key steps in the technology-selection process in a warehouse field?

3. What is the most difficult problem in making an auto-ID decision?

4. What are the ways to overcome the problem?

5. Please indicate how important are the following warehouse structural factors?

	not at all important	**slightly important**	**moderately important**	**very important**	**extremely important**
Warehouse size	☐	☐	☐	☐	☐
Number of aisles	☐	☐	☐	☐	☐
Number of Racks	☐	☐	☐	☐	☐
Departments layout	☐	☐	☐	☐	☐
Mechanisation level	☐	☐	☐	☐	☐
Product/Material type	☐	☐	☐	☐	☐
Product carrier of stock keeping unit (SKU) (pallet, case, or	☐	☐	☐	☐	☐

item)					
Temperature	☐	☐	☐	☐	☐
Humidity	☐	☐	☐	☐	☐
Noise	☐	☐	☐	☐	☐
Dust and dirt	☐	☐	☐	☐	☐
Pressure	☐	☐	☐	☐	☐
E-Plane (electric field)	☐	☐	☐	☐	☐
H-Plane (magnetic field)	☐	☐	☐	☐	☐

6. Please indicate how important are the following warehouse operational factors?

	not at all important	**slightly important**	**moderately important**	**very important**	**extremely important**
Receiving	☐	☐	☐	☐	☐
Put away	☐	☐	☐	☐	☐
Forward reserve allocation	☐	☐	☐	☐	☐
Picking	☐	☐	☐	☐	☐
Order accumulation and sorting	☐	☐	☐	☐	☐
Zoning	☐	☐	☐	☐	☐
Batching	☐	☐	☐	☐	☐
Routing	☐	☐	☐	☐	☐
Shipping	☐	☐	☐	☐	☐
Storage assignment policy	☐	☐	☐	☐	☐

7. Please indicate how important are the following resources-related factors?

	not at all important	**slightly important**	**moderately important**	**very important**	**extremely important**
Storage units	☐	☐	☐	☐	☐
Storage systems	☐	☐	☐	☐	☐
Warehouse management system (WMS)	☐	☐	☐	☐	☐
Material handling equipment	☐	☐	☐	☐	☐
Warehouse staff members (labour)	☐	☐	☐	☐	☐
Storage space capacity	☐	☐	☐	☐	☐

8. Please indicate how important are the following organisational factors?

	not at all	**slightly**	**moderately**	**very**	**extremely**

	important	important	important	important	important
Top management support	☐	☐	☐	☐	☐
IT Knowledge capability	☐	☐	☐	☐	☐
Warehouse internal needs	☐	☐	☐	☐	☐

9. Please indicate how important are the following technological factors?

Technology costs	☐	☐	☐	☐	☐
Deployment costs	☐	☐	☐	☐	☐
Line-of-sight	☐	☐	☐	☐	☐
Labour	☐	☐	☐	☐	☐
Visibility	☐	☐	☐	☐	☐
Accuracy	☐	☐	☐	☐	☐
Reliability	☐	☐	☐	☐	☐
Item level tracking	☐	☐	☐	☐	☐
Traceable warranty	☐	☐	☐	☐	☐
Product recalls	☐	☐	☐	☐	☐
Quality control	☐	☐	☐	☐	☐
Tag data storage	☐	☐	☐	☐	☐
Information properties	☐	☐	☐	☐	☐
Tag weight	☐	☐	☐	☐	☐
Tag read/ write capabilities	☐	☐	☐	☐	☐
Operational life	☐	☐	☐	☐	☐
Memory	☐	☐	☐	☐	☐
Communication range	☐	☐	☐	☐	☐
Multi-tag collection	☐	☐	☐	☐	☐
Security	☐	☐	☐	☐	☐
Privacy	☐	☐	☐	☐	☐
Environmental issues	☐	☐	☐	☐	☐
Interference	☐	☐	☐	☐	☐
Ongoing innovations	☐	☐	☐	☐	☐
Ease of use	☐	☐	☐	☐	☐
Established standards	☐	☐	☐	☐	☐
Performance	☐	☐	☐	☐	☐
Return on Investment (ROI)	☐	☐	☐	☐	☐

10. Please indicate how important are the following external environmental factors?

	not at all important	**slightly important**	**moderately important**	**very important**	**extremely important**
Government pressure	☐	☐	☐	☐	☐
Competitive pressure	☐	☐	☐	☐	☐
Supplier support	☐	☐	☐	☐	☐
Customer pressure	☐	☐	☐	☐	☐

11. Any additional Comments?

Respondent Profile

12. What is your name?* ……………………………….

13. What is your email address?* ……………………..................

14. What is your country of birth? ....

15. Please indicate your gender.

☐Male

☐Female

16. Please indicate your age group.

☐Below 25 years

☐26-35

☐36-45

☐46-55

☐56-65

☐Above 65 years

17. What is your primary area(s) of expertise? Please be as specific as possible.

18. Please select all that apply to you:

- ☐ Have a rare practical skill or knowledge
- ☐ Published papers, books, or articles on area of expertise
- ☐ Hold high-level educational degrees (PhD, Masters, etc.)
- ☐ Testified in court on area of expertise
- ☐ Recognized by peers as being an expert
- ☐ Have extensive (15+ years) industry experience of particular area

19. Do you have your resume/CV on the Internet?

- ☐ I do not have my resume / CV on the Internet
- ☐ Personal website
- ☐ Company website
- ☐ Consulting group website
- ☐ Online expert directories
- ☐ Expert referral services
- ☐ Social networking sites (e.g., Linked-In)

Other (Please specify)

*** = Required Fields**

Thank you for your co-operation and support.

Appendix 5: Delphi Study – Round 2 Questionnaire

Delphi Study

Auto-Identification Technologies in Warehouse Environment

Round One Questionnaire

Mayadah Hassan

Brunel Business School, Brunel University, London

Introduction:

To begin with let me take this opportunity to thank you very much for agreeing to participate in this piece of research and also for completing Round 1 questionnaire.

The purpose of this study is to determine the key factors that need to be taken into account at the start of the selection of auto-ID technologies (Barcode/RFID) in warehouse management.

During the first round qualitative data concerning the factors affecting auto-ID technology selection in a warehouse was gathered and analysed. Also, the ratings of the previous round have been incorporated into this round's questionnaire.

The aim of this questionnaire is try to come to a consensus regarding the motivations of warehouses that seek to use auto-ID technology, the key steps in the selection process of auto- ID technology in warehouse environment, the most difficult problem in making an auto-ID decision and the ways to overcome the problem, and the relative importance rankings of the major factors and sub-factors affecting auto-ID selection decision in warehouse field.

This questionnaire will not take longer than 15 minutes to be completed.

Please complete the questionnaire by 25th March 2013 using the following web:

https://docs.google.com/forms/d/1CjOdEfyOqYNzOD42wgYwKegsA0HDt5IwkwReC936kzQ/edit#

If another round is required it will be sent out by 30th March 2013.

Q.1 Please indicate how strongly you agree/disagree with the following statement regarding the motivations of warehouses that seek to use auto-ID technology:

	Strongly Disagree	**Disagree**	**Neutral**	**Agree**	**Strongly Agree**
1- Optimising the overall performance of warehouse operations and processes	☐	☐	☐	☐	☐
2- Improving the level of customer service and satisfaction	☐	☐	☐	☐	☐
3- Handling and managing warehouse resources effectively	☐	☐	☐	☐	☐
4- Enhancing physical control and security of people and objectives	☐	☐	☐	☐	☐
5- Increase and sustain competitive advantages	☐	☐	☐	☐	☐

Q. 2 Do you feel that there are any additions and/or amendments that you would like to make to the selection in Question 1?

☐Yes

☐No

Q.3 If you have answered “Yes” to Question 2 please explain your reasoning.

Q. 4 Please indicate how strongly you agree/disagree with the following key steps in the selection process of auto- ID technology in warehouse environment:

	Strongly Disagree	**Disagree**	**Neutral**	**Agree**	**Strongly Agree**
1. Organisational issues					
1.1 Secure top management support for the initiative	☐	☐	☐	☐	☐
1.2 Absolute clarity of the internal problems, needs and requirements	☐	☐	☐	☐	☐
1.3 Make clear the objectives for the overall business both in the short and long term	☐	☐	☐	☐	☐
1.4 Setting reasonable expectations and understanding the warehouse manager's perceptions of auto-ID's capabilities	☐	☐	☐	☐	☐
1.5 Educate workers as to why the company is moving to the new system	☐	☐	☐	☐	☐
2. Comprehensive warehouse study					
2.1 Understanding key operations and processes of the warehouse and determining points to be improved	☐	☐	☐	☐	☐
2.2 Evaluate the overall business process design / re-design	☐	☐	☐	☐	☐
2.3 Defining company's preferred process flow and the system requirements necessary to implement that process	☐	☐	☐	☐	☐
2.4 Evaluate the overall Warehouse Management System	☐	☐	☐	☐	☐

design / re-design					
2.5 Overall definition of the IT infrastructure	☐	☐	☐	☐	☐
2.6 Overall evaluation of warehouse resources	☐	☐	☐	☐	☐
2.7 Amount of metal and liquid	☐	☐	☐	☐	☐
2.8 Other types of RF devices in the area	☐	☐	☐	☐	☐
3. External environment study					
3.1 Consider your customer	☐	☐	☐	☐	☐
3.2 Check providers support	☐	☐	☐	☐	☐
3.3 Define the industry competitors	☐	☐	☐	☐	☐
3.4 In-country service support	☐	☐	☐	☐	☐
4. Technological analysis					
4.1 Requirements definition for the technology (necessary and optional)	☐	☐	☐	☐	☐
4.2 Analysis of the different auto-ID solutions (possibilities, and limitations)	☐	☐	☐	☐	☐
4.3 Think about adopting a hybrid and/ or integrating various auto-ID technologies	☐	☐	☐	☐	☐
4.4 Initial cost-benefit analysis/ Return On Investment (ROI) analysis / feasibility	☐	☐	☐	☐	☐
4.5 Pilot test part of the system in the actual warehouse environment	☐	☐	☐	☐	☐
4.6 Review the pilot test to identify strengths, weakness and as well as additional opportunities to deploy the system	☐	☐	☐	☐	☐
4.7 Final cost- benefits	☐	☐	☐	☐	☐

analysis/ ROI including both quantitative and qualitative factors					
5. Decision – Making					
5.1 Select and get buy in from all the relevant people involved in the process	☐	☐	☐	☐	☐

Q.5 The 6 main steps in Q 4 should be followed in the same order mentioned above. Do you feel that there are any additions and/ or amendments that you would like to make to the statements/steps in Question 4?

☐Yes

☐No

Q.6 If you have answered "Yes" to Question 5 please explain your reasoning.

Q.7 Please indicate how strongly you agree/disagree with the following problems in making an auto-ID decision in warehouse environment:

	Strongly Disagree	**Disagree**	**Neutral**	**Agree**	**Strongly Agree**
1.Technological issues					
1.1 Cost-benefit analysis/ ROI analysis	☐	☐	☐	☐	☐
1.2 Changing the practices and processes to suit auto ID technology Or adapt the technology to facilitate practices	☐	☐	☐	☐	☐
1.3 Evaluation of the technology by yourself	☐	☐	☐	☐	☐

1.4 Integration complexity with existing systems (WMS/ERP)	☐	☐	☐	☐	☐
1.5 How to leverage the system across internal processes and external partners	☐	☐	☐	☐	☐
1.6 Missing standardization	☐	☐	☐	☐	☐
1.7 Competing with other internal projects	☐	☐	☐	☐	☐
1.8 Stability / low maintenance costs	☐	☐	☐	☐	☐
1.9 Planning for 99% read accuracy	☐	☐	☐	☐	☐
2. Decision process					
2.1 Decision process is complex and many factors involved in it e.g. benefits, costs, expected risks, ROI, complexity, social needs	☐	☐	☐	☐	☐
3. Information					
3.1 Quality of information about a system integrator, hardware, and software providers	☐	☐	☐	☐	☐
3.2 Missing overview of a technology providers	☐	☐	☐	☐	☐
3.3 Comparison of alternatives	☐	☐	☐	☐	☐
3.4 Missing best practices	☐	☐	☐	☐	☐
4. Management Issues					
4.1 limit knowledge capabilities on auto-ID technology	☐	☐	☐	☐	☐
4.2 Missing to address the underlying problem	☐	☐	☐	☐	☐
4.3 Diversion of warehouses' managers from the evaluation process by the 'shiny objects' of technology	☐	☐	☐	☐	☐

that does not meet its objectives					
4.4 Warehouse managers and IT managers are not geared for evaluating the multi-faceted aspects of auto-ID technology	☐	☐	☐	☐	☐
5. People					
5.1 Ability and/ or rationality of decision maker	☐	☐	☐	☐	☐
5.2 Experience of the analyst	☐	☐	☐	☐	☐
5.3 Available time	☐	☐	☐	☐	☐
6. Customer					
6.1 Understanding the customer needs and ensuring that they are the real issues	☐	☐	☐	☐	☐

Q.8 Should any of the problems in Q 7 be removed / amended in any way?

☐Yes

☐No

Q.9 If you have answered “Yes” to Q 8 please explain your reasoning.

Q.10 Please indicate how strongly you agree/disagree with the following recommendations that should be followed to overcome the problems during auto-ID selection in warehouse management:

	Strongly Disagree	**Disagree**	**Neutral**	**Agree**	**Strongly Agree**

1. Prudent evaluation process					
1.1 Empower cross-functional team to serve on the project in a warehouse and to work with supply chain partners	☐	☐	☐	☐	☐
1.2 Building a thorough and rigorous business case methodology	☐	☐	☐	☐	☐
1.3 Comprehensive and accurate information	☐	☐	☐	☐	☐
1.4 Careful analysis of all impacts of the technology including the overall SCM	☐	☐	☐	☐	☐
1.5 Good planning and screening of the market	☐	☐	☐	☐	☐
1.6 Technology selection and deployment must be strictly based on need alone	☐	☐	☐	☐	☐
1.7 Process of reviewing the best practices of class warehouses	☐	☐	☐	☐	☐
1.8 Visit to conference and exhibition on auto-ID	☐	☐	☐	☐	☐
1.9 Continuous decision process based on good involvement of warehouse's executives	☐	☐	☐	☐	☐
1.10 Require for a demonstration	☐	☐	☐	☐	☐
1.11 Install an experimental setup / Mini-pilot	☐	☐	☐	☐	☐
1.12 Visit similar installations	☐	☐	☐	☐	☐
2. Specialist advice/expertise					
2.1 Employ qualified consultants and / or	☐	☐	☐	☐	☐

professional advisors to investigate and pull all stakeholders together at the beginning of the auto-ID selection process					
2.2 Strong understanding of auto-ID physics by having physics experts who can support and recommend the best hardware and configuration	☐	☐	☐	☐	☐
3. Techniques/Tools					
3.1 Advanced numerical models for cost-benefit analysis	☐	☐	☐	☐	☐
3.2 Comprehensive and robust ROI calculations including quantitative and qualitative factors	☐	☐	☐	☐	☐
3.3 Multi analysis tools	☐	☐	☐	☐	☐
3.4 Multiple testing and stages	☐	☐	☐	☐	☐
4. Incentives					
4.1 Develop appropriate incentives scheme and relevant organisational structures to improve the quality of information and help in decision- making process	☐	☐	☐	☐	☐
5. Standardisation					
5.1 Movement towards international standards for the technology, especially, RFID products	☐	☐	☐	☐	☐

Q.11 Are there any other additions/ amendments that in your opinion should be made to the above list?

☐Yes

☐No

Q.12 If you have answered “Yes” to Q 11 please explain your reasoning.

Q.13 The relative importance of the following major factors influencing auto-ID technology selection is ranked in decreasing order. Please indicate how strongly you agree/disagree with the following importance ranking:

	Strongly Disagree	**Disagree**	**Neutral**	**Agree**	**Strongly Agree**
1-Organisational Factors	☐	☐	☐	☐	☐
2- Operational Factors	☐	☐	☐	☐	☐
3- Structural Factors	☐	☐	☐	☐	☐
4-Resources-Related Factors	☐	☐	☐	☐	☐
5-External Environmental Factors	☐	☐	☐	☐	☐
6-Technological Factors	☐	☐	☐	☐	☐

Q.14 The relative importance of the following organisational sub-factors is ranked in decreasing order. Please indicate how strongly you agree/disagree with the following importance ranking:

	Strongly Disagree	**Disagree**	**Neutral**	**Agree**	**Strongly Agree**
1- Warehouse internal needs	☐	☐	☐	☐	☐
2- Top management support	☐	☐	☐	☐	☐
3- IT Knowledge capability	☐	☐	☐	☐	☐

Q.15 The relative importance of the following operational sub-factors is ranked in decreasing order. Please indicate how strongly you agree/disagree with this importance ranking:

	Strongly Disagree	**Disagree**	**Neutral**	**Agree**	**Strongly Agree**
1- Shipping	☐	☐	☐	☐	☐
2-Receiving	☐	☐	☐	☐	☐
3-Storage assignment policy	☐	☐	☐	☐	☐
4-Picking	☐	☐	☐	☐	☐
5-Zoning	☐	☐	☐	☐	☐
6-Routing	☐	☐	☐	☐	☐
7-Put away	☐	☐	☐	☐	☐
8-Batching	☐	☐	☐	☐	☐
9-Order accumulation and sorting	☐	☐	☐	☐	☐
10-Forward reserve allocation	☐	☐	☐	☐	☐

Q.16 The relative importance of the following structural sub-factors is ranked in decreasing order. Please indicate how strongly you agree/disagree with this importance ranking:

	Strongly Disagree	**Disagree**	**Neutral**	**Agree**	**Strongly Agree**
1-Product/Material type	☐	☐	☐	☐	☐
2-Mechanisation level	☐	☐	☐	☐	☐
3-E-Plane (electric field)	☐	☐	☐	☐	☐
4-Departments layout	☐	☐	☐	☐	☐
5-Warehouse size	☐	☐	☐	☐	☐
6-Number of racks	☐	☐	☐	☐	☐
7-H-Plane (magnetic - field)	☐	☐	☐	☐	☐
8-product carrier of SKU (pallet, case, or item)	☐	☐	☐	☐	☐
9-Number of aisles	☐	☐	☐	☐	☐

Q.17 The relative importance of the following sub-factors of resources-related factors is ranked in decreasing order. Please indicate how strongly you agree/disagree with this importance ranking:

	Strongly Disagree	**Disagree**	**Neutral**	**Agree**	**Strongly Agree**
1- Material handling	☐	☐	☐	☐	☐

equipment					
2-Warehouse management system (WMS)	☐	☐	☐	☐	☐
3-Warehouse staff members (labour)	☐	☐	☐	☐	☐
4-Storage systems	☐	☐	☐	☐	☐
5-Storage units	☐	☐	☐	☐	☐
6-Storage space capacity	☐	☐	☐	☐	☐

Q.18 The relative importance of the following external environmental sub-factors is ranked in decreasing order. Please indicate how strongly you agree/disagree with this importance ranking:

	Strongly Disagree	**Disagree**	**Neutral**	**Agree**	**Strongly Agree**
1- Customer pressure	☐	☐	☐	☐	☐
2- Supplier support	☐	☐	☐	☐	☐
3-Competitive pressure	☐	☐	☐	☐	☐
4-Government pressure	☐	☐	☐	☐	☐

Q.19 The relative importance of the following technological sub-factors is ranked in decreasing order. Please indicate how strongly you agree/disagree with this importance ranking:

	Strongly Disagree	**Disagree**	**Neutral**	**Agree**	**Strongly Agree**
1-Return on Investment (ROI)	☐	☐	☐	☐	☐
2-Deployment costs	☐	☐	☐	☐	☐
3-Reliability	☐	☐	☐	☐	☐
4-Performance	☐	☐	☐	☐	☐
5-Technology costs	☐	☐	☐	☐	☐
6-Accuracy	☐	☐	☐	☐	☐
7-Visibility	☐	☐	☐	☐	☐
8-Security	☐	☐	☐	☐	☐
9-Privacy	☐	☐	☐	☐	☐
10-Quality control	☐	☐	☐	☐	☐
11-Product recalls	☐	☐	☐	☐	☐
12-Multi-tag collection	☐	☐	☐	☐	☐
13-Labour	☐	☐	☐	☐	☐
14-Ease of use	☐	☐	☐	☐	☐
15-Item level tracking	☐	☐	☐	☐	☐
16-Traceable warranty	☐	☐	☐	☐	☐
17-Interference	☐	☐	☐	☐	☐

18-Established standards	☐	☐	☐	☐	☐
19-Communication range	☐	☐	☐	☐	☐
20-Tag read/ write capabilities	☐	☐	☐	☐	☐
21-Environmental sensitivity	☐	☐	☐	☐	☐
22-Line-of-sight	☐	☐	☐	☐	☐
23-Information properties	☐	☐	☐	☐	☐

Q. 20 Please include any additional comments that you may have.

Respondent Profile

Q.21 What is your name?* ……………………………….

Q.22 What is your email address?* ……………………..................

Q.23 What is your country of birth? ....

Q.24 Please indicate your gender.

☐Male

☐Female

Q.25 Please indicate your age group.

☐Below 25 years

☐26-35

☐36-45

☐46-55

☐56-65

☐Above 65 years

Q. 26 Please select all those apply to you regarding the primary area(s) of expertise.

☐AIDC Technology (RFID/ or Barcode)

☐Warehouse Management

☐Logistics

☐Supply Chain Management

☐Operations Management

Q. 27 Please indicate your position.

☐Academic

☐Industry Practitioner

☐AIDC Technology (RFID/ or Barcode) Consultant

☐Warehouse Management Consultant

☐Logistics Consultant

☐ Supply Chain Management Consultant

☐Operations Management Consultant

Other (Please specify)

*** = Required Fields**

Thank you very much for your support and co-operation

Appendix 6: E-Mail Invitation to Interviews Participants

Dear Dr. Rangarajan,

Hopefully you are great!
I am Mayadah Hassan, PHD Student at Brunel University /London.
I am really interested in your experience and publications such as: **"Enhancing Supply Chain Management Using RFID".**

In fact, I have conducted a research to investigate the critical factors, and their relative importance, affecting decisions makers when choosing an auto-ID technology (barcode & RFID) for a warehouse environment.

I have conducted a Delphi Study where open-ended and closed questions were sent by email to 120 international experts. I am aiming to conduct an in-depth interview in order to verify and confirm the Delphi results. So, I would be greatly appreciated if you could join me in this study and if you do not mind that, I will be so happy to discuss with you the critical points over phone which of course, will enrich my research!
If not, would you kindly suggest some experts in this area you might know!
Looking forward to hearing from you shortly.

Kind Regards,
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Appendix 7: Interviews Protocol

1. What are the motivations of warehouses that seek to use auto-ID technology?
2. What are the key steps in the selection process of auto- ID technology in warehouse environment?
3. Do you think that only the big warehouses who will follow a complex and long auto-ID decision process?
4. What is the most difficult problem in making an auto-ID decision and the ways to overcome the problem?
5. In your opinion, when warehouses think about hybrid solution (RFID and barcode systems)?