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A study of the relationship between radio frequency identification (RFID) technology and lean manufacturing

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A Study of the Relationship between Radio Frequency Identification (RFID) Technology and Lean Manufacturing

by

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Dedication

This dissertation is dedicated to my encouraging and loving wife, Enas, for her support, love, and patience that helped me to fulfill this dream and to my son, Kenan.

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Finally, I would like to extend my sincere appreciation to all my immediate family members. Special gratitude goes to my parents, wife, brothers, and sisters for their non-stop love, encouragement, and support.

Abstract

The primary purpose of this research effort is to investigate the relationship between Radio Frequency Identification (RFID) technology and reducing waste in a manufacturing setting where a lean manufacturing system has been implemented. This research identifies implementation areas where RFID can have the greatest impact on work-in-progress management, inventory management, manufacturing assets tracking and maintenance, and manufacturing control in lean manufacturing environments. The study specifically focuses on how RFID can help identify, reduce, and eliminate the seven common types of waste identified by Taiichi Ohno in the Toyota Production System. These seven include overproduction, waiting time, inefficient transportation, inappropriate processing, unnecessary inventory, unnecessary motion, and rejects & defects. The study expands the knowledge of manufacturing waste reduction through the use of RFID technology.

Through the use of a forty-question survey, this research involved the collection, review, analysis, and classification of the perceptions of participants across six U.S. manufacturing industries regarding where RFID can have the greatest impact on lean manufacturing. Data collection involved a structured survey administered to 1900+ members of the Society of Manufacturing Engineers (SME). Based on the perceptions of the respondents, RFID technology can be used in several areas/functions/locations within manufacturing that helps to identify and reduce the seven types of manufacturing waste and that RFID technology may improve work-in-progress management, inventory management, and manufacturing control.

The study concluded that the reduction of manufacturing waste can be achieved through the deployment of RFID technology in 23 of 35 potential applications. This study fulfills an identified need to study the implementation areas where RFID can have the greatest impact and add value within lean manufacturing settings. The research includes implications for industry practitioners, RFID suppliers, researchers and scholars by providing a better understanding of the benefits of RFID in manufacturing.

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Chapter 1 – Introduction

This dissertation research presents a descriptive study to determine the relationship between Radio Frequency Identification (RFID) technology and lean manufacturing. Chapter 1 focuses on the problem statement, background, justification, the significance of the problem, purpose and objectives of this research, research questions, limitations and delimitations, and assumptions of this study. Chapter 2 of this dissertation provides a detailed review of literature related to the problem to be investigated in this study. Chapter 3 presents a review of the research design and specific methodology to be utilized for this research. Chapter 4 of this dissertation presents data and findings from this study. Chapter 5 provides a systematic analysis of the results of this study. Chapter 6 presents research conclusions, practical implications, theoretical implications, and recommendations for future research.

Statement of the Problem

It is unclear how and where RFID technology can be implemented within manufacturing to help identify, reduce, and ultimately eliminate the seven types of waste defined by Taiichi Ohno in the Toyota Production System.

Nature and Significance of the Problem

"The term 'lean' refers to using less of everything during production – less labor, less manufacturing space, less equipment, less inventory, and less engineering inputs during development and processing – all of which results in fewer defects and more variety" (Russell, 2009, p. 721). Reducing costs and maximizing profits are two main reasons why manufacturing companies embrace lean manufacturing strategies. "In implementing this philosophy, it is essential that lean benefits are measured in order to benchmark savings. Normally time and method study approaches are used to measure day-to day outputs. Radio

Frequency Identification technology (RFID) may speed up this measurement process… The application of RFID technology is widened into the process improvement field through its innovative implementation" (Dunlop, 2007, p. 2). Lean manufacturing is a practice that seeks to minimize the amount of resources (including time) used in the various activities of a business. Lean manufacturing practices seek to identify, reduce, and ultimately eliminate non-value adding activities. These types of activities are frequently referred to as "waste" in lean manufacturing (Brintrup, Roberts & Astle, 2008).

RFID technology is defined as "a technology that allows items to be 'tagged' with a device which can be read electronically" (Lin, 2008, p. 489). It is believed that the wide spread use of this technology started in 2003 when Wal-Mart required some of its suppliers to place RFID tags on pallets and cases. Most of supplier were not ready for the implementation of RFID technology and thus they simply started to attach RFID tags to shipments sent to Wal-Mart (Aichlmayr, 2008). "While RFID has traditionally been used to track inventory throughout the extended supply chain, operations managers today are seeing new value in the use of RFID within their four walls" (p. 16).

The implementation of lean through the innovative application of Radio Frequency Identification (RFID) technology is novel in its approach (Dunlop, 2007). RFID technology has been used in many industries for many applications, mainly to track the distribution of physical goods. Furthermore, lean manufacturing provides many benefits, but implementing it with RFID technology may lead to more improvements.

It has been found that one of the main obstacles to the implementation of RFID technology is the lack of analysis tools to show where and how this technology can bring value (Brintrup, Roberts & Astle, 2008). Saygin and Sarangapani (2006) suggest the need for a complete understanding of business processes affected by RFID implementation to identify potential benefits this technology may bring to businesses.

"RFID is a great technology and can be used in such a vast number of ways that with times being slow for companies right now, there is extra time to research RFID and look into what savings it can offer if implemented" (Busch, 2009, p. 28). Confusion remains as to where RFID technology best helps in manufacturing. "Questions remain as to what aspects should be considered when selecting applications, which manufacturing wastage RFID may specifically address and how these wastages can be identified and eliminated" (Brintrup, Roberts & Astle, 2008, p. 5). "After many years of hyping the RFID technology, it becomes increasingly evident that the actual adoption and diffusion of RFID lags behind the expectations of its optimistic promoters" (Schmitt, Thiesse, & Fleisch, 2007, p. 3). Studies of where RFID technology can help in manufacturing tend to approach the issue in one of the following three ways:

1) A small group of studies argue that RFID can provide benefits to firms and may eliminate some of the production wastes (Brintrup, Roberts & Astle, 2008; Hill, 2004; Patti & Narsing, 2008).

2) A second considerably larger set of studies explore RFID within supply chain management, particularly how RFID will revolutionize supply chains through item-level tracking of goods, and increase levels of product and asset visibility (Aichlmayr, 2008; Leavitt, 2005; Lin, 2008; Zuckerman & Rowley, 2006).

3) A third set of studies examine how RFID may be related to *kanban*, *just-in-time*, and *Six Sigma* applications (H. Chan & F. Chan, 2008; Li & Visich, 2006; Zhang, Jiang, & Huang, 2008).

These three approaches have been used to identify the benefits of RFID. The evidence is almost uniformly consistent in indicating that organizations reap a wide array of positive benefits from the implementation of RFID applications in one way or another. Only a relative handful of studies (Brintrup, Roberts & Astle, 2008, 2008; Hill, 2004; Patti & Narsing, 2008) have specifically examined whether lean and RFID are connected. Such studies focused on which of the wastes RFID technology can help identify, but overlooked explicitly examining how RFID technology may be used to eliminate them.

This study contributes to the knowledge base of lean and RFID in several ways. First, it advances the understanding of RFID technology and its implementation in manufacturing and manufacturing waste reduction by RFID. Second, the outcomes of this study can greatly assist the analysis of a lean process and help a wide range of organizations and individuals to realize significant productivity gains and efficiencies through the use of RFID. Third, this research is a valuable reference for the academic community where facts can be extracted and more research activities can be built on its outcomes.

Objective of the Research

The purpose of the study was to determine the relationship between RFID technology and lean manufacturing based on the knowledge of the selected participants. The study specifically focused on how RFID can help identify, reduce, and eliminate the seven common types of waste identified by Taiichi Ohno in the Toyota Production System. These seven include overproduction, waiting time, inefficient transportation, inappropriate processing, unnecessary inventory, unnecessary motion, and rejects & defects (Adams, 2006). Four manufacturing functions were selected for investigation. These are work-in-progress management, inventory management, manufacturing asset tracking and maintenance, and manufacturing control. This study also identifies potential applications of RFID technology in manufacturing and areas that will be affected by RFID technology. Appendix Q represents a detailed research model.

Research Questions

This research study focused on answering the following three research questions:

Q1: Where does RFID technology have the potential of identifying, reducing, and eliminating the seven types of waste in lean manufacturing?

Q.2: What demographic variables significantly affect the perceived relationship between RFID applications in a lean manufacturing environment?

Q3: Are lean and RFID compatible with one another?

Research Hypotheses

H0 (Null Hypothesis) There is no significant relationship between lean manufacturing waste reduction and the adoption of RFID technologies.

H1: (Alternate Hypothesis) Manufacturing waste will be different in organizations implementing RFID technology in work-in-progress management.

H2: (Alternate Hypothesis) Manufacturing waste will be different in organizations implementing RFID technology in inventory management.

H3: (Alternate Hypothesis) Manufacturing waste will be different in organizations implementing RFID technology in manufacturing asset tracking and maintenance processes.

H4: (Alternate Hypothesis) Manufacturing waste will be different in organizations implementing RFID technology in manufacturing control processes.

Delimitations

A delimitation of this study was that it focuses on the manufacturing industries within the United States. A second delimitation was that respondents will be selected from organizations with 250 or more employees.

Assumptions

1. It was assumed that the participants in the survey would:
    a. Accurately depict the characteristics of the population.
    b. Provided an accurate, honest, and un-manipulated portrayal of data.
    c. Have knowledge of lean and RFID.
2. It is also assumed that lean implementation at each of the selected organizations is sufficiently similar.

Definitions of Terms

Lean "refers to using less of everything during production – less labor, less manufacturing space, less equipment, less inventory, and less engineering inputs during development and processing – all of which results in fewer defects and more variety" (Russell, 2009, p. 721).

Radio Frequency Identification (RFID) “is a technology that allows items to be ‘tagged’ with a device which can be read electronically” (Lin, 2008, p. 489).

Just-in-Time (JIT) “is a pull system where production at each step does not begin until it is signaled for by the customer (the downstream step)” (Staats & Upton, 2007. p 4).

SME.

> The Society of Manufacturing Engineers is the world's leading professional society advancing manufacturing knowledge and influencing more than half a million manufacturing practitioners annually. SME promotes an increased awareness of manufacturing engineering and keeps manufacturing professionals up to date on leading trends and technologies. Headquartered in Michigan, the Society has members in more than 70 countries and represents manufacturing practitioners across all industries ("SME: where manufacturing,").

Summary

This chapter provides brief information about lean production and RFID technology’s implementation within manufacturing organizations. In this section, the need for the study to better understand where the implementation of RFID technology can add value within a manufacturing organization has been highlighted. In the following chapter, a review of literature in the discipline and related disciplines will provide a discussion of the work of previous scholars that supports, offers a counter position, and provides a context for this research study.

Chapter 2 – Background and Review of the Literature

Introduction

This chapter provides a review of relevant literature about Radio Frequency Identification (RFID) technology, lean manufacturing, the common types of waste in lean production, and literature related to the problem investigated in this research.

Radio Frequency Identification (RFID) Technology

RFID History Overview

"It all started back in 2003, when Wal-Mart first announced that its suppliers would have to tag crates and pallets. At the time, Wal-Mart mandated that its top 100 suppliers would have to complete the move by January 2005" (Gaudin, 2008, p. 12). Initially, Wal-Mart estimated the following savings: $6.7 Billion in reduced labor costs (no bar-code scanning required), $600 Million in out-of-stock supply chain cost reduction, $575 Million in theft reduction, $300 Million in improved tracking through warehousing and distribution centers, and $180 Million in reduced inventory holding and carrying costs (Asif & Mandviwalla, 2005, p.3).

Before this announcement, most people had not heard of RFID (Hardgrave, 2010). During the 1990s, RFID applications in supply chain management and article tracking have grown rapidly. However, many argue that RFID technology had existed well before that. This goes back to the year 1948 when Harry Stockman published a paper entitled "Communication by means of reflected power" that discussed the theory and implementation of RFID (Yu, 2008). Filing patents related to RFID has started in the seventies. "The first patent for RFID was filed by Charles Walton in 1973" (Asif & Mandviwalla, 2005, p. 3).

Landt (2005) indicated that the development of RFID technology and its applications can be categorized based on the decade which they were developed. See Table 1 below for more details:

Table 1

The Decades of RFID

Decade	Event
1940-1950	Radar refined and used major World War II development effort. RFID invented in 1948.
1950-1960	Early explorations of RFID technology and laboratory experiments
1960-1970	Development of the theory of RFID and the start of applications field trails.
1970-1980	Explosion of RFID development. Tests of RFID accelerate. Very early adopter implementations of RFID.
1980-1990	Commercial applications of RFID enter mainstream.
1990-2000	Emergence of standards. RFID widely deployed. RFID becomes a part of everyday life.
2000 - 2010	RFID explosion continues

What is RFID Technology and How Does an RFID System Work?

"RFID uses radio-frequency tags to enable the physical tracing of goods through the receiving process, raw material stores, production, finished goods inventory, and shipping" (Stambaugh and Carpenter, 2009, p. 36). An RFID system consists of a tag, reader, local software and infrastructure, and integration software (enterprise applications). "A RFID system is composed of several elements—readers, tags, software and security programs for the readers" (Azevedo & Ferreira, 2009, p. 8). Yang, Prasanna, & King (2009) describe RFID as:

> RFID is a generic term for technologies that use radio waves to automatically identify and track people or objects. The method is to store a unique serial code in a microchip, an antenna is attached to the chip so that the identification code can be transmitted. The chip and its antenna together are called a RFID transponder or a RFID tag. To receive and identify the information sent by tags, a *RFID reader* is required to communicate with the RFID tags. The RFID reader then forwards the information collected from the RFID tags to an information system. (p. 15)

Figure 1 below presents the four main components of the RFID system. As shown below, RFID tags can be attached to items, boxes, pallets, and containers (trucks). RFID readers can be fixed/mounted, handheld/mobile, or a form of gates. The readers communicate with the tags and collect data. These data then pass through and are stored on local software ready for processing. Different organizations use different enterprise applications, but the common ones are (a) Engineering Resource Planning (ERP), (b) Customer Relationship Management (CRM), and (c) Supply Chain Management (SCM).

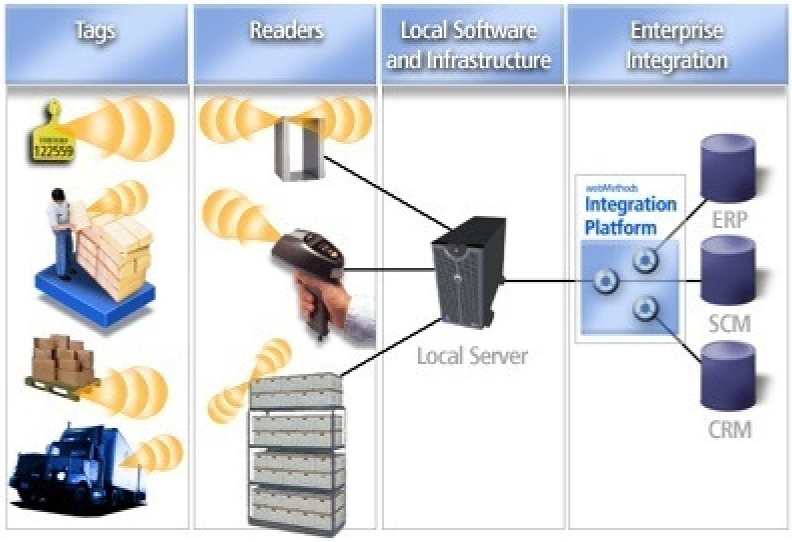

Figure 1. The Four Main Components of an RFID System

Source: http://www.foodylife.com/food-industry/201/rfid-system-and-food-traceability/. Accessed March 27, 2010.

"The challenges here include the choice of RFID solution including the hardware and software required. The choice of tag types in terms of read range, read/write capability, reader type, and middleware" (Ngai & Gunasekaran, 2009, p. 6). The following section provides detailed information about each of the four main components of the RFID system as mentioned earlier.

RFID tags. RFID tags are low-cost devices with limited data storage space. "RFID tags are made of a microchip attached to a radio antenna that is then surrounded by some form of casing, usually plastic" (Fink, Gillett, & Grzeskiewicz, 2007, p. 36). "The tag picks up signals from and sends signals to a reader. Most RFID tags work in a passive mode without an own source of energy and transmit signals only on demand from a reader" (Steffen et al., 2010, p. 1). RFID tags can be classified according to a number of characteristics. First, (a) active, (b) semiactive (semipassive), or (c) passive. Second, (a) read-write tags, and (b) read-only tags. These tags differ in their design, use, cost and readability (Parker, Bishop, & Sylvestre, 2008).

Active tags. “Active tags contain a battery and can transmit its signal autonomously” (Busch, 2009, p. 28). "Active tags have a battery that runs the microchip's circuitry and broadcast a signal to the RFID reader, which can read these tags from up to 1000' [305 m] away” (Koelsch, 2007, p. 112). “Active tags operate on higher frequencies ranging from 850 MHz to 950 MHz or from 2.4 GHz to 2.5 GHz” (Parker, Bishop, & Sylvestre, 2008, p. 32). Active tags use the batteries to power their communication circuitry, sensors, and microcontroller. RFID active tags can achieve high data and sensor activity rates, but the use of batteries as a source of power is considered disadvantageous for the tag’s cost, lifetime, weight, and volume (Sample et al., 2008). To overcome the constraints of tag life, cost, performance, and size, producing tags with lower power circuits and even printed batteries will be the way forward in the near future (Harrop, 2006). “Research has determined that the value of sales of active systems, including the tags, will now grow very rapidly from $0.55 billion in 2006 to $6.78 billion 2016” (p. 36). These tags are more expensive than passive tags and cost upward to $50 per tag (Parker, Bishop, & Sylvestre, 2008). These tags are suitable for tracking expensive products/items.

Passive tags. “Passive tags don't have a battery and require an external source to initiate signal transmission” (Busch, 2009, p. 28). Passive sensor tags receive all of their operating power from an RFID reader and are not limited by battery life (Sample et al., 2008). “Passive tags (the preferred tag for pallet, case, and item-level tagging in the DC)…can be read to a maximum of 100 feet” (Napolitano, 2010, p. 1). As compared to active tags, passive tags are more economical but generally store less data (Stambaugh & Carpenter, 2009).

Relying on external sources of power makes passive tags "significantly less expensive than active tags, but this limits their reading range and makes them not be considered exactly real time. Their level of reading accuracy is more in the 20-foot range, making them most appropriate for outdoor, yard management use" (Specter, 2009, p.1). Passive tags operate on frequencies of 30 KHz to 500 KHz (Parker, Bishop, & Sylvestre, 2008). Because passive tags have no battery, they are smaller and lighter in weight than the active tags. Some are as light as, or even lighter than, the bar-coded labels (Azevedo & Ferreira, 2009). "Passive tag prices range from $0.15 to $1.10 depending upon the volume of tags produced and the complexity of tag functions" (Zhang, Ouyang, & He, 2008, p. 113). "These tags are ideal for tracking and accounting for low-dollar inventory items. Given the price, many businesses are focusing on passive tags" (Parker, Bishop, & Sylvestre, 2008, p. 32).

Semi-active tags. A third type of RFID tags is called a semi-passive or semi-active. Although a battery powers its chip's circuitries, the reader provides the power for transmitting data and communicating information. "This allows the tag to respond to the reader from a slightly longer distance" (Koelsch, 2007, p. 112). Semi-active tags remain inactive until they are energized by a signal from the reader. This results in conserving their battery life (Parker, Bishop, & Sylvestre, 2008).

Read-write vs. read-only (write once, read many) tags. "Tags can be read-only (stored data can be read but not changed), read/write (stored data can be altered or re-written), or a combination, in which some data (such as the serial number identification or SID) is permanently stored while other memory is left accessible for later encoding or updates" (Sandoval-Reyes & Soberanes Perez, 2005, p. 6). RFID readers can store, read, modify, and erase data stored in read-write tags. The stored data can be overwritten and re-used. "These are more expensive than the read-only tags that can only be used for the one product that the original information is written for" (Hingley, Taylor, & Ellis, 2007, p. 804). Read-only passive tags are cheaper than read-write tags and are better-suited for item, case or pallet-level tagging of goods.

RFID readers. An RFID reader is an electronic device that generates signals to communicate with RFID tags. "Readers can execute read, write and overwrite commands on each tag over the wireless interface" (Huang & Shieh, 2010, p. 15). Readers transmit signals to energize the tags and then receive data stored on the chip of the tag. Fink, Gillett, & Grzeskiewicz (2007) state that:

> RFID transceivers provide the mode of communication between the tag and the computer system. Most readers have three main components. The first component transmits the electromagnetic field to produce the energy needed to power the tags and emit radio waves. The device that actually reads the tag's information is the second component. Third, readers need a decoder to convert the information into digital format. (p. 36)

"In a nutshell, readers emit a radio wave so that all tags in their range answer by broadcasting their embedded information" (Solanas & Castellà-Roca, 2008, p. 23). RFID readers can be configured, based on mobility, either as portable/handheld readers or fixed readers. They can also be classified, based on function, as read-only readers and read-write readers.

Portable/handheld vs. fixed RFID readers. Fixed readers can only read data from tags by capturing the movement of tagged products/items as they pass through major choke points, such as dock doors. Handheld RFID readers enable the deployment of RFID read points virtually everywhere within the operations stages (Motorola, 2007). “Fixed-mount readers are usually more expensive but also have a longer read range and can be less labor-intensive than using hand-held” (Ross et al., 2009, p. 167). In 2005, sales of handheld RFID readers accounted for just 9.2% of RFID reader sales, while fixed readers accounted for 81.4% of the market. In 2010, it is predicted that handhelds will make up 13% of the RFID reader market (Growing market, 2006).

Read-only vs. read-write RFID readers. RFID readers can either read data from an RFID tags only or read and write information to an RFID tag. “A passive-tag reader can constantly broadcast its signal or broadcast it on demand” (Weinstein, 2005, p. 28). “Read/write readers can write new data to a suitably designed read/write memory tag, as well as read the information from it” (Curran, & Porter, 2007, p. 598).

RFID Infrastructure. RFID requires the installation of information technology “infrastructure which is necessary to collect, filter and enrich raw RFID data before being processed by the backend systems” (Frischbier, Sachs, & Buchmann, n.d, p. 1). RFID infrastructure is also referred to as middleware. The term “middleware” broadly refers to hardware devices and software that are used to connect RFID readers and the collected data to enterprise applications/systems. “RFID middleware applies filtering, formatting or logic to tag data captured by a reader so the data can be processed by a software application” (Burnell, 2006, p. 1). Smaller companies may invest an estimate of $100,000 to $300,000 in RFID infrastructure. Large companies could hit $20 million (Webster, 2008). In general, RFID middleware should meet the following application requirements (Floerkemeier, Roduner, & Lampe, 2007):

- RFID data disseminations

- RFID data aggregation
- RFID data filtering
- Writing to a tag
- Trigger RFID reader by eternal sensors
- Fault and configuration management
- RFID data interpretation
- Sharing of RFID triggered business events
- Lookup and directory management
- Tag identifier management, and
- Privacy protection.

Enterprise Applications. "The enterprise subsystem is the computer system and software that utilizes information stored on RFID tags" (Sabbaghi & Vaidyanathan, 2008, p. 72). RFID enables businesses to integrate the captured data with internal business processes to create values such as improved logistics efficiency, responsiveness, enhanced service, reduce labor costs, improve out-of-stock rate, and reduce inventory level (Chuang & Shaw, 2008). Enterprise applications include Engineering Resource Planning (ERP), Customer Relationship Management (CRM), and Warehouse Management System (WMS). "ERP is a system for integrating internal business data and processes" (p. 676). ERP system is mainly used as the central repository of information of supply and demand, as well as inventory, for the entire supply chain (Napolitano, 2010). ERP system is also used to boost operational efficiency and provide real-time information for just-in-time production (Tan, 2009).

RFID technology provides benefits for both front-office and back-office Customer Relationship Management (CRM) systems. This is normally achieved by feeding information to support sales-force automation (SFA) systems in front-office "systems and by providing more accurate and more-detailed information about inventory stock and replenishment times" (Stambaugh & Carpenter, 2009, p. 39).

Warehouse Management System (WMS) refers to special software that can be installed to track the location of items in a warehouse and the quantity stored in each location. WMS can also verify what is being received versus what was ordered. This software/database can determine when it is time to pull overflow down, how much to pull, and where to put it (Friedman, 2009). RFID is used to collect data that are fed into WMS software through capturing data from the tags at locations as shown below: (1) in the yard, (2) at the pallet level, (3) at the receiving dock, (4) in the warehouse, (5) at shipping, (6) in transit, and (7) infrastructure.

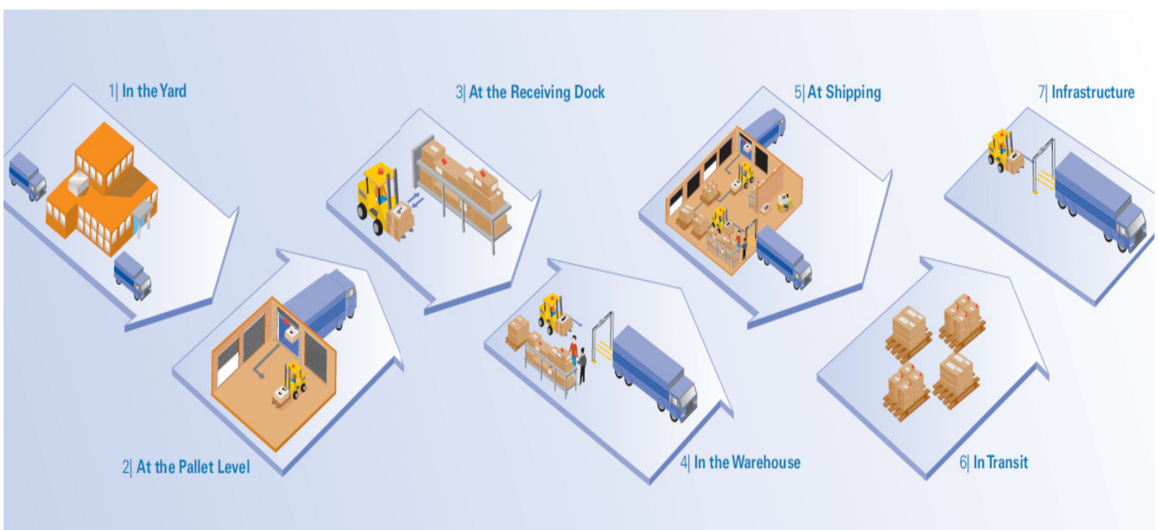

Figure 2. RFID Use in Warehouse Management

Source: http://www.tycoasia.com/media/brochures/rfid/RFID_Brochure.pdf . Accessed 20 Mar 2010.

Benefits of RFID Technology

There are three main purposes why companies use RFID: "to reduce cost, to better serve customers, and to support business growth through for example increasing market share" (Wen, Zailani, & Fernando, 2009, p. 24). Weinstein (2005) state that businesses favor RFID to barcode technology because of the following reasons: "RFID does not require line-of-sight access to read, the read range of RFID is larger than that of a bar code reader, and tags can store more data than bar codes" (p. 30) and readers can simultaneously communicate with multiple RFID tags.

"RFID delivers significant increases in productivity, reduces labor costs, and enhances information for decision making" (Stambaugh & Carpenter, 2009, p. 40). The technology also provides advantages in security, authorization, safety, convenience, and process efficiency. "RFID can help supply chain partners improve logistics efficiency, responsiveness, enhanced service, reduce labor costs, improve out-of-stock rate, and reduce inventory level" (Chuang & Shaw, 2008). RFID application in supply chain management offers solutions to transparency problems. "RFID technology can be used to: (a) reduce the time taken to reorder shipments, (b) reduce product shrinkage and theft, (c) improved [sic] tracking of pallets, cases and individual products, and (d) provide better planning and optimization of inventory and reusable assets" (Coltman, Gadh, & Michael, 2008, p. iii). Among all industries, supply chain reaps the most benefit from RFID. "Retailers lose between $180 billion and $300 billion annually because they have imprecise ability to maintain constant and accurate inventory data" (Hildner, 2006, p. 135).

Challenges and Issues with RFID

Although RFID applications provide potential and promising benefits, there are several challenges that arise from technical and usage aspects. "The likelihood of several potential security and privacy risks varies according to the type of RFID technology used as much as according to the context in which RFID is implemented" (OECD, 2008, p. 14).

There are three main issues associated with this: (a) privacy concerns, (b) security, and (c) integrations with legacy systems (Weinstein, 2005). Privacy issues loom as one of the biggest threats to the success of RFID (Michael & McCathie, 2005). "Several privacy and civil rights groups are concerned about, and have even protested against, RFID technology deployment" (Hennig, Ladkin, & Sieker, p. 3). Opponents argue that the implementation of RFID in some industries is another step in the consumer's loss of privacy (Willey, 2007). "Businesses must realize that the cost of obtaining and networking consumer information could ultimately dissipate the privacy of consumers, which will lead to distrust" (Hubbell & Redding, 2003, p. 49). The second big concern associated with RFID is security. In general, security risks associated with the use of RFID system (tags, readers, communications) include "availability, integrity, and confidentiality" (OECD, 2008, p. 14). "Companies need to be aware of the security risks, such as profiling, eavesdropping, denial of service attacks and inventory jamming" (Ngai & Gunasekaran, 2009, p. 3). The third main issue with RFID is the integrations with legacy systems. Sule and Shah (2004) state that "the issue starts right from integrating the readers for identifying the data, to monitoring the data in the ERP and SCM systems, to later manage this data. The most likely areas where challenges can be foreseen are (p. 6):

- Incomplete packages and inflexible solutions need to integrate legacy,
- Need to incorporate new functions,
- Diversity in technological standards, and incompatibility in business processes.

Applications of RFID Technology in Different Industries

Several industries implement RFID in all kinds of fields. Major industries adopting RFID in a large scale include aerospace, defense, consumer packed goods (CPG), healthcare, logistics, manufacturing, pharmaceuticals, retails, and libraries. RFID is also used in fields such as "electronic article surveillance (EAS), document authorization, access control, production traceability, employee monitor, environmental test, electronic finance, mass control, exercise time, transportation routing, industrial automation, and supply chain integration" (Yu, 2008, p. 401).

RFID in aerospace industry. Aerospace, automotive, and industrial products are three manufacturing sectors that are expected to have the greatest RFID market growth. "RFID applications in those three industry segments [are] expected to grow from $71.3 million in 2005 to $225.7 million in 2012" (Neil, 2006, p. 2). Boeing has used RFID technology in inbound activities. It required about 60 suppliers to tag their shipments when delivering major systems to Boeing dreamliner project (Hannon, 2007). "Boeing selected RFID to track from 1,700 to 2,000 mission-critical parts on each of its 787 jetliners, parts that particularly expensive or that require frequent maintenance and replacement" (Staff, 2009, p. 1). Boeing managed to achieve two main benefits from RFID adoption: improved maintenance operations and improved traceability (Blanchard, 2009).

In 2008, the global airline industry lost around $3 billion as a result of mishandled luggage (Karp, 2010). The adoption of RFID has already helped reduce this problem. This will save the industry US$760 million annually. It is expected that "the passenger claims will be reduced by 5.7 million when RFID technology is adopted … the sector of the RFID tags market in airline baggage is scheduled to rise from $20 million in 2006 to $100 million in 2016" (Zhang, Ouyang, & He, 2008, p. 107). The industry has started to achieve some improvement in baggage handling. "Mishandled bags fell 22.6% from 42.4 million in 2007 to 32.8 million in 2008" (Karp, 2010, p. 40).

RFID in defense industry. "The Defense Department and Wal-Mart are leading the way in pushing for aggressive deployment of RFID in the hopes that the technology will cut supply-chain costs and improve efficiencies" (Bacheldor, 2003, p. 30). Like many major retailers, the U.S. Department of Defense (DoD) mandated its suppliers that eventually anything sold to them must be tagged with an RFID chip (Hartman, 2005). Initially, the U.S. DoD wanted all of its 43,000 suppliers to implement RFID by January 2005 (Bacheldor, 2003). It was looking for the same benefits from RFID as Wal-Mart (Weier, 2009).

The Department of Defense is already a globally sophisticated user of active RFID. It is expected that the DoD spends more than $115 billion every year for its RFID solutions (Qiao et al., 2009). In 2004, a policy was issued requiring the implementation of RFID across the DoD (Estevez, 2006). The policy required active tags to be attached on all pallets and containers of all goods moving outside the U.S. through DoD transportation system (Zuckerman & Rowley, 2006). "The U.S. Transportation Command plans to spend $744 million to integrate RFID into the entire Defense supply chain by 2015" (Brewin, 2008, p. 42).

RFID in consumer packaged goods (CPG) industry. "The RFID trend started out with the consumer packaged goods (CPG) groups - that was the whole initiative a few years ago with Wal-Mart"(Kos, 2009, p. 21). It is anticipated that the largest use of RFID within the next ten years is in tags to track the movement of consumer product goods from the manufacturer to the point of sale (Garfinkel & Holtzman, 2005). A number of packaging companies have been mandated by their customers to implement RFID at the case and pallet level; experts believe that many opportunities exist for early adopters of RFID technology within packaging industry (Vijayaraman, Osyk, & Chavada, 2008). "The early thinking about item-level tagging was driven largely by Consumer Packaged Goods (CPG) companies, which sell low-value, high-volume goods” (Roberti, 2006, p. 56). Item-level tagging helps companies to minimize counterfeiting and improve on-shelf availability. The U.S. apparel industry has adopted RFID in (CPG) applications. This early wins of RFID in the apparel industry will set the groundwork for widespread use of RFID in CPG (Hardgrave, 2010). One of the challenges facing the CPG industry's use of RFID labels is the concern about the fragility of the tiny chips and antennas. Potential damage including physical breakage or damage of the RFID tag may occur on virtually every step of the conversion process, from initial assembly, through application of the inlay and winding of the roll-stock (Kos, 2009).

RFID in health care. RFID technology “has potential applications in hospitals and health-care facilities to help staff members track medical supplies, equipment, and even patients” (Rowe, 2009, p. 21). Other uses include monitoring environmental conditions e.g. temperature or humidity level (Bosavage, 2009). “Hospitals are using RFID for asset tracking to streamline workflows and to improve health care processes; use of RFID at hospitals has tripled from 2005 to 2008” (Attaran, 2009, p. 48). HIPAA (Health Insurance Portability and Accountability Act of 1996) mandates privacy, confidentiality and security requirements on confidential information such as patient personal identity or medical conditions (Yang et al., 2009, p. 2). Privacy protection and security problems are two of the main concerns associated with the adoption of RFID in the healthcare industry (p. 3). A recent report expected that the market for RFID tags and systems in healthcare will rise rapidly from $94.6 million in 2009 to $1.43 billion in 2019 (Harrop, Das, & Holland, 2009).

RFID in logistics and supply chain management. RFID is increasingly adopted in logistics and supply chain management in recent years, particularly in the US and Europe

(Ngai, 2009). Early adopters have enjoyed several benefits from RFID mainly in optimization and efficiency areas (Azevedo & Ferreira, 2009). Other deployment benefits include eliminating shipping and receiving errors, improving productivity, establishing traceability, and achieving inventory control and accuracy (Napolitano, 2010). RFID is a flow control technology, and tracking is the typical application of RFID in logistics management (Shi, Pan, & Lang, 2009). The promise of RFID in logistics is to make each item visible by providing transient information about where goods are, where they are destined, and who has title to them as they pass through a distribution chain (Dyson & Dean, 2003). For better supply chain management, “RFID may be used in demand management, order fulfillment, manufacturing flow management, and return management” (Sabbaghi & Vaidyanathan, 2008, p. 74).

RFID in manufacturing. RFID technology has been used in manufacturing industry and has offered many benefits to manufacturing businesses. The market is expected to grow to reach revenues of $261.8 million in 2012 (The total North American RFID, 2006). “The total North American RFID market for manufacturing and logistics generated $74.8 million in 2005” (p. 1). “RFID can reduce the amount of paper needed to create the product, it allows for better tracking of inventory, more accurate status of WIP, fewer manufacturing errors and a higher quality product” (Waggoner, 2008. p. 45). Jones et al. (2007) state that RFID technology allows for locating the correct assets and time and provide information about each individual asset and its physical status. “RFID offers the unique ability to provide benefits across the four stages of a product's life cycle: production, distribution, service and disposal” (RFID's move upstream, 2009, p. 158). Manufacturers are also cutting costs by using RFID to gain visibility into production-line processes. This is achieved through the integration of components, process and testing data using RFID-enabled work-in-process. This creates a detailed history of manufacturing activities and provided an accurate record of components and assemblies as they come together as finished products (Aichlmayr, 2008). Unlike most of industries that adopt RFID technology, protection of privacy is not an issue in manufacturing applications (Baudin & Rao, 2007).

RFID in pharma. The pharmaceutical industry is currently using RFID technology to combat drug counterfeiting (Crooker, 2009). The World Health Organization estimated that 10% of all pharmaceuticals worldwide are believed to be counterfeit (Young, 2005). The U.S. “Food and Drug Administration (FDA) called for the pharmaceutical industry to apply RFID tags to pallets and cases by 2007” (Juels, 2005, p. 6). It is expected that the adoption of RFID will “yield short-term benefits for businesses from combating the estimated US$1 billion to US$12 billion loss from counterfeit drugs” (Gale, Rajamani, & Sriskandarajah, 2006, p. 3).

In pharmaceutical industry, RFID is mainly used to “track and trace pharmaceuticals, prevent product theft and fraud, and avoid replacement costs associated with product recalls and diminished brand value” (RFID pilot takes pharma, 2007, p. 54). An analysis revealed that “RFID in healthcare and pharmaceutical applications markets earned revenues of $370 million in 2004, and estimates indicate that it will reach $2,318.8 million in 2011” (Banerjee & Gouthaman, 2006, p. 43).

RFID in retail. In 2008, the total consumption of RFID tags in the retails industry was 468 million (Weier, 2009). RFID retail market revenue was $400.2 million in 2004, and is expected to grow to $4,169 million by 2011 (Bhattacharya, Chu, & Mullen, 2008).

The use of RFID in food supply chain continues to rise and is estimated to be approximately $5 billion in 2018 (Attaran, 2009). "Wal-Mart buys $178 billion dollars worth of packaged goods annually, and is looking to RFID to improve visibility into inventories from distribution centers through to retail shelves" (Baudin & Rao, 2007, p.3). Some of the common uses of RFID in retail industry are tracking, inventory management, supply chain management, shrinkage, in-stock correction, and authentication (Kumar, Anselmo, & Berndt, 2009). For instance, temperature-controlled supply chains, or cold chains, encounter 56% damage to perishable food of all product shrinkage in the United States (White, 2007). By adopting RFID technology, such losses will eventually be minimized. Other applications include "reduction in the number of incorrect manual counts, unreported stock loss, mislabeling, and inaccessible/ misplaced inventory" (Azevedo & Ferreira, 2009, p. 14).

Common constraints that can impede RFID usefulness within retail industry include extreme temperature ranges, labeling standards and packaging (Sellitto, Burgess, & Hawking, 2007). In addition to this, security issues and data privacy remain as the two major concerns associated with the use of RFID in retailing industry. Privacy concerns were that initially hampered the first major RFID retail trials in the United States (Coltman, Gadh, & Michael, 2008). "Consumer action groups like the Electronic Frontier Foundation, Electronic Privacy Information Center, or CASPIAN have successfully prevented the introduction of item-level tracking at Wal-Mart and other store chains" (Baudin & Rao, 2007, p. 10).

RFID in library. Libraries are a suitable business for adopting RFID systems because the adoption of this technology offers new services, improves existing services, and increases customer satisfaction. These factors are more important than return on investment (Curran & Porter, 2007). "RFID systems can improve the efficiency of the main processes carried out in any library, increase the quality of service provided, quick identification of books on the shelf and stocktaking" (p. 600). "Libraries have implemented RFID applications in collection management, circulation services, and inventory operations to employ the functions of identification, rapid response and durability to enhance efficiency and accuracy" (Yu, 2009, p. 399). The use of RFID technology in libraries is gaining momentum. The number of libraries using RFID technology worldwide tripled from 2007 to 2009 (Boss, n.d).

RFID Technology: The Future Trend

It is estimated that the value of the RFID market in 2009 was $5.56 billion compared to $5.25 billion in 2008 (Stambaugh & Carpenter, 2009). "According to a forecast, the global RFID industry will be valued at $9.7 billion by 2013, equaling nearly a 15 percent annual growth rate over the next five years" (Attaran, 2009, p. 46). RFID marketplace has grown. In 2008, the global market worth $5.29 billion. "The tagging of pallets and cases as mandated by retailers in 2008 amounted to 325 million RFID labels" (Blanchard, 2009, p. 51). By 2015, the value of the total market, including systems and service, is expected to reach $24.5 billion (Das, 2005).

The food supply chain is expected to use RFID applications more than any other application. Approximately $5 billion will be spent by the food supply chain industry on RFID technology in 2018 (Attaran, 2009). The strongest five-year (2008-2014) expected revenue growth will be realized within five applications segments: supply chain management item-level tracking (22.9%), cargo tracking and security (22.7%), real-time locating systems (28.2%), point-of-sale contactless payments (23.7%), and animal ID (22.8%) (Trebilcock, 2009, p. 9). "RFID is expected to grow at approximately 20 percent for the next five to 10 years and companies will need to be prepared to adopt the technology" (Yug, Patankar, & Legnine, n.d, p. 8).

Lean Manufacturing

This section provides background about lean manufacturing in details. This includes the history of waste reduction thinking, Toyota Production System (TPS), lean manufacturing, types of waste in lean production, the five key lean principles, and benefits of lean change initiatives.

History of Waste Reduction Thinking

Waste reduction/lean thinking is not a new management practice or concept as it has been on the leading front for manufacturing automobiles since the advent of Henry Ford's assembly lines in the early 1900s (Stacks & Ulmer, 2009). "Henry Ford developed a production system focused on high output, continually optimized workflow and elimination of waste" (Schiele, 2009, p. 10). Henry Ford's books, *My Life and Work* (1922) and *Moving Forward* (1930), describe lean manufacturing techniques (Stier, 2003). "These references are a strong indication that lean manufacturing actually began in the United States decades ago" (p. 2). Henry Ford perfected the mass-production philosophy using the assembly line to manufacture large volumes of affordable cars (Jordan & Michel, 2001). Taiichi Ohno, the father of Toyota Production System (TPS), revealed that he learned most of his methods from Ford who described lean manufacturing very explicitly in his two books (Levinson, 2009).

Toyota Production System (TPS)

Waste reduction philosophy continued to gain the interest of several manufacturing practitioners, including Taiichi Ohno, who later invented the Toyota Production System (TPS). “After World War II, Toyota engineers Taiichi Ohno and Shigeo Shingo built on Ford's earlier work and developed what is known as the Toyota Production System” (Schiele, 2009, p. 10). Within Toyota Corporation, four prominent people are credited with the development of TPS: “Sakichi Toyoda, who founded the Toyoda Group in 1902; Kiichiro Toyoda, son of Sakichi Toyoda, who headed the automobile manufacturing operation between 1936 and 1950; Eiji Toyoda, Managing Director between 1950 and 1981 and Chairman between 1981 and 1994; and Taiichi Ohno” (Becker, 2001, p. 64). In 1950, Toyota faced series of problems, including (a) fragmented markets demanding many products in low volumes, (b) tough competition, (c) fixed or falling prices, (d) rapidly changing technology, (e) high cost of capital, and (f) capable workers demanding higher levels of involvement (Dennis, 2007). “Taiichi Ohno solved these problems one by one, and pushed his system through Toyota” (p. 12). Toyota Production System (TPS) and lean manufacturing are well-known management practices that have been implemented in production practices since the 1950s (Pande, 2009). The TPS system was developed to eliminate production waste and achieve the best quality, with lowest cost, and shortest lead time (Liker, 2003).

Lean Manufacturing

The term *Lean Manufacturing* was first introduced by an MIT researcher, John Krafcik, in a Fall 1988 article, "*Triumph of the Lean Production System*” (Cusumano, 1994). Lean manufacturing is a practice that seeks to minimize the amount of resources (including time) used in the various activities of a business. Lean manufacturing involves identifying and eliminating non-value adding activities. These types of activities are frequently referred to as “waste” in lean manufacturing (Brintrup, Roberts & Astle, 2008). Lean manufacturing can be best described as a combination of the best techniques of mass and craft production. Womack and Jones (1996) stated that “those techniques are the ability to provide a customer with a wide variety of products, at the right time and place, at the lowest cost and the highest quality” (Mcleod, 2009, p. 4).

Russell (2009) stated that the term lean “refers to using less of everything during production – less labor, less manufacturing space, less equipment, less inventory, and less engineering inputs during development and processing – all of which results in fewer defects and more variety” (p. 721). Spencer and Plenert (2007) defined lean as a systematic approach to identifying and eliminating non-value-added activities through continuous improvement by flowing the product at the pull of the customer in pursuit of perfection (p. 34). Dennis (2007) described The House of Lean Production, shown in Figure 2, which consists of six main elements: (a) stability, (b) standardization, (c) just-in-time, (d) Jidoka (automation with a human touch), (e) involvement, and (d) customer focus. Stability and standardization are the foundation of the lean system. Just-in-time deliveries of parts of products and Jidoka (or automation with a human mind) are the walls of the system. The goal of the system is to deliver the highest quality to the customer, at the lowest cost, in the shortest lead time (customer focus). Employees’ involvement is the heart of the system who they continually seek a better way of doing things (Dennis, 2007).

- Stability is achieved through standardized work, 5S, Jidoka, TPM, heijunka, and kanban.

- Standardization is achieved through visual order (5S), Hoshin planning, kanban, A3 thinking, and standardized work.
- Just-in-time is achieved through flow, heijunka, takt time, pull system, kanban, visual order (S5), robust process, and involvement.
- Involvement is achieved through standardized work, S5, TPM, kaizen circles, suggestions, safety activities, and Hoshin planning.
- Jidoka is achieved through poka-yoke, zone control, 5S, problem solving, abnormality control, separate human and machine work, and involvement.
- Customer focus is achieved through Hoshin planning, takt, heijunka, involvement, lean design and A3 thinking.

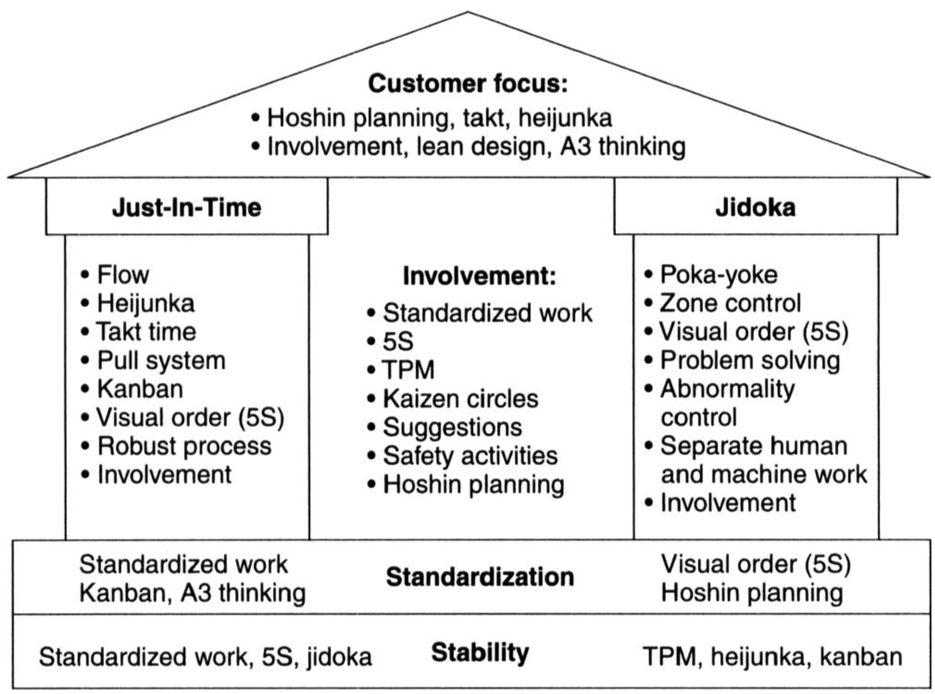

Figure 3. The House of Lean Production

Source: Dennis, P. (2007). *Lean production simplified (2nd ed.)*. University Park, IL: Productivity Press. (p. 18).

Types of Waste in Lean Production

Muda is a Japanese word that means waste. Taiichi Ohno suggests that *muda* accounts for up to 95% of all costs in non-lean manufacturing environments (Kilpatrick, 2003). The focus of lean thinking is to reduce and ultimately remove all kinds of waste (muda) from a company's processes. Taiichi Ohno initially identified seven types of muda. He later added the eighth. These are (1) overproduction, (2) waiting (human or machine), (3) transportation, (4) over-processing, (5) inventory or work in process, (6) motion, (7) rework, and (8) un-utilized people (Adams, 2006).

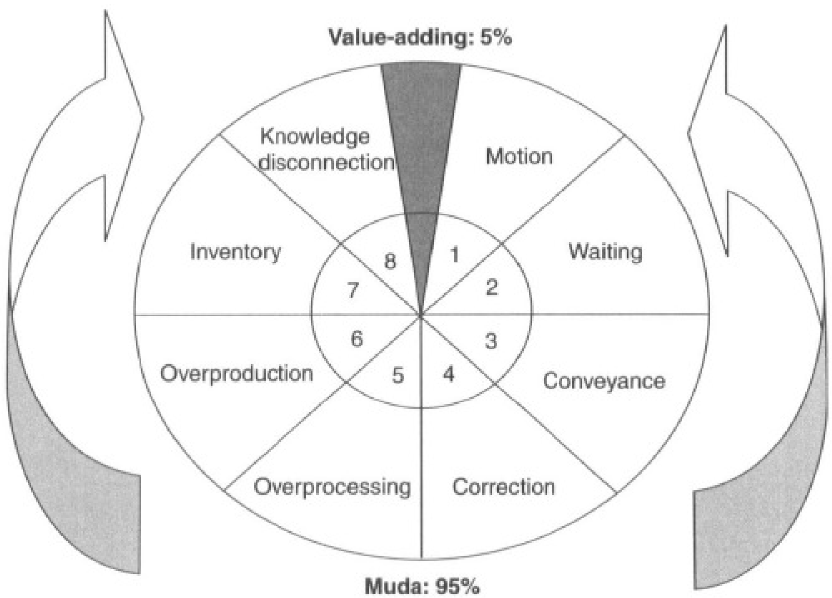

Figure 4. The 5:95 Ratio of Muda Common in Most Operations

Source: Dennis, P. (2007). *Lean production simplified (2nd ed.)*. University Park, IL: Productivity Press.

The waste of overproduction. Overproduction simply means making more, earlier or faster than required by the next process (Alukal, 2003). Overproduction results in overtime that customers don't pay for and large amounts of floor space clogged with work-in-progress skids and process bottlenecks (Rizzo, 2009). Taiichi Ohno saw overproduction as the root of all manufacturing waste. For example, (a) Overproduction makes workers busy making things that nobody ordered (motion waste), (b) Overproduction creates unnecessary raw materials, parts, and WIP (inventory waste), and (c) Overproduction makes early detection of defects is more difficult with large batches (Dennis, 2007). To avoid this kind of waste by applying lean principles, manufacture based upon a pull system, or produce products just as customers order them (Kilpatrick, 2003).

The waste of waiting. Waiting waste is the “idle time waiting for such things as manpower, materials, machinery, measurement or information” (Alukal, 2003, p. 30). Lean requires that all resources are provided on a just-in-time (JIT) basis to avoid this type of waste (Kilpatrick, 2003). Examples of waiting waste “include downtime, machine breakdowns, long make-readies and setups, and defective product awaiting inspection” (Rizzo, 2009, p. 21). Waiting waste also refers to situations when:

- A worker waits for material to be delivered
- A worker waits to clear a stopped line, or
- Employees stand around waiting for a machine to process a part (Dennis, 2007).

The waste of unnecessary transportation. “Transporting waste occurs when supplies, materials, WIP, and raw materials inventory are scattered across a plant” (Rizzo, 2009, p. 21). This situation leads to extra movements of people, raw material and products that are considered as non-value adding activities (waste). In lean, this waste can be avoided by shipping materials “directly from the vendor to the location in the assembly line where it will be used…this technique is called *point-of-use-storage* (POUS)” (Kilpatrick, 2003, p. 1).

The waste of unnecessary inventory. This waste refers to keeping a stock of materials that exceed the need for a one-piece flow through the manufacturing process. This may include raw materials, work-in-process or finished materials/goods (Alukal, 2003). “The muda of inventory is related to the keeping of unnecessary raw materials, parts, and WIP” (Dennis, 2007, p. 25). Excessive inventory include dollar costs of purchased materials and used floor space (Rizzo, 2009).

The waste of over-processing. “Extra processing refers to any actions that don't add value” (Rizzo, 2009, p. 22). More specifically, over- processing waste is the extra effort that adds no value to the product from the customer’s point of view (Alukal, 2003). Over-processing can also refer to “the redundant checks or processes intended to backup or support certain operations. These usually serve as safety or quality checks” (Wilcox, 2008, p. 12).

The waste of unnecessary motion. The waste of motion is referred to as “any movement of people, tooling and equipment that does not add value to the product or service” (Alukal, 2003, p. 30). Examples of such unnecessary motion include time spent searching for and retrieving tools and materials, poor process layout (Rizzo, 2009). To identify this type of waste, value stream mapping is used (Kilpatrick, 2003).

The waste of defects. This type of waste is related to fixing or remaking of defective products (Dennis, 2007). Defect products require inspection, sorting, scrapping, downgrading, and replacement or repair (Alukal, 2003). The waste of defects also includes the cost of time and raw materials spent manufacturing unacceptable product (Rizzo, 2009). Rework of defect product “is a silent waste that seems acceptable in many companies for two reasons. It is either too difficult to remedy or no one recognizes it for what it is” (Wilcox, 2008, p. 11).

The waste of people. The waste of people occurs when people's mental and creative skills and experience are not fully utilized (Alukal, 2003). Other causes of this waste may result from employees' knowledge, skills, creativity, process experience, and teamwork not being fully used (Rizzo, 2009). "More common causes for this waste include – poor workflow, organizational culture, inadequate hiring practices, poor or non-existent training, and high employee turnover" (Kilpatrick, 2003, p. 2) .

The Five Key Lean Principles

To get lean, companies need to fully understand where they want to go and how they want to get there (Cohen, Hasan, Stonich, & Waco, 2009). Womack and Jones (1996) summarized lean thinking in five principles. To successfully adopt and continuously sustain lean philosophies, companies need to follow these five principles: (1) identify value, (2) map the value stream, (3) create flow, (4) establish pull, and (5) seek perfection.

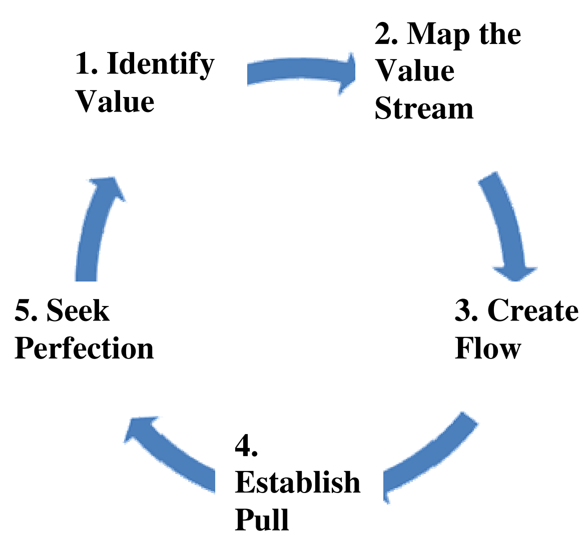

Figure 5. The 5 Key Lean Principles

Source: Lean Enterprise Institute. Principles of Lean www.lean.org/whatslean/principles.cfm Accessed April 9, 2010.

Principle one: Identify value. The customer defines value in a lean thinking system. Product design objectives are identified though the definition of value. Value may include reliability, maintainability, availability, multiple functions, and attractive styling (Dettmer, 2001). "Value is expressed in terms of how the specific product meets the customer's needs, at a specific price, at a specific time" (Nave, 2002, p. 75).

Principle two: Map the value stream. After value is identified, activities that involve fulfilling value are identified. The sequence of these activities is called the value stream (Nave, 2002). In this step, the product is required to go through three critical management tasks: problem solving, information management, and physical information (Dettmer, 2001).

Principle three: Create flow. "Flow is the uninterrupted movement of product or service through the system to the customer" (Nave, 2002, p. 75). The objective of lean system is to make work valued by the customer move through the system quickly and smoothly (Dettmer, 2001).

Principle four: Establish pull. Womack and Jones (1996) defined *Pull* as "a manufacturing philosophy based on synchronizing production objectives and rates with actual customer demand, rather than on forecasts or arbitrary finished inventory levels" (Dettmer, 2001, p. 9). Through pull philosophy, the company should provide the product or service only when the customer needs it - not before, not after (Nave, 2002).

Principle five: Seek perfection. This is a constant effort attempting to: remove non-value adding activities, improve flow, and satisfy customer delivery needs (Nave, 2002). Womack and Jones (1996) stated that lean thinking has no end to the process of reducing effort, time space, cost, and mistakes, while offering products that continually approach exactly what customers want (Dettmer, 2001, p. 9).

Benefits of Lean Change Initiatives

The primary lean goals are to improve quality, eliminate waste, reduce time, and reduce total costs (Barker, 1994). Ferch (1998) stated that lean manufacturing can help to reduce waste by 40 per cent, cut costs by between 15 and 70 per cent, decrease space and inventory requirements by 60 percent, push productivity up between 15 and 40 per cent, and cutting process changeover by 60 per cent (Bhasin & Burcher, 2006). Proper application of lean can lead to the following positive improvements in the manufacturing environment (Dunlop & Fitzgerald, 2007):

Table 2

Positive Improvements as a Result of Lean Implementation

Area	Improvement
Productively	Increases between 10-100%
Throughput times	Decrease between 40-90%
Inventories	Decrease between 40-90%
Scrap	Reduces between 10-50%
Space	Savings between 30-60%
Overtime	Decreases up to 90%
Safety-related injuries	Decrease up to 50%
Product development time	Decreases up to 30%

Four Selected Manufacturing Functions

For the purpose of this research, four manufacturing functions have been selected for investigation. These are work-in-progress management, inventory management, manufacturing asset tracking and maintenance, and manufacturing control. The following section describes these four functions in detail.

Work-in-Progress Management

Unfinished items for products in a production process(es) that is normally found within production steps or sub-processes of a production process is known as work in progress (WIP). Such unnecessary inventory indicates the existence of unreliable production process. In lean manufacturing, this work-in-progress is considered a type of waste. Lean practices aim to reduce work-in-progress to free up resources that could be used elsewhere in the manufacturing process. The lean idea is that less money should be wrapped up in work-in-progress inventories (Mcleod, 2009). Excess work in progress results in many delays and longer lead-time that increases the cost of production. Manufacturers are using RFID to gain visibility into production-line processes. This is achieved through the integration of components, process, and testing data using RFID-enabled work-in-process. This creates a detailed history of manufacturing activities and provides an accurate record of components and assemblies as they come together as finished products (Aichlmayr, 2008).

Inventory Management

Inventory is the keeping of raw materials, supplies, components, work in progress, and finished goods at various points throughout the production and logistics channels (Ballou, 2004). "Inventories can represent from 20% to 60% of a manufacturing company's total assets and the cost for carrying inventory increases operating expenses and decreases profits"

(Visich, Powers, & Roethlein, 2009, p. 122). It is important to have the sufficient stock when needed – the stock should not be too much or too little. Effective inventory management should implement just-in-time practices that ensures items be available at the right time, at the right quantities, and at the right location (Saygin, 2007). Frazelle (2002) indicated that businesses can improve inventory management through one or more of these five approaches: improve forecast accuracy, reduce cycle times, lower purchase order/setup costs, improve inventory visibility, and lower inventory carrying costs (p. 92). RFID applications have been used to monitor and control inventory in a variety of manufacturing processes including raw materials receiving, the transportation of these materials and components to the storage spaces of point of use on the line, the transportation of work-in-progress and finished goods (Visich, Powers, & Roethlein, 2009).

Manufacturing Asset Tracking and Maintenance

The purpose of asset tracking is to “ensure products arrive at the right location, at the right time and in the right condition. There are two primary technologies used for asset tracking: barcodes and RFID” (Drum, 2009, p. 37). Firms employing RFID in an asset tracking achieve benefits in the areas of greater visibility, more accuracy, fast tracking, and higher efficiency. It is also important to understand the importance of asset maintenance. A study “shows that nearly 87% of respondents consider asset maintenance as either extremely important or very important to their organizations' success, yet only 7% say they are completely satisfied with their maintenance performance” (Jusko, 2007, p. 30). Poorly managed equipment maintenance can lead to lost production time, missed deliveries, and increased machines’ and workers’ idle times.

Manufacturing Control

The manufacturing control is all activities and processes related to the management and monitoring of the product as it is being produced. This includes planning activities, monitoring the progress, and executing the manufacturing plans (Leitão, 2009). Manufacturing systems are becoming more complex, and controlling them in a real-time becomes a big challenge (Vlad, Ciufudean, Graur, & Filote, 2009). RFID systems have been used in manufacturing to control and track products moving on assembly lines since the early 1990s (Visich, Powers, & Roethlein, 2009). The focus is how to implement RFID technology in manufacturing control systems to improve the flexibility of the production process (Panjaitan & Fery, 2006).

Literature Related to Previous Assessment Tools and Surveys

This section presents an overview of tools and surveys used in previous research studies. The first part of this section identifies and reviews a summary of seven lean assessment tools and five lean research surveys. The second part identifies and reviews six different RFID research surveys.

Review of Lean Assessment Tools and Surveys

There are a number of lean assessment tools that have been developed to help businesses assess the degree of their leanness. For the purpose of this reach, seven different assessment tools and five different research surveys were identified and reviewed. Table 3 represents a summary of seven industrial assessment tools and Table 4 represents a summary of five research surveys. The two mentioned tables were borrowed from (Doolen & Hacker, 2005).

Table 3

Summary of Seven Industrial Assessment Tools

Survey Identification	Description and Lean Aspects Included
Lean Learning Center (2003), The Lean Company Survey	This benchmark survey requests information on (a) changes to attributable to lean efforts, (b) infrastructure details (who is responsible for lean efforts), (c) functional involvement in lean, and (d) implementation types of lean tools implemented.
Robert Abair Associates, Inc. (2002). Lean Checklist	This tool includes a range of management and lean practices, such as lean education, training, statistical

Self-assessment.	process control, JIT, kaizen, heijunka, 5S, SMED, poka-yoke, waste, workforce flexibility, performance measures, and QFD.
Northwest High Performance Enterprise Consortium (2002) HPEC Assessment	This tool measures the outcomes resulting from a lean implementation. This includes change in management, quality achievements, employee involvement, flexible manufacturing practices, maintenance practices, inventory management processes, and new product development processes.
Wisconsin Manufacturing Extension Partnership (2002). Lean Business Assessment	This self-assessment tool addresses 10 lean principles and a range of lean practices including flow production, leveled mixed-model production, quick changeover, automation with human touch, pull systems, autonomous maintenance, and kaizen.
Wisconsin Manufacturing Extension Partnership (2001). How Lean is Your Culture	This short self-assessment is designed to help managers identify cultural factors that can support or inhibit the sustainability of lean manufacturing initiatives.
Jordan and Michel (2001). Survey of Perceptions of Company’s Leanness	This is a 36-question survey tool used to assess a company’s leanness. There are three different versions of the survey: (a) executives, (b) employees, (c) investors, (d) suppliers, and (e) customers.

Lean Enterprise Implementation Group (1999). The 360° Lean Audit	This assessment tool is used to evaluate the level of implementation of policies, process management, lean tools and techniques, and supply chain integration activities. Assessment included workplace organization, waste, flow, pull, quality, standards, PDCA, equipment effectiveness and reliability, and level production.

Table 4

Summary of Five Lean Research Surveys

Survey Identification	Description and Lean Aspects Included
Fullerton, McWatters, and Fawson (2003).	This research was based on a survey developed to measure the level of JIT implementation within an organization. Ten JIT elements were defined for the research and 11 corresponding survey items were developed to assess the level of JIT implementation.
Shah and Ward (2003)	This research study was based on an annual survey of manufacturing managers in 1999 by publishers of *Industry Week*. The survey included question on the level of implementation of 22 different lean practices, including practices related to JIT, TPM, TQM, and human resource management.
Nightingale and Mize (2002). Lean Enterprise Self-assessment	This research study describes the structure of an assessment tool created by the Lean Aerospace

Tool	Initiative. This tool included three sections: (a) lean transformation leadership, (b) lifecycle processes, and (c) enabling infrastructure. Fifty-four lean practices are included in this tool.
Perez and Sanches (2000)	This research was based in a field survey of automotive suppliers in Aragon. Data collection included organizational demographics, source of technology innovation, use of flexible production technologies (JIT), and workforce and workplace flexibility measures (teams, job rotation, and training).
Panizzolo (1998)	This research was based on field surveys on Italian manufacturers from a wide range of industrial sectors. The survey items were developed to probe the implementation of lean practices in six different areas of intervention: (a) processes and equipment, (b) manufacturing planning and control, (c) human resources, (d) product design, (e) supplier relationships, and (f) customer relationships.

Review of RFID Assessment Tools and Surveys

There are a number of RFID related studies that have developed surveys to help businesses understand the state of RFID implementation and/or the perception of different stakeholders about this technology. For the purpose of this reach, six different RFID research surveys were identified and reviewed.

Table 5

Summary of Six RFID Research Surveys

Survey Identification	Description and RFID Aspects Included
The National Institute of Governmental Purchasing, Inc (2009).	This study was based on a survey to study the current state of RFID implementation, key market trends, systems' requirements and expenditures. Three groups were examined by this study (current users, interested users, and those who are not planning to adopt RFID). The study concluded that there are significant differences among the three groups.
AMR Research of	500 companies' RFID plans were surveyed in this study. The survey studied the state of RFID implementation such as (a) currently in pilot use, (b) currently in full deployment, (c) plan to implement, (d) plan to evaluate, and (e) have no plans for RFID.
Information- Week RFID Survey (2005).	This research included a survey that targeted IT managers in forty four large firms either currently using or pilot testing RFID.

Computing Technology Industry Association CompTIA (2005).	This study was based on a survey to study the state of RFID. Target respondents included IT resellers, VARs, solution providers, systems integrators, IT end-customers, and others directly involved in the delivery of IT products/services. In total, there were 80 respondents.
Lin (2008)	This research was based on a survey developed to study the factors influencing RFID technology implementation by logistics service providers. The data collected a sample of 142 logistics service providers in Taiwan. The examined factors included explicitness of technology, employees support and encouragement, quality of human resources, and governmental support.
Frost & Sullivan, Mountain View (1998).	This study investigated the state of RFID adoption and related workforce issues in North America. The major applications covered in the study included security and access control, manufacturing and logistics management, transportation, and animal tracking.

Summary

Chapter 2 provided a background about lean manufacturing and RFID technology. This section also provided a review of lean assessment tools and surveys and review of RFID assessment tools and surveys. The chapter indicated that RFID and lean are widely used in different industries and gain increased interest. Chapter 3 will provide details about research methodology that was selected for this research study.

Chapter 3 – Research Methodology

Study Design and Study Type

In order to learn about the impact of RFID technology deployments on manufacturing waste reduction and lean practices, descriptive research using a survey was selected. Some of the advantages of descriptive research are that it is informative, can help to identify further investigations, and allows us to study things we cannot manipulate. The disadvantage of this research method is that events cannot be controlled to isolate cause and effect, thus one cannot infer causes. Subsequent sections begin with the study population and sampling and end with a proposed timeline.

Study Population and Sampling

The population for this research included leaders working in the US manufacturing industry with knowledge of lean manufacturing and RFID technology. Those leaders have executive job titles that included management, president, owner, V.P., supervisor, senior, director, leader, executive, CEO, Chief, Chairman and industrial job titles that include (Operations, Production, Plant, Quality, and Maintenance). In addition, job functions included were Manufacturing Production, Corporate Executive, Manufacturing Engineering, Product Design, Quality Management, and Control Engineering. This population includes industries classified by the North American Industry Classification System (NAICS), which include fabricated metal products, machinery manufacturing, computers and electronics, electrical equipment, transportation equipment, furniture and related products, and miscellaneous manufacturing. Finally, only plants with 250 employees or more were considered for this research.

The research sample included those leaders who fit into the above stated population criteria and are currently active US members with the Society of Manufacturing Engineers (SME) and have self-reported that lean manufacturing is their technical interest when applying for the SME membership. Table 6 below represents the selection criteria of the selected recipients from (SME) members for this research survey. This selection is based on the SME Masterfile List categories (see Appendix J).

Table 6

Study Population and Sampling

Criterion	Description
Technical Interest:	Lean Manufacturing
Job Title:	- Executive (all job titles) - Industrial (Operations, Production, Plant, Quality, and Maintenance)
Job Function:	Manufacturing Production, Corporate Executive, Manufacturing Engineering, Product Design, Quality Management, and Control Engineering
Industries:	North American Industry Classification System (NAICS) Industries including: fabricated metal products, machinery manufacturing, computers & electronics, electrical equipment, transportation equipment, furniture & related products, and miscellaneous manufacturing
Plant Size:	250 and over
Geographical areas:	US based members only

Instrumentation Design

For the purpose of this research, a forty-question survey was used to gather data and was administered electronically using the SurveyMonkey website. All questions were close-ended. Thirty five questions were based on a five-point Likert-type scale and five were related to demographic information. Questions were developed using two approaches: first, 23 questions were developed utilizing information from existent literature mainly from a study conducted on businesses within the European Union region as shown on Figure 7 (Brintrup, Roberts & Astle, 2008). Second, a panel of experts that consisted of three industry experts and three university scholars verified the selected questions and added 12 more (Appendix F lists the names of these experts). Appendix (G) shows the matrix that was used by the panel of experts to verify the initially selected questions and to add the new questions. The validity of the final instrument was established through a review by this selected panel.

The survey consisted of five sections. The first section contains five demographic and general information questions. These include: what is participants' job, what is their company's primary industry, what is the current number of employees in their company, and how they describe their knowledge about RFID applications in manufacturing. The second section of the survey consists of thirteen questions to explore where the use of RFID technology may improve work-in-progress management through the reduction of the seven common types of waste in lean manufacturing. This is specifically to investigate if there is a significant relationship between lean manufacturing waste reduction and the adoption of RFID technologies in work-in-progress management

Table 7

Toyota Production System Types of Wastage Reduction Through RFID

	Work-in-progress management	**Inventory management**	**Manufacturing asset tracking and maintenance**	**Manufacturing control**
Overproduction	how much of which goods/materials are WIP	how much of which goods/materials are in stock	N/A	Enable automated JIT strategies
Waiting time	Where finished goods/materials are	where finished goods/raw materials are	Know where assets are/ Know condition of assets	Increase product autonomy in distributed control systems
Inefficient transportation	where WIP goods/materials should be brought to	where nearest finished goods /raw materials are	Know location of nearest available assets	Where applicable implement automated routing on production lines
Inappropriate processing	which goods/materials are suitable for which processing	which raw materials suitable for which processing	Eliminate production errors due to incorrect manufacturing asset maintenance	Know which goods/materials are suitable for which processing
Unnecessary inventory	Eliminate mistaken WIP goods/inventory association improve visibility level	Improve inventory visibility	Eliminate unnecessary buffers waiting for asset maintenance	N/A
Unnecessary motion	Eliminate manual data collection	Eliminate manual counts	Eliminate manual checks for maintenance	N/A
Rejects & defects	Reduced scraps due to improved traceability	finished goods /raw materials expiry dates and implement suitable protocols	N/A	N/A

The third section of the survey consists of nine questions to explore where the use of RFID technology may improve inventory management through the reduction of the seven common types of waste in lean manufacturing. These questions were designed to investigate whether there is a significant relationship between lean manufacturing waste reduction and the adoption of RFID technologies in inventory management.

The fourth section of the survey includes six questions to explore where the use of RFID technology may improve manufacturing asset tracking and maintenance through the reduction of the seven common types of waste in lean manufacturing. This set of questions helped determine if there is a significant relationship between lean manufacturing waste reduction and the adoption of RFID technologies in manufacturing asset tracking and maintenance processes.

The fifth section of the survey consists of seven questions to explore where the use of RFID technology may improve manufacturing control through the reduction of the seven common types of waste in lean manufacturing. This part aimed to investigate if there is a significant relationship between lean manufacturing waste reduction and the adoption of RFID technologies in manufacturing control processes.

All the 40 questions on the survey are close-ended. Questions six to 40 used the following five-point level of agreement Likert-type scale: (1) Strongly disagree, (2) Disagree, (3) Neutral, (4) Agree, (5) Strongly agree. A copy of the survey is included in Appendix A.

Instrument Validity

In this study, construct validity was determined by content validity, internal consistency, and principal components analysis. Content validity was established by an extensive literature review, by the research committee, along with a panel of six experts in the subject matter field consisting of three university professors and three lean manufacturing industry practitioners. The survey was also sent to the Marketing and Research Department at the Society of Manufacturing Engineers to gain their feedback. They reviewed its contents and accepted it. Construct validity was tested through the use of Cronbach’s alpha coefficient to determine the internal consistency of each individual item and of the main scales as a whole. Principal component analysis was also used to determine how, and to what extent, the items are linked to their underlining factors. "Content validity refers to the extent to which items or questions adequately capture the concept to be measured in the study" (Zhang, Prybutok, & Koh, 2006, p. 60).

Scales Reliability

The Statistical Package for the Social Sciences (SPSS) was used to calculate the Cronbach's alpha coefficient values to test the instrument's construct validity. Cronbach's alpha internal consistency reliability tests have been utilized to measure the degree to which participants' responses are consistent and measure a single un-dimensional latent construct (Gall, Borg, & Gall, 2003).

Pilot Study

After face and content validity were established by the panel of experts, a pilot study was conducted on an Eastern Michigan University's Supply Chain Management graduate class in July 2010. This pilot study was conducted mainly to validate the relevance, accuracy, and wording of the contents of the survey. A face-to-face 30-minute session was administered. The URL for the online survey was given to the students and they were asked to access the survey on their computers in the class. Then students were asked to complete the online survey and provide any feedback they may have had. Most of the participating students worked for manufacturing companies and were asked to comment on the validity of the questions. They were also asked to comment on the overall design of the survey, readability (including grammar and ambiguity), ease-of-browsing, and transition from one section to another, and to add any other observations. Comments from the pilot study were considered that include adding definitions of the seven types of waste, adding definitions of the four selected areas, and including a brief goal at the beginning of each of the four main scales in the survey. Some modifications to the survey were made.

Data-gathering Procedure

The final format of the survey was electronically created using the SurveyMonkey. An account was purchased for this purpose. The URL link for the survey was sent to the Marketing Research Department at the Society of Manufacturing Engineer (SME). After gaining the Human Subjects Approval for this study (see copy Appendix E), arrangements with SME were made, and a suitable date and time were identified to send the survey out to the selected SME members. The SurveyMonkey recommends that if the survey audience is mostly working professionals, it is best to avoid sending surveys on Friday, Saturday, Sunday, or Monday (SurveyMonkey, n.d). Based on this advice, the survey was sent out on Wednesday, October 6, 2010. The selected participants were invited to participate in the study (a copy of the initial email is included in Appendix C). A first reminder email was sent one week after the initial invitation email and a second reminder sent another week later (a copy of the reminder emails are included in Appendix D). Data collection concluded on Monday, October 25, 2010 (a copy of the official email sent by SME is included in Appendix H). An investigation of non-respondent bias was not implemented based on the reluctance of the SME to further bother its members. All submitted responses were electronically collected, i.e., when participants completed, and submitted, the online questionnaire, their response was automatically sent back and stored on the SurveyMonkey website database where only the survey administrator could access it. The SurveyMonkey offers the option to save data on excel sheets to be used by researchers when analyzing data. After concluding data-collection, all data were saved as Excel spreadsheets and then entered into the Statistical Package for the Social Sciences (SPSS) software to prepare it for data analysis.

Safety, Confidentiality, and Anonymity for Human Subjects

There were no safety concerns or feasible risks to participants associated with the completion of this survey. Participants were not asked to provide demographic information (name, age, or gender). All responses were coded, and confidentiality was maintained. Data were to be presented in aggregate form only and summarized as input for articles, webinars, conferences, and other academic-related events.

Data Analysis

All gathered data were analyzed using the Statistical Package for the Social Sciences (SPSS) version 17 computer software. Data were divided into four scales: work-in-progress management (13 items), inventory management (9 items), manufacturing asset tracking and maintenance (6 items), and manufacturing control (7 items). Each scale includes questions related to one of the mentioned seven types of production waste.

First, the mentioned four measures were assessed. Cronbach's alpha coefficients were calculated to determine the estimated reliability of each scale and of each item within the scale. Statistics for each scale were also computed that include n, mean, variance, and standard deviation. In addition to this, item statistics within each scale were also calculated including item means, item variances, inter-item correlations, item-total statistics (scale mean if item deleted, scale variance if item deleted, corrected item-total correlation, squared multiple correlation, and alpha if item deleted). Second, in addition to using Cronbach's alpha coefficient to assess the internal consistency, factor analysis was used to validate the research instrument construct validity to determine to what extent the items are linked to their underlining factors. Third, items within each scale were examined by calculating mean, standard deviation, item skewness, and item-to-total correlations. Fourth, research hypotheses were tested by computing mode values of each item within each scale to measure the central tendency. This measure suits five-point Likert-type scale data sets. Furthermore, a chi-square test representing residual values for each of the five-point Likert-type scale items was also calculated to make the data analysis much easier to understand. Finally, by computing mean and mode values, all items were divided into two main categories: (a) supported items, and (b) not supported items. Items within each category were ranked based on the extent to which respondents supported these items.

Summary

Chapter 3 provides a description of the population, an overview of the research sampling procedure, reveals the research design, describes steps for ensuring instrument validity and reliability, and explains procedures for conducting this research. This section also provides data collection and data analysis methods procedures. The following chapter presents details about the results from this research study.

Chapter 4 - Results

Data collection began on October 6, 2010, and concluded on October 25, 2010. Questionnaires were electronically sent to a pre-identified sample through the Society of Manufacturing Engineers database system. Out of 1938 sent surveys, a total of 85 questionnaires were completed and returned and out of this number, seven were discarded as incomplete with 78 questionnaires usable. The return-rate was 4.38 percent. Due to the non-disclosure of personal details by the SME, it was not possible to obtain contact details of the selected participants who did not respond to the survey in order to obtain the non-respondent bias. Data from the usable questionnaires were then analyzed using the Statistical Package for the Social Sciences SPSS version 17 for MS Windows for analyses.

Demographic Characteristics of the Sample

The demographic characteristics of the sample data are shown in Table 8 below (respondents' job titles are shown on Appendix I). The respondents' job functions were: (31.3 percent) manufacturing productions, (21.7 percent) manufacturing engineering, (19.3 percent) other job functions, (12.0 percent) quality management, (8.4 percent) corporate executive, and (7.2 percent) product design. More than half of the respondents work in manufacturing production and manufacturing engineering functions.

Respondents worked for different manufacturing industries as follows: (25.6 percent) fabricated metal products, (6.1 percent) machinery manufacturing, (6.1 percent) miscellaneous manufacturing, (3.7 percent) computers & electronics, (3.7 percent) electrical equipment, (3.7 percent) transportation equipment, (2.4 percent) furniture & related products, (48.8 percent) other manufacturing industries. It is important to emphasize that respondents who stated their industry was "other" indicated that they are manufacturing firms that supply different sectors e.g. Aero Space and Medical firms with equipment. Respondents work in four categories of business sizes. This includes: (50.6 percent) 250 – 499 employees, (13.0 percent) 500 – 999 employees, (11.9 percent) 1000 – 2499 employees, (24.7 percent) 2500 and over. All participants had indicated Lean Manufacturing as their technical interest when applying for SME membership. All participants work in senior positions including senior managers, directors, vice presidents and leaders. Appendix I lists the job titles of each participant along with their response date and time.

Table 8

Demographic Characteristics of the Sample

Classification		Count	Percent
Job Function	Manufacturing Production	26	31.7
	Manufacturing Engineering	18	21.7
	Other	16	19.3
	Quality Management	10	12.0
	Corporate Executive	8	8.4
	Product Design	6	7.2
Company's Primary Industry			
	Other Manufacturing Industries	40	48.8
	Fabricated Metal Products	21	25.6
	Machinery Manufacturing	5	6.1
	Miscellaneous Manufacturing	5	6.1
	Computers & Electronics	3	3.7
	Electrical Equipment	3	3.7
	Transportation Equipment	3	3.7
	Furniture & Related Products	2	2.4
Business Size	250 – 499	39	50.6
	500 – 999	10	13.0
	1,000 - 2,499	9	11.9
	2,500 and over	19	24.7

Assessment of Measures

Incomplete responses were excluded from the data analysis. After unusable responses were removed, the usable questionnaires were tested for reliability. The reliability was evaluated using Cronbach's alpha coefficient in order to assess the internal consistency of the five-point Likert-type scale study items utilizing the SPSS software. Cronbach’s alpha is based on the average inter-item correlation and it is the most generally accepted instruments internal consistency reliability test (DeVellis, 2003). Rivard and Huff (1988) suggest that Cronbach's values exceeding alpha coefficient of 0.7 thresholds provide reliability evidence for internal consistency of the measurement scales. Although 0.7 or higher is normally what considered to be an acceptable reliability coefficient, lower thresholds are sometimes used in the literature (Santos, 1999). The closer Cronbach’s alpha coefficient is to 1.0, the greater the internal consistency of the items in the scale (J. Gliem & R. Gliem, 2003). The reliability test is conducted on each individual construct in this study, starting with work-in-progress management, inventory management, manufacturing asset tracking and maintenance, and manufacturing control. The results demonstrated that the Cronbach's alpha coefficient values for work-in-progress management (0.895), inventory management (0.871), manufacturing asset tracking and maintenance (0.869), and manufacturing control (0.888) are all greater than 0.70; hence these are considered to have superficial reliability.

Table 9

Reliability Statistics for the Four Main Sections of the Survey

	Case Processing Summary			Reliability Statistics	
Variable	Cases Valid	Excluded	N	Number of Items	Cronbach's alpha
Work-in Progress Management	69	9	78	13	0.895
Inventory Management	72	6	78	9	0.871
Asset Tracking and Maintenance	72	6	78	6	0.869
Manufacturing Control	69	9	78	7	0.888

The following section provides details about each of the four main sections of the research survey along with the number of questions and corresponding Cronbach's alpha coefficient values for each section.

Work-in-progress Management Items Reliability Test

This 13-question instrument assessed the extent to which subjects believe the use of RFID technology reduces the seven common types of lean manufacturing waste and improves work-in-progress management. Each item used a five-point Likert-type scale: Strongly Disagree (1), Disagree (2), Neutral (3), Agree (4), and Strongly Agree (5). The scores can range from 13 to 65. This section demonstrated internal consistency with a Cronbach's alpha of 0.895. Table 10 shows the item-analysis output from SPSS for the multi-item scale of the extent to which subjects believe the use of RFID technology reduces the seven common types of lean manufacturing waste and improves work-in-progress management. A description of the sections and related terms (format adapted from J. Gliem

& R. Gliem, 2003) are as follows:

- Statistics for Scale: these summary statistics comprise the 13 items in the scale. The summated scores for this section can range from a low of 13 to a high of 65.
- Item Means: These are the calculated means for the 13 individual items.
- Item Variances: These statistics are summary for the 13 individual item variances.
- Inter-Item Correlations: This section describes information about the correlation of each of the 13 items with the sum of all remaining items.

Table 10

Work-in-progress Item-Analysis from SPSS Output

	N	Mean	Variance	SD
Statistics for Scale	13	42.78	70.908	8.421

	Mean	Min.	Max.	Range	Max/Min	Variance
Item Means	3.291	2.623	3.913	1.290	1.492	.139
Item Variances	.948	.610	1.338	.728	2.194	.038
Inter-Item Correlations	.396	.073	.735	.662	10.123	.017

	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Squared Multiple Correlation	Cronbach's Alpha if Item Deleted
Item 1	39.25	60.777	.624	.662	.886
Item 2	39.14	61.067	.665	.712	.885
Item 3	39.32	60.014	.601	.498	.887
Item 4	39.30	60.509	.656	.607	.885
Item 5	39.25	59.394	.755	.692	.880
Item 6	39.41	59.803	.630	.520	.886
Item 7	39.77	59.122	.587	.513	.888
Item 8	39.64	59.176	.682	.623	.883
Item 9	39.39	60.771	.629	.609	.886
Item 10	39.97	61.911	.506	.479	.892
Item 11	38.87	66.409	.305	.267	.899
Item 12	40.16	60.254	.571	.442	.889
Item 13	39.93	63.098	.516	.408	.891

Reliability Cronbach's alpha coefficient for the 13 items 0.895

- Item-total Statistics: The items in this section are as follows:
  - Scale Mean if Item Deleted: this section shows how the mean for the whole scale changes if one of the listed items is deleted. For example in Table 10, if item 4 is excluded, the mean of the summated scores of the remaining items will be 39.30.
  - Scale Variance if Item Deleted: this section shows how the variance of the summated items changes if one listed item is deleted. For example, when excluding item 1, the variance of the summated scores will be 60.777.
  - Corrected Item-Total Correlation: this section represents the correlation of one item designated with the summated score for all other items. For example in Table 10, the correlation between item 3 and the summated score is 0.60. The rule here is that this value should be at least 0.40 (J. Gliem & R. Gliem, 2003).
  - Squared Multiple Correlation: this value is obtained by regressing an identified item on all the remaining items. This is called the predicted Squared Multiple Regression Correlation. For example in Table 10, by regressing item 6 on items 1, 2, 3, 4, 5, 7, 8, 9, 10, 11, 12, and 13, the predicted Squared Multiple Regression Correlation will be 0.520.
  - Alpha if Item Deleted: this part probably represents the most important information in the table. It represents the scale's Cronbach's alpha reliability coefficient for internal consistency should an individual item be excluded from the scale. For example in Table 10, if item 4 is removed from the scale, the scale's Cronbach's alpha will be .885. This section helps to identify which item demonstrated a low Cronbach's alpha value that may have resulted in decreasing the scale's overall Cronbach's alpha coefficient. Such items can be excluded from

the construct in order to obtain a reliability Cornbach's alpha value of 0.7 or higher.

- Alpha: this is the scale's Cronbach's alpha reliability coefficient of internal consistency, and it is the most frequently used.

Inventory Management Items Reliability Test

This nine-question instrument assesses the extent to which subjects believe the use of RFID technology reduces the seven common types of lean manufacturing waste in the area of inventory management.

Table 11

Inventory Management Item-Analysis from SPSS Output

	N	Mean	Variance	SD
Statistics for Scale	9	31.49	34.422	5.867

	Mean	Minimum	Maximum	Range	Maximum / Minimum	Variance
Item Means	3.498	2.847	3.861	1.014	1.356	.090
Item Variances	.864	.694	1.007	.313	1.451	.009
Inter-Item Correlations	.428	.231	.774	.543	3.350	.013

	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Squared Multiple Correlation	Cronbach's Alpha if Item Deleted
Item 1	27.81	28.243	.536	.348	.863
Item 2	27.83	27.155	.654	.639	.852
Item 3	27.97	26.901	.672	.650	.851
Item 4	28.14	27.783	.571	.421	.860
Item 5	27.79	28.139	.632	.518	.855
Item 6	28.18	27.333	.603	.458	.857
Item 7	27.62	28.266	.564	.475	.861
Item 8	28.64	28.854	.505	.340	.866
Item 9	27.90	26.061	.718	.619	.846

Reliability Cronbach's alpha coefficient for the 9 items 0.871

Each item used a five-point Likert-type scale: Strongly Disagree (1), Disagree (2), Neutral (3), Agree (4), and Strongly Agree (5). The summated scores can range from 9 to 45. This section demonstrated internal consistency with a Cronbach's alpha of 0.871 in this study. Full detailed statistics are shown on Table 11. Table 11 shows the item-analysis output from SPSS for the multi-item scale of the extent to which subjects believe the use of RFID technology reduces the seven common types of lean manufacturing waste and improves inventory management. For full description of the sections and related terms, please refer to the section following Table 10.

Manufacturing Asset Tracking and Maintenance Items Reliability Test

This six-question instrument assesses the extent to which subjects believe the use of RFID technology reduces the seven common types of lean manufacturing waste and improves manufacturing asset tracking and maintenance. Each item used a five-point Likert-type scale: Strongly Disagree (1), Disagree (2), Neutral (3), Agree (4), and Strongly Agree (5). The summated scores can range from 6 to 30. This section demonstrated internal consistency with a Cronbach's alpha of 0.869 in this study. Full detailed statistics are shown on Table (12). Table 12 represents the item-analysis output from SPSS for the multi-item scale of the extent to which subjects believe the use of RFID technology reduces the seven common types of lean manufacturing waste and improves manufacturing asset tracking and maintenance. For full description of the sections and related terms, please refer to the section following Table 10.

Table 12

Manufacturing Asset Tracking and Maintenance Item-Analysis from SPSS Output

	N	Mean	Variance	SD
Statistics for Scale	6	19.28	20.541	4.532

	Mean	Minimum	Maximum	Range	Max / Min	Variance
Item Means	3.213	2.944	3.556	.611	1.208	.060
Item Variances	.946	.757	1.139	.382	1.504	.019
Inter-Item Correlations	.526	.375	.665	.290	1.773	.008

	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Squared Multiple Correlation	Cronbach's Alpha if Item Deleted
Item 1	15.81	15.201	.613	.519	.855
Item 2	15.72	15.133	.625	.519	.853
Item 3	16.24	13.676	.725	.568	.836
Item 4	16.13	14.280	.694	.534	.841
Item 5	16.17	14.479	.652	.471	.849
Item 6	16.33	15.070	.698	.510	.842

Reliability Cronbach's alpha coefficient for the 6 items 0.869

Manufacturing Control Items Reliability Test

This seven-question instrument assesses the extent to which subjects believe the use of RFID technology reduces the seven common types of lean manufacturing waste and improves manufacturing control. Each item used a five-point Likert-type scale: Strongly Disagree (1), Disagree (2), Neutral (3), Agree (4), and Strongly Agree (5). The summated scores can range from seven to 55. This section demonstrated internal consistency with a Cronbach’s alpha of 0.888 in this study. Full detailed statistics are shown on Table 13 bellow.

Table 13 shows the item-analysis output from SPSS for the multi-item scale of the extent to which subjects believe the use of RFID technology reduces the seven common types of manufacturing waste and improves manufacturing control. For full description of the sections and related terms, please refer to the section following Table 10.

Table 13

Manufacturing Control Item-Analysis from SPSS Output

	N	Mean	Variance	SD
Statistics for Scale	7	22.80	23.694	4.868

	Mean	Minimum	Maximum	Range	Max / Min	Variance
Item Means	3.257	2.594	3.594	1.000	1.385	.124
Item Variances	.808	.683	.951	.268	1.392	.011
Inter-Item Correlations	.535	.366	.707	.340	1.929	.010

	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Squared Multiple Correlation	Cronbach's if Item Deleted
Item 1	19.20	17.694	.763	.656	.863
Item 2	19.41	18.303	.666	.487	.874
Item 3	19.33	16.961	.731	.542	.865
Item 4	19.39	17.830	.597	.470	.883
Item 5	19.41	17.509	.737	.633	.865
Item 6	19.84	17.401	.715	.622	.867
Item 7	20.20	18.429	.580	.460	.884

Reliability Cronbach's alpha coefficient for the 7 items 0.888

In summary, Cronbach's alpha reliability coefficient values of all items for work-in-progress, inventory management, manufacturing asset tracking and maintenance, and manufacturing control were .842 and above – this is very acceptable. George and Mallery (2003) provide the following role of thumb: (0.5 and below) unacceptable, (0.6 and above) questionable, (0.7 and above) acceptable, (0.8 and above) good, (0.9 and above) excellent.

Factor Analysis

Given the fact that the adapted research survey has not been applied in the context of U.S manufacturing industry, an exploratory factor analysis was used to validate the research instrument construct validity. It is very helpful to use principal component analysis to determine how, and to what extent, the items are linked to their underlining factors (Chong et al., 2009). Factor loadings less than 0.30 are considered insignificant. A rule-of-thumb is that factor loadings greater than 0.30 are considered significant, loadings greater than 0.40 are considered more important, and loadings that are 0.50 or greater are very significant (Hair et al., 2005). From Table 14 below, all items for the four scales had factor loadings values of greater than 0.45. Out of 35 items, only five had factor loadings values less than 0.50 and the remaining 30 items were greater than 0.50. Thus, each construct is valid in measuring the relationship between RFID technology deployment and manufacturing waste reduction in lean manufacturing environment.

Table 14 shows a number of items with factor loading of 0.7 and higher. Such high factor loadings indicate RFID technology has potential impact on the applications each item represents. These are: RFID helps to identify how much of which goods/materials are WIP, RFID enables more effective tracking of materials throughout manufacturing process, RFID technology helps businesses to identify where WIP materials should be brought to, RFID eliminates manual data collection and human errors, RFID can help to determine where finished goods/materials are, RFID can also help to locate where nearest finished goods/raw materials are, RFID technology helps tracking finished goods/raw material expiry dates and implement suitable protocols, and RFID can also enable automated JIT strategies.

Table 14

Survey Factor Analysis

Scale	Scale item	Factor loading	Percent of variance
Work-in-progress Management	1	.701	70.908
	2	.765	
	3	.503	
	4	.621	
	5	.752	
	6	.550	
	7	.517	
	8	.622	
	9	.647	
	10	.548	
	11	.705	
	12	.554	
	13	.727	
Inventory Management	1	.462	34.422
	2	.759	
	3	.730	
	4	.630	
	5	.668	
	6	.496	
	7	.457	
	8	.608	
	9	.770	
Manufacturing Asset Tracking and Maintenance	1	.536	20.541
	2	.548	
	3	.683	
	4	.638	
	5	.586	
	6	.643	
Manufacturing Control	1	.708	23.694
	2	.581	
	3	.666	
	4	.495	
	5	.675	
	6	.645	
	7	.461	

Scales Results

This section provides the results of the four main scales developed for this study. This includes work-in-progress management scale (13 items), inventory management scale (9 items), manufacturing asset tracking and maintenance scale (6 items), and manufacturing control scale (7 items). Table 15 below represents an overview of some of the main scale statistics for the four mentioned scales.

Table 15

Overview of Scales Results

	No of Items	Mean	Variance	SD	Summated Scores Range
• Work-in-Progress Management	13	42.78	70.908	8.421	13-65
• Inventory Management	9	31.49	34.422	5.867	9-45
• Manufacturing Asset Tracking and Maintenance	6	19.28	20.541	4.532	6-30
• Manufacturing Control	7	22.80	23.694	4.868	7-35

Item Statistics for Work-in-progress Management Scale

The scale mean was 42.78 and standard deviation was 8.421 with a variance of 70.90. The scale statistics are presented in Table 16 below. The items means ranged from 2.62 to 3.91 with an overall mean of 3.29. Items 7, 8, 10, 12, and 13 had means below the average. This indicated that respondents tended to respond on the positive side of the five-point Likert-type scale. Corrected item-to-total correlation for item 7 was 0.75. Items 1, 2, 3, 4, 6, 8, and 9 had corrected item-to-total correlations ranged from 0.60 to 0.68. Item 11 had an item-to-total correlation of 0.30. A rule-of-thumb is that these values should be at least 0.40 (J. Gliem & R. Gliem, 2003). Eight items of 13 had significant item skewness above +/- 0.5.

Table 16

Item Statistics for Work-in-progress Management Scale

	Mean	Std. Dev.	Item Skewness	Item-to-total correlations
1. The use of RFID technology helps reduce “overproduction” by knowing how much of which goods/materials are Work-In-Progress.	3.54	.948	-.123	.624
2. The utilization of RFID technology helps reduce “overproduction” by enabling more effective tracking of materials throughout manufacturing process.	3.64	.874	-.890	.665
3. The use of RFID technology helps reduce “waiting time” by knowing where finished goods/materials are.	3.46	1.051	-.648	.601
4. The utilization of RFID technology helps reduce “inefficient transportation” by managing the whereabouts of materials during transportation between processes.	3.48	.933	-.696	.656
5. The use of RFID technology helps reduce “inefficient transportation” by knowing where Work-In-Progress goods/materials should be brought to.	3.54	.917	-.580	.755
6. The use of RFID technology helps reduce “inappropriate processing” by knowing which goods/ materials are suitable for which processing.	3.38	1.030	-.372	.630
7. The use of RFID technology helps reduce “inappropriate processing” by assisting in identifying product that has been processed inappropriately.	3.01	1.157	-.077	.587
8. The use of RFID technology helps reduce “unnecessary inventory” by eliminating mistaken Work-In-Progress goods/ inventory association.	3.14	1.019	-.187	.682
9. The use of RFID technology helps reduce “unnecessary inventory” by allowing for reduced queuing between processes.	3.39	.943	-.580	.629
10. The use of RFID technology helps reduce “unnecessary motion” by allowing shorter physical distances between manufacturing processes.	2.81	1.004	.511	.506
11. The use of RFID technology helps reduce “unnecessary motion” by eliminating manual data collection and human errors.	3.91	.781	-.886	.305

12. The use of RFID technology helps reduce “defects” by directly or indirectly reducing manufacturing non-conformances.	2.62	1.072	.110	.571
13. The use of RFID technology helps reduce “defects” by reducing scraps through improved traceability.	2.86	.862	-.123	.516

These data indicated highly homogenous responses by respondents. Most responses were at the end of the Likert-type scale with a mode of 4.00 for items 1, 2, 3, 4, 5, 6, 8, 9, 11, and 12. Items 7 and 13 had a mode value of 3, and item 10 had a mode of 2. All skewed items were negatively skewed except for items 10 and 12. The 25th percentile was 3 for Items 1, 2, 3, 4, 5, 6, and 9 had. It was 4.00 for item 11 and it was 2.00 for items 7, 8, 10, 12, and 13. The 75th percentile of item 12 was 3 the remaining items were 4.00.

Item Statistics for Inventory Management Scale

The scale mean was 31.49 and standard deviation was 5.86 with a variance of 34.42. The scale statistics are presented in Table 17 below. The items means ranged from 2.86 to 3.69 with an overall mean of 3.49. Items 4, 6, and 8 had means below the average. All items' mean averages were above 3.00 except item 8 (2.86). This indicated that respondents tended to respond on the positive side of the five-point Likert-type scale. Corrected item-to-total correlation for item 9 was 0.718. Items 2, 3, 5, and 6 had corrected item-to-total correlations ranged from 0.603 to 0.672. Items 1, 4, 7, and 8 had an item-to-total correlation from 0.505 to 0.571. A rule-of-thumb is that these values should be at least 0.40 (J. Gliem & R. Gliem, 2003). Except items 4, 6, and 8, the remaining items had significant item skewness above +/- 0.7. These data indicated highly homogenous responses by respondents. Most responses were at the end of the Likert-type scale with a mode of 4.00 for items 1, 2, 3, 5, 6, 7, and 9. Items 4 and 8 had a mode of 3.00. All skewed items were negatively skewed. The 25th percentile was

3 for items 1, 2, 3, 4, 5, 6, 7, and 9. It was 2.00 for item 8. The 75th percentile of item 8 was 3.6, and the remaining items were 4.00.

Table 17

Item Statistics for Inventory Management Scale

	Mean	Std. Dev.	Item Skewness	Item-to-total correlations
1. The use of RFID technology helps reduce "overproduction" by knowing how much of goods/materials are in stock.	3.68	.926	-1.157	.536
2. The use of RFID technology helps reduce "waiting time" by knowing where finished goods/materials are.	3.66	.931	-1.166	.654
3. The use of RFID technology helps reduce "inefficient transportation" by knowing where nearest finished goods/raw materials are.	3.52	.944	-.824	.672
4. The use of RFID technology helps reduce "inappropriate processing" by knowing which raw material is suitable for which processing.	3.34	.946	-.238	.571
5. The use of RFID technology helps reduce "unnecessary inventory" by improving inventory visibility.	3.69	.833	-1.022	.632
6. The use of RFID technology helps reduce "unnecessary inventory" by eliminating the need for material queuing, and assisting in the application of Just-in-Time methodology.	3.32	.970	-.490	.603
7. The use of RFID technology helps reduce "unnecessary motion" by eliminating manual counts and human error.	3.85	.892	-.780	.564
8. The use of RFID technology helps reduce "defects" by identifying non-conforming material and in turn reducing the overall inventory required.	2.86	.887	-.093	.505
9. The use of RFID technology helps reduce "defects" by knowing finished goods/ raw material expiry dates and implement suitable protocols.	3.59	.998	-.727	.718

Item Statistics for Manufacturing Asset Tracking & Maintenance Scale

The scale mean was 19.28, and standard deviation was 4.53 with a variance of 20.54. The scale statistics are presented in Table 18 below. The items means ranged from 2.94 to 3.56 with an overall mean of 3.21. Items 3, 4, 5, and 6 had means below the average. All items' mean averages were above 3.00 except item 6 (2.94). This indicated that respondents tended to respond on the positive side of the five-point Likert-type scale.

Table 18

Item Statistics for Manufacturing Asset Tracking and Maintenance Scale

	Mean	Std. Dev.	Item Skewness	Item-to-total correlations
1. The use of RFID technology helps reduce "waiting time" by knowing where assets are and conditions of assets.	3.47	.934	-.770	.519
2. The use of RFID technology helps reduce "inefficient transportation" by knowing the location of nearest available assets.	3.56	.933	-1.023	.519
3. The use of RFID technology helps reduce "inappropriate processing" by eliminating production errors due to incorrect manufacturing asset maintenance.	3.04	1.067	.058	.568
4. The use of RFID technology helps reduce "unnecessary inventory" by eliminating unnecessary buffers' waiting time for asset maintenance.	3.15	1.002	-.229	.534
5. The use of RFID technology helps reduce "unnecessary motion" by eliminating manual checks for maintenance.	3.11	1.015	.104	.471
6. The use of RFID technology helps reduce "defects" by quickly identifying process breakdown and reducing manufacturing downtime.	2.94	.870	-.418	.510

Corrected item-to-total correlation for item 5 was 0.47. Items 1, 2, 3, 4, and 6 had corrected item-to-total correlations ranged from 0.510 to 0.568. A rule-of-thumb is that these values should be at least 0.40 (J. Gliem & R. Gliem, 2003). Items 1, 2, and 6 had significant item skewness above +/- 0.4. Item 3 skewness was 0.058 and item 5 skewness was 0.104. All skewed items were negatively skewed except items 3 and 5. The scale had a mode of 4.00 for items 1 and 2. Items 4, 5, and 6 had a mode of 3.00, and item 3 had a mode of 2.00. The 25th percentile was 3.00 for items 1 and 2. It was 2.00 for items 3 and 5. Items 4 and 6 had a 25th percentile of 2.25. The 75th percentile of item 6 was 3.75 and the remaining items were 4.00.

Item Statistics for Manufacturing Control Scale

The scale mean was 22.80, and standard deviation was 4.868 with a variance of 23.694. The scale statistics are presented in Table 19 below. The items means ranged from 2.60 to 3.63 with an overall mean of 3.25. Items 6 and 7 had means below the average. All items' mean averages were above 3.00 except item 7 (2.60). This indicated that respondents tended to respond on the positive side of the five-point Likert-type scale. Corrected item-to-total correlation for item 4 was 0.597. Item 2 was 0.666, and items 1, 3, 6, and 7 had corrected item-to-total correlations that ranged from 0.715 to 0.763. A rule-of-thumb is that these values should be at least 0.40 (J. Gliem & R. Gliem, 2003). Items 1, 2, 3, 4, and 5 had significant item skewness above -0.6. Item 6 skewness was 0.00 and item 7 skewness was 0.012. All skewed items were negatively skewed except items 6 and 7. The scale had a mode of 4.00 for items 1, 3, 4, and 5. Items 2 and 6 had a mode of 3.00, and item 7 had a mode of 2. The 25th percentile was 3.00 for items 1, 2, 3, 4 and 5. It was 2.00 for items 6 and 7. The 75th percentile of item 7 was 3.00 and the remaining items were 4.00.

Table 19

Item Statistics for Manufacturing Control Scale

	Mean	Std. Dev.	Item Skewness	Item-to-total correlations
1. The use of RFID technology helps reduce “overproduction” by enabling automated Just-in-Time strategies.	3.63	.830	-1.325	.763
2. The use of RFID technology helps reduce “waiting time” by increasing product autonomy in distributed control systems.	3.41	.838	-.751	.666
3. The use of RFID technology helps reduce “inefficient transportation” by knowing where applicable to implement automated routing on production line	3.50	.979	-.603	.731
4. The use of RFID technology helps reduce “inappropriate processing” by knowing which goods/ materials are suitable for which processing.	3.39	.963	-.678	.597
5. The use of RFID technology helps reduce “unnecessary inventory” by eliminating the need for material queuing, which will assist in the application of Just-in-Time methodology.	3.43	.901	-.737	.737
6. The use of RFID technology helps reduce “unnecessary motion” by enabling a reduction in motion between manufacturing processes.	3.00	.941	.000	.715
7. The use of RFID technology helps reduce “defects” by identifying defects in the manufacturing process.	2.60	.883	.012	.580

Hypotheses Testing

In order to test the four research hypotheses of this study, the best measure that suits five-point Likert-type scale data sets is the mode to measure the central tendency. For the purpose of this study, each item that has a mode of 4 or 5 will be accepted. Items with modes of 3, 2, or 1 will be rejected. To make the data results much easier to understand, a chi square test representing residual values for each of the five-point Likert-type scale categories was also be provided. Chi-square test is comparing expected N to observed N. A decision about the expected values against which the actual frequencies are to be tested was made by setting all categories to equal value because this is the most common choice. These equal values are determined by dividing the total number of usable responses by the number of the used Likert-types scale. In this study, the usable responses were 77 and the used Likert scales were five. By dividing 77 by five, the result was 15.4. Figure 6 bellow represents an example of chi-square test result for the first item of the work-in-progress scale.

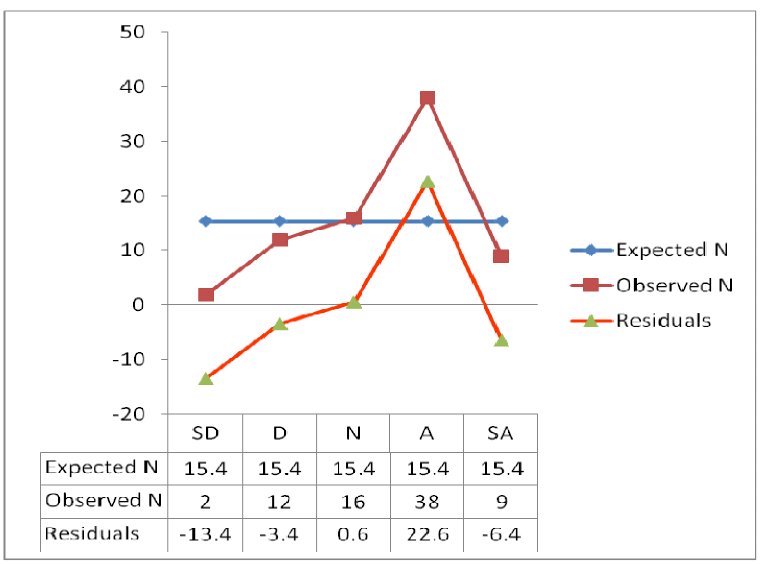

Figure 6. An Example of Chi-square Test Results

Figure 6 indicates that the expected N for the five categories on Likert scale are 15.4. The observed values for the five categories were 2, 12, 16, 38, and 9, consecutively. By subtracting the expected N values from the observed N values, the results were residual values of -13.4, -3.4, 0.6, 22.6, and -6.4. It can be inferred that the most significant category was the fourth one (Agree). The highest residual value will be the decisive factor when selecting under which of the five categories the majority of responses were. The following section will test each of the four scales with their respected alternate hypothesis in order to determine which items were supported and which were not. Each alternate hypothesis is followed by a discussion about whether the null hypothesis was accepted or rejected. The null hypotheses H0: *There is no significant relationship between lean manufacturing waste reduction and the adoption of RFID technologies.*

Work-in-progress Management

Alternate hypothesis1: *Manufacturing waste will be different in organizations implementing RFID technology in work-in-progress management.*

The mode and residual values were calculated for each of the 13 items as presented in Table 20. Items 1, 2, 3, 4, 5, 6, 8, and 9 had a mode of 4. This is equal to level 4"Agree" of the used Likert-type scale and thus were supported by the respondents. Items 7 and 13 had a mode of 3. This is equal to level 3 "Neutral" of the used Likert-type scale. Items 10 and 12 had a mode of 2. This is equal to level 2 "Disagree" of the used Likert-type scale. Items 7, 10, 12, and 13 were not supported based on this test.

The highest residual values for items 1, 2, 3, 4, 5, 6, 8, and 9 were under the "Agree" category and thus were supported. Whereas, the highest residual values for items 7 and 13 were under "Neutral" category and item 10 were under "Disagree" category. Item 12 residual value was equal under "Disagree" and "Neutral" categories. Thus, items 7, 10, 12, and 13 were not supported. Full details about how residual values were calculated can be found on page 76 and 77.

Based on these results, the majority of respondents agreed that work-in-progress management will improve through the adoption of RFID technology that reduces the following six lean manufacturing waste: overproduction, waiting time, inefficient transportation, inappropriate processing, unnecessary inventory, and unnecessary motion. However, respondents did not think the adoption of RFID technology helps reduce the waste of *defects* in lean manufacturing settings. This indicates clear evidence that there is a significant relationship between lean manufacturing waste reduction and the adoption of RFID technologies. Thus, the null hypothesis is rejected based on the testing of the items of work-in-progress management scale.

See Appendix K for the distribution of responses of each of the 13 questions showing percentages that strongly disagree, disagree, neutral, agree, and strongly agree. This is displayed in a bar chart graphic with one bar for each response category.

Table 20

Work-in-progress Management Hypothesis Testing

	Mode	Chi Square Test – (Frequencies Residual Values)					Item supported
		SD	D	N	A	SA	
1. The use of RFID technology helps reduce “overproduction” by knowing how much of which goods/materials are Work-In-Progress.	4	-13.4	-3.4	.6	22.6	-6.4	Yes
2. The utilization of RFID technology helps reduce “overproduction” by enabling more effective tracking of materials throughout manufacturing process.	4	-13.4	-7.4	-.4	27.6	-6.4	Yes
3. The use of RFID technology helps reduce “waiting time” by knowing where finished goods/materials are.	4	-10.4	-6.4	3.6	17.6	-4.4	Yes
4. The utilization of RFID technology helps reduce “inefficient transportation” by managing the whereabouts of materials during transportation between processes.	4	-12.4	-6.4	4.6	21.6	-7.4	Yes
5. The use of RFID technology helps reduce “inefficient transportation” by knowing where Work-In-Progress goods/materials should be brought to.	4	-12.4	-9.4	9.6	16.6	-4.4	Yes
6. The use of RFID technology helps reduce “inappropriate processing” by knowing which goods/ materials are suitable for which processing.	4	-12.2	-4.2	7.8	12.8	-4.2	Yes
7. The use of RFID technology helps reduce “inappropriate processing” by assisting in identifying product that has been processed inappropriately.	3	-8.2	2.8	6.8	5.8	-7.2	**No**
8. The use of RFID technology helps reduce “unnecessary inventory” by eliminating mistaken Work-In-Progress goods/ inventory association.	4	-10.8	2.2	7.2	10.2	-8.8	Yes
9. The use of RFID technology helps reduce “unnecessary inventory” by allowing for reduced queuing between processes.	4	-12.0	-7.0	11.0	17.0	-9.0	Yes
10. The use of RFID technology helps reduce “unnecessary motion” by allowing shorter physical distances between manufacturing processes.	2	-12.0	14.0	9.0	-2.0	-9.0	**No**
11. The use of RFID technology helps reduce “unnecessary motion” by eliminating manual data collection and human errors.	4	-14.2	-11.2	-2.2	25.8	1.8	Yes
12. The use of RFID technology helps reduce “defects” by directly or indirectly reducing manufacturing non-conformances.	2	-3.0	8.0	8.0	.0	-13.0	**No**
13. The use of RFID technology helps reduce “defects” by reducing scraps through improved traceability.	3	-11.2	6.8	13.8	4.8	-14.2	**No**

SD=Strongly Disagree, D=Disagree, N=Neutral, A=Agree, SA=Strongly Agree

Inventory Management

Alternate hypothesis 2: *Manufacturing waste will be different in organizations implementing RFID technology in inventory management.*

The mode and residual values were calculated for each of the 9 items as presented in Table 21. Items 1, 2, 3, 5, 6, 7, and 9 had a mode of 4. This is equal level 4 (Agree) of the used Likert-type scale. Items 4 and 8 had a mode of 3. This is equal to level 3 (Neutral) of the used Likert-type scale. Items 4 and 8 were not supported based on this test. The highest residual values for items 1, 2, 3, 5, 6, 7, and 9 were under “Agree” category, whereas, the highest residual values for items 4 and 8 were under “Neutral” category. Thus, items 4 and 8 were not supported. Full details about how residual values were calculated can be found on page 76 and 77. Based on these results, the majority of respondents agreed that inventory management will improve through the adoption of RFID technology that reduces the following six lean manufacturing waste: overproduction, waiting time, inefficient transportation, unnecessary inventory, unnecessary motion, and defects. However, respondents did not think the adoption of RFID technology helps reduce the waste of inappropriate processing in lean manufacturing settings. Respondents agreed that RFID use in inventory management will reduce manufacturing waste in seven applications out of nine. This indicates that there is a relationship between the implementation of RFID technology and manufacturing waste reduction. This leads to reject the null hypothesis based on the testing of the items of inventory management scale.

See Appendix K for the distribution of responses of each of the nine questions showing percentages that strongly disagree, disagree, neutral, agree, and strongly agree. This is displayed in a bar chart graphic with one bar for each response category.

Table 21

Inventory Management Hypothesis Testing

	Mode	Chi Square Test – (Frequencies Residual Values)					Item supported
		SD	D	N	A	SA	
1. The use of RFID technology helps reduce "overproduction" by knowing how much of goods/materials are in stock.	4	-11.6	-9.6	-1.6	28.4	-5.6	Yes
2. The use of RFID technology helps reduce "waiting time" by knowing where finished goods/materials are.	4	-11.6	-8.6	-2.6	29.4	-6.6	Yes
3. The use of RFID technology helps reduce "inefficient transportation" by knowing where nearest finished goods/raw materials are.	4	-11.6	-7.6	4.4	22.4	-7.6	Yes
4. The use of RFID technology helps reduce "inappropriate processing" by knowing which raw material is suitable for which processing.	3	-12.6	-3.6	12.4	11.4	-7.6	**No**
5. The use of RFID technology helps reduce "unnecessary inventory" by improving inventory visibility.	4	-12.4	-11.4	3.6	26.6	-6.4	Yes
6. The use of RFID technology helps reduce "unnecessary inventory" by eliminating the need for material queuing, and assisting in the application of Just-in-Time methodology.	4	-11.6	-2.6	7.4	16.4	-9.6	Yes
7. The use of RFID technology helps reduce "unnecessary motion" by eliminating manual counts and human error.	4	-13.6	-9.6	-.6	22.4	1.4	Yes
8. The use of RFID technology helps reduce "defects" by identifying non-conforming material and in turn reducing the overall inventory required.	3	-10.6	6.4	15.4	2.4	-13.6	**No**
9. The use of RFID technology helps reduce "defects" by knowing finished goods/ raw material expiry dates and implement suitable protocols.	4	-11.6	-7.6	3.4	19.4	-3.6	Yes

SD=Strongly Disagree, D=Disagree, N=Neutral, A=Agree, SA=Strongly Agree

Manufacturing Asset Tracking and Maintenance

Alternate hypothesis 3: *Manufacturing waste will be different in organizations implementing RFID technology in manufacturing asset tracking and maintenance processes.*

The mode and residual values were calculated for each of the six items as presented in Table 22. Items 1 and 2 had a mode of 4. This is equal to level 4 “Agree” of the used Likert-type scale. Items 4, 5, and 6 had a mode of 3. This is equal to level 3 “Neutral” of the used Likert-type scale. Items 3 had a mode of 2 that is equal to level 2 “Disagree” of the used Likert-type scale. Based on this test, items 3, 4, 5, and 6 were not supported.

The highest residual values for items 1 and 2 were under the “Agree” category, whereas the highest residual values for items 4, 5, and 6 were under the “Neutral” category. Item 3 had an equal residual values under “Neutral” and “Disagree” categories. Thus, items 3, 4, 5, and 6 were not supported. Full details about how residual values were calculated can be found on page 76 and 77. Based on these results, the majority of respondents agreed that manufacturing asset tracking and maintenance will only improve through the adoption of RFID technology that reduces the following two lean manufacturing wastes: overproduction and waiting time. However, respondents did not think the adoption of RFID technology improves manufacturing asset tracking and maintenance through the reduction of the following manufacturing wastes: inefficient transportation, unnecessary inventory, inappropriate processing, unnecessary motion, and defects waste. Because respondents agreed that the implementation of RFID in manufacturing asst tracking and maintenance would help reduce only two out of the seven manufacturing waste, this indicates that there is no significant relationship between the adoption of RFID and manufacturing waste reduction. Thus, the null hypothesis is accepted for this scale.

See Appendix M for the distribution of responses of each of the six questions showing percentages that strongly disagree, disagree, neutral, agree, and strongly agree. This is displayed in a bar chart graphic with one bar for each response category.

Table 22

Manufacturing Asset Tracking and Maintenance Hypothesis Testing

	Mode	Chi Square Test – (Frequencies Residual Values)					Item supported
		SD	D	N	A	SA	
1. The use of RFID technology helps reduce "waiting time" by knowing where assets are and conditions of assets.	4	-11.4	-7.4	6.6	20.6	-8.4	Yes
2. The use of RFID technology helps reduce "inefficient transportation" by knowing the location of nearest available assets.	4	-11.4	-7.4	.6	26.6	-8.4	Yes
3. The use of RFID technology helps reduce "inappropriate processing" by eliminating production errors due to incorrect manufacturing asset maintenance.	2	-10.4	6.6	6.6	5.6	-8.4	**No**
4. The use of RFID technology helps reduce "unnecessary inventory" by eliminating unnecessary buffers' waiting time for asset maintenance.	3	-10.4	-.4	11.6	8.6	-9.4	**No**
5. The use of RFID technology helps reduce "unnecessary motion" by eliminating manual checks for maintenance.	3	-11.4	2.6	13.6	2.6	-7.4	**No**
6. The use of RFID technology helps reduce "defects" by quickly identifying process breakdown and reducing manufacturing downtime.	3	-9.4	-1.4	21.6	2.6	-13.4	**No**

SD=Strongly Disagree, D=Disagree, N=Neutral, A=Agree, SA=Strongly Agree

Manufacturing Control

Alternate hypothesis 4: *Manufacturing waste will be different in organizations implementing RFID technology in manufacturing control processes.*

The mode and residual values were calculated for each of the seven items as presented in Table 23. Items 1, 3, 4, and 5 had a mode of 4. This is equal level 4 (Agree) of the used Likert-type scale. Items 2 and 6 had a mode of 3. This is equal to level 3 (Neutral) of the used Likert-type scale. Item 7 had a mode of 2 that is equal to level 2 “Disagree” of the used Likert-type scale. Based on this test, items 2, 6, and 7 were not supported.

The highest residual values for items 1, 3, 4, and 5 were under “Agree” category. Whereas, the highest residual values for items 2 and 6 were under “Neutral” category. Item 7 highest residual value was under “Disagree” category. Thus, items 2, 6, and 7 were not supported. Full details about how residual values were calculated can be found on page 76 and 77. Based on these results, the majority of respondents agreed that manufacturing control will improve through the adoption of RFID technology that reduces the following four lean manufacturing wastes: overproduction, inefficient transportation, inappropriate processing, and unnecessary inventory. However, respondents did not think that the adoption of RFID technology improves manufacturing control through the reduction of the following three manufacturing wastes: waiting time, unnecessary motion, and defects. This indicates that there is a relationship between RFID technology implementation and manufacturing waste reduction. Thus, the null hypothesis is rejected for this scale.

See Appendix N for the distribution of responses of each of the seven questions showing percentages that strongly disagree, disagree, neutral, agree, and strongly agree. This is displayed in a bar chart graphic with one bar for each response category.

Table 23

Manufacturing Control Hypothesis Testing

	Mode	Chi Square Test – (Frequencies Residual Values)					Item supported
		SD	D	N	A	SA	
1. The use of RFID technology helps reduce "overproduction" by enabling automated Just-in-Time strategies.	4	-11.4	-12.4	4.6	28.6	-9.4	Yes
2. The use of RFID technology helps reduce "waiting time" by increasing product autonomy in distributed control systems.	3	-11.2	-11.2	16.8	15.8	-10.2	**No**
3. The use of RFID technology helps reduce "inefficient transportation" by knowing where applicable to implement automated routing on production line	4	-12.4	-3.4	1.6	20.6	-6.4	Yes
4. The use of RFID technology helps reduce "inappropriate processing" by knowing which goods/ materials are suitable for which processing.	4	-11.2	-4.2	4.8	19.8	-9.2	Yes
5. The use of RFID technology helps reduce "unnecessary inventory" by eliminating the need for material queuing, which will assist in the application of Just-in-Time methodology.	4	-11.4	-8.4	10.6	18.6	-9.4	Yes
6. The use of RFID technology helps reduce "unnecessary motion" by enabling a reduction in motion between manufacturing processes.	3	-11.2	4.8	12.8	4.8	-11.2	**No**
7. The use of RFID technology helps reduce "defects" by identifying defects in the manufacturing process.	2	-11.0	9.0	8.0	-6.0	0	**No**

SD=Strongly Disagree, D=Disagree, N=Neutral, A=Agree, SA=Strongly Agree

As shown on Table 24 below, the majority of the items of the first, second, and fourth research scales were supported, whereas only 1/3 of the items on the third scale were supported. Overall, around 63 percent of the items were supported, and the remaining 37 percent of the items were not supported. This indicates that there is a relationship between lean manufacturing waste reduction and the adoption of RFID technologies.

Table 24

Summary of Hypotheses Testing

Hypothesis	Total Tested Items	Not supported Items	Supported Items	Null Hypothesis
1. Manufacturing waste will be different in organizations implementing RFID technology in work-in-progress management.	13	4	9	Rejected
2. Manufacturing waste will be different in organizations implementing RFID technology in inventory management.	9	2	7	Rejected
3. Manufacturing waste will be different in organizations implementing RFID technology in manufacturing asset tracking and maintenance processes.	6	4	2	Accepted
4. Manufacturing waste will be different in organizations implementing RFID technology in manufacturing control processes.	7	3	4	Rejected

Chapter 5 – Discussion

In this chapter, a detailed discussion of the three research questions will be provided. Referring to data and information provided in Chapter 4, the following three research questions will be investigated:

- Where does RFID technology have the potential of identifying, reducing, and eliminating the seven types of waste in lean manufacturing?
- What demographic variables significantly affect the perceived relationship between RFID applications in a lean manufacturing environment?
- Are lean and RFID compatible with one another?

Answers to Research Question 1

"Where does RFID technology have the potential of identifying, reducing, and eliminating the seven types of waste in lean manufacturing?"

As shown on Table 25 bellow, 13 potential RFID technology uses within manufacturing have not been supported and thus were rejected. These potential uses were ranked from 1 to 12 with the first item being the least supported. The second column of the table represents the name of each item's corresponding manufacturing waste. These 13 items are distributed according to the four main measuring scales of this research as follows: work-in-progress management (4 items), inventory management (2 items), manufacturing assets tracking and maintenance (4 items), and manufacturing control (3 items). Furthermore, the deleted items can be distributed based on the manufacturing wastes they correspond to as follows: defect (5 items), unnecessary motion (3 items), inappropriate processing (3 items), unnecessary inventory (1 item), and waiting time (1 items). Four of the 13 items had mode values of 2 each. This is a clear "Disagree" response. The remaining 8 items had mode values of 3, which are more of a "Neutral" opinion rather than disagreeing. Thus, these items were not supported.

Based on their mode and mean averages, the 13 items were ranked as represented on Table 25 below. Items ranked first means they were the least supported by the respondents of this study.

Table 25

Not Supported Potential RFID Technology Applications [Ranked]

Potential use of RFID Technology	Manufacturing Waste	Mode	Mean	Rank
• Identifying defects in the manufacturing process	Defects	2	2.60	1
• Directly or indirectly reducing manufacturing non-conformances	Defects	2	2.62	2
• Allowing shorter physical distances between manufacturing processes	Unnecessary motion	2	2.81	3
• Reducing scraps through improved traceability	Defects	3	2.86	4
• Identifying non-conforming material and in turn reducing the overall inventory required	Defects	3	2.86	4
• Quickly identifying process breakdown and reducing manufacturing downtime	Defects	3	2.94	5
• Enabling a reduction in motion between manufacturing processes	Unnecessary motion	3	3.00	6
• Assisting in identifying product that has been processed inappropriately	Inappropriate processing	3	3.01	7
• Eliminating production errors due to incorrect manufacturing asset maintenance	Inappropriate processing	2	3.04	8
• Eliminating manual checks for maintenance	Unnecessary motion	3	3.11	9
• Eliminating unnecessary buffers waiting time for asset maintenance	Unnecessary inventory	3	3.15	10
• Knowing which raw material is suitable for which processing	Inappropriate processing	3	3.34	11
• Increasing product autonomy in distributed control systems	Waiting time	3	3.41	12

On the other hand, this research supported the use of RFID technology in lean manufacturing settings in 22 potential applications (see Table 26). These 22 items are distributed based on the four measuring scales in this research as follow: work-in-progress management (9 items), inventory management (7 items), manufacturing asset tracking and maintenance (2 items), and manufacturing control (4 items). The potential RFID applications that have been supported under work-in-progress management scale include (a) knowing how much of which goods/materials are work-in-progress, (b) enabling more effective tracking of materials throughout manufacturing process, (c) knowing where finished goods/materials are, (d) managing the whereabouts of materials during transportation between processes, (e) knowing where work-In-progress goods/materials should be brought to, (f) knowing which goods/materials are suitable for which processing, (g) eliminating mistaken Work-In-Progress goods/ inventory association, (h) allowing for reduced queuing between processes, (i) eliminating manual data collection and human errors.

RFID can be used to improve inventory management through (a) eliminating manual counts and human error, (b) eliminating the need for material queuing, and assisting in the application of just-in-time methodology, (c) improving inventory visibility, (d) knowing finished goods/ raw material expiry dates and implement suitable protocols, (e) knowing where nearest finished goods/raw materials are, (f) knowing where finished goods (or materials) are, and (g) knowing how much of goods/materials are in stock.

Among the six tested items under manufacturing assets tracking and maintenance category, RFID technology have the potential in (a) knowing the location of nearest available assets, and (b) knowing where assets are and conditions of assets.

Finally, RFID technology can be applied in manufacturing control to help (a) enabling automated just-in-time strategies, (b) knowing where applicable to implement automated routing on production line, (c) knowing which goods/materials are suitable for which processing, and (d) eliminating the need for material queuing, which will assist in the application of just-in-time methodology.

Based on their mode and mean averages, the 22 items were ranked as represented on Table 26 below. Items ranked first means they were the most supported items by the respondents of this study.

Table 26

Supported Potential RFID Technology Applications [Ranked]

Potential use of RFID Technology	Reduced Waste	Mode	Mean	Rank
• Eliminating manual data collection and human errors	Unnecessary motion	4	3.91	1
• Eliminating manual counts and human error	Unnecessary motion	4	3.85	2
• Improving inventory visibility	Unnecessary inventory	4	3.69	3
• Knowing how much of goods/materials are in stock	Overproduction	4	3.68	4
• Knowing where finished goods/materials are in inventory management	Waiting time	4	3.66	5
• Enabling more effective tracking of materials throughout manufacturing process	Overproduction	4	3.64	6
• Enabling automated just-in-time strategies	Overproduction	4	3.63	7
• Knowing finished goods/ raw material expiry dates and implement suitable protocols	Defects	4	3.59	8
• Knowing the location of nearest available assets	Inefficient transportation	4	3.56	9
• Knowing how much of which goods/materials are work-in-progress	Overproduction	4	3.54	10
• Knowing where work-in-progress goods/materials should be brought to	Inefficient transportation	4	3.54	10
• Knowing where nearest finished goods/raw materials are	Inefficient transportation	4	3.52	11
• Knowing where applicable to implement automated routing on production line	Inefficient transportation	4	3.50	12
• Managing the whereabouts of materials during transportation between processes	Inefficient transportation	4	3.48	13
• Knowing where assets are and conditions of assets	Waiting time	4	3.47	14
• Knowing where finished goods/materials are in work-in-progress	Waiting time	4	3.46	15
• Eliminating the need for material queuing, which will assist in the application of Just-in-Time methodology	Unnecessary inventory	4	3.43	16
• Allowing for reduced queuing between processes	Unnecessary inventory	4	3.39	17

• Knowing which goods/ materials are suitable for which processing in manufacturing control	Inappropriate processing	4	3.39	17
• Knowing which goods/ materials are suitable for which processing in work-in-progress	Inappropriate processing	4	3.38	18
• Eliminating the need for material queuing, and assisting in the application of just-in-time methodology	Unnecessary inventory	4	3.32	19
• Eliminating mistaken work-in-progress goods/ inventory association	Unnecessary inventory	4	3.14	20

Furthermore, and as shown on Table 27 below, the supported items can also be distributed based on the manufacturing waste that each item belongs to as follows: inefficient transportation (5 items), unnecessary inventory (5 items), overproduction (4 items), waiting time (3 items), inappropriate processing (2 items), unnecessary motion (2 items), and defects (1 item).

Table 27

Distribution of the Supported Items Based on Manufacturing Wastes

Manufacturing waste	Number of supported items
• Unnecessary inventory	5
• Inefficient transportation	5
• Overproduction	4
• Waiting time	3
• Inappropriate processing	2
• Unnecessary motion	2
• Defects	1

This study suggests that the adoption of RFID technology in manufacturing helps reduce the following types of lean manufacturing wastes:

Unnecessary inventory: (a) improving inventory visibility, (b) eliminating the need for material queuing which will assist in the application of just-in-time methodology, (c) allowing for reduced queuing between processes, (d) eliminating the need for material queuing and assisting in the application of just-in-time methodology, and (e) eliminating mistaken work-in-progress goods/inventory association.

Inefficient transportation: (a) knowing the location of nearest available assets, (b) knowing where work-in-progress goods/materials should be brought to, (c) knowing where nearest finished goods/raw materials are, (d) knowing where applicable to implement automated routing on production line, and (e) managing the whereabouts of materials during transportation between processes.

Overproduction: (a) knowing how much of goods/materials are in stock, (b) enabling more effective tracking of materials throughout manufacturing process, (c) enabling automated just-in-time strategies, and (d) knowing how much of which goods/materials are work-in-progress.

Waiting time: (a) knowing where finished goods/materials are in work-in-progress management, (b) knowing where assets are and conditions of assets, and (c) knowing where finished goods/materials are in inventory management.

Unnecessary motion: (a) eliminating manual data collection and human error, and (b) eliminating manual counts and human error.

Inappropriate processing: Knowing which goods/materials are suitable for which processing in work-in-progress management and manufacturing control.

Defects: Knowing finished goods/raw material expiries dates and implementing suitable protocols.

Answer to Research Question 2:

"What demographic variables significantly affect the perceived relationship between RFID applications in a lean manufacturing environment?"

Items analyses based on business size. Mode values for each item within the four measuring scales have been calculated for the four different business sizes that include 250 – 499, 500 – 999, 1000 – 2499, and 2500 and over. Items with mode values of 2 and 3 have been excluded (full details in Appendix O). As shown on Table 28 below, out of 35 measured items, respondents working for businesses of 250-499 employees supported 18 items. Respondents working for businesses with 500-999 employees supported 19 items. Furthermore, respondents working in businesses of 1000-2499 employees supported 20 items. Finally, respondents working for business of a size 2500 and over supported 27 items. It can be inferred that the size of businesses significantly affects the perceived relationship between RFID applications in a lean manufacturing environment. To conclude, large businesses perceive RFID technology as more useful if deployed in manufacturing to reduce lean manufacturing waste and improve, work-in-progress, inventory management, manufacturing assets tracking and maintenance, and manufacturing control.

Table 28

Items' Analyses Based on Business Sizes

Measuring Scale	Total Items	Accepted Items for each Business Size			
		250 – 499	500 – 999	1000 – 2499	2500 +
• Work-in-progress Management	13	7	6	7	10
• Inventory Management	9	5	8	7	8
• Manufacturing Assets Tracking and maintenance	6	2	3	1	3
• Manufacturing Control	7	4	2	5	6
Total Accepted Items	35	18	19	20	27

Items analyses based on job function. Mode values for each item within the four measuring scales have been calculated for the five different respondents' job functions that include manufacturing production, corporate executive, manufacturing engineering, production design, quality management, and other job functions. Items with mode values of 2 and 3 have been excluded (see Appendix P for full details). As shown on Table 29 below, out of 35 measured items, respondents whose job function is manufacturing production supported 16 items. Respondents who indicated their job function as corporate executive have supported 19 items. Respondents whose job function was manufacturing engineering have supported 30 items. Furthermore, respondents who indicated their job functions as product design have supported 17 items, whereas respondents whose job function was quality management have supported 21 items. Finally, respondents who indicated their job function as "other" have supported 28 items.

Table 29

Items' Analyses Based on Job Functions

		Accepted Items by Job Functions					
	Total Items	Manufacturing Production	Corporate Executive	Manufacturing Engineering	Product Design	Quality Management	Other Job Functions
• Work-in-progress Management	13	4	8	8	5	7	11
• Inventory Management	9	7	5	9	6	7	8
• Manufacturing Assets Tracking and maintenance	6	2	2	6	3	3	4
• Manufacturing Control	7	3	4	7	3	4	5
Total Accepted Items	35	16	19	30	17	21	28

It can be inferred that job roles of the employees significantly affect the perceived relationship between RFID applications in a lean manufacturing environment.

To conclude, and based on these analyses, respondents who work in manufacturing engineering are more aware of the potential benefits RFID technology may bring to lean manufacturing and to manufacturing waste reduction process.

Answers to Research Question 3:

"*Are l*ean *and RFID compatible with one another?"* Data analyses in Chapter 4 indicated that RFID technology and lean manufacturing are compatible with one another, particular in work-in-progress management and inventory management.

Table 30

RFID Applications in Work-in-progress Management and Inventory Management

	Work-in-progress Management	Inventory Management
Overproduction	• Knowing how much of which goods/materials are Work-In-Progress • Enabling more effective tracking of materials throughout manufacturing process	• Knowing how much of goods/materials are in stock
Waiting time	• Knowing where finished goods/materials are	• Knowing where finished goods/materials are
Unnecessary inventory	• Eliminating mistaken Work-In-Progress goods/ inventory association • Allowing for reduced queuing between processes	• Improving inventory visibility • Eliminating the need for material queuing, and assisting in the application of Just-in-Time methodology
Unnecessary motion	• Eliminating manual data collection and human errors	• Eliminating manual counts and human error
Inefficient transportation	• Managing the whereabouts of materials during transportation between processes • Knowing where Work-In-Progress goods/materials should be brought to	• Knowing where nearest finished goods/raw materials are
Inappropriate processing	• Knowing which goods/ materials are suitable for which processing.	
Defects		• Knowing finished goods/ raw material expiries dates and implementing suitable protocols.

Table 30 represents a matrix of where RFID technology can be used to reduce the seven common types of lean manufacturing waste in work-in-progress management and inventory management. It seems it would be very beneficial to organizations to adopt lean philosophies and RFID technology at the same time. Implementing each strategy has proven to be very effective. However, management should have a comprehensive business strategy that includes lean and RFID technology.

Chapter 6 – Conclusion and Implication

Conclusion

This study presents the relationships between lean manufacturing waste reduction and RFID technology adoptions as perceived by selected participants in the U.S manufacturing industry. The study showed that the adoption of RFID technology is perceived to influence the reduction of the following seven manufacturing wastes: overproduction, waiting time, unnecessary inventory, unnecessary motion, inefficient transportation, inappropriate processing, and defects. Ranking the responses to see which of the seven types of waste are best-eliminated through RFID resulted in the following sequence: unnecessary inventory (best-eliminated), inefficient transportation, overproduction, waiting time, inappropriate processing, unnecessary motion, defects (least-eliminated). The study concluded that the reduction of manufacturing wastes can be achieved through the deployment of RFID technology in 22 of 35 potential applications. This study also identified 13 uses of RFID technology in manufacturing that were not perceived to be significant.

The study also showed that there is a significant relationship between lean manufacturing waste reduction and the adoption of RFID technologies in three manufacturing areas/functions: work-in-progress management, inventory management, and manufacturing control. However, the study did not find a significant relationship between lean manufacturing waste reduction and the adoption of RFID technologies in manufacturing assets tracking and maintenance based on the perceptions of the respondents.

Practical Contribution

Regarding practical contributions, this study presents implications for organizations utilizing RFID to help them identify more implementation areas/functions where RFID can have the greatest impact. Findings of this research may help organizations to understand various issues associated with this technology. Furthermore, findings of this research can also be used to build an appropriate business case for RFID and therefore help potential manufacturing businesses to start implementing this technology. In addition, this study identifies a need to study the implementation areas where RFID can have the greatest impact and add value within lean manufacturing settings. Finally, this research provides industry practitioners, RFID suppliers, researchers, and scholars with a better understanding of the benefits of RFID implemented in manufacturing.

Theoretical Contribution

This study advances the understanding of the relationship between RFID and lean manufacturing waste reduction. The study expands the domain of manufacturing waste reduction by RFID technology. This study builds upon previous lean and technology literature by providing a different perspective on how RFID can help organizations to reduce the various types of wastes associated to any production process. This research also benefits a great number of stakeholders who are interested in studying the compatibility of RFID technology and lean practices. The finding of this study can greatly assist the analysis of lean processes and help a wide range of organizations and individuals to realize significant productivity gains and efficiencies through the adoption of RFID technology. Furthermore, in the academia, the findings of this study can be used as case studies, comparative analyses reports, and teaching materials for Engineering Management, Manufacturing Engineering, Lean Thinking, and Supply Chain Management for undergraduate and/or graduate programs. Finally, this research has resulted in the development of an instrument that can be used by researchers in future studies of a similar nature to the topic that has been researched.

Limitation and Future Studies

First, this study was conducted on the U.S. Manufacturing Industry, and results may (or may not) be consistent with similar studies conducted in other countries. Therefore, further research would be needed to verify whether the results are consistent in other countries. Second, the study measures perceptions and expectations of respondents rather than objective, factual data. Further research is needed to determine whether the respondent perceptions are consistent with actual events. Third, this research may also lack generalization due to limiting participations to SME members. Therefore, future research could focus on employees working in other industries within the U.S. Fourth, those respondents with manufacturing engineering job titles seemed more knowledgeable of RFID potential benefits in manufacturing. Therefore, further research should focus on this particular group. Fifth, researchers may also focus on detailed case studies that investigate cross-functional applications across the organization. In addition to this, further studies related to lean and RFID may focus on individuals working in Manufacturing Production and Manufacturing Engineering because these two jobs functions returned a good response rate in this research. Finally, it would be feasible to conduct quasi-experimental studies. The essential aim of such an experiment is to recruit two groups of participating manufacturing businesses: (a) those that are or have been exposed to the implementation of lean production and RFID technology, and (b) a strictly identical group that allows to assess what is happening in the absence of the implementation of either lean production, RFID technology, or both.

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Appendices

Appendix A

Informed Consent

Project Title: A Study of the Relationship between Radio Frequency Identification Technology (RFID) and Lean Manufacturing.

Investigator: Abubaker Haddud, Eastern Michigan University

Purpose of the Study: The purpose of the study is to determine the effectiveness of RFID technology as a lean manufacturing tool based on the knowledge of the selected participants. The study will specifically focus on how RFID can help identify, reduce, and eliminate the seven common types of waste identified by Taiichi Ohno in the Toyota Production System. These seven include: overproduction, waiting time, inefficient transportation, inappropriate processing, unnecessary inventory, unnecessary motion, and rejects & defects. This study is mainly conducted for a PhD dissertation research.

Procedure: Following this informed consent is a series of forty online questions that you will be asked to answer (mostly) using the following five-point level of agreement Likert-type scale: (1) Strongly disagree, (2) Disagree, (3) Neutral, (4) Agree, (5) Strongly agree. The approximate time to complete the questionnaire should be about 20 minutes or less.

Please answer all questions, since incomplete questionnaire create problems in data analysis and are often rendered non-usable. If you are not sure about any answer, please choose 'Neutral'.

You are free to print a copy of the questionnaire if you like. Or, you may contact the investigator and he will provide a copy for you.

Confidentiality: You will not be asked to provide your name, name of your company, your age, gender, or nationality. Only a code number will identify your questionnaire response. The results will be stored separately from the consent form. All information will be kept in password-protected personal computer accessed by the research investigator. The responses will be confidential and summarized as input for articles, webinars, conferences, and other academic-related events.

Expected Risks: There is minimal risk to you by completing the survey, as data and all results will be kept completely anonymous.

Expected Benefits: Insight derived may be used as input to further develop current educational material. With your response you will therefore help advance knowledge and education of the field.

Voluntary Participation: Participation in this study is voluntary. You may choose not to participate. If you do decide to participate, you can change your mind at any time and withdraw from the study without negative consequences.

Use of Research Results: Results will be presented in aggregate form only. No names or individually identifying information will be revealed. Results may be presented at research meetings and conferences, and in scientific publications

Future Questions: If you have any questions concerning your participation in this study now or in the future, you can contact the researcher:

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This research protocol and informed consent document has been reviewed and approved by the Eastern Michigan University Human Subjects Review Committee for use from September 2010 to December 2010.

If you have questions about the approval process, please contact Dr. Deb de Laski-Smith (734.487.0042), Interim Dean of the Graduate School and Administrative Co-Chair of UHSCR, mailto: human.subjects@emich.edu

Consent to Participate: I have read all of the above information about this research study, including the research procedures, possible risks, side effects, and the likelihood of any benefit to me. The content and meaning of this information has been explained and I understand. All my questions, at this time, have been answered. By clicking on the 'Next' button bellow, I hereby consent and do voluntarily offer to follow the study requirements and take part in the study.

Appendix B

Data-gathering Instrument

Section One: Demographic Questions

1. What is your job title?

2. What is your job function?

○ Manufacturing Production
○ Corporate Executive
○ Manufacturing Engineering
○ Product Design
○ Quality Management
○ Control Engineering
○ Other (please specify)

3. What is your company's primary industry?

○ Fabricated Metal Products
○ Machinery Manufacturing
○ Computers & Electronics
○ Electrical Equipment
○ Transportation Equipment
○ Furniture & Related Products
○ Miscellaneous Manufacturing
○ Other (please specify)

4. What is the current number of employees in your company?

○ 250 – 499 ○ 500 – 999 ○ 1,000 - 2,499 ○ 2,500 and over

5. **How do you describe your knowledge of RFID technology applications in manufacturing environment?**

○1 (low) ○2 ○3 ○4 ○5 ○6 ○7 ○8 ○9 (high)

Section Two: Work-In-Progress Management Scale

Goal:
The aim of this part is to explore how the use of RFID technology may improve work-in-progress management through the reduction of the seven common types of waste in lean manufacturing.

Definitions:
- Work-in-process: includes the set at large of unfinished items for products in a production process.
- Overproduction: means making more, earlier or faster than required by the next process.
- Waiting time: is the idle time waiting for such things as manpower, materials, machinery, measurement or information.
- Inappropriate processing: extra processing refers to any actions that don't add value.
- Unnecessary inventory: is related to the keeping of unnecessary raw materials, parts, and WIP.
- Inefficient transportation: occurs when supplies, materials, WIP, and raw materials inventory are scattered across a plant.
- Unnecessary motion: any movement of people, tooling and equipment that does not add value to the product or service.
- Rejects & defects: this type of waste is related to fixing or remaking of defective products.

---

1. **The use of RFID technology helps reduce 'overproduction' by knowing how much of which goods/materials are Work-In-Progress.**

☐ Strongly disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly agree

2. **The utilization of RFID technology helps reduce 'overproduction' by enabling more effective tracking of materials throughout manufacturing process.**

☐ Strongly disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly agree

3. **The use of RFID technology helps reduce 'waiting time' by knowing where finished goods/materials are.**

☐ Strongly ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly disagree agree

4. **The utilization of RFID technology helps reduce 'inefficient transportation' by managing the whereabouts of materials during transportation between processes.**

☐ Strongly disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly agree

5. **The use of RFID technology helps reduce 'inefficient transportation' by knowing where Work-In-Progress goods/materials should be brought to.**

☐ Strongly disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly agree

6. **The use of RFID technology helps reduce 'inappropriate processing' by knowing which goods/materials are suitable for which processing.**

☐ Strongly disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly agree

7. **The use of RFID technology helps reduce 'inappropriate processing' by assisting in identifying product that has been processed inappropriately.**

☐ Strongly disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly agree

8. **The use of RFID technology helps reduce 'unnecessary inventory' by eliminating mistaken Work-In-Progress goods/ inventory association.**

☐ Strongly disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly agree

9. **The use of RFID technology helps reduce 'unnecessary inventory' by allowing for reduced queuing between processes.**

☐ Strongly disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly agree

10. **The use of RFID technology helps reduce 'unnecessary motion' by allowing shorter physical distances between manufacturing processes.**

☐ Strongly disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly agree

11. **The use of RFID technology helps reduce 'unnecessary motion' by eliminating manual data collection and human errors.**

☐ Strongly disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly agree

12. The use of RFID technology helps reduce 'defects' by directly or indirectly reducing manufacturing non-conformances.

☐ Strongly disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly agree

13. The use of RFID technology helps reduce 'defects' by reducing scraps through improved traceability.

☐ Strongly disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly agree

Section Three: Inventory Management Scale

Goal:
The aim of this part is to explore how the use of RFID technology may improve inventory management through the reduction of the seven common types of waste in lean manufacturing.

Definitions:
- Inventory management is primarily about specifying the size and placement of stocked goods.
- Overproduction: means making more, earlier or faster than required by the next process.
- Waiting time: is the idle time waiting for such things as manpower, materials, machinery, measurement or information.
- Inappropriate processing: extra processing refers to any actions that don't add value.
- Unnecessary inventory: is related to the keeping of unnecessary raw materials, parts, and WIP.
- Inefficient transportation: occurs when supplies, materials, WIP, and raw materials inventory are scattered across a plant.
- Unnecessary motion: is any movement of people, tooling and equipment that does not add value to the product or service.
- Rejects & defects: this type of waste is related to fixing or remaking of defective products.

---

1. The use of RFID technology helps reduce 'overproduction' by knowing how much of goods/materials are in stock.

☐ Strongly disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly agree

2. The use of RFID technology helps reduce 'waiting time' by knowing where finished goods/materials are.

☐ Strongly disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly agree

3. The use of RFID technology helps reduce 'inefficient transportation' by knowing where nearest finished goods/raw materials are.

☐ Strongly disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly agree

4. The use of RFID technology helps reduce 'inappropriate processing' by knowing which raw material is suitable for which processing.

☐ Strongly disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly agree

5. The use of RFID technology helps reduce 'unnecessary inventory' by improving inventory visibility.

☐ Strongly disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly agree

6. The use of RFID technology helps reduce 'unnecessary inventory' by eliminating the need for material queuing, and assisting in the application of Just-in-Time methodology.

☐ Strongly disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly agree

7. The use of RFID technology helps reduce 'unnecessary motion' by eliminating manual counts and human error.

☐ Strongly disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly agree

8. The use of RFID technology helps reduce 'defects' by identifying non-conforming material, and in turn reducing the overall inventory required.

☐ Strongly disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly agree

9. The use of RFID technology helps reduce ‘defects’ by knowing finished goods/ raw material expiry dates and implement suitable protocols.

☐ Strongly disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly agree

Section Four: Manufacturing Asset Tracking and Maintenance Scale

----

Goal:

The aim of this part is to explore how the use of RFID technology may improve manufacturing asset tracking and maintenance through the reduction of the seven common types of waste in lean manufacturing.

Definitions:
- Asset tracking is the instant determination of the general location of tagged objects anywhere within a defined space.
- Overproduction: means making more, earlier or faster than required by the next process.
- Waiting time: is the idle time waiting for such things as manpower, materials, machinery, measurement or information.
- Inappropriate processing: extra processing refers to any actions that don't add value.
- Unnecessary inventory: is related to the keeping of unnecessary raw materials, parts, and WIP.
- Inefficient transportation: occurs when supplies, materials, WIP, and raw materials inventory are scattered across a plant.
- Unnecessary motion: is any movement of people, tooling and equipment that does not add value to the product or service.
- Rejects & defects: this type of waste is related to fixing or remaking of defective products.

----

1. The use of RFID technology helps reduce 'waiting time' by knowing where assets are and conditions of assets.

☐ Strongly disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly agree

2. The use of RFID technology helps reduce 'inefficient transportation' by knowing the location of nearest available assets.

☐ Strongly disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly agree

3. The use of RFID technology helps reduce 'inappropriate processing' by eliminating production errors due to incorrect manufacturing asset maintenance.

☐ Strongly disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly agree

4. The use of RFID technology helps reduce 'unnecessary inventory' by eliminating unnecessary buffers' waiting time for asset maintenance.

☐ Strongly disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly agree

5. The use of RFID technology helps reduce 'unnecessary motion' by eliminating manual checks for maintenance.

☐ Strongly disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly agree

6. The use of RFID technology helps reduce 'defects' by quickly identifying process breakdown and reducing manufacturing downtime.

☐ Strongly disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly agree

Section Five: Manufacturing Control Scale

Goal:
The aim of this part is to explore how the use of RFID technology may improve manufacturing control through the reduction of the seven common types of waste in lean manufacturing.

Definitions:
- Manufacturing control is the process of monitoring and controlling manufacturing processes through automation.
- Overproduction: means making more, earlier or faster than required by the next process.
- Waiting time: is the idle time waiting for such things as manpower, materials, machinery, measurement or information.
- Inappropriate processing: extra processing refers to any actions that don't add value.
- Unnecessary inventory: is related to the keeping of unnecessary raw materials, parts, and WIP.
- Inefficient transportation: occurs when supplies, materials, WIP, and raw materials inventory are scattered across a plant.
- Unnecessary motion: any movement of people, tooling and equipment that does not add value to the product or service.
- Rejects & defects: this type of waste is related to fixing or remaking of defective products.

----

1. The use of RFID technology helps reduce 'overproduction' by enabling automated Just-in-Time strategies.

☐ Strongly disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly agree

2. The use of RFID technology helps reduce 'waiting time' by increasing product autonomy in distributed control systems.

☐ Strongly disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly agree

3. The use of RFID technology helps reduce 'inefficient transportation' by knowing where applicable to implement automated routing on production line

☐ Strongly disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly agree

4. The use of RFID technology helps reduce 'inappropriate processing' by knowing which goods/ materials are suitable for which processing.

☐ Strongly disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly agree

5. The use of RFID technology helps reduce 'unnecessary inventory' by eliminating the need for material queuing, which will assist in the application of Just-in-Time methodology.

☐ Strongly disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly agree

6. The use of RFID technology helps reduce 'unnecessary motion' by enabling a reduction in motion between manufacturing processes.

☐ Strongly disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly agree

7. The use of RFID technology helps reduce 'defects' by identifying defects in the manufacturing process.

☐ Strongly disagree ☐ Disagree ☐ Neutral ☐ Agree ☐ Strongly agree

Appendix C

Initial Invitation Email

Date: Wednesday, October 06, 2010

Dear SME member:

We kindly request your assistance in an important research project entitled "A Study of the Effectiveness of Radio Frequency Identification (RFID) Technology as a Lean Manufacturing Tool." You have been selected to receive this invitation through the assistance of SME – The Society of Manufacturing Engineers.

The purpose of the study is to determine the effectiveness of RFID technology as a lean manufacturing tool based on the knowledge of the selected participants. The study will specifically focus on how RFID can help identify, reduce, and eliminate the seven common types of waste identified by Taiichi Ohno in the Toyota Production System. These seven include: overproduction, waiting time, inefficient transportation, inappropriate processing, unnecessary inventory, unnecessary motion, and rejects & defects.

Please complete the online questionnaire that will take approximately 15 minutes or less of your time. To access and complete the online questionnaire, please click the following URL, or copy and paste it into the address bar of your browser window.
http://www.surveymonkey.com/s.aspx?sm=bTR7PKe6zZe6SvU5rI2iSw_3d_3d

If you have any questions or concerns about this study, please do not hesitate to contact the researcher:

Abu Haddud
Department of Engineering Management
School of Engineering Technology
Eastern Michigan University
111 Sill Hall
Ypsilanti, MI, USA 48197
Telephone: (734) 922 3193
E-mail: ahaddud@emich.edu

We look forward to your participation in this study.

Sincerely,

Appendix D

Reminder Email

Date: Wednesday, October 13, 2010

Dear SME Member;

This is a follow up to an email that was sent on Oct 6, 2010, in which we requested your participation in an important research project entitled “A Study of the Effectiveness of Radio Frequency Identification (RFID) Technology as a Lean Manufacturing Tool”.
If you have already responded, we sincerely appreciate your input and please ignore this reminder. If you did not have the chance to complete the online questionnaire yet, we would highly appreciate your insight. The survey is scheduled to close by Oct 25, 2010 and it would be very helpful if you could respond by then.
To access and complete the online questionnaire, please click the following URL, or copy and paste it into the address bar of your browser window.

http://www.surveymonkey.com/s.aspx?sm=bTR7PKe6zZe6SvU5rI2iSw_3d_3d

If you have any questions or concerns about this study, please do not hesitate to contact the researcher: ahaddud@emich.edu

Abu Haddud
Department of Engineering Management
School of Engineering Technology
Eastern Michigan University 111 Sill Hall
Ypsilanti, MI, USA 48197
Telephone: (734) 922 3193
E-mail: ahaddud@emich.edu

We look forward to your participation in this study.

Sincerely

Appendix E

EMU Human Subjects Approval Letter

EASTERN MICHIGAN UNIVERSITY
Education First

UHSRC Initial
Application Determination
EXEMPT APPROVAL

September 2, 2010

To: Abu Haddud
Engineering

Re: **UHSRC** #100811 Category: EXEMPT #2
Approval Date: September 1, 2010

Title: A Study of the Effectiveness of Radio Frequency Identification (RFID) Technology as a Lean Manufacturing Tool

The Eastern Michigan University Human Subjects Review Committee (UHSRC) has completed their review of your project. I am pleased to advise you that **your research has been deemed as exempt** in accordance with federal regulations.

The UHSRC has found that your research project meets the criteria for exempt status and the criteria for the protection of human subjects in exempt research. **Under our exempt policy the Principal Investigator assumes the responsibility for the protection of human subjects** in this project as outlined in the assurance letter and exempt educational material.

Renewals: Exempt protocols do not need to be renewed. If the project is completed, please submit the **Human Subjects Study Completion Form** (found on the UHSRC website).

Revisions: Exempt protocols do not require revisions. However, if changes are made to a protocol that may no longer meet the exempt criteria, a **Human Subjects Minor Modification Form** or new **Human Subjects Approval Request Form** (if major changes) will be required (see UHSRC website for forms).

Problems: If issues should arise during the conduct of the research, such as unanticipated problems, adverse events, or any problem that may increase the risk to human subjects and change the category of review, notify the UHSRC office within 24 hours. Any complaints from participants regarding the risk and benefits of the project must be reported to the UHSRC.

Follow-up: If your exempt project is not completed and closed after three years, the UHSRC office will contact you regarding the status of the project and to verify that no changes have occurred that may affect exempt status.

Please use the UHSRC number listed above on any forms submitted that relate to this project, or on any correspondence with the UHSRC office.

Good luck in your research. If we can be of further assistance, please contact us at 734-487-0042 or via e-mail at human.subjects@emich.edu. Thank you for your cooperation.

Sincerely,

Deb de Laski-Smith, Ph.D.
Interim Dean
Graduate School
Administrative Co-Chair
University Human Subjects Review Committee

University Human Subjects Review Committee · Eastern Michigan University · 200 Boone Hall
Ypsilanti, Michigan 48197
Phone: 734.487.0042 Fax: 734.487.0050
E-mail: human.subjects@emich.edu
www.ord.emich.edu (see Federal Compliance)

The EMU UHSRC complies with the Title 45 Code of Federal Regulations part 46 (45 CFR 46) under FWA00000050.

Appendix G

Instrument Development Matrix Used by the Panel of Experts

Instructions:

- Please read items provided in each cell
- Choose one of the following three actions: (Keep, Modify, delete)
- If an additional item should be added in any cell, please insert accordingly
- Once you complete the file, save your changes and email it as an attachment to haddud@hotmail.com

	Work-in-progress management	**Inventory management**	**Manufacturing assts tracking and maintenance**	**Manufacturing control**
Overproduction	RFID technology helps knowing how much of which goods/materials are WIP Add:	RFID technology helps knowing how much of which goods/materials are in stock Add:	RFID technology helps enabling automated JIT strategies Add:	RFID technology helps knowing where finished goods/materials are Add:
Waiting time	RFID technology helps knowing where finished goods/ raw materials are Add:	RFID technology helps knowing where assets are Add:	RFID technology helps knowing condition of assets Add:	RFID technology helps increase product autonomy in distributed control systems Add:
Inefficient transportation	RFID technology helps knowing where WIP goods/materials should be brought to Add:	RFID technology helps knowing where nearest finished goods /raw materials are Add:	RFID technology helps knowing location of nearest available assets Add:	RFID technology helps knowing where applicable implement automated routing on production lines Add:
Inappropriate processing	RFID technology helps knowing which goods/materials are suitable for which processing Add:	RFID technology helps knowing which raw materials suitable for which processing Add:	RFID technology helps eliminating production errors due to incorrect manufacturing asset maintenance Add:	RFID technology helps knowing which goods/materials are suitable for which processing Add:
Unnecessary inventory	RFID technology eliminates mistaken WIP goods/inventory association Improve visibility level	RFID technology helps improve inventory visibility	RFID technology helps eliminating unnecessary buffers waiting for asset maintenance	

	Add:	Add:	Add:	Add:
Unnecessary motion	RFID technology helps eliminating manual data collection Add:	RFID technology helps eliminating manual counts Add:	RFID technology helps eliminating manual checks for maintenance Add:	Add:
Defects	RFID technology reduces scraps due to improved traceability Add:	RFID technology helps knowing finished goods/raw materials expiry dates and implement suitable protocols Add:	Add:	Add:

Appendix I

Respondents' Job Titles and Response Date

A Study of the Effectiveness of Radio Frequency Identification (RFID) Technology as a Lean Tool	
What is your job title?	
Answer Options	Response Count
	76
answered question	76
skipped question	9

Number	Response Date	Job Title
1	Oct 6, 2010 12:35 PM	Senior Engineering Manager
2	Oct 6, 2010 12:36 PM	Manufacturing Superintendent
3	Oct 6, 2010 12:36 PM	engineering manager
4	Oct 6, 2010 12:38 PM	Engineering and Lean Manager
5	Oct 6, 2010 12:39 PM	Engineering and Process Development Manager
6	Oct 6, 2010 12:40 PM	Project Manager
7	Oct 6, 2010 12:41 PM	Supervisor
8	Oct 6, 2010 12:41 PM	Lean Specialist
9	Oct 6, 2010 12:42 PM	Senior Manufacturing Engineer
10	Oct 6, 2010 12:43 PM	Machining Supervisor
11	Oct 6, 2010 12:47 PM	Sr. Quality Engineer
12	Oct 6, 2010 12:48 PM	Production engineering manager
13	Oct 6, 2010 12:51 PM	Sr. Manufacturing Engineer
14	Oct 6, 2010 12:52 PM	Manager, Continuous Improvement & Lean
15	Oct 6, 2010 12:55 PM	Manufacturing Engineering Manager
16	Oct 6, 2010 12:55 PM	Plant Manager
17	Oct 6, 2010 12:58 PM	Product Manager
18	Oct 6, 2010 1:07 PM	Production Manager
19	Oct 6, 2010 1:17 PM	Supplier Technical Engineer
20	Oct 6, 2010 1:26 PM	Prin Configuration Assurance Adminastrator
21	Oct 6, 2010 1:29 PM	Manufacturing Engineering Manager
22	Oct 6, 2010 1:30 PM	Consultant
23	Oct 6, 2010 1:31 PM	Supplier Quality Engineer
24	Oct 6, 2010 1:33 PM	Management Analyst
25	Oct 6, 2010 1:42 PM	Continueous Improvement / H&S Manager Black Belt
26	Oct 6, 2010 1:45 PM	Lean Manufacturing
27	Oct 6, 2010 1:45 PM	Vice President & Gereral Manager
28	Oct 6, 2010 1:47 PM	Sr. Manufacturing Manager
29	Oct 6, 2010 1:49 PM	Director of MFG
30	Oct 6, 2010 1:56 PM	manufacturing engineer
31	Oct 6, 2010 2:10 PM	Head of Marketing
32	Oct 6, 2010 2:21 PM	Lean Coach
33	Oct 6, 2010 2:32 PM	Business Improvement Director
34	Oct 6, 2010 2:33 PM	Staff Mechanical Engineer
35	Oct 6, 2010 2:43 PM	Owner
36	Oct 6, 2010 3:15 PM	SR SALES ENGINEER
37	Oct 6, 2010 3:36 PM	Technical Program Manager
38	Oct 6, 2010 3:41 PM	VP of Technology
39	Oct 6, 2010 4:13 PM	Manufacturing Project Specialist
40	Oct 6, 2010 4:18 PM	Senior Quality Aiditor
41	Oct 6, 2010 4:18 PM	Inventory Control Manager
42	Oct 6, 2010 4:30 PM	Tooling Manager
43	Oct 6, 2010 4:32 PM	CHIEF TECHNOLOGY OFFICER
44	Oct 6, 2010 4:34 PM	Quality Manager

45	**Oct 6, 2010 4:55 PM**	Quality Engineer
46	**Oct 6, 2010 5:08 PM**	Continuous Improvement Coordinator
47	**Oct 6, 2010 5:09 PM**	Manufacturing Manager
48	**Oct 6, 2010 6:22 PM**	Staff Engineer
49	**Oct 6, 2010 7:00 PM**	Production Group Leader
50	**Oct 6, 2010 7:07 PM**	Vice President , Quality Compliance
51	**Oct 6, 2010 7:59 PM**	Chief Product Engineer
52	**Oct 6, 2010 8:12 PM**	Safety coordinator
53	**Oct 6, 2010 9:07 PM**	supply chain magt. engineer
54	**Oct 7, 2010 6:51 AM**	Lead Quality Assurance Inspector
55	**Oct 7, 2010 11:53 AM**	Manufacturing Group Leader
56	**Oct 7, 2010 12:13 PM**	Manager, Cable Process Engineering
57	**Oct 7, 2010 1:20 PM**	Continuous Improvement Manager
58	**Oct 7, 2010 2:04 PM**	Production Manager
59	**Oct 7, 2010 3:47 PM**	Value Stream Manager
60	**Oct 7, 2010 3:57 PM**	Lean Champion
61	**Oct 7, 2010 5:09 PM**	Sr. Design Check Engineer
62	**Oct 7, 2010 6:21 PM**	Vice President Sales & Marketing
63	**Oct 7, 2010 7:36 PM**	Operations Manager
64	**Oct 7, 2010 8:26 PM**	Plant Manager
65	**Oct 7, 2010 8:40 PM**	Quality Assurance Engineer
66	**Oct 8, 2010 1:21 AM**	Quality Engineer
67	**Oct 8, 2010 2:37 AM**	Manager
68	**Oct 8, 2010 7:47 PM**	Product Engineer
69	**Oct 9, 2010 7:55 AM**	General Manager
70	**Oct 10, 2010 3:44 PM**	Operations Manager
71	**Oct 11, 2010 2:25 AM**	Technical Consultant
72	**Oct 11, 2010 6:30 PM**	President & Executive Director
73	**Oct 12, 2010 7:28 PM**	Special Projects Manager
74	**Oct 14, 2010 10:58 PM**	Sr Manager Continuous Improvment
75	**Oct 18, 2010 12:30 AM**	Engineer
76	**Oct 24, 2010 10:49 PM**	Engineering Manager:Valve Automation Hardware

Appendix J

The Society of Manufacturing Engineers Masterlist

SME MASTERFILE LIST

Over 1,117,500 Engineers, Managers and Technical Professionals!

Society of Manufacturing Engineers

- Continuously updated
- 100% Named individuals
- 100% Response-generated
- 99% Deliverability guaranteed
- NCOA updated/CASS Certified

RATES

Base price: .... $140/M (Per thousand)
Minimum order charge: $550.00
Selections/Charges:

Geographic (State or zip code)	$15/M
Plant size	$15/M
SIC code (2 or 4-digit)	$15/M
Job function/classification	$15/M
Job title keyword(s)	$15/M
Technical interest	$15/M
Phone Numbers	$65/M

Combination Pricing	Base Rate*
Telemarketing & Mailing List	$290/M
Mail & Email	$395/M
Email & Telemarketing	$425/M
Mail, Telemarketing & Email	$485/M

*Selects and Transmission fee are additional.

Masterfile Name Sources*

Name Source	Description
Exposition Attendees and Pre-Registers	Buyers and specifiers of capital equipment
Paid SME Members	$125+/year Dues
Paid Attendees, SME Continuing Education Events	$500-$1,000+ Unit of Sale
Mail Order Buyers: Books, Videos and Video Training, CD-Roms (2/3 are multi-buyers)	$50-$5,000+ Unit of Sale
Magazine Subscribers: *Manufacturing Engineering*	Qualified titles and job functions; BPA-audited; Circulation statement available on request

*Totals are over 100% since most names are multi-buyers with multiple activity codes.

OUTPUT OPTIONS

Pressure Sensitive Labels (peel & stick)	$15/M
Diskette (ASCII/comma-delimited)	$50/flat
Electronic/E-mail (ASCII/comma-delimited)	$50/flat
FTP (ASCII/comma-delimited)	$50/flat

Select by Technical Interest

Automated Manufacturing & Assembly	***390,277***
Assembly & Joining	116,120
Automation & Controls	19,256
Machine Vision Systems	6,162
Material Handling	126,125
NC/ CNC/DNC	125,468
Robotic Fundamentals	119,868
Engineering Materials	***101,136***
Composites	22,682
Heat Treating Fundamentals	2,213
Metals	12,365
Finishing & Coating	**135,597**
Automated Coating	3,027
Finishes,Curing	3,201
Liquid Coating	4,530
Plastic Finishing	21,097
Parts Cleaning & Degreasing	47,041
Powder Coating Processes	5,156
Spray Finishing	3,353
Plastics Molding & Manufacturing	**126,996**
Blow Molding	9,071
Extrusion	18,345
Injection Molding	57,192
Moldmaking	53,336
Plastic Materials & Compounding	24,957
Electronics Manufacturing	**7,173**
Mold, Tool & Die Design	**71,209**
Manufacturing Services	**51,716**
Research & Development	**9,212**
Forming & Fabricating	**366,795**
Casting	9,004
Coil Handling & Processing	31,054
Coolants & Lubricants	33,956
Dies	29,836
Extruding	20,255
Hydroforming	15,686
Laser & Plasma Cutting	78,768
Lasers & Related Equipment	78,723
Plate & Structural Fabricating	30,139
Press Brakes	67,441
Presses	24,464
Punching	78,005
Roll Forming	25,270
Sheet Metal Fabricating Proc.	35,450
Stamping	48,505
Tooling, Forming & Fabricating	23,358
Tube & Pipe	43,216
Welding	144,354
Machining & Material Removal	**461,107**
Chucks	87,024
Cutting Tools & Accessories	155,891
Deburring & Edge Finishing	85,206
Drilling/Reaming/Tapping	83,859
Electrical Discharge Machining (EDM)	77,032
Grinding	116,145
Jigs & Fixtures	20,636
Machining Centers	164,995
Milling	173,535
Sawing Machines & Systems	105,601
Screw Machining	47,650
Turning & Boring	164,415
Product & Process Design Management	**401,198**
Computer-Aided-Design (CAD)	52,107
Cost Estimating	4,902
Internet & E-Manufacturing	4,299
Lean Manufacturing	95,456
Plant Engineering & Maintenance	20,120
Plant Layout	3,861
Product Design & Automation	74,639
Rapid Prototyping	51,915
Workplace Safety & Ergonomics	93,018
Quality	**148,818**
Geometric Dimensioning & Tolerancing	1,868
Quality Certification & Registration	1,671
Statistical Process Control	6,791
Controls, CAD/CAM Software	**263,740**
Software, CAD/CAM:	139,868
Computer-Aided-Engineering Equip.	8,399
Computer-Integrated-Mfg.	19,469
Software, Manufacturing:	79,425
Flexible Manufacturing Systems	59,829
Simulation	2,929
Software, ERP/MRP & Supply Chain Management	16,267
Software, Project Management	8,710
Software,Purchasing & Inventory Control	8,901
Measurement, Inspection & Testing	**101,734**
Coordinate Measuring Machines	49,973

Questions? Mary Venianakis (800) 523-0922 - listrentals@sme.org

SME MASTERFILE LIST

continued...

Society of Manufacturing Engineers

Select by Industry Groupings

Machine Shops	80,887
Autos & Auto Parts	50,305
Tool & Die Shops	28,430
Aircraft, Aircraft Engines & Parts	25,764
Medical/Dental Instruments	22,676
Plastic Parts/Products	25,651
Farm/Construction/Lawn/ Mining Machines	16,561
Machine Tools	15,078
Metal Stampings	13,382

Other Industries also selectable by SICs and NAICS.

Select by NAICS Industries

332 Fabricated Metal Products	188,633
333 Machinery Manufacturing	144,814
334 Computers & Electronics	40,324
335 Electrical Equipment	19,121
336 Transportation Equipment	82,356
337 Furniture & Related Products	7,450
339 Miscellaneous Manufacturing	41,711

Select by Industry Types / SICs

33 Primary Metal Industries	25,120
34 Fabricated Metal Products	114,407
35 Machinery, except Electrical	250,326
36 Electric and Electronic Equipment	42,839
37 Transportation Equipment	74,608
38 Instruments and Related Products	42,114

Other SICs and NAICS also selectable

Select by Plant Size

1-19	248,195
20-49	195,623
50 - 99	122,403
100 - 249	147,967
250 - 499	84,842
500 - 999	57,000
1,000 - 2,499	41,830
2,500 and over	34,189

Select by Job Function

Manufacturing Production	261,428
Corporate Executive	225,314
Manufacturing Engineering	142,530
Product Design / R&D	86,046
Job Shop Owner	63,617
Sales/Marketing	66,374
Purchasing	28,684
Quality Management	28,586
Control Engineering	16,642

Select by Job Title (Individual Keywords)

EXECUTIVE	**478,087**
Management	132,994
President	90,809
Owner	73,765
V.P.	44,341
Supervisor	33,607
Senior	25,216
Director	24,940
Purchasing	18,789
Leader	12,604
C.E.O.	8,875
Executive	5,036
Chief	4,583
Chairman	2,528
TECHNICAL	**273,872**
Engineer	175,560
Technician	19,507
Design	19,106
Project	15,522
Programmer	12,200
Process	11,049
Mechanical	8,317
Development	8,292
CAD/CAM	2,114
Systems	2,205

INDUSTRIAL	**202,073**
Operations	43,261
Tools	26,505
Production	41,885
Plant	23,196
Quality	16,805
Maintenance	11,233
Foreman	10,066
Mechanical	8,317
Molding	6,381
Welding	7,175
Industrial	4,164
Materials	3,085

Additional SIC Codes (2 or 4-digit) or NAICS Codes (3 or 6-digit) Industry Groupings, and Title Keyword selects are available.

Questions?
Call Mary Venianakis
(800) 523-0922
E-mail: listrentals@sme.org
FAX your order to (800) 820-0991
or
Ph. (313) 425-3265 Fax (313) 425-3417

Select Geographically

New England	**92,536**
Maine	3,071
New Hampshire	9,649
Vermont	3,042
Massachusetts	37,418
Rhode Island	5,301
Connecticut	34,055
Middle Atlantic	**66,033**
New York	27,909
New Jersey	11,384
Pennsylvania	26,740
East North Central	**273,153**
Ohio	65,150
Indiana	31,256
Illinois	69,553
Michigan	74,268
Wisconsin	32,926
West North Central	**58,470**
Minnesota	23,494
Iowa	10,759
Missouri	11,918
North Dakota	1,235
South Dakota	1,954
Nebraska	3,460
Kansas	5,650
South Atlantic	**87,328**
Delaware	885
Maryland	4,876
Virginia	9,149
West Virginia	1,529
North Carolina	25,420
South Carolina	13,421
Georgia	12,848
Florida	19,200
East South Central	**31,716**
Kentucky	8,625
Tennessee	13,405
Alabama	7,117
Mississippi	2,569
West South Central	**51,754**
Arkansas	3,610
Louisiana	3,391
Oklahoma	5,250
Texas	39,503
Mountain	**25,408**
Montana	719
Idaho	1,877
Wyoming	493
Colorado	5,793
New Mexico	1,920
Arizona	7,557
Utah	4,370
Nevada	2,679
Pacific	**184,524**
Alaska	252
Washington	9,128
Oregon	5,386
California	169,423
Hawaii	335
Total US	**870,922**
Canada	**200,085**

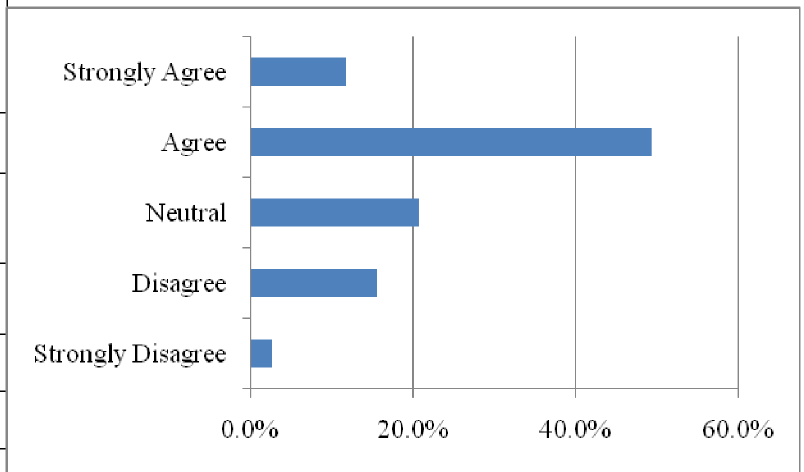
International geographic selects (by country) also available.

9/09

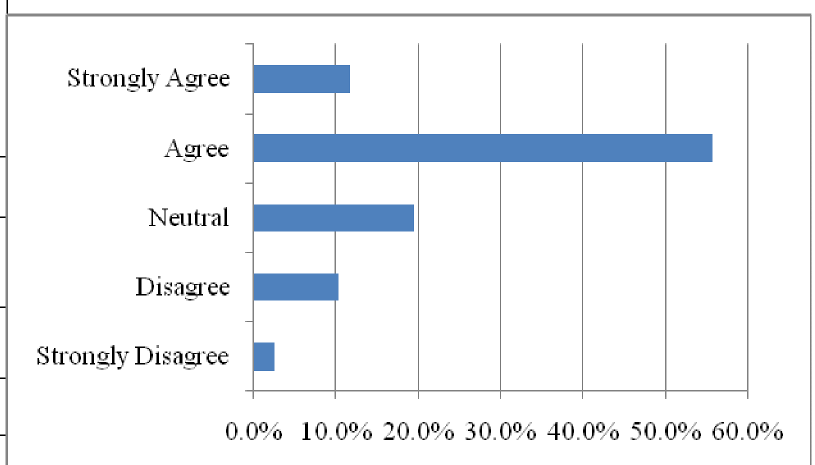
Appendix K

Analysis of Responses to Work-in-progress Management Individual Questions

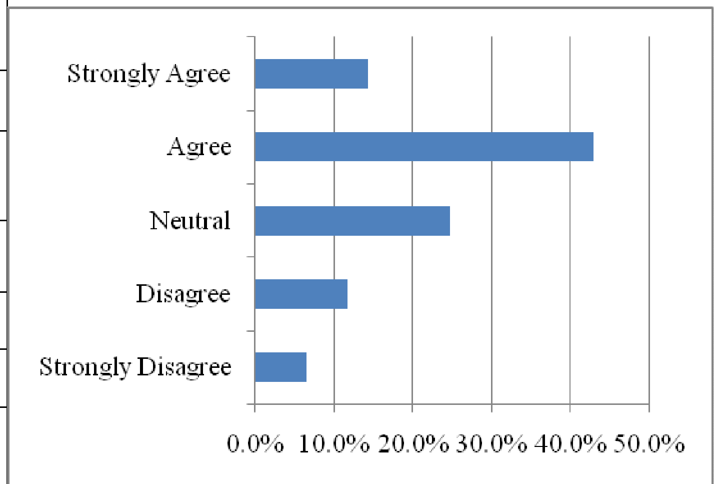
Work-in-progress Management Items		
1. The use of RFID technology helps reduce 'overproduction' by knowing how much of which goods/materials are Work-In-Progress		
	N	%
Strongly Disagree	2	2.6
Disagree	12	15.6
Neutral	16	20.8
Agree	38	49.4
Strongly Agree	9	11.7
Total	77	100.0



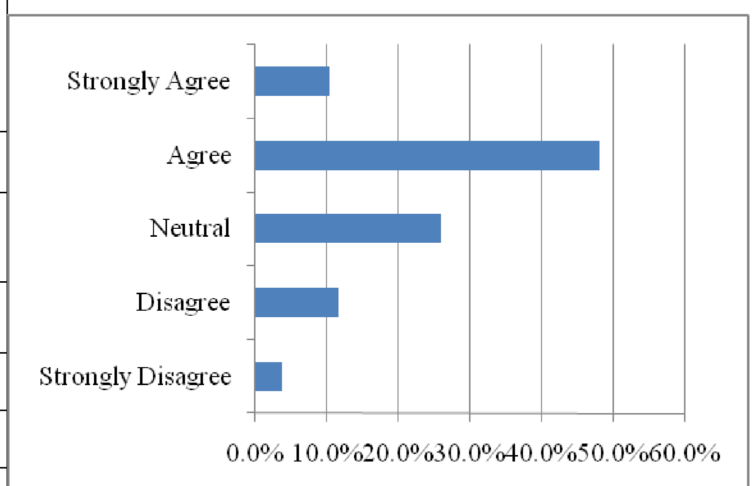
Work-in-progress Management Items		
2. The utilization of RFID technology helps reduce 'overproduction' by enabling more effective tracking of materials throughout manufacturing process.		
	N	%
Strongly Disagree	2	2.6
Disagree	8	10.4
Neutral	15	19.5
Agree	43	55.8
Strongly Agree	9	11.7
Total	77	100.0



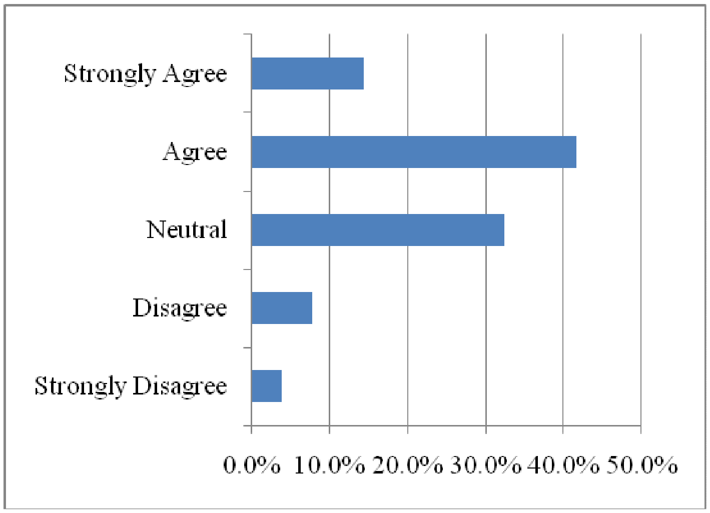
Work-in-progress Management Items		
3. The use of RFID technology helps reduce 'waiting time' by knowing where finished goods/materials are.		
	N	%
Strongly Disagree	5	6.5
Disagree	9	11.7
Neutral	19	24.7
Agree	33	42.9
Strongly Agree	11	14.3
Total	77	100.0



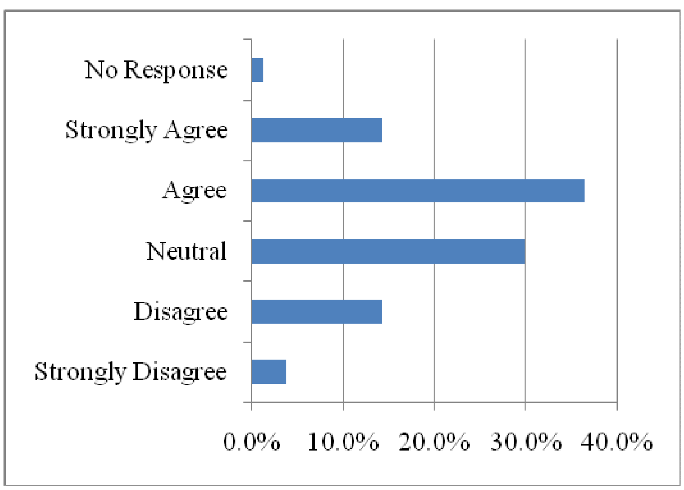
Work-in-progress Management Items		
4. The utilization of RFID technology helps reduce 'inefficient transportation' by managing the whereabouts of materials during transportation between processes.		
	N	%
Strongly Disagree	3	3.9
Disagree	9	11.7
Neutral	20	26.0
Agree	37	48.1
Strongly Agree	8	10.4
Total	77	100.0



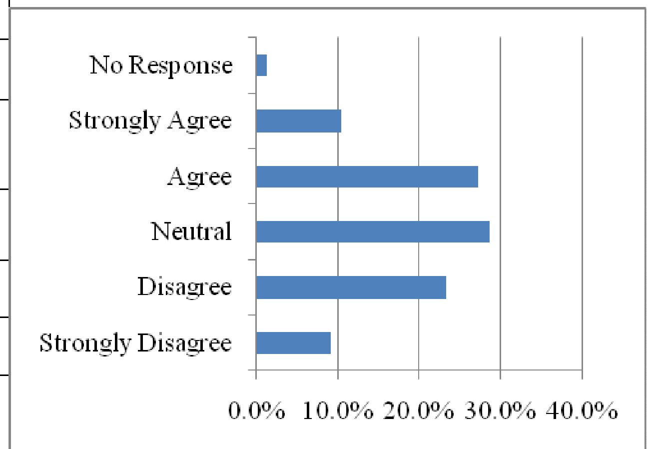
Work-in-progress Management Items		
5. The use of RFID technology helps reduce 'inefficient transportation' by knowing where Work-In-Progress goods/materials should be brought to.		
	N	%
Strongly Disagree	3	3.9
Disagree	6	7.8
Neutral	25	32.5
Agree	32	41.6
Strongly Agree	11	14.3
Total	77	100.0



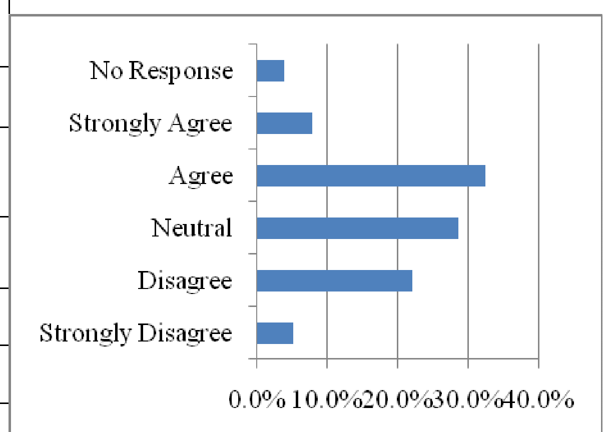
Work-in-progress Management Items		
6. The use of RFID technology helps reduce 'inappropriate processing' by knowing which goods/ materials are suitable for which processing.		
	N	%
Strongly Disagree	3	3.9
Disagree	11	14.3
Neutral	23	29.9
Agree	28	36.4
Strongly Agree	11	14.3
No Response	1	1.3
Total	77	100.0



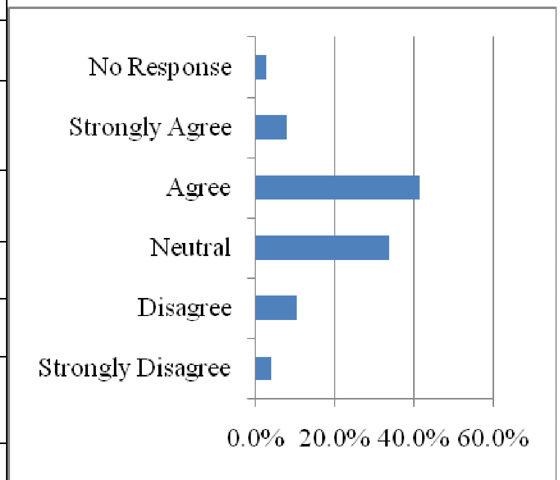
Work-in-progress Management Items		
7. The use of RFID technology helps reduce 'inappropriate processing' by assisting in identifying product that has been processed inappropriately.		
	N	%
Strongly Disagree	7	9.1
Disagree	18	23.4
Neutral	22	28.6
Agree	21	27.3
Strongly Agree	8	10.4
No Response	1	1.3
Total	77	100.0



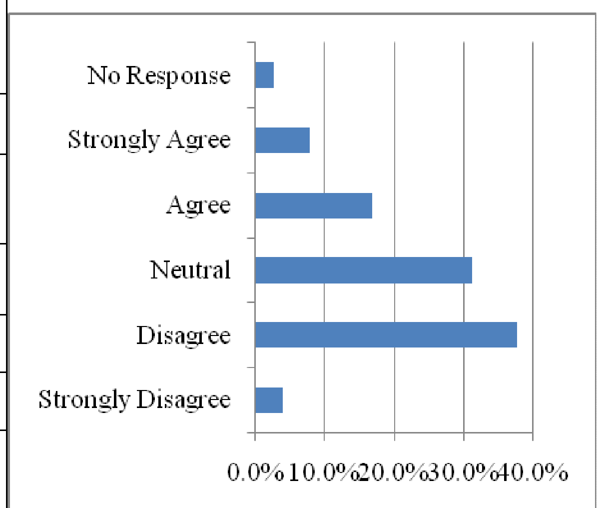
Work-in-progress Management Items		
8. The use of RFID technology helps reduce 'unnecessary inventory' by eliminating mistaken Work-In-Progress goods/ inventory association.		
	N	%
Strongly Disagree	4	5.2
Disagree	17	22.1
Neutral	22	28.6
Agree	25	32.5
Strongly Agree	6	7.8
No Response	3	3.9
Total	77	100.0



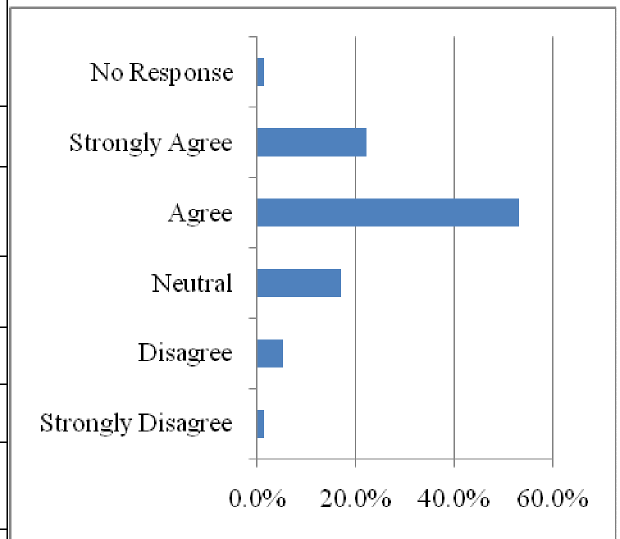
Work-in-progress Management Items		
9. The use of RFID technology helps reduce ‘unnecessary inventory’ by allowing for reduced queuing between processes.		
	N	%
Strongly Disagree	3	3.9
Disagree	8	10.4
Neutral	26	33.8
Agree	32	41.6
Strongly Agree	6	7.8
No Response	2	2.6
Total	77	100.0



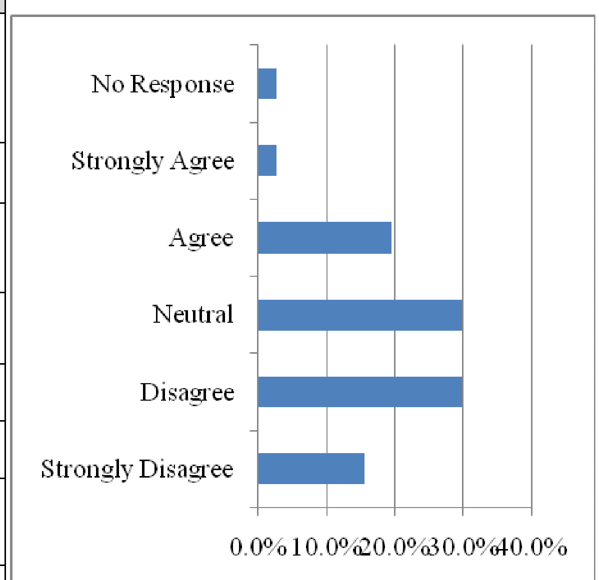
Work-in-progress Management Items		
10. The use of RFID technology helps reduce ‘unnecessary motion’ by allowing shorter physical distances between manufacturing processes.		
	N	%
Strongly Disagree	3	3.9
Disagree	29	37.7
Neutral	24	31.2
Agree	13	16.9
Strongly Agree	6	7.8
No Response	2	2.6
Total	77	100.0



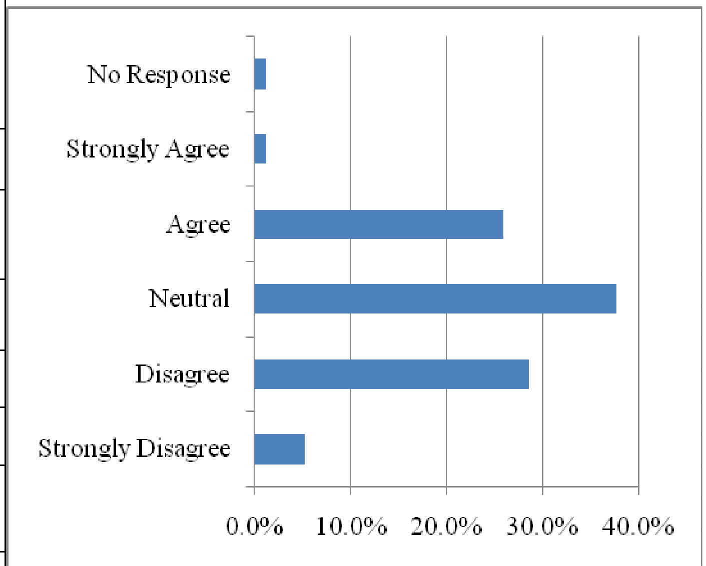
Work-in-progress Management Items		
11. The use of RFID technology helps reduce 'unnecessary motion' by eliminating manual data collection and human errors.		
	N	%
Strongly Disagree	1	1.3
Disagree	4	5.2
Neutral	13	16.9
Agree	41	53.2
Strongly Agree	17	22.1
No Response	1	1.3
Total	77	100.0



Work-in-progress Management Items		
12. The use of RFID technology helps reduce 'defects' by directly or indirectly reducing manufacturing non-conformances.		
	N	%
Strongly Disagree	12	15.6
Disagree	23	29.9
Neutral	23	29.9
Agree	15	19.5
Strongly Agree	2	2.6
No Response	2	2.6
Total	77	100.0



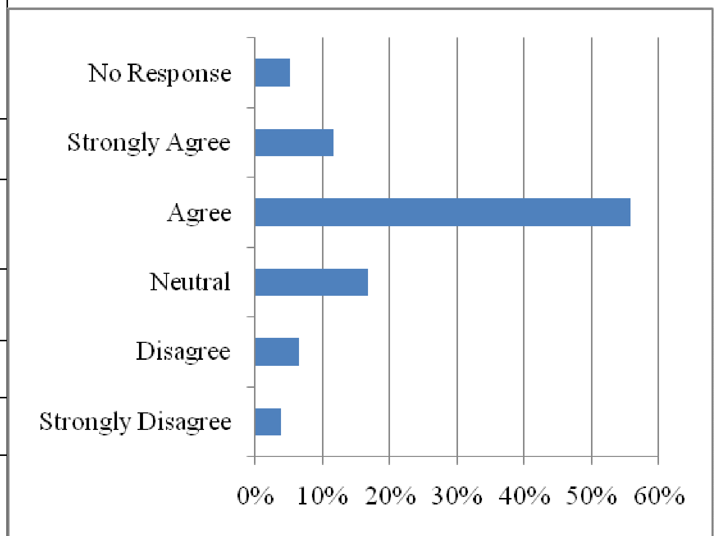
Work-in-progress Management Items		
13. The use of RFID technology helps reduce 'defects' by reducing scraps through improved traceability.		
	N	%
Strongly Disagree	4	5.2
Disagree	22	28.6
Neutral	29	37.7
Agree	20	26.0
Strongly Agree	1	1.3
No Response	1	1.3
Total	77	100.0



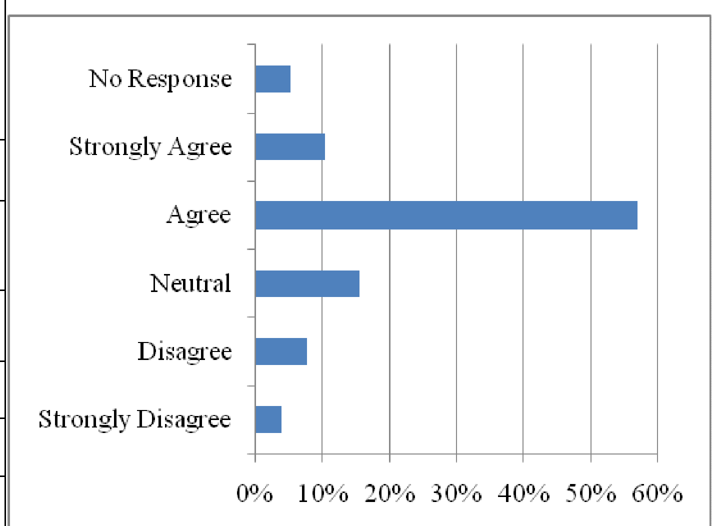
Appendix L

Analysis of Responses to Inventory Management Individual Questions

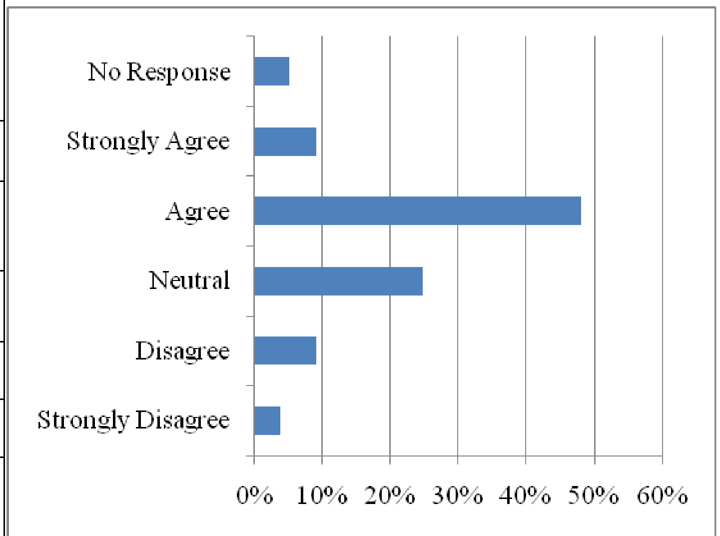
Inventory Management Items		
1. The use of RFID technology helps reduce 'overproduction' by knowing how much of goods/materials are in stock.		
	N	%
Strongly Disagree	3	3.9
Disagree	5	6.5
Neutral	13	16.9
Agree	43	55.8
Strongly Agree	9	11.7
No Response	4	5.2
Total	77	100.0



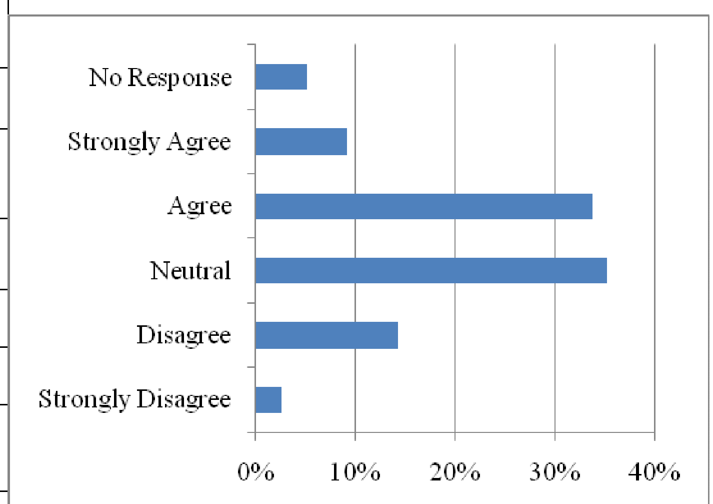
Inventory Management Items		
2. The use of RFID technology helps reduce 'waiting time' by knowing where finished goods/materials are.		
	N	%
Strongly Disagree	3	3.9
Disagree	6	7.8
Neutral	12	15.6
Agree	44	57.1
Strongly Agree	8	10.4
No Response	4	5.2
Total	77	100.0



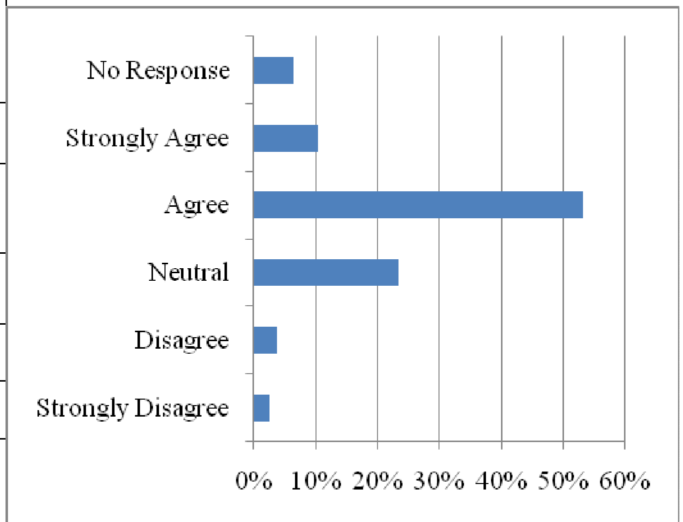
Inventory Management Items		
3. The use of RFID technology helps reduce 'inefficient transportation' by knowing where nearest finished goods/raw materials are.		
	N	%
Strongly Disagree	3	3.9
Disagree	7	9.1
Neutral	19	24.7
Agree	37	48.1
Strongly Agree	7	9.1
No Response	4	5.2
Total	77	100.0



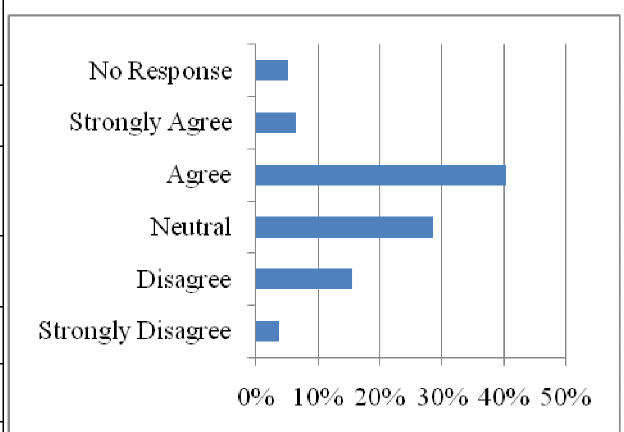
Inventory Management Items		
4. The use of RFID technology helps reduce 'inappropriate processing' by knowing which raw material is suitable for which processing.		
	N	%
Strongly Disagree	2	2.6
Disagree	11	14.3
Neutral	27	35.1
Agree	26	33.8
Strongly Agree	7	9.1
No Response	4	5.2
Total	77	100.0



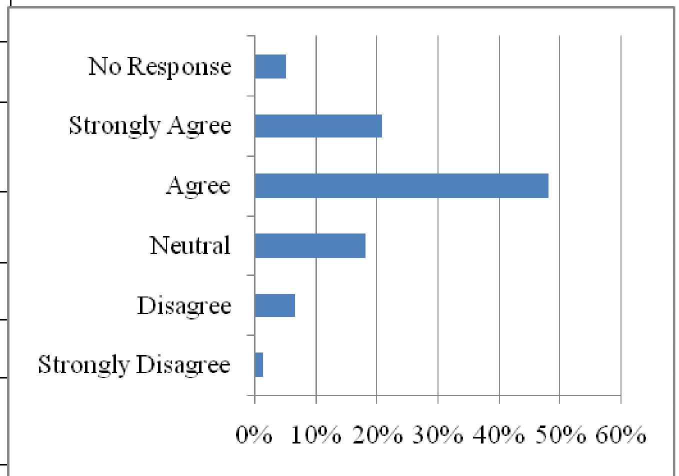
Inventory Management Items		
5. The use of RFID technology helps reduce ‘unnecessary inventory’ by improving inventory visibility.		
	N	%
Strongly Disagree	2	2.6
Disagree	3	3.9
Neutral	18	23.4
Agree	41	53.2
Strongly Agree	8	10.4
No Response	5	6.5
Total	77	100.0



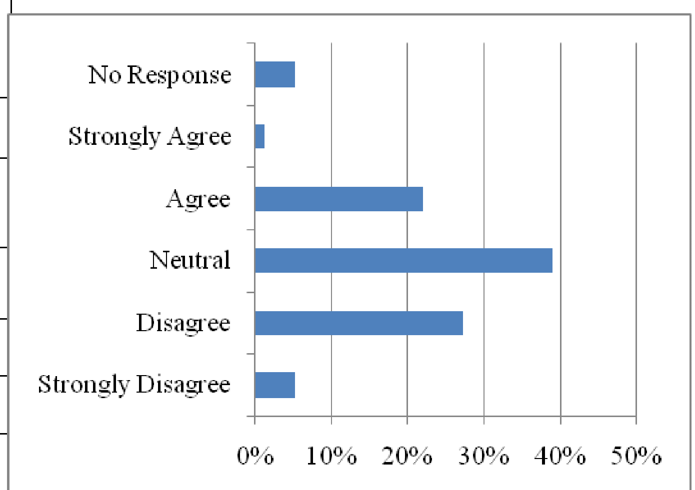
Inventory Management Items		
6. The use of RFID technology helps reduce ‘unnecessary inventory’ by eliminating the need for material queuing, and assisting in the application of Just-in-Time methodology.		
	N	%
Strongly Disagree	3	3.9
Disagree	12	15.6
Neutral	22	28.6
Agree	31	40.3
Strongly Agree	5	6.5
No Response	4	5.2
Total	77	100.0



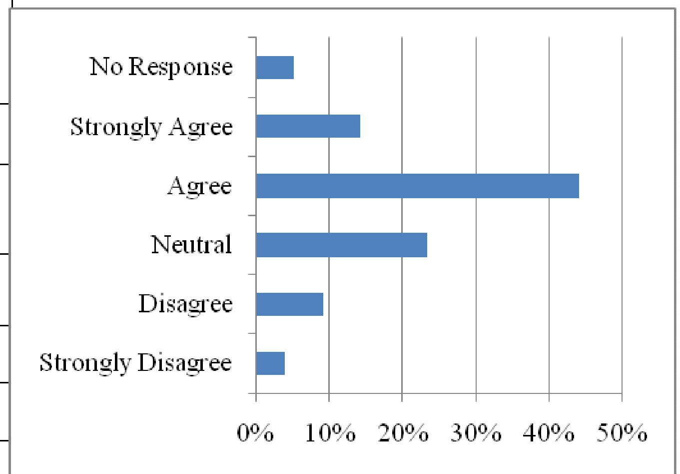
Inventory Management Items		
7. The use of RFID technology helps reduce 'unnecessary motion' by eliminating manual counts and human error.		
	N	%
Strongly Disagree	1	1.3
Disagree	5	6.5
Neutral	14	18.2
Agree	37	48.1
Strongly Agree	16	20.8
No Response	4	5.2
Total	77	100.0



Inventory Management Items		
8. The use of RFID technology helps reduce 'defects' by identifying non-conforming material and in turn reducing the overall inventory required.		
	N	%
Strongly Disagree	4	5.2
Disagree	21	27.3
Neutral	30	39.0
Agree	17	22.1
Strongly Agree	1	1.3
No Response	4	5.2
Total	77	100.0



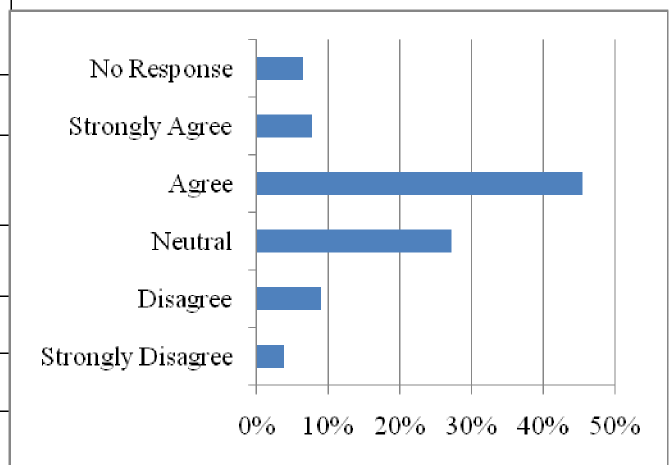
Inventory Management Items		
9. The use of RFID technology helps reduce 'defects' by knowing finished goods/ raw material expiry dates and implement suitable protocols.		
	N	%
Strongly Disagree	3	3.9
Disagree	7	9.1
Neutral	18	23.4
Agree	34	44.2
Strongly Agree	11	14.3
No Response	4	5.2
Total	77	100.0



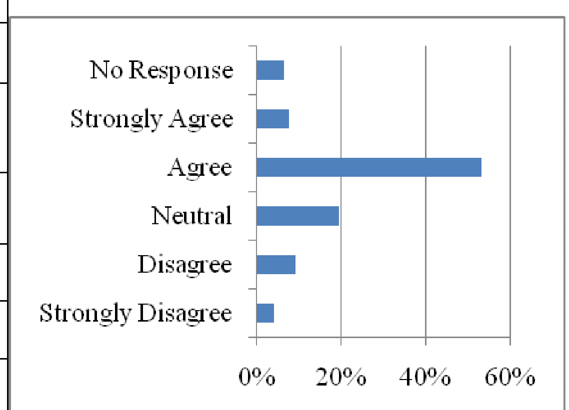
Appendix M

Analysis of Responses to Assts Tracking and Maintenance Individual Questions

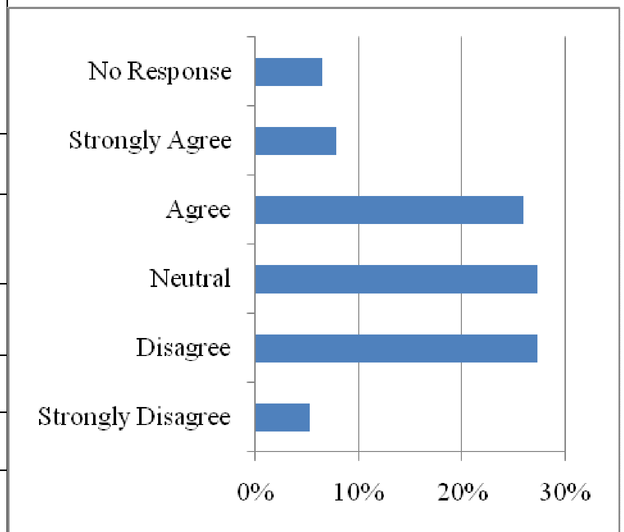
Assets Tracking & Maintenance Items		
1. The use of RFID technology helps reduce 'waiting time' by knowing where assets are and conditions of assets.		
	N	%
Strongly Disagree	3	3.9
Disagree	7	9.1
Neutral	21	27.3
Agree	35	45.5
Strongly Agree	6	7.8
No Response	5	6.5
Total	77	100.0



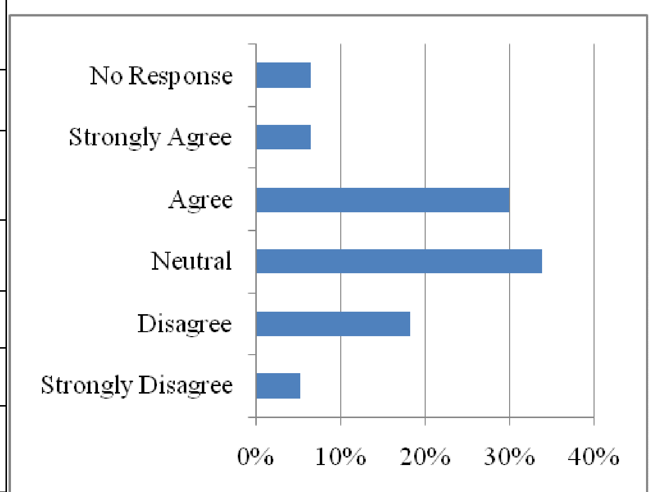
Assets Tracking & Maintenance Items		
2. The use of RFID technology helps reduce 'inefficient transportation' by knowing the location of nearest available assets.		
	N	%
Strongly Disagree	3	3.9
Disagree	7	9.1
Neutral	15	19.5
Agree	41	53.2
Strongly Agree	6	7.8
No Response	5	6.5
Total	77	100.0



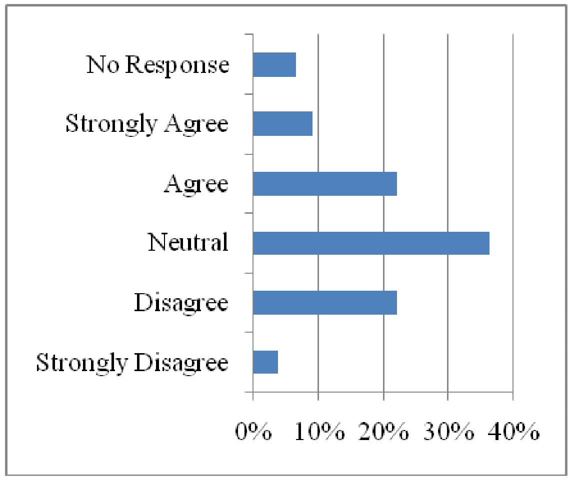
Assets Tracking & Maintenance Items		
3. The use of RFID technology helps reduce 'inappropriate processing' by eliminating production errors due to incorrect manufacturing asset maintenance.		
	N	%
Strongly Disagree	4	5.2
Disagree	21	27.3
Neutral	21	27.3
Agree	20	26.0
Strongly Agree	6	7.8
No Response	5	6.5
Total	77	100.0



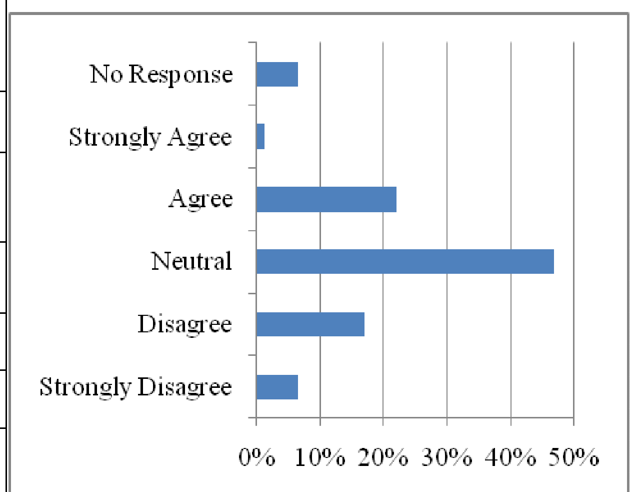
Assets Tracking & Maintenance Items		
4. The use of RFID technology helps reduce 'unnecessary inventory' by eliminating unnecessary buffers' waiting time for asset maintenance.		
	N	%
Strongly Disagree	4	5.2
Disagree	14	18.2
Neutral	26	33.8
Agree	23	29.9
Strongly Agree	5	6.5
No Response	5	6.5
Total	77	100.0



Assets Tracking & Maintenance Items		
5. The use of RFID technology helps reduce 'unnecessary motion' by eliminating manual checks for maintenance.		
	N	%
Strongly Disagree	3	3.9
Disagree	17	22.1
Neutral	28	36.4
Agree	17	22.1
Strongly Agree	7	9.1
No Response	5	6.5
Total	77	100.0



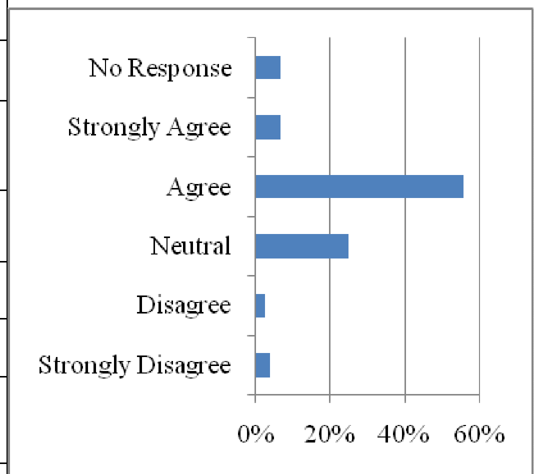
Assets Tracking & Maintenance Items		
6. The use of RFID technology helps reduce 'defects' by quickly identifying process breakdown and reducing manufacturing downtime.		
	N	%
Strongly Disagree	5	6.5
Disagree	13	16.9
Neutral	36	46.8
Agree	17	22.1
Strongly Agree	1	1.3
No Response	5	6.5
Total	77	100.0



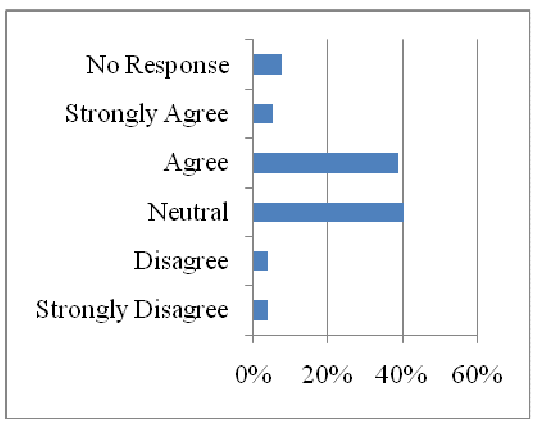
Appendix N

Analysis of Responses to Manufacturing Control Individual Questions

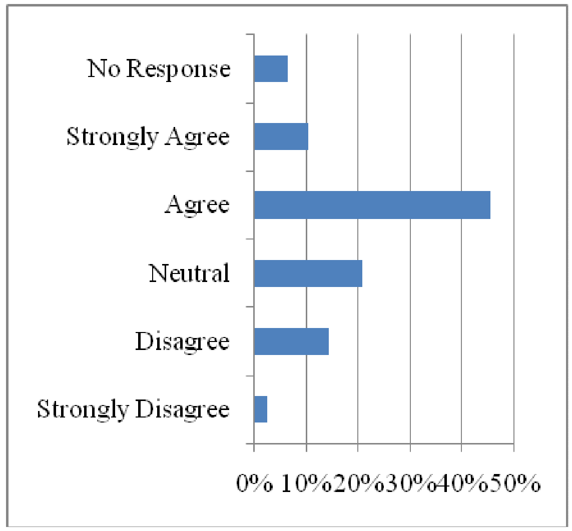
Manufacturing Control Items		
1. The use of RFID technology helps reduce 'overproduction' by enabling automated Just-in-Time strategies.		
	N	%
Strongly Disagree	3	3.9
Disagree	2	2.6
Neutral	19	24.7
Agree	43	55.8
Strongly Agree	5	6.5
No Response	5	6.5
Total	77	100.0



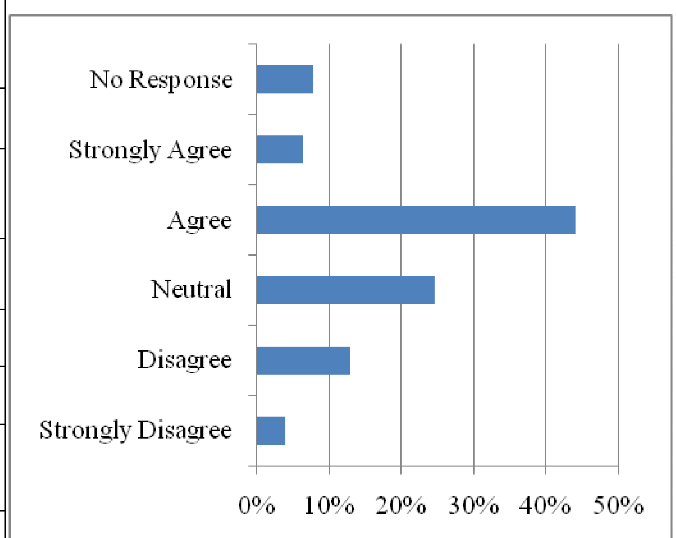
Manufacturing Control Items		
2. The use of RFID technology helps reduce 'waiting time' by increasing product autonomy in distributed control systems.		
	N	%
Strongly Disagree	3	3.9
Disagree	3	3.9
Neutral	31	40.3
Agree	30	39.0
Strongly Agree	4	5.2
No Response	6	7.8
Total	77	100.0



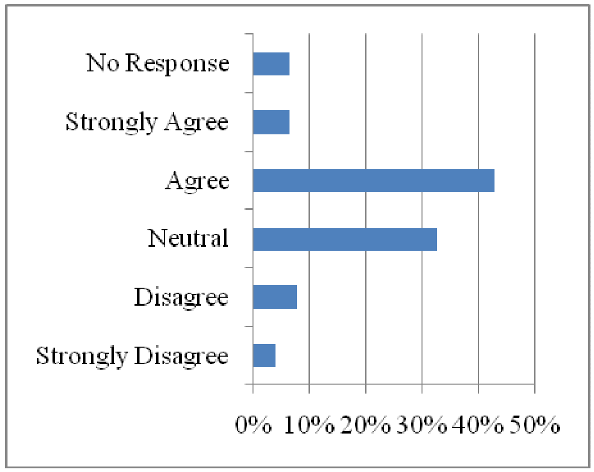
Manufacturing Control Items		
3. The use of RFID technology helps reduce 'inefficient transportation' by knowing where applicable to implement automated routing on production line		
	N	%
Strongly Disagree	2	2.6
Disagree	11	14.3
Neutral	16	20.8
Agree	35	45.5
Strongly Agree	8	10.4
No Response	5	6.5
Total	77	100.0



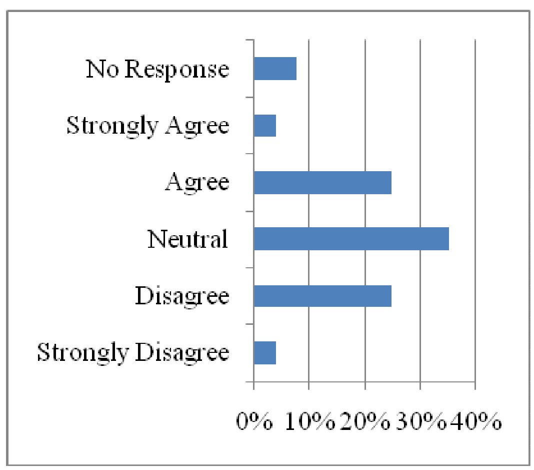
Manufacturing Control Items		
4. The use of RFID technology helps reduce 'inappropriate processing' by knowing which goods/ materials are suitable for which processing.		
	N	%
Strongly Disagree	3	3.9
Disagree	10	13.0
Neutral	19	24.7
Agree	34	44.2
Strongly Agree	5	6.5
No Response	6	7.8
Total	77	100.0



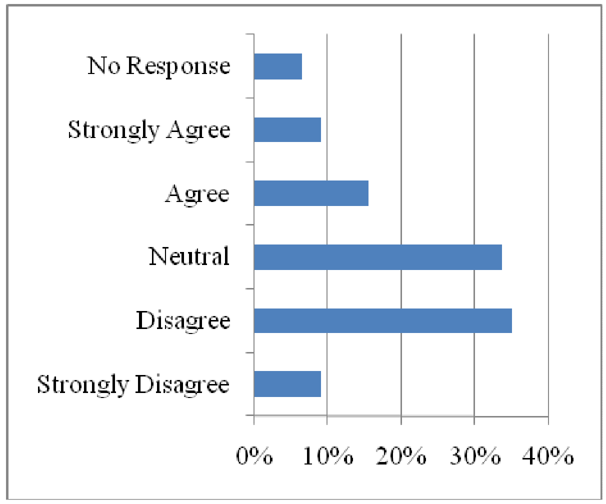
Manufacturing Control Items		
5. The use of RFID technology helps reduce 'unnecessary inventory' by eliminating the need for material queuing, which will assist in the application of Just-in-Time methodology.		
	N	%
Strongly Disagree	3	3.9
Disagree	6	7.8
Neutral	25	32.5
Agree	33	42.9
Strongly Agree	5	6.5
No Response	5	6.5
Total	77	100.0



Manufacturing Control Items		
6. The use of RFID technology helps reduce 'unnecessary motion' by enabling a reduction in motion between manufacturing processes.		
	N	%
Strongly Disagree	3	3.9
Disagree	19	24.7
Neutral	27	35.1
Agree	19	24.7
Strongly Agree	3	3.9
No Response	6	7.8
Total	77	100.0



Manufacturing Control Items		
7. The use of RFID technology helps reduce 'defects' by identifying defects in the manufacturing process.		
	N	%
Strongly Disagree	7	9.1
Disagree	27	35.1
Neutral	26	33.8
Agree	12	15.6
Strongly Agree	7	9.1
No Response	5	6.5
Total	77	100.0



Appendix O

Items Analyses based on Business Size

Work-in-progress management items analyses based on business sizes

Work-in-progress Scale	250 – 400	500 – 999	1000 – 2499	2500 +
	Items Mode Values			
1. The use of RFID technology helps reduce 'overproduction' by knowing how much of which goods/materials are Work-In-Progress.	4	3	4	4
2. The utilization of RFID technology helps reduce 'overproduction' by enabling more effective tracking of materials throughout manufacturing process.	4	4	3	4
3. The use of RFID technology helps reduce 'waiting time' by knowing where finished goods/materials are.	4	3	4	4
4. The utilization of RFID technology helps reduce 'inefficient transportation' by managing the whereabouts of materials during transportation between processes.	4	3	3	4
5. The use of RFID technology helps reduce 'inefficient transportation' by knowing where Work-In-Progress goods/materials should be brought to.	4	5	3	4
6. The use of RFID technology helps reduce 'inappropriate processing' by knowing which goods/ materials are suitable for which processing.	3	4	4	4
7. The use of RFID technology helps reduce 'inappropriate processing' by assisting in identifying product that has been processed inappropriately.	3	5	2	4
8. The use of RFID technology helps reduce 'unnecessary inventory' by eliminating mistaken Work-In-Progress goods/ inventory association.	3	2	4	4
9. The use of RFID technology helps reduce 'unnecessary inventory' by allowing for reduced queuing between processes.	4	3	4	4
10. The use of RFID technology helps reduce 'unnecessary motion' by allowing shorter physical distances between manufacturing processes.	2	2	2	2
11. The use of RFID technology helps reduce 'unnecessary motion' by eliminating manual data collection and human errors.	4	4	4	4
12. The use of RFID technology helps reduce 'defects' by directly or indirectly reducing manufacturing non-conformances.	2	4	4	3
13. The use of RFID technology helps reduce 'defects' by reducing scraps through improved traceability.	3	2	3	3
Total supported items (out of 13 items)	7	6	7	10

Inventory management items analyses based on business sizes

Inventory management scale	250 – 400	500 – 999	1000 – 2499	2500 +
	Items Mode Values			
1. The use of RFID technology helps reduce ‘overproduction’ by knowing how much of goods/materials are in stock.	4	4	4	4
2. The use of RFID technology helps reduce ‘waiting time’ by knowing where finished goods/materials are.	4	4	4	4
3. The use of RFID technology helps reduce ‘inefficient transportation’ by knowing where nearest finished goods/raw materials are.	4	4	3	4
4. The use of RFID technology helps reduce ‘inappropriate processing’ by knowing which raw material is suitable for which processing.	3	3	4	4
5. The use of RFID technology helps reduce ‘unnecessary inventory’ by improving inventory visibility.	4	4	4	4
6. The use of RFID technology helps reduce ‘unnecessary inventory’ by eliminating the need for material queuing, and assisting in the application of Just-in-Time methodology.	3	4	4	4
7. The use of RFID technology helps reduce ‘unnecessary motion’ by eliminating manual counts and human error.	4	4	4	4
8. The use of RFID technology helps reduce ‘defects’ by identifying non-conforming material and in turn reducing the overall inventory required.	3	4	3	3
9. The use of RFID technology helps reduce ‘defects’ by knowing finished goods/ raw material expiry dates and implement suitable protocols.	3	4	4	4
Total supported items (out of 9 items)	5	8	7	8

Manufacturing asst tracking and maintenance items analyses based on business sizes

Manufacturing Asset Tracking and Maintenance Scale	250 – 400	500 – 999	1000 – 2499	2500 +
	Items Mode Values			
1. The use of RFID technology helps reduce ‘waiting time’ by knowing where assets are and conditions of assets.	4	4	3	4
2. The use of RFID technology helps reduce ‘inefficient transportation’ by knowing the location of nearest available assets.	4	4	4	4
3. The use of RFID technology helps reduce ‘inappropriate processing’ by eliminating production errors due to incorrect manufacturing asset maintenance.	2	3	2	3
4. The use of RFID technology helps reduce ‘unnecessary inventory’ by eliminating unnecessary buffers’ waiting time for asset maintenance.	3	3	3	4
5. The use of RFID technology helps reduce ‘unnecessary motion’ by eliminating manual checks for maintenance.	2	4	3	3
6. The use of RFID technology helps reduce ‘defects’ by quickly identifying process breakdown and reducing manufacturing downtime.	3	3	3	3
Total supported items (out of 6 items)	2	3	1	3

Manufacturing control items analyses based on business sizes

Manufacturing Control Scale	250 – 400	500 – 999	1000 – 2499	2500 +
	Items Mode Values			
1. The use of RFID technology helps reduce ‘overproduction’ by enabling automated Just-in-Time strategies.	4	4	4	4
2. The use of RFID technology helps reduce ‘waiting time’ by increasing product autonomy in distributed control systems.	3	3	4	4
3. The use of RFID technology helps reduce ‘inefficient transportation’ by knowing where applicable to implement automated routing on production line	4	3	4	4
4. The use of RFID technology helps reduce ‘inappropriate processing’ by knowing which goods/ materials are suitable for which processing.	4	4	4	4
5. The use of RFID technology helps reduce ‘unnecessary inventory’ by eliminating the need for material queuing, which will assist in the application of Just-in-Time methodology.	4	3	4	4
6. The use of RFID technology helps reduce ‘unnecessary motion’ by enabling a reduction in motion between manufacturing processes.	3	3	2	4
7. The use of RFID technology helps reduce ‘defects’ by identifying defects in the manufacturing process.	2	2	2	3
Total supported items (out of 7 items)	4	2	5	6

Appendix P

Items Analyses based on Job Function

Work-in-progress Management Items Analyses Based on Job Function

Work-in-progress Management Scale	Manufacturing Production	Corporate Executive	Manufacturing Engineering	Product Design	Quality Management	Other Roles
	Items Mode Values					
1. The use of RFID technology helps reduce 'overproduction' by knowing how much of which goods/materials are Work-In-Progress.	4	4	4	4	4	4
2. The utilization of RFID technology helps reduce 'overproduction' by enabling more effective tracking of materials throughout manufacturing process.	4	4	4	4	4	4
3. The use of RFID technology helps reduce 'waiting time' by knowing where finished goods/materials are.	3	4	4	3	2	4
4. The utilization of RFID technology helps reduce 'inefficient transportation' by managing the whereabouts of materials during transportation between processes.	3	4	4	3	4	4
5. The use of RFID technology helps reduce 'inefficient transportation' by knowing where Work-In-Progress goods/materials should be brought to.	3	4	4	4	3	4
6. The use of RFID technology helps reduce 'inappropriate processing' by knowing which goods/ materials are suitable for which processing.	3	4	4	4	4	3
7. The use of RFID technology helps reduce 'inappropriate processing' by assisting in identifying product that has been processed inappropriately.	2	3	4	3	2	4
8. The use of RFID technology helps reduce 'unnecessary inventory' by eliminating mistaken Work-In-Progress goods/ inventory association.	2	3	2	3	4	4
9. The use of RFID technology helps reduce 'unnecessary inventory' by allowing for reduced queuing between processes.	4	3	3	3	4	4
10. The use of RFID technology helps reduce 'unnecessary motion' by allowing shorter physical distances between manufacturing processes.	2	3	2	3	2	3
11. The use of RFID technology helps reduce 'unnecessary motion' by eliminating manual data collection and human errors.	4	4	4	4	4	4
12. The use of RFID technology helps reduce 'defects' by directly or indirectly reducing manufacturing non-conformances.	2	3	2	2	3	4
13. The use of RFID technology helps reduce 'defects' by reducing scraps through improved traceability.	2	4	3	3	3	4
Total supported items (out of 13 items)	4	8	8	5	7	11

Inventory Management Items Analyses Based on Job Function

Inventory Management Scale	Manufacturing Production	Corporate Executive	Manufacturing Engineering	Product Design	Quality Management	Other Roles
	Items Mode Values					
1. The use of RFID technology helps reduce 'overproduction' by knowing how much of goods/materials are in stock.	4	4	4	4	4	4
2. The use of RFID technology helps reduce 'waiting time' by knowing where finished goods/materials are.	4	4	4	4	4	4
3. The use of RFID technology helps reduce 'inefficient transportation' by knowing where nearest finished goods/raw materials are.	4	3	4	4	4	4
4. The use of RFID technology helps reduce 'inappropriate processing' by knowing which raw material is suitable for which processing.	3	3	4	3	3	4
5. The use of RFID technology helps reduce 'unnecessary inventory' by improving inventory visibility.	4	4	4	4	4	4
6. The use of RFID technology helps reduce 'unnecessary inventory' by eliminating the need for material queuing, and assisting in the application of Just-in-Time methodology.	4	3	4	3	4	4
7. The use of RFID technology helps reduce 'unnecessary motion' by eliminating manual counts and human error.	4	4	4	4	4	4
8. The use of RFID technology helps reduce 'defects' by identifying non-conforming material and in turn reducing the overall inventory required.	3	3	4	2	3	3
9. The use of RFID technology helps reduce 'defects' by knowing finished goods/ raw material expiry dates and implement suitable protocols.	4	4	4	4	4	4
Total supported items (out of 9 items)	7	5	9	6	7	8

Manufacturing Assets Tracking and Maintenance Items Analyses Based on Job Function

Manufacturing Assets Tracking and Maintenance Scale	Manufacturing Production	Corporate Executive	Manufacturing Engineering	Product Design	Quality Management	Other Roles
	Items Mode Values					
1. The use of RFID technology helps reduce 'waiting time' by knowing where assets are and conditions of assets.	4	4	4	4	4	4
2. The use of RFID technology helps reduce 'inefficient transportation' by knowing the location of nearest available assets.	4	4	4	2	4	4
3. The use of RFID technology helps reduce 'inappropriate processing' by eliminating production errors due to incorrect manufacturing asset maintenance.	2	3	4	4	4	3
4. The use of RFID technology helps reduce 'unnecessary inventory' by eliminating unnecessary buffers' waiting time for asset maintenance.	3	3	4	4	3	4
5. The use of RFID technology helps reduce 'unnecessary motion' by eliminating manual checks for maintenance.	2	3	4	3	3	4
6. The use of RFID technology helps reduce 'defects' by quickly identifying process breakdown and reducing manufacturing downtime.	3	3	4	3	3	3
Total supported items (out of 6 items)	2	2	6	3	3	4

Manufacturing Control Items Analyses Based on Job Function

Manufacturing Control Scale	Manufacturing Production	Corporate Executive	Manufacturing Engineering	Product Design	Quality Management	Other Roles
	Items Mode Values					
1. The use of RFID technology helps reduce 'overproduction' by enabling automated Just-in-Time strategies.	4	4	4	4	4	4
2. The use of RFID technology helps reduce 'waiting time' by increasing product autonomy in distributed control systems.	3	4	4	3	3	4
3. The use of RFID technology helps reduce 'inefficient transportation' by knowing where applicable to implement automated routing on production line	2	4	4	3	4	4
4. The use of RFID technology helps reduce 'inappropriate processing' by knowing which goods/ materials are suitable for which processing.	4	4	4	4	4	4
5. The use of RFID technology helps reduce 'unnecessary inventory' by eliminating the need for material queuing, which will assist in the application of Just-in-Time methodology.	4	3	4	4	4	4
6. The use of RFID technology helps reduce 'unnecessary motion' by enabling a reduction in motion between manufacturing processes.	3	2	4	2	3	3
7. The use of RFID technology helps reduce 'defects' by identifying defects in the manufacturing process.	2	3	4	2	3	3
Total supported items (out of 7 items)	3	4	7	3	4	5

Appendix Q

Research Model

<u>The use of RFID technology</u> in **<u>four manufacturing-related functions</u>** to minimize **<u>the seven common types</u>** of manufacturing waste