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Improving Asset Visibility: Fundamental Practices for Implementing RFID Technologies

CAPSTONE REPORT

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Abstract

for

Improving Asset Visibility: Fundamental Practices for Implementing RFID Technologies

Radio Frequency Identification (RFID) has the potential to enhance tracking and identification activities across business processes (Finkenzeller, 2003). This study examines the potential for improved asset visibility in three RFID technologies: (a) low frequency (LF); (b) high frequency (HF); and ultra-high frequency (UHF). Outcomes, presented in summary tables, highlight factors that influence choices information managers must make to incorporate these technologies in medium to large organizations, with emphasis on pros, cons and costs.

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Chapter I – Purpose of the Study

Brief Purpose

The purpose of this study is to examine three Radio Frequency Identification (RFID) technologies (Finkenzeller, 2003) that could be incorporated within medium to large organizations (Ouchi, 1977) for automatic identification (Zhekun, Gadh, & Prabhu, 2004) and tracking of corporate tangible assets (Lampe, & Strassner, 2005). Laptop computers and automobiles (RFID Journal, 2003, July 21), rack mounted servers (Schwartz, 2005), and tools (Sullivan, 2005) are all examples (selected from the literature) of assets tracked with RFID technologies in medium to large organizations. The three RFID technologies examined in this study are (a) low frequency (LF), (b) high frequency (HF), and ultra-high frequency (UHF).

The intended audience is information managers (de Alwis, 2001) in the process of selecting, creating and/or updating automatic identification systems designed to improve tangible asset visibility (Bornhövd, Lin, Haller, & Schaper, 2004). According to the University of Phoenix (2006),

> "Information managers regulate the flow of information, either electronically or procedurally, within and among offices. For many companies, the rate at which work can be done is limited by the rate at which information can be transmitted to the people who need it, so the information manager fills a critical role." (In University of Phoenix, 2006, Career Profiles: Information Managers, para. 1)

A critical decision for information managers in medium to large organizations is the type of RFID technology to adopt (RFID Journal, 2003, March 31). Information managers must also anticipate a number of technical problems still facing the use of RFID technology (RFID Journal, 2002, September 23). Because of the potential process improvements RFID technologies present (UPS, 2005), this study should be especially beneficial for information managers currently working within organizations utilizing manual tangible asset tracking systems such as bar code scanning (McFarland & Sheffi, 2003; Nelson, 1997; Strand, Wangler, & Lundell, 2005).

Labor intensive manual processes for identification and tracking of corporate tangible assets are still used in medium to large organizations (Lampe & Strassner, 2005). According to Curtin, Kauffman and Riggins (2005), many large organizations utilize modern information systems (Halfway, Newton, & Vanier, 2006; Haynes, 2001; Osztermayer, Zhang, & Feser, 2002; Whitworth, Fjermestad, & Mahinda, 2006) to acquire, interpret, retain, and distribute information about organizational assets. However, determining the exact location and identification of tangible assets can be challenging (Johansson, 2005; RFID Journal, 2003, July 21).

This study fits in the larger context of wireless technologies (Ni, Liu, Lau, & Patil, 2004). According to Bornhövd et al. (2004), wireless technologies, including RFID, hold the potential of improving asset visibility. An asset that incorporates an RFID tag can communicate data about itself and its location, thereby improving asset visibility (Bornhövd, et al., 2004; Lampe & Strassner, 2005). RFID technology is changing quickly as RFID technology suppliers move to address the issues and opportunities associated with current and future RFID technologies (Shutzberg, 2004).

This study is designed as a literature review (Leedy & Ormrod, 2005) in which literature is collected, assessed, and organized for further analysis. Literature published between 2001 and

2006 is collected in the larger context of wireless technology (Ni, et al., 2004), current RFID technology (Dudley, et al., 2005), and RFID technology incorporated within medium to large organizations (Ouchi, 1977) for automatic identification (Zhekun, et al., 2004) and tracking of corporate tangible assets (Lampe, & Strassner, 2005). Using a content analysis (Krippendorff, 2004) process, literature is analyzed to identify two categories of information related to RFID: (a) the specific RFID technologies utilized by medium to large organizations for tangible asset visibility, and (b) contextual examinations of these technologies within specific settings, including pros and cons of three specific characteristics, and key factors for consideration of the factors determining the cost of different RFID technologies. Results of the content analysis process are tabulated in a table representing the type, characteristics and factors determining costs of RFID technologies used in automatic identification and tangible asset visibility (see Table 3: Identification of RFID Technologies As Reported in Selected References).

The outcome of the study is presented in two forms: (a) summary tables (see Table 4a: Contextual Examination of RFID Radio Frequencies, Table 4b: Contextual Examination of RFID Tag Types, and Table 4c: Contextual Examination of RFID Configurations) provides a contextual examination of RFID technologies, as reported in the literature (pros [benefits and advantages] and cons [drawbacks and limitations]) along three specific characteristics, and comparative view of the factors determining the cost of RFID technologies; and (b) a narrative discussion of the summary table provides information managers a means of analyzing RFID technologies designed for automatic identification and for improving tangible asset visibility as related to labor intensive manual processes for identification and tracking of corporate tangible assets used in medium to large organizations (Lampe & Strassner, 2005). The intent is that information managers will be able to use these outcomes as a decision making tool for selecting RFID technologies for automatic identification and improved asset visibility.

Full Purpose

To understand the characteristics and benefits of RFID technologies, information managers need to evaluate numerous RFID implementation studies (DeLoitte & Touche, 2004). According to the AMB Property Corporation (2004), there are significant near-term challenges to widespread adoption of RFID technology. These are:

- **Understanding RFID technologies** – According to Roberti (2004, June 14) “Companies aren’t even aware of how much they don’t know about RFID… But … learn that understanding the technology will improve their chances of deploying it successfully” (para. 1).
- **RFID standards** – There are currently no globally agreed-upon standards and, because of this limitation, it is difficult for companies to commit significant resources for the implementation of RFID technologies (AMB, 2004).
- **RFID tag type, factors determining cost, and performance** – According to Boushka et al. (2003), “There are as many tag variants on the market, as there are potential applications and changes in form factor, memory, capacity, read or read-write capability, active or passive configurations and range, all impact the cost of tags. When calculating tag costs, the application requirements are the primary driver” (p. 23, para. 1).
- **RFID hardware configurations** – According to Wilding and Delgado (2004), fixed position RFID readers are effective for recording RFID tag information through

> ingress, egress, or other fixed locations. In contrast, mobile RFID reader configurations create opportunities for more innovative ways to use RFID for automatic identification and tangible asset visibility (Holmqvist, & Stefansson, 2006).

In order to help information managers meet these challenges, the purpose of this study is to provide those who are in the process of selecting, creating and/or updating automatic identification systems, with an understanding of how RFID technologies can be used within medium to large organizations to improve processes for identification and tracking of corporate tangible assets over use of bar code systems. To that end, this study is conducted as a literature review (Leedy & Ormrod, 2005) of sources published between 2001 and 2006. Literature within this time frame represents current information related to the evolution of RFID technologies for asset management and tracking. The decade of 1980 to 1990 saw commercial applications of RFID enter the mainstream and the years 1990 to 2000 saw the emergence of standards, and a wider deployment of RFID (Landt, 2001). RFID mandates at the beginning of the current decade helped fuel a large number of articles relative to RFID technologies and asset visibility (Shutzberg, 2004). In 2004 Wal-Mart initiated its RFID compliance mandate (Wal-Mart, 2006). The years 2001 to 2006 represent a three year period before and after Wal-Mart's RFID compliance mandate in which a majority of literature related to expanding the role of RFID into automatic identification and tracking of corporate tangible assets was published (Ward & van Kranenburg, 2006).

Literature for the study is collected from materials that cover one of two areas; (a) RFID technologies, or the specific RFID hardware and associated products utilized by medium to large organizations in support of tangible asset visibility; and (b) contextual examinations of these technologies within specific settings, including pros and cons, and the factors determining the cost of different RFID technologies. As a research methodology, Leedy and Ormrod (2005, pp. 64-65) suggest that a literature review can reveal sources of previously unknown data and can help researchers interpret and make sense of findings and, ultimately, help tie results to the work of preceding researchers.

Selected literature is subjected to a qualitative content analysis (Leedy & Ormrod, 2005, pp. 142-143). This content analysis strategy is used to analyze selected sources for information relevant to RFID technologies utilized in automatic identification and asset tracking applications. According to Leedy and Ormrod (2005), a content analysis process involves searching for instances of a pre-determined set of concepts. When applied to this study, the pre-defined concepts searched for within the selected literature include: (a) Specific pre-selected RFID technologies (low, high, or ultra-high frequencies) utilized by medium to large organizations for tangible asset visibility; and (b) Contextual examinations of these technologies in specific settings (revealed through case examples), including a comparative pros and cons analysis of RFID technologies, and factors determining the cost of different RFID technologies. For the purpose of this study, the examination of pros (benefits or advantages) and cons (drawbacks or limitations) of RFID technologies within selected literature addresses four specific characteristics:

a. **Radio frequencies (low, high, and ultra-high frequencies)** – a comparison and contrast of frequencies used for RFID technologies. For example, according to Finkenzeller (2003) high frequency (HF) systems are preferred over ultra-high frequency (UHF) systems when tracking items with absorptive or dampening materials. But an inherent drawback to high frequency systems is the relatively low data transfer rate for communicating tag data.

b. **RFID tag types (active and passive)** –specific advantages or disadvantages of active tags versus passive tags for automatic identification and asset tracking. For example, passive tags are lighter, smaller and cheaper compared to active tags (Johansen, & Storm, 2004).
c. **RFID configurations (fixed and mobile)** – specific advantages or disadvantages of fixed versus mobile RFID systems. For example, according to Trebilcock (2006) if an RFID reader is installed at a dock door it is possible to know that an asset left the building but not much else; if an RFID reader is mounted on a lift truck it is possible to read an RFID tag and report its location anywhere in an enterprise.
d. **Factors Determining the Cost of RFID technologies, tag, or configuration** – technologies are ranked with respect to individual or overall cost of hardware components for automatic identification and asset tracking.

The results of the content analysis are tabulated into a series of three tables (see Appendix C; Tables C-1, C-2, and C-3). Table C-1 presents the types of RFID technologies (low, high, or ultra-high frequencies) used in automatic identification and tangible asset visibility and the associated factors determining costs in relation to each technology type. Tables C-2 and C-3 present the results of the analysis of RFID tag type and RFID configuration characteristics listed above, in relation to each technology type. The primary audience of this study, information managers, is responsible for technology selection, implementation and operating strategies within their organizations (Gottschalk, 2000). As stated by Harps (2005), proper planning by information managers for new technologies will ensure a seamless transition from old to new technologies. Information managers regulate the flow of information, either electronically or procedurally, within and among offices. For many companies, the rate at which work can be done is limited by the rate at which information can be transmitted to the people who need it, so the information manager fills a critical role (University of Phoenix, 2006).

The outcome of the study is presented in two forms. First, summary tables (see Tables 4a, 4b, and 4c) provide a targeted report of the information presented in the content analysis results tables. Focus is on the contextual examinations of: (1) the reported benefits and advantages of using one technology over another, termed *pros*; and (2) the reported drawbacks of limitations of using one technology over another, termed *cons*. The tables are designed as a decision point tool to help information managers weigh the pros and cons of each RFID technology along four characteristics (frequency, tag type, configuration and factors determining cost) in order to choose the one that will best support automatic identification and improved tangible asset visibility in their particular setting. Then, in the Conclusions chapter of this study, a narrative discussion about the tool is designed to further assist information managers who are preparing to select an RFID technology to replace manual processes and in support of automatic identification and tracking of tangible assets. An example of how information managers might use this tool is provided. In order to select the most appropriate type of RFID technology (RFID Journal, 2003, March 31), it is critical that information managers anticipate a number of technical and contextual problems still facing the use of RFID technology (RFID Journal, 2002, September 23). This study attempts to filter out RFID technologies not applicable for automatic identification and tracking, with the goal to provide a more valuable tool for information managers exploring the selection of RFID technologies. However, RFID implementations are not all identical and the technologies identified in this study will not be applicable to all projects. Additional information, outside the scope of this study, will no doubt be required.

Significance of the Study

RFID compliance mandates from large organizations like Wal-Mart Stores Inc., the U.S. Department of Defense (DoD) and the Department of Homeland Security require suppliers to tag their goods with RFID tags. These requirements have expedited the adoption of RFID technologies into mainstream business (Ferguson, 2005). RFID technologies have additional benefits reaching far beyond compliance mandates (Sun, 2005). By combining RFID tags with asset management systems, enterprises are implementing sophisticated, real-time asset control processes (Gruman, 2005). Cost reductions of RFID components and efforts by EPCglobal and industry giants, such as Wal-Mart, are causing the supply chain industry to shift towards broad adoption of RFID technology, based on emerging open standards (Pradhan, et al., 2005).

RFID has drawn industry attention because it has already demonstrated the potential to enhance efficiencies of activities across business processes by providing a means to affix unique identification and related information to individual items and enable the items to travel with the information, which can be utilized as the items pass through the different process stages, increasing productivity, minimizing errors, improving accuracy, and potentially reducing labor costs (Finkenzeller, 2003; IBM, 2003).

The number of companies actively involved in the development and sale of RFID systems indicates that this is a technology and market that should be taken seriously

(Finkenzeller, 2003). According to Shutzberg (2004), “Long term, we expect RFID will increase revenue, reduce operating costs, facilitate optimization of assets, enhance safety and quality control, and much more” (p. 8).

Many companies are waiting for RFID technology to evolve beyond its current dynamic development stage and until standards are more established (McFarland, & Sheffi, 2004), technology costs decrease (Logistics Management, 2003, March 1), and a global infrastructure emerges (Cooke, 2004). Despite these barriers, the potential value of RFID for automatic identification and tracking of corporate tangible assets compels companies to at least explore potential solutions. Pisello (2006) suggests that organizations currently utilizing manual asset tracking systems hold the greatest potential for process improvement.

Limitations to the Research

This study is conducted as a literature review (Leedy & Ormrod, 2005) of sources published between 2001 and 2006. This timeframe covers the emergence of RFID mandates and the evolution of RFID technologies for automatic identification and tracking of assets. During this time period, many quick, unplanned RFID implementations did not result in the expected return on investment (ElAmin, 2006) and, a large number of papers citing organizational challenges of implementing RFID were published (Landt, 2001).

This study seeks to identify and summarize examples of RFID technologies employed within medium to large organizations for automatic identification and tracking of tangible assets. According to Landt (2001), much data has been published regarding RFID compliance mandates however, published literature related to the utilization of RFID for automatic identification and tracking of assets is relatively new.

This study does not focus on the following aspects of, or implementations for RFID technologies:

1. *RFID standards*. RFID standards can be applied to various aspects of the RFID infrastructure: tags, readers, frequencies, data storage, and intra-system communications (Horowitz, 2005) but are beyond the scope of this study.
2. *Asset management.* According to Lampe and Strassner (2005), "The goal of … asset management is to make assets available when needed and ensure their efficient use. Asset management encompasses activities like locating assets, tracking their usage and ensuring their maintenance." (p. 1, para. 1).
3. *Cost analysis and/or benefits of RFID implementation.* In its most basic form, RFID implementations require three elements which are beyond the scope of this study:
    a. **Readers** – readers play a critical role in monitoring RFID tag traffic and are mission critical equipment (Lampe & Strassner, 2005).
    b. **Middleware** – middleware provides many critical roles including connecting readers to enterprise systems and data repositories and, methods and tools for filtering data (Kinsella, 2004).
    c. **Processes and systems** – RFID greatly impacts existing processes and provides new capabilities (Kinsella, 2004). Unless a company uses a closed-loop RFID system (in which everything is tagged even if only for internal use), companies must maintain current processes while adding RFID processes. Accordingly, these

> companies will have to use dual processes until RFID becomes the norm rather than the exception (Shutzberg, 2004).

The focus of this study is on RFID technologies appropriate for medium to large organizations for automatic identification and tracking of tangible assets. Medium to large organizations require large numbers of assets to accomplish their mission and therefore have larger asset tracking problems (Burns, 2002). RFID technologies used for these purposes could also be used for additional processes which are beyond the scope of this study. Key examples include Electronic Article Surveillance (EAS) and RFID compliance mandates. Though EAS and RFID compliance mandates meet the requirement of providing asset visibility, they do not provide total asset visibility within, for example, a warehouse or throughout a manufacturing workflow process.

This study reviews only types of RFID technologies that are used for automatic identification and tracking of tangible assets. This study does not examine the evolution of the disparate components that make up the RFID technologies used within these examples but does emphasize literature related to RFID technologies published on professional organization websites. Examples of these websites include EPCglobal, AIMglobal, and RFID Journal.

Sources provided in this study are selected from professional white papers, case studies, and websites. Professional, industry specific white papers and case study research literature provides significant foundation for this study and are given precedence. Several academic research papers reviewed in this study, such as those published by Massachusetts Institute of Technology (MIT), are given precedence because of their involvement with RFID research.

By relying on content analysis (Krippendorff, 2004), this study focuses on text-based descriptions of RFID technologies in relation to automatic identification and tracking of tangible assets, for example, *what* particular technologies are in use for automatic identification and tracking of tangible assets; *when* a particular RFID technology is utilized within medium to large organizations; and *how* a particular RFID technology is utilized for improved asset visibility. The goal of the content analysis approach is to identify data that are *reliable* and *replicable* (Krippendorff, 2004).

Content analysis is focused on four pre-selected characteristics of RFID technologies. These are: frequency; tag type, configuration and factors determining cost. The reason for selecting these four characteristics, and not others, is that by concentrating on these characteristics, information managers can define a complete RFID system for automatic identification and asset tracking. A typical RFID system consists of transponders (tags utilizing a specific frequency – LF, HF, or UHF), reader(s), antennas and a host (computer to process the data) (Prabhu, Su, Ramamurthy, Chu, & Gadh, 2005).

Literature selection for this study is determined relevant based on one or more of the following criteria:

- *Literature describes an RFID technology currently used in medium to large organizations for automatic identification and tracking of tangible assets* – literature must describe current, open standard, non-proprietary, replicable RFID technologies.
- *Literature describes basic features of the RFID technology related to automatic identification and tracking of tangible assets* – literature must have sufficient depth and not just cursory reference to chosen technology.

- *Literature presents case-based examination of the RFID technology related to automatic identification and tracking of tangible assets* – literature must examine the technology within specific contextual circumstances, supported by documentation or citation.
- *Literature is referenced or quoted in other publications* – literature must have reference to external sources and/or be referenced in similar works related to this research topic.

Problem Area

Labor intensive manual processes that incorporate bar code scanning for identification and tracking of corporate assets are still used in medium to large organizations (Lampe & Strassner, 2005). The bar code labels that started a revolution in identification systems and asset tracking are now being found to be inadequate in an increasing number of cases (Finkenzeller, 2003). According to Finkenzeller (2003), bar codes may be inexpensive but they have low data storage capacity and cannot be reprogrammed.

In today’s fast paced e-business environment (Markus, 2000), manual processes for tracking critical assets can bring even the most supercharged supply chain (Asif & Mandviwalla, 2005) to a halt, making asset tracking a pivotal process in the supply chain (Shankar, & O’Driscol, 2004). Medium to large organizations require large numbers of assets to accomplish their mission and therefore have larger asset tracking problems (Burns, 2002).

RFID technology has been around for over 50 years with little fanfare (Landt, 2001). Today, much attention has been placed on RFID with the emergence of RFID compliance mandates from retailers like Wal-Mart, Metro, Tesco, and Target, manufacturers like Procter & Gamble and Kimberly Clark, and even the U.S. Department of Defense (DoD) (Bornhövd, et al., 2004).

RFID has also gained great traction in areas outside the original driving thrust of compliance mandates, including healthcare, logistics, asset management, and manufacturing (Asif, & Mandviwalla, 2005). This is not to say however, that the technology has reached full maturity. Much like the automobile, new technology is phased in over long periods of time while still being refined (Gragg, 2003).

According to Curtin, et al. (2005), innovations in information technology continue to improve the cost-performance capabilities of organizations to perform identification and tracking of corporate assets. The Economist (2003) introduces RFID in an article with the title "*The Best Thing Since the Bar-Code.*" However, RFID is not a "plug-and-play" technology (Sommer, 2006). In other words, according to Barker and Mahadevan (2004), organizations will need to be capable of managing a mixed architecture as RFID won't replace bar codes overnight. Both systems will need the ability to feed each other, and a *nesting* capability will be essential (Mitchell, & Chappell, 2003).

Government has also recognized the potential of RFID. Underscoring the notion that the technology's core application is inventory control, the most important government use of RFID to date is asset management by the Pentagon. The military has spent about $100 million over the last decade implementing RFID technology to track everything from rations, uniforms, and tanks (Gilbert, 2004). In a world where manufacturing occurs on other continents, lost time can quickly erode profits, and companies need reliable means for tracking asset visibility (Unisys, 2006). When deciding to make investments in asset visibility, it is important to understand the magnitude of the potential savings and what methods will be required to realize this value (Luedtke, & White, 2004).

According to Barker and Mahadevan (2004), RFID technologies have the following advantages over bar codes.

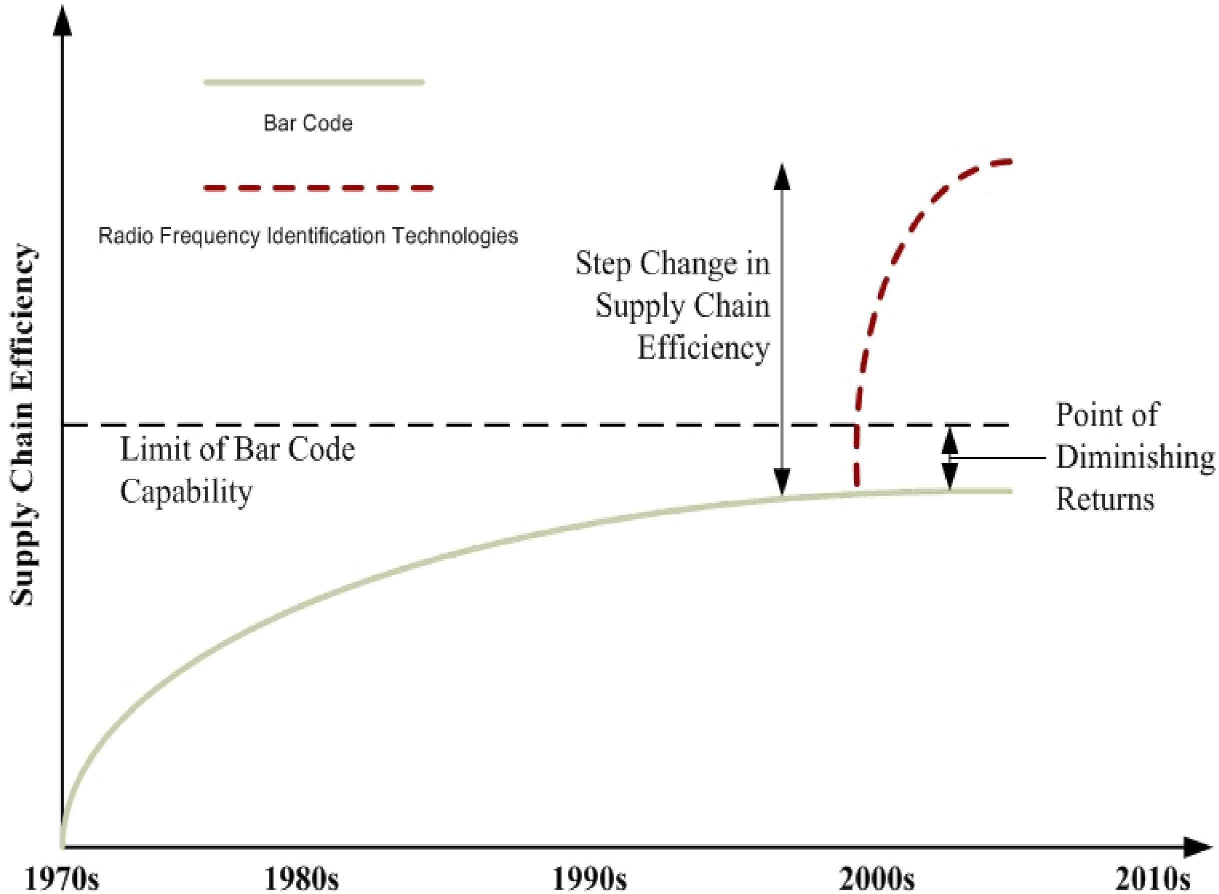
- **Simultaneous, multiple data reads** – identifying multiple labels, containers or items all at the same time as they pass a reading location or are read using a mobile RFID scanner. This need is critical in asset tracking where there could be multiple items in a case traveling on a pallet and passing through a tunnel RFID reader or portal all at the same time (Hartman, 2004).
- **Data can be captured automatically** – automatic data capture (ADC) is a collective term that included bar coding, magnetic stripe, radio frequency identification (RFID), optical and magnetic ink character recognition (OCR, MICR), smartcards and vision and voice recognition systems. RFID is capable of reading RFID tags at significant distances (Roberti, 2004, October 28) and without line of sight (Finkenzeller, 2003).
- **RFID based systems can be always capturing data** –The always on nature of RFID has presented a whole new set of challenges the resulting cascaded of data continuously feeds an enormous amount of stored data (Hildebrandt, & Meints, 2006). If RFID active tags are used, information can be constantly transferred to

RFID systems to confirm any tagged item’s existence and location (Mitchell, & Chappell, 2003).

- **Data can be captured beyond the line of sight** – bar codes require line of sight to capture data but, RFID can capture data beyond line of sight (Dinning & Schuster, 2004).
- **Far more information can be stored and communicated right to the individual asset** – Since many RFID tags are rewritable, they can be reused on different jobsites and for different material (Schneider, 2003). RFID systems enable efficient and systematic collection, storage, query, retrieval, management, analysis, and reporting or asset information (Halfway, Newton, & Vanier, 2006).

Mitchell and Chappell (2003) further illustrate the relationship between manual, bar code data capture and RFID technologies graphically, in Figure 1.

Figure 1: **Limitations of Bar Code Capability Compared to RFID**



Source: *Mitchell & Chappell, 2003*

According to Asif and Mandviwalla (2005), the U.S. Department of Defense (DoD) is planning to overhaul its entire supply chain because it believes that RFID will reduce losses due to lack of information. The General Accounting Office substantiated the need in a December 2003 report that showed a $1.2 billion discrepancy between the material shipped and the material received in Iraq by the Army (Tegtmeier, 2004).

RFID has benefits that reach far beyond compliance mandates. By combining RFID tags with asset management systems, enterprises are implementing sophisticated, real-time asset control processes (Gruman, 2005). Cost reductions of RFID components and efforts by EPCglobal and industry giants, such as Wal-Mart, are causing the supply chain industry to shift towards broad adoption of RFID technology, based on emerging open standards (Pradhan, et al., 2005). RFID has drawn industry attention because it has already demonstrated the potential to enhance efficiencies of activities across business processes by providing a means to affix unique identification and related information to individual items and enable the items to travel with the information, which can be utilized as the items pass through the different process stages, increasing productivity, minimizing errors, improving accuracy, and potentially reducing labor costs (Finkenzeller, 2003; IBM, 2003).

The modern-day RFID industry continues to evolve and discover new areas of opportunity (Evans, 2005). Each week articles are published about companies that are finding new and creative ways to use RFID to deliver business benefits (Roberti, 2006). Articles selected for review for this study analyze one or more aspects mentioned above and/or are determined to present process improvements for automatic identification or asset visibility. This study provides information managers, and any executive involved with the evaluation of RFID technologies, with a valuable tool for exploring the selection of RFID technologies in relation to automatic identification and tracking of corporate tangible assets.

According to Asif and Mandviwalla (2005), unlike bar codes, RFID requires no line-of-sight to read the tag data and therefore reduces the manual process of physically locating the bar code and scanning the bar code to retrieve its contents. Bar codes allow only object level identification (Maloni, & DeWolf, 2006) but RFID tags can contain an encoded unique serial number which allows item level visibility (Curtin, et al., 2005; Wilding & Delgado, 2004).

Bar code systems cannot deliver the ever-increasing returns enjoyed in previous decades (Barker, & Mahadevan, 2004). According to Wilding and Delgado (2004), compared to other automatic or manual identification systems like bar codes, RFID offers many potential benefits. Benefits of RFID over bar code systems – as identified from the twenty-two selected resources in this study – include:

- **Lower system cost** (AMB, 2004; Asif, & Mandviwalla, 2005; Das, 2004; Engels, et al., 2003; Gambon, 2006; Maloni, & DeWolf, 2006).
- **Labor Savings** (AMB, 2004; Asif, & Mandviwalla, 2005; Barker & Mahadevan, 2004; Boushka, et al., 2003; Curtin, et al., 2005; Dinning & Schuster, 2004; Gambon, 2006; Loebbecke, et al., 2006; Lu, et al., 2006; Maloni, & DeWolf, 2006; Prabhu, et al., 2005; RFID Journal, July 21, 2003; Ward, & van Kranenburg, 2006; Wilding, & Delgado, 2004).
- **Reliability and accuracy** (AMB, 2004; Barker, & Mahadevan, 2004; Bornhövd, et al., 2004; Boushka, et al., 2003; Corsette, et al., 2005; Curtin, et al., 2005; Das, 2004; Dempsey, 2004; Engels, et al., 2003; Gambon, 2006; Loebbecke, et al., 2006; Lu, et al., 2006; Maloni, & DeWolf, 2006; Prabhu, et al., 2005; Ward, & van Kranenburg, 2006; Wilding & Delgado, 2004).
- **Longer read range** (AMB, 2004; Anusha, 2005; Asif, & Mandviwalla, 2005; Bornhövd, et al., 2004; Boushka, et al., 2003; Corsette, et al., 2005; Curtin, et al., 2005; Das, 2004; Dempsey, 2004; Dinning & Schuster, 2004; Engels, et al., 2003; Loebbecke, et al., 2006; Lu, et al., 2006; Maloni, & DeWolf, 2006; Pradhan, et al., 2005; Ward, & van Kranenburg, 2006).

- **Contains more data** (AMB, 2004; Asif, & Mandviwalla, 2005; Barker, & Mahadevan, 2004; Bornhövd, et al., 2004; Boushka, et al., 2003; Curtin, et al., 2005; Das, 2004; Engels, et al., 2003; GAO, 2006; Lu, et al., 2006; Maloni, & DeWolf, 2006; Prabhu, et al., 2005; Ward, & van Kranenburg, 2006).
- **Improved read speed** (AMB, 2004; Asif, & Mandviwalla, 2005; Barker, & Mahadevan, 2004; Boushka, et al., 2003; Curtin, et al., 2005; Das, 2004; Dinning & Schuster, 2004; Gambon, 2006; Loebbecke, et al., 2006; Lu, et al., 2006; Maloni, & DeWolf, 2006; Prabhu, et al., 2005; Ward, & van Kranenburg, 2006).
- **Multiple reading** (AMB, 2004; Asif, & Mandviwalla, 2005; Barker, & Mahadevan, 2004; Bornhövd, et al., 2004; Curtin, et al., 2005; Das, 2004; Gambon, 2006; Loebbecke, et al., 2006; Lu, et al., 2006; Prabhu, et al., 2005; Pradhan, et al., 2005; RFID Journal, July 21, 2003; Ward, & van Kranenburg, 2006).
- **Read and write data** (AMB, 2004; Anusha, 2005; Asif, & Mandviwalla, 2005; Barker, & Mahadevan, 2004; Bornhövd, et al., 2004; Boushka, et al., 2003; Curtin, et al., 2005; Das, 2004; Lu, et al., 2006; Prabhu, et al., 2005; Pradhan, et al., 2005; RFID Journal, July 21, 2003; Ward, & van Kranenburg, 2006).
- **Improved security** (Asif, & Mandviwalla, 2005; Barker, & Mahadevan, 2004; Boushka, et al., 2003; Corsette, et al., 2005; Curtin, et al., 2005; Das, 2004; Dempsey, 2004; Engels, et al., 2003; Maloni, & DeWolf, 2006; Prabhu, et al., 2005; Pradhan, et al., 2005; RFID Journal, July 21, 2003; Ward, & van Kranenburg, 2006).
- **No line of sight requirement** (AMB, 2004; Anusha, 2005; Asif, & Mandviwalla, 2005; Barker, & Mahadevan, 2004; Boushka, et al., 2003; Das, 2004; Dinning &

Schuster, 2004; Maloni, & DeWolf, 2006; Prabhu, et al., 2005; Ward, & van Kranenburg, 2006).

- **Robustness** (Boushka, et al., 2003; Das, 2004; Dempsey, 2004; Lu, et al., 2006; Ward, & van Kranenburg, 2006; Wilding & Delgado, 2004).

Chapter II – Review of References

The following review of references provides an annotated bibliography and detailed summary of the key literature used in developing the foundation and data set used for content analysis for this study. Each annotation is intended to convey the primary contribution of the selected reference to the study. The entries include a summary of the reference, information on the relevance to selected areas of this study, and the criteria used to determine the credibility of the author(s). Additional references, utilized in the data set for coding, are found in Appendix B of this study. The selection of key references for review, listed in alphabetic order, is determined by one or more of the following criteria:

- the reference is fundamental to the development of the Purpose, Significance, Problem, Method, or Definitions (see Appendix A); and
- the reference is a key selection for the data set used for coding

References selected for reviews are organized into the following categories:

- literature providing an understanding of *Content Analysis Practices*
- foundational readings on the larger topic of *RFID Technologies*
- literature describing *RFID Technologies for Asset Management and Asset Visibility*
- literature describing *RFID Technologies Implementations for Asset Management and Asset Visibility*

Literature on Content Analysis Practices

Krippendorff, K. (2004). *Content analysis: An introduction to its methodology.* Thousand Oaks, CA: Sage Publications, Inc.

In this text, Professor Klaus Krippendorff offers a comprehensive exploration of content analysis, its procedures and protocols. The text discusses three characteristics of contemporary content analysis: (a) it is an exploratory process that is fundamentally empirically grounded and predictive or inferential in intent; (b) it surpasses traditional opinions of symbols, contents, and intents; and (c) it has a methodology of its own. Krippendorff is a Professor of Communication and Gregory Bateson Term Professor for Cybernetics, Language, and Culture at the University of Pennsylvania's Annenberg School for Communication. The text is cited 1,412 times in the work of others (Google™ Scholar, December 31, 2006, http://scholar.google.com/scholar?q=Krippendorff+2004&hl=en&lr=).

This reference is used in the Purpose and Method chapters to define this study's strategy for research and data analysis. Specific areas referenced from the text include defining a research methodology and criteria for source selection, and formulation of research recording and context units.

Leedy, P. D., & Ormrod, J. E. (2005). *Practical research: Planning and design.* (7th Ed.). Upper Saddle River, NJ: Merrill/Prentice Hall

This reference is used in the Purpose and Method chapters of this study to support methods of collection, assessment, and organization of literature for further analysis. The text supports this study's research method of literature review and qualitative content analysis. Additionally, the discussions of qualitative research (pp. 133-160 and content analysis (pp. 142-143) provide the foundation of the data analysis section in the Method chapter of this study.

This text was chosen for inclusion in this study because it is a required text of the University of Oregon's AIM Masters program and, the authors' work is cited 477 times in the work of others (Google™ Scholar, December 31, 2006, http://scholar.google.com/scholar?hl=en&lr=&cluster=4336418542314447615). The book is in the seventh edition of printing and has been available since 1989.

Palmquist, M, Busch, C., De Maret, S., Flynn, T., Kellum, R., Le, S., Meyers, B., Saunders, M., White, R. (2007). *Content Analysis.* Writing@CSU. Colorado State University Department of English. Retrieved November 28, 2006, from http://writing.colostate.edu/guides/research/content/

This resource is used in the Method chapter to help develop the content analysis process for this study. Palmquist's eight-step conceptual analysis procedure of content analysis research method was chosen for inclusion in this study because it offers a step-by-step means for understanding the content analysis process.

The resource was chosen based on its association with Colorado State University's Writing Center. Michael Palmquist is the Director of the Institute for Learning and Teaching, Co-Director of the Center for Research on Writing and Communication Technologies at Colorado State University. Palmquist teaches undergraduate writing courses and graduate seminars in rhetorical theory, computers and writing, research methodology, and nonfiction writing.

Literature on RFID Technologies

Curtin, J., Kauffman, R. J., & Riggins, F. J. (2005). *Making the "most" out of RFID technology: A research agenda for the study of the adoption, usage and impact of RFID.* Retrieved October 25, 2006, from https://www.misrc.umn.edu/workingpapers/fullpapers/2005/0522_103005.pdf

This resource explores RFID and proposes a research agenda to address a series of broad research questions related to how RFID technology: (1) is developed, adopted, and implemented by organizations; (2) is used, supported, and evolved within organizations and alliances; and (3) impacts individuals, business processes, organizations, and markets. Additionally, this resource examines: (a) how many large organizations utilize modern information systems to acquire, interpret, retain, and distribute information about organizational assets; (b) how innovations in information technology continue to improve the cost-performance capabilities of organizations to perform identification and tracking of corporate assets; (c) the purpose of an interrogator and reader; and (d) how low frequencies (LF) are not good near metal objects. The resource provided foundational material for developing the Purpose section of this paper and, select terminology for content analysis in the Method section of this paper. The article is selected as one part of the data set used for coding during data analysis.

This paper was presented to the University of Minnesota's Carlson School of Management. John Curtin is a Research Fellow at the University of Minnesota (UMN) Management Information Systems (MIS) Research Center. Robert Kauffman is a Director, MIS Research Center, and Professor and Chair. Frederick Riggins is an RFID

Project Leader, MIS Research Center and Assistant Professor. This article has been cited 4 times in other scholarly journals (Google™ Scholar, December 31, 2006, http://scholar.google.com/scholar?hl=en&lr=&cites=987252707597331092) and contains 140 references.

Finkenzeller, K. (2003). *RFID handbook.* (2nd Ed.). West Sussex, England: Wiley

This highly technical text examines RFID technology from the point of view of students and engineers confronted with RFID technology for the first time. Elements of the text utilized in this study include: (a) how high frequency (HF) systems are preferred over ultra-high frequency (UHF) systems when tracking items with absorptive or dampening materials; (b) RFID systems are a technology and market that should be taken seriously; (c) RFID has drawn industry attention because it has already demonstrated the potential to enhance efficiencies of activities across business processes by providing a means to affix unique identification and related information to individual items and enable the items to travel with the information, which can be utilized as the items pass through the different process stages, increasing productivity, minimizing errors, improving accuracy, and potentially reducing labor costs; and (d) the bar code labels that started a revolution in identification systems and asset tracking are now being found to be inadequate in an increasing number of cases – bar codes may be inexpensive but they have low data storage capacity and cannot be reprogrammed. Elements of this resource contributed to the Purpose section of this study – specifically the significance and problem areas – and the Definitions section (see Appendix A).

Finkenzeller is employed at Giesecke & Devrient GmbH, Munich Germany – a leading provider of smart card technology used in electronic payment, healthcare, corporate identification, national identification, driver's license, and chip passport applications. Utilization of this resource provided significant validity to the study because it has been cited 239 times in other scholarly journals (Google™ Scholar, December 31, 2006, http://scholar.google.com/scholar?hl=en&lr=&cites=15712857135086370119) and contains 152 references. This author's work is referenced and cited in by other sources in this study including Lampe and Strassner (2001) *The potential of RFID for movable asset management*. The book is in the second edition of printing and has been available since 1999.

Landt, J. (2001). *Shrouds of time: The history of RFID.* AIM Publication. Retrieved November 9, 2006, from http://www.aimglobal.org/technologies/rfid/resources/shrouds_of_time.pdf

In this article, Dr. Jeremy Landt explores the history of RFID and its related scientific concepts. Specifically, Dr. Landt reviews: (a) how the decade of 1980 to 1990 saw commercial applications of RFID enter the mainstream and the years 1990 to 2000 saw the emergence of standards, and a wider deployment of RFID; (b) how the period of 2000 to 2006 saw a large number of published papers citing organizational challenges of implementing RFID; and (c) why much data has been published regarding RFID compliance mandates however, published literature related to the utilization of RFID for automatic identification and tracking of assets is relatively new. This resource is used in this research to help establish the Purpose section – specifically the limitations and problem area.

According to Caitlin (2001), Dr. Jeremy Landt is one of the foremost worldwide authorities on radio frequency identification (RFID), and is one of the original five scientists from Los Alamos National Laboratories who developed this technology for the federal government. This article has been cited 29 times in other scholarly journals (Google™ Scholar, December 31, 2006, http://scholar.google.com/scholar?hl=en&lr=&cites=16024888924261912982) and contains 34 references.

Literature on RFID Technologies for Asset Visibility

Bornhövd, C., Lin, T., Haller, S., & Schaper, J. (2004). *Integrating automatic data acquisition with business processes experiences with SAP's auto-id infrastructure.* Retrieved October 25, 2006 from http://www.ee.washington.edu/research/ncs/papers/iecon03.pdf

In this article, the authors evaluate process automation that includes RFID technologies and sensor networks. Additionally, the authors discuss lessons learned from successful customer pilots, and point out some of the open research issues. Specifically, the authors evaluate: (a) the process of selecting, creating and/or updating automatic identification systems designed to improve tangible asset visibility; (b) wireless technologies, including RFID, which hold the potential of improving asset visibility; and (c) and why much attention has been placed on RFID with the emergence of RFID compliance mandates from retailers like Wal-Mart, Metro, Tesco, and Target, manufacturers like Procter & Gamble and Kimberly Clark, and even the U.S. Department of Defense. Material found in this article provided additional information for developing the problem area in the Purpose section and helped define research concepts in the

Methods section. The article is selected as one part of the data set used for coding during data analysis.

This resource is credible in part because it was presented to the 30th VLDB (Very Large Data Base) Conference in Toronto, Canada and because of the authors' affiliation with the SAP Research Center in Palo Alto, CA and Karlsruhe, Germany. Founded in 1972 as Systems Applications and Products in Data Processing, SAP is the recognized leader in providing collaborative business solutions for all types of industries and for every major market (SAP, http://www.sap.com/company/index.epx). This article has been cited 13 times in other scholarly journals (Google™ Scholar, December 31, 2006, http://scholar.google.com/scholar?hl=en&lr=&cites=9404961517244670495) and contains 10 references.

Boushka, M., Ginsburg, L. Haberstroh, J., Haffey, T., Richard, J., Tobolski, J. (2003). *Auto-id on the move: The value of auto-id technology in freight transportation.* Auto-ID Center, Massachusetts Institute of Technology. Retrieved October 16, 2006 from http://www.accenture.com/NR/rdonlyres/C7414A0A-AC0B-42CA-961D-452AE3B79216/0/autoid_freight.pdf

This article is a review of Auto-ID technologies – Electronic Product Codes (EPCs)™ coupled with radio frequency identification (RFID) technologies. Applications for Auto-ID technologies include: asset utilization, operational efficiency, and safety and security. Key elements of this resource, referenced in this study, include RFID tag variants and their impact on overall RFID technology implementations. This article discusses two of this study's context units: specific RFID technologies and the pros, cons and factors determining the cost of these technologies. Additionally, the authors address specific RFID tag types and the factors determining their costs (Boushka, et al., 2002, p. 23). The article is selected as one part of the data set used for coding during data analysis.

The authors of this article have over 80 years experience planning, designing and installing customer distribution and commerce systems. This article has been cited 10 times in other scholarly journals (Google™ Scholar, December 31, 2006, http://scholar.google.com/scholar?hl=en&lr=&cites=956104924318415326) and contains 7 references.

Dinning, M., & Schuster, E. W. (2004). *Fighting friction.* Retrieved October 16, 2006 from http://www.mitdatacenter.org/Dinning-Schuster (comments ews 1-17-02).pdf

The authors of this article review asset automatic identification methods associated with RFID and Auto-ID technologies. According to Dinning and Schuster, Auto-ID is a promising technology that will take identification and data capture to a new level of automation (p. 15). Elements of the article helped define the Problem Area in this paper.

The author of this article, Mark Dinning is a graduate of MIT's Master of Engineering in Logistics program and is currently with the Supply Chain Strategies group at Dell Inc, Austin, TX. The corresponding author of this paper, Edmund Schuster is the Co-Director, Administration and Research Associate, Massachusetts Institute of Technology. This article has been cited 7 times in other scholarly journals (Google™

Scholar, December 31, 2006,

http://scholar.google.com/scholar?hl=en&lr=&cites=17538634488494419239).

Lampe, M., & Strassner, M. (2005). *The potential of RFID for movable asset management.* Retrieved October 16, 2006 from http://www.m-lab.ch/pubs/lampe_strassner.pdf

The authors of this resource provide valuable insight into the use of RFID technologies for automatic identification and asset visibility. Specific areas of this resource included in this study include: (a) tracking of corporate tangible assets; (b) labor intensive manual processes for identification and tracking of corporate tangible assets are still used in medium to large organizations; (c) "The goal of … asset management is to make assets available when needed and ensure their efficient use. Asset management encompasses activities like locating assets, tracking their usage and ensuring their maintenance." (p. 1, para. 1); and (d) readers play a critical role in monitoring RFID tag traffic and are mission critical equipment This work helped define the Limitations and Problem Area of this paper.

The authors of this article belong to the Mobile and Ubiquitous Computing Lab (M-Lab), a joint research project between the Distributed Systems Group at the Institute for Pervasive Computing, ETH Zürich, and the Institute of Technology Management at the University of St. Gallen, Switzerland. This article has been cited 15 times in other scholarly journals (Google™ Scholar, December 31, 2006, http://scholar.google.com/scholar?hl=en&lr=&cites=6089963733834043491) and contains 17 references.

Literature on RFID Technologies Implementations

Asif, Z., & Mandviwalla, M. (2005). *Integrating the supply chain with RFID: a technical and business analysis.* Retrieved October 27, 2006, from http://www.ebi.temple.edu/programs/RFID/RFIDSupplyChain.pdf

This resource presents an in-depth analysis of the technical and business implications of adopting Radio Frequency Identification (RFID) in organizational settings. This article provided significant support in developing the Problem Area of this paper. Specific content used in this study include: (a) that the U.S. Department of Defense (DoD) is planning to overhaul its entire supply chain because it believes that RFID will reduce losses due to lack of information; and (b) RFID has also gained great traction in areas outside the original driving thrust of compliance mandates, including healthcare, logistics, asset management, and manufacturing. The article is selected as one part of the data set used for coding during data analysis.

Zaheeruddin Asif holds an MBA in Management Information Systems from the University of Karachi, Pakistan and is pursuing his PhD in Management Information Systems from Temple University. Dr. Munir Mandviwalla is the Founding Chair and Associate Professor at Temple University. The authors submitted this article to the Association for Information Systems, Fox School of Business and Management, Temple University. This article has been cited 6 in other scholarly journals (Google™ Scholar, December 31, 2006, http://scholar.google.com/scholar?hl=en&lr=&cites=991962222027605491) and contains 39 references and 40 bibliographic references.

Haynes, S. R. (2001). *Explanation in information systems: A design rationale approach.* Retrieved December 1, 2006, from http://www.princetonreview.com/cte/profiles/dayInLife.asp?careerID=80

The basis of this resource is a dissertation for the degree of Doctor of Philosophy through the London School of Economics and Political Science, Department of Information Systems. The article investigates the relationship between the information systems (IS) development context, and the context in which such systems are used. Material found in this article provided significant contributions for developing the Purpose section of this study, specifically regarding the way many medium to large organizations use modern large, distributed, and extremely complex information systems to develop a framework for RFID information analysis and design processes (p. 107).

Steven R. Haynes is currently an Assistant Professor, School of Information Sciences & Technology, Penn State University. This article has been cited 9 times in other scholarly journals (Google™ Scholar, December 31, 2006, http://scholar.google.com/scholar?hl=en&lr=&cites=14826499436521200317) and contains 420 references.

Ni, L. M., Liu, Y., Lau, Y. C., & Patil, A. P. (2004). *LANDMARC: Indoor location sensing using active RFID.* Retrieved November 1, 2006, from http://www.cs.ust.hk/~liu/Landmarc.pdf

The authors of this article focus on the growing convergence among mobile computing devices and embedded technology which sparks the development and deployment of context-aware applications, where location is the most essential context.

Information gleaned from this article helped define the larger aspect of this study's Purpose section – specifically the larger aspect of RFID technologies which serve as the conduit to this study's main themes of automatic identification and asset visibility.

The authors of this article include: Dr. Lionel Ni, Professor and Head of Computer Science and Technology, Hong Kong University of Science and Technology; Dr. Yunhao Liu is an Assistant Professor in the Department of Computer Science at Hong Kong University of "Science and Technology; Mr. Yiu Lau has a Masters from Michigan University; and Mr. Abhishek Patil is a Ph.D. candidate in the Department of Computer Science and Engineering at Michigan State University. This article has been cited 101 times in other scholarly journals (Google™ Scholar, December 31, 2006, http://scholar.google.com/scholar?hl=en&lr=&cites=14264087119537752072) and contains 15 references.

Prabhu, B. S., Su, X., Ramamurthy, H., Chu, C., & Gadh, R. (2005). *WinRFID – a middleware for the enablement of radio frequency identification (RFID) based applications.* Retrieved October 25, 2006, from http://wireless.ucla.edu/techreports2/UCLA-WinRFID.PDF

The authors of this article discuss the different challenges and the corresponding research approach in developing a RFID middleware to provide a seamless environment from the edge of the enterprise network; moving data from the point of transaction to the enterprise systems. According to Prabhu, et al. (2005), enterprises are looking for new paradigms which can provide real time visibility for assets (p. 1). This resource is used in this study to help establish the Purpose chapter – specifically the limitations area – and the Data Analysis section of the Methods chapter. The article is selected as one part of the data set used for coding during data analysis.

The authors of this article present a comprehensive analysis of RFID based applications which has been cited 5 times in other scholarly journals (Google™ Scholar, December 31, 2006, http://scholar.google.com/scholar?hl=en&lr=&cites=8133944731963072256) and contains 70 references.

Chapter III – Method

The research question that guides this study is: “How can RFID technologies improve tangible asset visibility in medium to large organizations?” The overarching research methodology selected for this study is a literature review (Leedy & Ormrod, 2005). The purpose of a literature review is to collect, review, and analyze bodies of research on a specific topic to collect data (Leedy & Ormrod, 2005).

Literature review is chosen as the primary research method because, as Leedy and Ormrod (2005, pp. 64-65) suggest, a literature review can reveal sources of previously unknown data and can help researchers interpret and make sense of findings and ultimately, help tie results to the work of preceding researchers. Literature is selected using topic-based search terms and cursory analysis of relevancy to this study’s research question. Literature collection is designed to gather recently published text documents that could help define RFID technologies used for automatic identification and tangible asset visibility in medium to large organizations.

Literature Collection

Literature collection is limited by currency. This limitation is important to this study due to significant ongoing changes in RFID technology as suppliers move quickly to address the issues and opportunities associated with current and future RFID technologies.

Collected literature concentrates on works that address current RFID technologies applied to two process improvements; automatic identification and tracking of tangible assets. Initial data collection for this study focuses on three areas; (a) identification of RFID technologies; (b) description of the basic features of these technologies related to automatic identification and tracking of tangible assets; and (c) contextual examination of the technologies within specific applied settings.

From the initial search findings, a set of search terms is established and used as a foundation for identification and selection of sources directly relevant to the study topic and research question. Table 1 displays the search terms used in this study.

Table 1: **Initial Set of Search Terms Used in Literature Search**

• Asset tracking	• Portable RFID Configuration
• Asset visibility	• Process improvement
• Auto-ID	• Radio frequencies
• Automatic identification	• Radio frequency identification
• Change management	• Real-time asset control
• Compliance mandate	• RFID
• Electronic Product Code	• RFID best practices
• Fixed RFID Configuration	• RFID tags
• Implementation processes	• RFID technology
• International Organization for Standardization	• RFID transponder
• Operational efficiencies	• RFID trends
	• Strategic planning RFID education

Limitations of search terms are required because of the thousands of search results acquired from individual search terms. For example, the term "RFID technology" returns approximately 2,900 hits on Google™ Scholar, but the concatenated terms "RFID technology" AND "automatic identification" results in approximately 400 sources. The following concatenation of terms represents the type of advanced search used for literature collection: "RFID terminology" AND "Change management". Several sources are used to locate and acquire literature for this study including the University of Oregon Academic Search Premier database, Google™ Scholar, and Google™.

Literature selected for the study is determined relevant based on any one or combination of the following criteria:

- the source describes a type of RFID technology in use in a medium to large organization for automatic identification and tracking of corporate tangible assets
- the source examines a particular RFID technology within a specific contextual setting
- the source is referenced or quoted in other publications directly related to the research topic

Once the final set of delimiters is established, twenty-two sources are identified for use in this study. Identified sources that comprise a data set for analysis are listed in Appendix B.

Data Analysis

The data analysis approach selected for use in this study is a qualitative content analysis (Leedy & Ormrod, 2005, pp. 142-143). This content analysis strategy is used to analyze selected sources for information relevant to RFID technologies utilized in automatic identification and tracking applications. Leedy and Ormrod (2005) define content analysis as, “A detailed and systematic examination of the contents of a particular body of material for the purpose of identifying patterns, themes, or biases” (p. 142). Leedy and Ormrod (2005) suggest that organizing and analyzing the data from qualitative studies allows the researcher to identify general categories or themes, with the result of identifying patterns (p. 150). That larger goal is applied to this study.

The specific operational process applied to the content analysis approach is supplied by Palmquist, et al. (2007). According to Palmquist, et al. (2007), the eight steps for conducting a conceptual analysis include:

Step 1: **Decide the level of analysis.** In this study the basic concepts addressed are framed as phrases including: RFID technologies; automatic identification, tangible assets; tracking applications.

Step 2: **Decide how many concepts to code for.** In this study, two larger pre-defined concepts are determined to guide the coding:

1. *Specific RFID technologies utilized by medium to large organizations for tangible asset visibility* – Literature addressing this concept describes (a) the RFID technologies that are currently used by medium to large organizations, including in-house (RFID solutions developed and built by the organization) or commercially available RFID products; (b) those technologies identified as state-of-the-art RFID technology; and (c) the particular focus of the technology – for example, what aspect of the automatic identification process is addressed, related to tracking of tangible assets.

2. *Contextual examinations of the technologies within specific applied settings* – Literature addressing this concept includes case examples of the application of selected RFID technologies. Issues of interest include reports of pros and cons of the technology within the specific context and factors determining the cost of the technologies.

The two concepts listed above serve as recording units (Krippendorff, 2004, p. 99) which guide the overall reading of the materials during the coding process.

Step 3: **Decide whether to code for existence or frequency of a concept.** In this study concepts are coded for existence.

Step 4: **Decide how to distinguish among concepts.** In this study, concepts are coded loosely when examined against broad definitions, to provide maximum inclusion. For example, several concepts are used interchangeably by authors within reviewed literature to refer to automatic identification: automatic identification and auto-id (Boushka, et al., 2003; Bornhövd, et al., 2004) interrogator and reader (Curtin, et al., 2005; Das, 2004), tag and transponder (Gragg, 2003; Prabhu, et al., 2005). Additionally, acronyms, such as RFID or UHF, are included in the coding. Terms that are hyphenated or spelled differently, such as automatic identification and auto-id, are counted. Table 2 represents translation rules utilized in this step.

Table 2: **Translation Rules**

Term / Acronym	Alternate Terms		
Asset Visibility	Asset tracking		
Automatic Identification	Auto-Id		
Con	Drawback	Limitation	
Fixed	Stationary	Reader	Interrogator
HF	High Frequency		
LF	Low Frequency		
Portable	Mobile	Handheld	
Pro	Benefit	Advantage	Savings
RF	Radio Frequency		
RFID	Radio Frequency Identification	RF Identification	
UHF	Ultra High Frequency		

Step 5: **Develop rules for coding texts.** The two recording units defined in Step 2 are truncated into an initial set of simplified terms: RFID technologies and cost. The term *RFID technologies* is further defined by element types which include (a) frequency (low, high, and ultra-high), (b) tag type (active or passive), (c) and configuration (fixed or mobile). Synonyms identified within analyzed literature for each of the three terms are recorded so that an iterative analysis can be performed on previously analyzed literature. In other words, as a new synonym is identified, it is used to reexamine previously analyzed literature and added to search terms for unexamined literature to identify relevant context units.

Step 6: **Decide what to do with irrelevant information.** In this study, any information not directly relevant to RFID technologies appropriate for medium to large organizations is ignored because it will not impact the outcome of the coding. Additionally, all information that, through review of context, does not meet the definition of or discussion about improved asset visibility is eliminated.

Step 7: **Code the texts.** The reviewed literature is coded manually. Selected literature is read and analyzed to identify context units (Krippendorff, 2004) which are then recorded into a spreadsheet. After all literature is categorized into context units, it is analyzed again for overlooked important codes.

Data Presentation

Step 8: **Analyze the results.** The results, identified from the conceptual analysis, are tabulated into three tables. The recording units represented in these tables include:

1. *Radio Frequencies* – low, high, and ultra-high, and factors determining costs relative to the other two (see Table C-1: RFID Radio Frequencies Content Analysis).
2. *RFID Tag Type* – active and passive, and factors determining the cost of each relative to the other tag type (see Table C-2: RFID Tag Type Content Analysis).
3. *RFID Configuration* – fixed and portable, and factors determining the cost of each relative to the other configuration type (see Table C-3: RFID Configuration Content Analysis).

The recording units are then framed into the final outcome of this study that incorporates two forms. First, data identified during conceptual analysis is presented in tables (see Tables 4a, 4b, and 4c) summarizing the contextual evaluation (pros, cons, and factors determining cost) of RFID technologies identified in step 5 above. Then, a discussion of the summary table is presented. The discussion is framed to build information manager intelligence and confidence regarding pros, cons, and factors determining cost analysis of RFID solutions.

The summary tables provide a targeted examination of the data presented in the three content analysis results tables (see Appendix C). The tables are designed as a decision support tool to support information managers as they compare the pros, cons, and factors determining the cost of various RFID technologies. Templates for the three tables are provided in Figures 2, 3 and 4. Within many large organizations, physical assets constitute a substantial part of total assets (Osztermayer, et al., 2002). Inherent physical properties of RFID technologies make some frequencies better suited for certain tangible assets. For example, low frequencies (LF) are not good near metal objects (Curtin, et al., 2005). Advantages over other RFID frequencies and over manual automatic identification and asset tracking are placed in the *Pros* column of Figures 2, 3 and 4. The *Cons* column contains limitations of selected RFID technology when compared to other technologies within the scope of Figures 2, 3 and 4. The *Factors Determining Cost* column in Figures 2, 3 and 4 focuses on the factors determining the cost of actual or relative costs of RFID technologies as defined within selected literature.

Figure 2: **Template Table 4a – Three Characteristics Examined in RFID Radio Frequencies**

Three Characteristics

		Pros	Cons	Factors Determining Cost
RFID Radio Frequencies	LF			
	HF			
	UHF			

Figure 3: **Template Table 4b – Three Characteristics Examined in RFID Tag Types**

Three Characteristics

		Pros	Cons	Factors Determining Cost
RFID Tag Type	Active			
	Passive			

Figure 4: **Template Table 4c – Three Characteristics Examined in RFID Configurations**

Three Characteristics

		Pros	Cons	Factors Determining Cost
RFID Configuration	Fixed			
	Mobile			

The narrative discussion based on the summary table is designed to build information manager intelligence and confidence regarding cost/benefit analysis of RFID solutions. This researcher intends that the discussion will help information managers to initially focus their search for the most appropriate RFID technology for their automatic identification and asset visibility goals. The goal of the discussion is to better enable these managers to conduct their own RFID research and forge their own RFID opportunities by directing them to focus on key issues, pertinent at this stage of the process. The ultimate goal of this paper is to support information managers in their own selection of RFID solutions for asset visibility.

Information managers must regulate the flow of information, either electronically or procedurally, within and among offices. For many companies, the rate at which work can be done is limited by the rate at which information can be transmitted to the people who need it, so the information manager fills a critical role (In University of Phoenix, 2006, Career Profiles: Information Managers, para. 1). It is therefore, with this fact in mind, that the discussion element of this summary focuses on providing a means of interpreting the Contextual Evaluation of RFID Technologies tables (Tables 4a, 4b, and 4c) as a tool to compare various RFID Technologies for specific enterprise needs. For example, if an enterprise needs to track assets composed of a high water content then the preferred RFID Technology would be low frequency – as defined by Table 4a.

Chapter IV – Analysis of Data

As described in the Methods section of this study, the analysis approach selected for use in this study is a qualitative content analysis (Leedy & Ormrod, 2005, pp. 142-143). According to Krippendorff (2004) content analysis should create valid and replicable inference from selected text (p. 18). According to Leedy and Ormrod (2005) a qualitative researcher seeks a better understanding of complex situations (p. 95). As Neuendorf (2002) notes, “Given that a goal of content analysis is to identify and record relatively objective (or at least intersubjective) characteristics of messages, reliability is paramount. Without the establishment of reliability, content analysis measures are useless” (p. 141).

An initial set of eighty-nine resources (articles, research papers, and case studies) are selected and accessed according to guidelines described in the Method chapter of this study. Resources are read as a preliminary review process to match literature selection directly relevant to the study topic and research question. From the initial set of resources, twenty-two are chosen for data analysis (see Appendix B). Data analysis of the twenty-two selected resources is performed according to the eight step process defined in the Data Analysis and Data Presentation sections in chapter three of this study. The data set is reviewed and concept occurrences are tabulated in Table 3. As defined in step 5, resources that articulate selected coding concepts are identified and a mark is placed next to the resources author(s) in Table 3. Table 3 displays the distribution of RFID technologies, tag type, configuration and cost factor context units identified throughout the selected resources. For example, as shown in Table 3, within the resource written by Maloni and DeWolf (2006), all context units were identified.

Table 3: **Identification of RFID Technologies As Reported in Selected References**

Source Author(s) / Date	RFID Radio Frequencies			RFID Tag Type		RFID Configuration		Factors Determining Cost
	LF	HF	UHF	Active	Passive	Fixed	Portable	
AMB / 2004	X			X				X
Anusha / 2005			X	X	X	X	X	X
Asif, Mandviwalla / 2005	X	X	X	X	X	X		X
Barker, Mahadevan / 2004				X	X	X		
Bornhövd, et al. / 2004				X	X			X
Boushka, et al. / 2004			X	X	X			X
Corsette, Malin, Ridgeway, Wolfenbarger, & Yu / 2005				X	X			X
Curtin, et al. / 2005		X	X	X	X			X
Das / 2004	X	X	X	X	X			X
Dempsey / 2004				X	X			X
Dinning, Schuster / 2004				X	X			X
Engels, Koh, Lai, & Schuster / 2003			X					X
Gambon / 2006					X		X	X
GAO / 2006				X	X			X
Loebbecke, Palmer, & Huyskens / 2006		X	X					
Lu, Bateman, & Cheng / 2006	X	X	X					
Maloni, DeWolf / 2006	X	X	X	X	X	X	X	X
Prabhu, et al. / 2005	X	X	X			X		X
Pradhan, et al. / 2005						X		
RFID Journal / July 21, 2003						X	X	
Ward, van Kranenburg / 2006	X	X	X	X	X	X	X	X
Wilding, Delgado / 2004						X	X	

As each concept is identified within a specific resource the raw data is manually entered into three tables (see Appendix C: Tables C-1, C-2, and C-3) representing Radio Frequencies (low, high, and ultra-high), RFID Tag Types (active and passive), and RFID Configuration (fixed and portable). Table C-1: RFID Radio Frequencies (Low, High and Ultra-high) contains information regarding RFID Radio Frequencies retrieved from the twenty-two sources chosen for analysis (see Appendix B). At the very simplest level, RFID technologies allow the transmission of a unique serial number wirelessly, using radio waves (Ward & van Kranenburg, 2006). The choice of a particular frequency depends on application requirements such as absorption in liquids, the reflection on surfaces, tag densities, power demand, size of tags, location of tags, exposure to temperature range, data transmission speed and data rates (Prabhu, et al., 2005). It is with these considerations in mind that Table C1 delineates RFID Radio Frequencies into low frequency (LF), high frequency (HF), and ultra-high frequency (UHF).

Table C-2: RFID Tag Type Factors contains information regarding RFID Active and Passive Tags retrieved from the twenty-two sources chosen for analysis (see Appendix B). The key component of an RFID system is the tag itself (Asif, & Mandviwalla, 2005). Consideration of the most appropriate RFID tag type is a critical consideration for the information manager as they recommend or design RFID asset visibility systems. One useful way of classifying tags is to divide them into active and passive classes. Each tag type has specific benefits and limitations. For example, active tags have a longer read/write range but cost more than passive tags (Bornhövd, et al., 2004).

Table C-3: RFID Configuration Factors contains information regarding RFID Fixed and Mobile Configurations retrieved from the twenty-two sources chosen for analysis (see Appendix

B). An RFID reader consists of a transmitter, receiver, and microprocessor that function to read the information contained on RFID tags (Maloni, & DeWolf, 2006). Fixed RFID readers must be placed within the read range of stationary RFID tagged assets or in traffic portals where RFID tagged mobile assets traverse (Anusha, 2005). Conversely, mobile RFID readers can be taken directly to the RFID tagged asset (Gambon, 2006). Information managers must be aware of the benefits, limitations and factors determining the cost of specific RFID configurations as they recommend or design RFID asset visibility systems.

Individual entries from the raw data tables reported in Appendix C are evaluated for relevance to the selected concept's pros, cons, or factors determining cost, and presented as the final outcome of this study in Tables 4a, 4b, and 4c (located and discussed in the Conclusions chapter). Any duplicate entry found in the raw data tables is removed. A declaration of a limitation or disadvantage is then copied from the corresponding raw data table and pasted into the corresponding Cons columns of Tables 4a, 4b, or 4c. Additionally, declarations related to pros or factors determining cost are copied into the corresponding columns of Tables 4a, 4b, or 4c along with a citation of the author and date. Tables are designed as a decision support tool to support information managers as they compare the pros, cons, and factors determining costs of various RFID technologies.

Chapter V – Conclusions

The goal of an RFID technology implementation in medium to large organizations is process improvement and improved asset visibility; when compared with other automatic identification systems like bar codes or manual data entry (Maloni, & DeWolf, 2006). According to Wilding and Delgado (2004) RFID offers many potential benefits over bar codes. The primary audience of this study, information managers must define the type of RFID technology to adopt (RFID Journal, 2003, March 31) and anticipate a number of technical problems still facing the use of RFID technology (RFID Journal, 2002, September 23). Each type of RFID technology reviewed in this study provides benefits (pros) and limitations (cons) which make an across-the-board comparison difficult. Each type of RFID radio frequency reviewed has its own strengths and weaknesses and, depending on the asset's physical makeup (e.g., water or metallic content), read distance, or tag data capacity, may or may not be appropriate to implement for different asset's visibility. Because of the potential process improvements RFID technologies present (UPS, 2005), this study is especially beneficial for information managers currently working within medium to large organizations utilizing manual tangible asset tracking.

The purpose of this study is to provide information managers, in the process of selecting, creating and/or updating automatic identification systems, with an understanding of how RFID technologies can be used within medium to large organizations to improve processes for identification and tracking of corporate tangible assets over use of bar code systems. To that end, this study is conducted as a literature review (Leedy & Ormrod, 2005) of sources published between 2001 and 2006. Literature within this time frame represents current information related to the evolution of RFID technologies for asset management and tracking. The years 2001 to

2006 represent a three year period before and after Wal-Mart's RFID compliance mandate in which a majority of literature related to expanding the role of RFID into automatic identification and tracking of corporate tangible assets was published (Ward & van Kranenburg, 2006).

Information managers must be aware of the benefits, limitations and factors determining the cost of specific RFID configurations as they recommend or assist the design of RFID asset visibility systems. To help information managers acquire this knowledge, the results of this study's analysis are framed in a set of four tables (see Tables 4a, 4b, and 4c). The first column in each of these three tables defines the pros (benefits and advantages) associated with three specific characteristics of RFID technologies; and the second column in each of these three tables defines the cons (drawbacks and limitations) along three specific characteristics of RFID technologies. According to Das (2004), several RFID technologies' characteristics overlap to some extent, and have various pros and cons; making them suitable for some applications and not others. For example, Table 4a defines typical applications for low frequency systems which include animal identification, car keys, controlled access, farming, financial cards, heavy logistics, manufacturing, vehicle immobilization, and work in progress pallets (Das, 2004; Lu, et al., 2006; Prabhu, et al., 2005). Therefore, these systems are useful for asset tracking applications requiring close range reading through RF lucent materials and/or water (Maloni, 2006).

To assist information managers as they evaluate RFID technologies, the third column in Tables 4a, 4b, and 4c lists factors determining costs of RFID technologies. Costs are a critical factor in the decision to implement a new technology (Roberti, 2006). As Table 4a demonstrates, the product being tagged greatly affects costs. For example, will the tag require a standoff (in the case of metal mounts)? Will the tag need to be concealed? Or, will the tag antenna be printed or metal coil? (Boushka, et al., 2003). Table 4a also demonstrates that, depending on the physical makeup of the asset, a specific RFID frequency is recommended. Further, Table 4a demonstrates that due to the combination of tag size, read range, ability to control the read zone through directional antennas on the reader, potential to drive down tag costs, and the beneficial read rate, most of the efforts to promote RFID at the item or pallet level currently are directed at UHF tags; but to be widely used, ultra-high frequency tags will need to drop to $0.05 each (Curtin, et al., 2005).

The number of assets managed by medium to large organizations will continue to grow, fueled by globalization, mass customization, stock keeping unit (SKU) proliferation, packaging, label and product postponement (AMB, 2004). This study evaluates three unique RFID technologies which offer benefits for improved asset visibility however, the information manager must be aware of the limitations associated with each technology. Using Tables 4a, 4b, and 4c the information manager can drill down on each technology to define their unique asset visibility requirements. Additionally, the data set drawn from the selected resources and tabulated in Appendix C provides additional resources for information managers as they evaluate RFID technologies for improved asset visibility. Asif and Mandviwalla (2005) suggest an awareness of RFID risks. This study will help the information manager mitigate risks by defining limitations of specific RFID technologies. For example, as defined in Table 4b, active tags have significant benefits over passive yet the cost of active tags is significantly higher and the expected lifespan is limited (Bornhövd, et al., 2004).

This study reveals that many factors impact the choice of RFID technology utilized for physical asset visibility. For example, if an RFID technology is chosen primarily on the number of asset tags to be purchased then, as demonstrated in tables 4a and 4b, the preferred technology would be read only passive UHF (Curtin, et al., 2005; Ward, & van Kranenburg, 2006). Or, if an RFID technology is chosen to acquire the maximum read range and coverage area then the preferred technology would be fixed readers and active tags operating in the UHF frequency range (Barker, & Mahadevan, 2004; Ward, & van Kranenburg, 2006).

RFID solutions have only primarily emerged in the last few years however, a significant amount of RFID literature exists; much of this is anecdotal in nature (Maloni & DeWolf, 2006). Very little advanced, empirical asset visibility research is available to information managers so exploratory research via case studies and surveys are needed to assess drivers of RFID in asset visibility applications. To stay abreast of rapidly changing RFID technologies, this researcher recommends subscribing to organizations associated with academic institutions (e.g., Auto-ID labs) and professional organizations based on unbiased, innovative core values and leading the drive to improve asset visibility (e.g., AIMglobal, and RFID Journal). The Auto-ID labs comprise seven of the world's most renowned research universities located on four different continents and their aim is to create a global system for tracking goods using a single numbering system called the Electronic Product Code (EPC). Professional organizations such as AIMglobal and RFID Journal provide resources for businesspeople that need to understand how RFID can help their companies improve asset visibility. These organizations provide timely news, strategic analysis, networking opportunities at events and in-depth education. For additional information on these and other additional resources see Bibliography section of this study. Each of the RFID technologies presented in Tables 4a, 4b, and 4c can improve asset visibility but, because of the limitations defined in this study, information managers will need to evaluate information from this study and additional resources to provide a total asset visibility solution.

Table 4a: **Contextual Evaluation of RFID Radio Frequencies**

		Pros	Cons	Factors Determining Costs
RFID Radio Frequencies	LF	• Low frequency (LF) systems (operating in the 100–500 kHz band) are suitable for high water content products such as fruits, or those packaged in tin cans (Prabhu, et al., 2005; Asif, & Mandviwalla, 2005). • LF systems are inexpensive compared to high and ultra-high frequency systems (Prabhu, et al., 2005). • Typical applications for LF systems are animal identification, car keys, controlled access, farming, financial cards, heavy logistics, manufacturing, vehicle immobilization, and work in progress pallets (Das, 2004; Lu, et al., 2006; Prabhu, et al., 2005). • Power consumption for LF systems is 20 micro Watts (Asif, & Mandviwalla, 2005).	• Read range of low frequency (LF) systems is limited to approximately 6 feet (Lu, et al., 2006). • The typical transfer rate for LF systems is slow (less than 1 kilobit per second) when compared to high and ultra-high frequency systems (Lu, et al., 2006).	• To keep low frequency system costs low, fewer tags are used per reader (Das, 2004).
	HF	• High frequency (HF) systems (operating in the 13.56MHz band) are suitable for access and security systems, airline baggage, consumer goods, contact-less travel cards, domestic electrical goods, electronic surveillance, laundry, toys, libraries, passports, smart cards, and smart labels (Das, 2004; Loebbecke, et al., 2006; Lu, et al., 2006; Prabhu, et al. 2005; Ward, & van Kranenburg, 2006). • HF systems are potentially inexpensive when compared to low frequency and ultra-high frequency systems (Prabhu, et al., 2005). • HF systems can be read through liquids (Prabhu, et al., 2005). • Power consumption for HF systems is 200 micro Watts (Asif, & Mandviwalla, 2005).	• Read range of high frequency (HF) systems is limited to approximately 8 feet (Prabhu, et al., 2005). • Typical transfer rates for HF systems is slow (10-25 kilobits per second) when compared to ultra-high frequency systems (Asif, & Mandviwalla, 2005; Ward, & van Kranenburg, 2006). • HF waves are absorbed more readily and are thus more susceptible to attenuation than LF systems (Asif, & Mandviwalla, 2005).	• To keep high frequency system cost low many tags are used per reader (Das, 2004).

Table 4a: **Contextual Evaluation of RFID Radio Frequencies (*Continued*)**

		Pros	Cons	Factors Determining Costs
RFID Radio Frequencies	**UHF**	• Ultra high frequency (UHF) systems (operating in the 866-960MHz band) are suitable for airline baggage, animal tracking, asset monitoring, consumer goods, item level tracking, laundry, logistics, toys, libraries, pallet level tracking, passports, supply chain, toll collection, and vehicle identification (Das, ; Engels, et al., 2003; Loebbecke, et al., 2006; Lu, et al., 2006; Prabhu, et al., 2005; Maloni, & DeWolf, 2006; Ward, & van Kranenburg, 2006). • Read range of UHF systems is up to 60 feet under controlled conditions (Curtin, et al., 2005). • Typical data transfer rate for UHF systems is 100 kilobits per second (Ward, & van Kranenburg, 2006).	• Ultra high frequency systems are less likely to pass through most materials (Curtin, et al., 2005).	• To be widely used, ultra-high frequency tags will need to drop from $0.50 each to $0.05 each (Curtin, et al., 2005). • Due to the combination of tag size, read range, ability to control the read zone through directional antennas on the reader, potential to drive down tag costs, and the beneficial read rate, most of the efforts to promote RFID at the item or pallet level currently are directed at UHF tags (Curtin, et al., 2005).

Table 4b: **Contextual Evaluation of RFID Tag Types**

		Pros	Cons	Factors Determining Costs
RFID Tag Type	**Active**	• RFID active tags contain batteries, allowing them to transmit their data over 300 feet (AMB, 2004; Asif & Mandviwalla, 2005). • The Department of Defense has been using active tags since the early 1990s to help with in-transit visibility of shipments (GAO, 2006). • Applications of RFID active tags include capital asset tracking and management (e.g., rail cars and steamship containers), and a car *clicker* on key rings (Das, 2004; Dinning, & Schuster, 2004). • Active tags can be equipped with built-in sensors (e.g., for monitoring temperature control and reporting unacceptable fluctuations on refrigerated products while in transit) (Ward, & van Kranenburg, 2006). • Active tags can provide location in addition to identification (Dempsey, 2004). • Active tag performance is not driven by antenna size (Dempsey, 2004). • Active tags have more memory than passive tags (Maloni, & DeWolf, 2006); Ward, & van Kranenburg, 2006). • Active tags can be read while moving at up to 100 miles an hour (e.g., in automatic toll-road payment systems) and the readers are capable of reading up to a thousand tags per second (Ward, & van Kranenburg, 2006).	• Because RFID active tags continually transmit their contents and contain batteries they have a limited lifespan of typically 3-5 years (Bornhövd, et al., 2004). • Active tags cost more than passive tags (AMB, 2004; Asif, & Mandviwalla, 2005; Dempsey, 2004).	• Ongoing battery replacement should be factored into operations and maintenance costs (Boushka, et al. 2003).

Table 4b: **Contextual Evaluation of RFID Tag Types (*Continued*)**

		Pros	Cons	Factors Determining Costs
RFID Tag Type	Passive	• Passive RFID tags have shown great success in asset real-time locating systems (RTLS) because of the cost savings (Gambon, 2006). • Passive tags draw power from the reader and are cheaper and smaller than active tags (Anusha, 2005; Curtin, et al., 2005; Dinning, & Schuster, 2004; Ward, & van Kranenburg, 2006). • Passive tags have a much longer life cycle when compared to active tags, and because of their minimal on-board circuitry they are much cheaper to produce (Ward, & van Kranenburg, 2006). • As the cost of RFID tags decrease, passive tags will selectively replace bar codes as a means of gathering information within supply chains (Dinning, & Schuster, 2004). • Passive tags are currently the most widely deployed as they are the cheapest to produce (Barker, & Mahadevan, 2004; Ward, & van Kranenburg, 2006).	• Passive RFID tags have a shorter read range than active tags (AMB, 2004; Asif & Mandviwalla, 2005). • Passive tags have a limited data storage, usually 96 bits of user programmable data (Maloni, & DeWolf, 2006). • Passive tags can only operate in the presence of an RFID reader (Ward, & van Kranenburg, 2006).	• Adding the ability to read and write to the Passive RFID tag increases the cost (Ward, & van Kranenburg, 2006). • The product being tagged greatly affects the costs; will the tag require a standoff (in the case of metal mounts)? Will the tag need to be concealed? Will the tag antenna be printed or metal coil? (Boushka, et al., 2003). • Tag volumes – either active or passive – will be the determining factor on cost per tag (Das, 2004). • The reuse of tags (active or passive) more than offsets the onetime costs (Ward, & van Kranenburg, 2006).

Table 4c: **Contextual Evaluation of RFID Configurations**

		Pros	Cons	Factors Determining Costs
RFID Configuration	Fixed	• Readers come in many form factors from huge frames covering an entire entrance to the size of a US quarter (Asif, & Mandviwalla, 2005). • RFID reader can read multiple RFID tags simultaneously (Prabhu, et al., 2005). • Fixed readers interrogate nearby RFID tags and obtain their ID numbers using radio frequency (RF) communication without requiring line of sight of contact with the RFID tag (Ward, & van Kranenburg, 2006).	• Some readers can only read tags while others can read and write tags (Asif, & Mandviwalla, 2005). • Covering a large geographic area requires a large number of fixed readers (Anusha, 2005). • The accuracy of some readers is well below 90 percent (Asif, & Mandviwalla, 2005).	• Installing readers at transition points will reduce the cost of replacing missing and lost items by 95 to 98 percent (Barker, & Mahadevan, 2004). • Using a fixed placement of readers to guarantee complete coverage at all times increases the deployment costs (Anusha, 2005).

Table 4c: **Contextual Evaluation of RFID Configurations (*Continued*)**

		Pros	Cons	Factors Determining Costs
RFID Configuration	Mobile	• Where complete coverage is required… using mobile readers instead of fixed readers is a cost-effective option (Anusha, 2005). • Mobile RFID readers mounted on a vehicle provide flexible solutions for asset tracking (Gambon, 2006). • Using mobile RFID readers attached to forklifts, operators can be instantly alerted if they attempt to pick the wrong asset. Additional benefits are seen for receiving RFID enabled assets via forklifts equipped with mobile RFID readers (Gambon, 2006). • Portable RFID readers provide greater flexibility and reduced costs when compared to stationary RFID readers covering the same area (Gambon, 2006). • Inventory with portable RFID readers allows operators to move from location to location (RFID Journal July 21, 2003). • Portable RFID readers can be incorporated into handheld devices such as PDAs (Portable Digital Assistants) and mobile phones (Ward, & van Kranenburg, 2006). • Many handheld RFID readers incorporate bar code reading capability and thereby expand flexibility (Wilding, & Delgado, 2004).		• Providing complete coverage of an area, the number of mobile readers needed is much less than the number of fixed readers (Anusha, 2005).

Appendix A: Definition of Terms

Active Tag "An RFID tag that has a transmitter to send back information, rather than reflecting back a signal from the reader, as a passive tag does. Most active tags use a battery to transmit a signal to a reader. However, some tags can gather energy from other sources. Active tags can be read from 300 feet (100 meters) or more, but they're expensive (typically more than US$20 each). They're used for tracking expensive items over long ranges. For instance, the U.S. military uses active tags to track containers of supplies arriving in ports." (RFID Journal, http://www.rfidjournal.com/article/glossary)

Asset "Any item of economic value owned by an individual or corporation, especially that which could be converted to cash. Examples are cash, securities, accounts receivable, inventory, office equipment, real estate, a car, and other property. On a balance sheet, assets are equal to the sum of liabilities, common stock, preferred stock, and retained earnings.

From an accounting perspective, assets are divided into the following categories: current assets (cash and other liquid items), long-term assets (real estate, plant, equipment), prepaid and deferred assets (expenditures for future costs such as insurance, rent, interest), and intangible assets (trademarks, patents, copyrights, goodwill)." (Investorwords.com http://www.investorwords.com/273/asset.html)

Asset Management "The systematic and coordinated activities and practices through which (organizations) optimally manage its physical assets and the associated performance risks and expenditures over the asset's life cycle." (BPA, 2006. http://www.bpa.gov/corporate/pubs/fact_sheets/06fs/fs0106.pdf)

Asset Tracking "To observe or monitor the course of" (Answers.com: American Heritage Dictionary http://www.answers.com/topic/track) assets.

"Asset tracking solutions using RFID enable organizations to effectively manage their physical assets and keep an effective inventory of what assets they own and how these assets are used through out their life cycles. Companies can use RFID to reduce their operating costs by improved asset tracking solutions to decrease shrinkage, lower maintenance costs, and optimize utilization." (Supply asset http://www.supplyinsight.com/Asset_tracking_using_RFID.htm)

Asset Visibility Answers.com provides the following definitions for visibility: (a) The distance within which something can be seen; (b) The fact, state, or degree of being visible (http://www.answers.com/visibility&r=67). Asset visibility is important for corporate systems when a delay in finding items leads to inefficiencies and shortages (Blackbay, 2006).

Automatic Identification "In its broadest definition, Automatic Identification Technology (AIT) includes bar codes, radio frequency ID (RFID), satellite tracking systems, smart cards, optical memory cards, contact memory buttons, and biometrics. Use of these

Appendix A: Definition of Terms (*Continued*)

technologies to automatically identify individuals is becoming increasingly commonplace. By enabling data collection and transmission to automated information systems, AIT helps to identify, track, and monitor [assets].” (Identity, Security and Democracy, http://www.biteproject.org/documents/advanced_research_workshop.pdf)

Backscatter “A method of communication between passive tags (ones that do not use batteries to broadcast a signal) and readers. RFID tags using backscatter technology reflect back to the reader radio waves from a reader, usually at the same carrier frequency. The reflected signal is modulated to transmit data.” (RFID Journal. http://www.rfidjournal.com/article/glossary/).

Bar code “An array of parallel rectangular bars and spaces arranged according to the encodation rules of a particular symbol specification in order to represent data in machine readable form.” (Nelson, 1997).

Bluetooth “A low-power, short-range, radio frequency (RF) technology that allows the connection of intelligent communications devices or appliances in a household or an office in a short-range wireless network. Examples of Bluetooth applications are transferring data between cell phones, radios, pagers, personal digital assistants (PDA), notebook computers, video and still cameras, audio players, and local area networks (LAN).” (ATIS Committee. http://www.atis.org/tg2k/_bluetooth.html)

Compliance Mandates “RFID are simply a first step toward improving supply-chain management. Each link in the supply chain has specific limitations and opportunities that must be identified and explored.” (RFID – Making It So… University of Florida http://edis.ifas.ufl.edu/AE286)

Content Analysis “Content analysis has been defined as a systematic, replicable technique for compressing many words of text into fewer content categories based on explicit rules of coding (Berelson, 1952, GAO, 1996, Kroppendorff, 1980, and Weber, 1990). (Steve Stemler, Yale University. http://pareonline.net/getvn.asp?v=7&n=17)

Data Capture Also called *Automated Identification Data Collection*. “Data Capture is the process or means of obtaining and storing external data for use at a later time. There are various ways in which this can be done; the best method depends on the application.” (Bitpipe http://www.bitpipe.com/tlist/AIDC.html)

e-business “E-business (electronic business), derived from such terms as ‘e-mail’ and ‘e-commerce,’ is the conduct of business on the Internet, not only buying and selling but also servicing customers and collaborating with business partners. One of the first to use the term was IBM, when, in October, 1997, it launched a thematic campaign built around the term. Today, major corporations are rethinking their businesses in terms of the Internet and its new culture and capabilities. Companies are using the Web to buy parts and supplies from other companies, to collaborate on sales promotions, and to do joint research. Exploiting the convenience, availability, and world-wide reach of the Internet,

Appendix A: Definition of Terms (*Continued*)

many companies, such as Amazon.com, the book sellers, have already discovered how to use the Internet successfully.

Increasingly, much direct selling (or e-tailing) is taking place on the Internet of computer-related equipment and software. One of the first to report sales in the millions of dollars directly from the Web was Dell Computer. Travel bookings directly or indirectly as a result of Web research are becoming significant. Custom-orderable golf clubs and similar specialties are considered good prospects for the immediate future.

With the security built into today's browsers and with digital certificates now available for individuals and companies from Verisign, a certificate issuer, much of the early concern about the security of business transaction on the Web has abated and e-business by whatever name is accelerating.

IBM considers the development of intranets and extranets to be part of e-business. e-business can be said to include *e-service*, the provision of services and tasks over the Internet by application service providers (ASP).” (SearchCIO.com http://searchcio.techtarget.com/sDefinition/0,,sid19_gci212026,00.html)

Electronic Article Surveillance (EAS) EAS tags are, “Simple electronic tags that can be turned on or off. When an item is purchased (or borrowed from a library), the tag is turned off. When someone passes a gate around holding an item with a tag that hasn’t been turned off, an alarm sounds. EAS tags are embedded in the packaging of most pharmaceuticals or DVDs. They can be RF-based, or acousto-magnetic.” (RFID Journal. http://www.rfidjournal.com/article/glossary/)

Electronic Product Code (EPC) “A serial, created by the Auto-ID center, which will complement barcodes. The EPC has digits to identify the manufacturer, product category and the individual item.” (RFID Journal, http://www.rfidjournal.com/article/glossary/).

Fixed Reader RFID reader typically used in supply chain applications – dock doors and conveyor belts. Fixed Reader systems typically consist of a RFID reader and a transmit and receive antenna. (Wasserman (2006). http://www3.ietf.org/proceedings/05mar/slides/slrrp-3/slrrp-3.ppt)

Frequency “The number of repetitions of a complete wave within one second. 1Hz equals one complete waveform in one second. 1kHz equals 1,000 waves in a second. RFID tags use low, high, ultra-high and microwave frequencies. Each frequency has advantages and disadvantages that make them more suitable for some applications than for others.” (RFID Journal. http://www.rfidjournal.com/article/glossary/)

High Frequency (HF) “This is generally considered to be from 3MHz to 30MHz. HF RFID tags typically operate at 13.56MHz. They can be read from less than 3 feet away and transmit data faster than low-frequency tags. But they consume more power than low-frequency tags.” (RFID Journal. http://www.rfidjournal.com/article/glossary/)

Appendix A: Definition of Terms (*Continued*)

Information Manager "Information managers regulate the flow of information, either electronically or procedurally, within and among offices. For many companies, the rate at which work can be done is limited by the rate at which information can be transmitted to the people who need it, so the information manager fills a critical role: To rapidly and accurately disseminate information to people who need it while maintaining security and creating a structure flexible enough to allow for company expansion or contraction." (University of Phoenix. http://www.princetonreview.com/cte/profiles/dayInLife.asp?careerID=80)

Infrared "Of or relating to the range of invisible radiation wavelengths from about 750 nanometers, just longer than red in the visible spectrum, to 1 millimeter, on the border of the microwave region." (Answers.com. http://www.answers.com/infrared&r=67)

Interrogator See reader.

Literature Review "A literature review surveys scholarly articles, books and other sources, for example dissertations, conference proceedings, relevant to a particular issue, area of research, or theory, providing a description, summary, and critical evaluation of each work. The purpose is to offer an overview of significant literature published on a topic." (University of California, Santa Cruz. http://library.ucsc.edu/ref/howto/literaturereview.html)

Low Frequency "From 30 kHz to 300 kHz. Low-frequency tags typical operate at 125 kHz or 134 kHz. The main disadvantages of low-frequency tags are they have to be read from within three feet and the rate of data transfer is slow. But they are less subject to interference than UHF tags." (RFID Journal, http://www.rfidjournal.com/article/glossary/2)

Medium to Large Organization For the purposes of the study, medium organizations have gross revenues of $250 to $750 million. Organizations generating in excess of $750 million are classified as large. (Computer Economics. http://www.computereconomics.com/article.cfm?id=1131)

Mobile Reader "[A] compact, rugged reader can be installed almost anywhere — on material handling equipment such as forklifts and clamp trucks, on mobile carts, portable skate wheel conveyors or even in hard to reach locations where a cabled fixed reader would not be practical." (Symbol Technologies, http://www.symbol.com/rd5000)

Modulation "Changing the radio waves traveling between the reader and the transponder in ways that enable the transmission of information. Waves can be changed in a variety of ways that can be picked up by the reader and turned into the ones and zeroes of binary code. Waves can be made higher or lower (amplitude modulation) or shifted forward (phase modulation). The frequency can be varied (frequency modulation), or data can be contained in the duration of pulses (pulse-width modulation)." (RFID Journal, http://www.rfidjournal.com/article/glossary/3)

Appendix A: Definition of Terms (*Continued*)

Passive Tag "An RFID tag without its own power source and transmitter. When radio waves from the reader reach the chip's antenna, the energy is converted by the antenna into electricity that can power up the microchip in the tag. The tag is able to send back information stored on the chip. Today, simple passive tags cost from U.S. 20 cents to several dollars, depending on the amount of memory on the tag, packaging and other features." (RFID Journal, http://www.rfidjournal.com/article/glossary/3)

Radio Frequency Identification (RFID) In its simplest form, (RFID) is "information carried by radio waves" (Finkenzeller, 2003).

"A method of identifying unique items using radio waves. Typically, a reader communicates with a tag, which holds digital information in a microchip. But there are chipless forms of RFD tags that use material to reflect back a portion of the radio waves beamed at them." (RFID Journal, http://www.rfidjournal.com/article/glossary/3)

Reader "A device used to communicate with RFID tags. The reader has one or more antennas, which emit radio waves and receive signals back from the tag. The reader is also sometimes called an interrogator because it 'interrogates' the tag." (RFID Journal, http://www.rfidjournal.com/article/glossary/3)

Real-time Asset Control Process Information generated at the point of process and forwarded to the decision point in real-time for processing or storage. (Gruman, 2005).

Stock Keeping Unit (SKU) An identification usually alphanumeric, of a particular product that allows it to be tracked for inventory purposes. Typically, an SKU is associated with any purchaseable item in a store or catalog. An SKU is not the same as a product model number from a manufacturer, although a model number could form all or part of a SKU. The SKU is established by the merchant (Search SMB, http://searchsmb.techtarget.com/sDefinition/0,,sid44_gci213590,00.html).

Supply chain "Supply chains include every company that comes into contact with a particular product. For example, the supply chain for most products will encompass all the companies manufacturing parts for the product, assembling it, delivering it and selling it." (Investopedia. http://www.answers.com/supply+chain&r=67)

Symbol "A combination of characters including start/stop characters, quiet zones, data characters, and check characters required by a particular Symbology, which form a complete scannable entity." (Nelson, 1997)

Tag Also known as an RFID tag. "A microchip attached to an antenna that is packaged in a way that it can be applied to an object. The tag picks up signals from and sends signals to a reader. The tag contains a unique serial number, but may have other information, such as a customers' account number. Tags come in many forms, such smart labels can have a bar code printed on it, or the tag can simply be mounted inside a carton or embedded in plastic. RFID tags can be active, passive or semi-passive." (RFID Journal, http://www.rfidjournal.com/article/glossary/3)

Appendix A: Definition of Terms (*Continued*)

Tangible asset “Real property or personal property, such as buildings, machinery, and real property. Tangible assets are distinguished from intangible assets such as trademarks, copyrights, and Goodwill, and natural resources (timberlands, oil reserves, and coal deposits). Also includes accounts receivable of a concern. Tangible and intangible assets are recorded separately on the balance sheet. Physical assets are depreciated over their useful life; intangibles are amortized. The book value of wasting assets, such as coal, gas, or oil is reduced through depletion. Accounting rules are vague on this distinction between tangibles and intangibles. Generally, any asset not expressly defined as an intangible is considered a tangible asset.” (Answers.com: Barron’s Banking Terms http://www.answers.com/tangible+asset&r=67#copyright)

Transponder “A radio transmitter-receiver that is activated when it receives a predetermined signal. RFID transponders come in many forms, including smart labels, simple tags, smart cards and keychain fobs. RFID tags are sometimes referred to as transponders.” RFID Journal, http://www.rfidjournal.com/article/glossary/4)

Ultra High Frequency “From 300MHz to 3GHz. Typically, RFID tags that operate between 866MHz to 960MHz. They can send information faster and farther than high- and low-frequency tags. But radio waves don’t pass through items with high water content, such as fruit, at these frequencies.” (RFID Journal. http://www.rfidjournal.com/article/glossary/4)

Wireless Technology “Wireless is a term used to describe telecommunications in which electromagnetic waves (rather than some form of wire) carry the signal over part or the entire communication path. Wireless technology is rapidly evolving, and is playing an increasing role in the lives of people throughout the world. In addition, ever-larger numbers of people are relying on the technology directly or indirectly.” (Whatis.com: Techtarget http://whatis.techtarget.com/definition/0,289893,sid9_gci213380,00.html)

Wireless Local Area Network “A wireless local area network (WLAN) is one in which a mobile user can connect to a local area network (LAN) through a wireless (radio) connection.” (SearchSecurity. http://searchsecurity.techtarget.com/gDefinition/0,294236,sid14_gci213379,00.html)

Appendix B: Content Analysis Data Set

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Corsette, V., Malin, G., Ridgeway, R., Wolfenbarger, C., Yu, B. (2005). Radio frequency identification and its applications in business.

Curtin, J., Kauffman, R. J., & Riggins, F. J. (2005). Making the "most" out of RFID technology: A research agenda for the study of the adoption, usage and impact of RFID.

Das, R. (2004). RFID explained.

Dempsey, M. (2004). Indoor Positioning Systems.

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Gambon, J. (2006). RFID contains solution to Chinese shipping problems.

Appendix B: Content Analysis Data Set (*Continued*)

GAO (2006). Defense logistics: More efficient use of activity RFID tags could potentially avoid millions in unnecessary purchases.

Loebbecke, C., Palmer, J., & Huyskens, C. (2006). RFID's potential in the fashion industry: A case analysis.

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RFID Journal (2003, July 21). Case Studies: Asset tracking in big organizations.

Ward, M., & van Kranenburg, R. (2006). RFID: Frequency, standards, adoption and innovation

Wilding, R. & Delgado, T. (2004). RFID - applications within the supply chain.

Appendix C: Results of Content Analysis

Table C- 1: **RFID Radio Frequencies (Low, High and Ultra-high)**

Source Author / Date	RFID Radio Frequencies			Factors Determining Cost
	LF	HF	UHF	
AMB / 2004	• Can be read from 1-2ft (p. 4, What is RFID? section, para. 1)			
Anusha / 2005			• Ultra-high frequency tags have a typical interrogation range of 10-16ft (p. 2, Problem Definition section, para. 1).	
Asif, Mandviwalla / 2005	• Low-frequency RFID tags operate at 125 to 134 kHz, for US and International use (p. 395, Transponders [a.k.a. tags] section, para. 7). • Low-frequency tags are more suitable for high water content products such as fruits, or those packaged in tin cans (p. 395, Transponders [a.k.a. tags] section, para. 8). • Transmission rates for low-frequency tags are 102kb/s (p. 398, Table 1). • Power consumption for low-frequency tags is 20μW (p. 398, Table 1).	• High-frequency systems use 13.56MHz (p. 395, Transponders [a.k.a. tags] section, para. 7). • High-frequency waves are absorbed more readily and are thus more susceptible to attenuation than low-frequency ones (p. 395, Transponders [a.k.a. tags] section, para. 8). • Transmission rates for high-frequency tags are 10-20kb/s (p. 398, Table 1). • Power consumption for high-frequency tags is 200μW (p. 398, Table 1).	• Frequencies of 866 to 960MHz are used in UHF (ultra-high-frequency) systems (p. 395, Transponders [a.k.a. tags] section, para. 7). • Transmission rates for ultra-high-frequency tags are 40-120kb/s (p. 398, Table 1). • Power consumption for ultra-high-frequency tags is 0.25-1.0W (p. 398, Table 1).	• Approximate cost of low-frequency passive tags is $0.20 to $1.00 (p. 398, Table 1). • Approximate cost of high-frequency tags are $1.00 to $10.00 (p. 398, Table 1). • Approximate cost of ultra-high-frequency active tags is $10 to $30 (p. 398, Table 1).

Appendix C: Results of Content Analysis (*Continued*)

Table C- 1: **RFID Radio Frequencies (Low, High and Ultra-high) (*continued*)**

Boushka, et al. / 2004			• Tags operating in the UHF range are more useful in terms of range and speeds (p. 21, Frequency Availability section, para. 1). • The UHF spectrum around 900MHz is not universally available at the same frequency and power levels worldwide ((p. 21, Frequency Availability section, para. 1).	• UHF read-only tags today cost approximately fifty cents per tag, in volume (p. 23, Tag Costs section, para. 2).
Curtin, et al. / 2005		• As of late 2005, tags operating at the worldwide-approved 13.56MHz high frequency (HF) level had a maximum range between the tag and reader of about one meter (p. 5, footnote 4).	• As of late 2005, pilot tests using the 915MHz ultra-high frequency (UHF) level had a range up to about 60 feet under controlled conditions (p. 5, footnote 4). • UHF tags operating in the 900MHz range use more power, are less expensive, and have signals that are less likely to pass through most materials (p. 5, footnote 4). • Due to the combination of tag size, read range, ability to control the read zone through directional antennas on the reader, potential to drive down tag costs, and the beneficial read rate, most of the efforts to promote RFID at the item or pallet level currently are directed at the UHF 915MHz tags (p. 5, The Technical Background of RFID section, para. 2).	• To be widely used, UHF tag costs will need to drop from $050 each to $0.05 each in five to ten years (p. 6, The Technical Background of RFID section, para.4).

Appendix C: Results of Content Analysis (*Continued*)

Table C- 1: **RFID Radio Frequencies (Low, High and Ultra-high) (*continued*)**

Das / 2004	• Typical applications of low frequency tags include manufacturers, heavy logistics (e.g., brewers), farming, car keys, financial cards (p. 2, Figure 1).	• Typical applications of high frequency tags is airlines (baggage), laundry, toys, libraries, passports (p. 2, Figure 1).	• Typical applications of high frequency tags is airlines (baggage), laundry, toys, libraries, passports (p. 2, Figure 1).	• To keep LF system cost low few tags are used per reader (p. 2, Figure 1). • To keep HF or UHF system cost low many tags are used per reader (p. 2, Figure 1).
Engels, et al. / 2003			• The US Army is using UHF tags for Automatic Vehicle Identification at Fort Monmouth, NJ (p. 3, Security section, para. 1).	• The cost of the UHF AVI tag is approximately US $10 (p. 3, Security section, para. 1).
Loebbecke, et al. / 2006		• High frequency RFID tags operating in the 13,56MHz range are used in consumer goods (p. 2, RFID in Brief section, para. 3). • HF tags can be read from 1.5 meters (5ft) (p. 2, RFID in Brief section, para. 3). • Tags operating in the HF range are less prone to disruptions, in particular those due to the deflection of radio waves by metals (p. 2, RFID in Brief section, para. 3). • Water does not influence the reading procedure at high frequencies (p. 5, Physics section, para. 1).	• Ultra high frequency RFID tags operating in the 868 – 960MHz range are used for consumer goods (p. 2, RFID in Brief section, para. 3). • UHF tags can be read up to 8 meters (26ft) (p. 2, RFID in Brief section, para. 3).	

Appendix C: Results of Content Analysis (*Continued*)

Table C- 1: **RFID Radio Frequencies (Low, High and Ultra-high) (*continued*)**

Lu, et al. / 2006	• The typical read only range for low frequency tags is up to 2 meters (6½ ft) (p. 75, Table 1). • The typical read/write range for LF tags is a few centimeters (1inch) (p. 75, Table 1). • Typical applications for LF tags are animal identification, car immobilizer, controlled access, and work in progress pallets (p. 75, Table 1). • Relative data transfer rates for LF is slow (p. 75, Table 1).	• The typical read only range for high frequency tags is up to 1 meter (3ft) (p. 75, Table 1). • The typical read/write range for HF tags is up to 0.5 meters (1½ft) (p. 75, Table 1). • Typical applications for HF tags are smart cards, smart labels, domestic electrical goods, and access and security systems (p. 75, Table 1). • Relative data transfer rates for HF is faster than LF but slower than UHF (p. 75, Table 1).	• Typical read only range for ultra-high frequency tags is up to 5 meters (16ft) (p. 75, Table 1). • Typical read/write range for UHF tags is up to 0.5 meters (1½ft) (p. 75, Table 1). • Typical applications for UHF tags are item level tracking and mass produced consumer durables (p. 75, Table 1). • Relative data transfer rates for UHF is fast (p. 75, Table 1).	
Maloni, DeWolf / 2006	• Low frequency systems have difficulty penetrating metals (p. 10, Tag Frequencies section, para. 1). • LF is useful for close range reading applications (p. 10, Tag Frequencies section, para. 1).	• High frequency systems operate more like light waves, greatly reducing their effects near metals, and liquids, and limiting their ability to penetrate materials (p. 10, Tag Frequencies section, para. 1).	• The current RFID Generation 1 (Gen 1) standard allows for multiple UHF spectrums worldwide. The new Generation 2 (Gen 2) standard will incorporate all UHF specifications into one international spectrum (p. 10, Tag Frequencies section, para. 1). • UHF systems will have read ranges greater than ten feet, usually averaging 10-15 feet (p. 10, Tag Frequencies section, para. 1). • UHF systems are used in most supply chain applications (p. 11, Tag Frequencies section, para. 1).	

Appendix C: Results of Content Analysis (*Continued*)

Table C- 1: **RFID Radio Frequencies (Low, High and Ultra-high) (*continued*)**

Prabhu, et al. / 2005	• Low frequency systems operate in the 100 – 500kHz band (p. 4, Table 1). • Read range of LF systems is up to 4 – 6 inches (p. 4, Table 1). • Characteristics of LF systems include low reading speed, and can read through liquids (p. 4, Table 1). • Typical applications of LF systems include access control, animal identification, inventory control, and vehicle immobilizer (p. 4, Table 1).	• High frequency systems operate in the 10 – 15MHz band (p. 4, Table 1). • Read range of HF systems is up to 8 feet (p. 4, Table 1). • Characteristics of HF systems include medium read speed, and can be read through liquids (p. 4, Table 1). • Typical applications of HF systems include access control, smart cards, item tracking, and electronic surveillance (p. 4, Table 1).	• Ultra-high Frequency systems operate in the 850 – 950MHz band (p. 4, Table 1). • Read range of UHF systems is 10-20 feet (p. 4, Table 1). • Characteristics of UHF systems include high reading speed, reduced chance of signal collision, and problems with liquids and metals (p. 4, Table 1). • Typical applications of UHF systems include railroad asset monitoring, toll collection systems, supply chain, and item tracking (p. 4, Table 1).	• Low frequency systems are inexpensive compared to HF and UHF systems (p. 4, Table 1). • High frequency systems are potentially inexpensive compared to LF and UHF systems (p. 4, Table 1).
Ward, van Kranenburg / 2006	• Approximate read range of low frequency systems is less than 0.5 meters (p. 10, Table 2). • Typical transfer rates for LF systems are less than 1 kilobit per second (kbit/sec) (p. 10, Table 2). • Characteristics of LF include short range, low data transfer rate, and penetrates water but not metal (p. 10, Table 2). • Typical uses of LF include animal ID and car immobilizer (p. 10, Table 2).	• Approximate read range of high frequency systems is up to 1.5 meters (p. 10, Table 2). • Typical data transfer rates for HF systems is approximately 25 kbit/sec (p. 10, Table 2). • Characteristics of HF include higher ranges than LF, reasonable data rate (similar to GSM phone), and penetrates water but not metal (p. 10, Table 2). • Typical uses of HF include smart labels, contact-less travel cards, and access & security (p. 10, Table 2).	• Approximate read range of ultra-high frequency systems is 0.5 to 5meters (p. 10, Table 2). • Typical data transfer rate for UHF systems is100 kbit/sec (p. 10, Table 2). • Characteristics of UHF include long ranges than HF or LF, higher data rates than HF or LF, concurrent read of <100 items, and cannot penetrate water or metals (p. 10, Table 2). • Typical uses of UHF include specialist animal tracking and logistics (p. 10, Table 2).	

Appendix C: Results of Content Analysis (*Continued*)

Table C- 2: **RFID Tag Type Factors**

Source Author / Date	RFID Tag Type		Factors Determining Cost
	Active	Passive	
AMB / 2004	• Contain batteries, allowing them to transmit their data over hundreds of feet (p. 4, What is RFID? section, para. 1).		• Costly from a few to several hundred dollars apiece (p. 4, What is RFID? section, para. 1).
Anusha / 2005	• Active tags have their own battery power and use it for their on-tag computations as well as for communication (p. 1, Radio Frequency Identification System section, para. 2).	• Passive tags derive the power for their computation and communication from the reader's signal (p. 1, Radio Frequency Identification System section, para. 2).	• For the system to be cost effective the tags used for most applications are passive; this puts a limit on the interrogation range of the reader (p. 2, Problem Definition section, para. 1).
Asif, Mandviwalla / 2005	• Ultra-high-frequency active tags have a read range of approximately 66 to 328ft (p. 398, Table 1).	• Low-frequency passive tags have a read range of approximately 3ft (p. 398, Table 1). • High-frequency passive tags have a read range of approximately 5ft (p. 398, Table 1).	• Approximate cost of low-frequency passive tags is \$0.20 to \$1.00 (p. 398, Table 1). • Approximate cost of high-frequency tags are \$1.00 to \$10.00 (p. 398, Table 1). • Approximate cost of ultra-high-frequency active tags are \$10 to \$30 (p. 398, Table 1). • Compared to passive tags, active tags are more expensive (p. 408, Hardware and Software are a Significant Expenditure section, para 1).
Barker, Mahedevan / 2004	• Active tags are more expensive (p. 3, Key Silent Silent Commerce Enabler – RFID section, para. 2).	• Passive and read-only tags are used the most at present in the corporate world due to its competitive price (p. 3, Key Silent Silent Commerce Enabler – RFID section, para. 2).	• The cost of RFID tags was around 50 US cents in early 2002. Its cost has declined and approached 5 US cents at the end of 2003. The cost is expected to drop further over the next few years which would justify the use of these tags across a broader range of products (p. 3, Major Driving Forces for RFID Adoption section, para. 4).

Appendix C: Results of Content Analysis (*Continued*)

Table C- 2: **RFID Tag Type Factors (*continued*)**

Bornhövd, et al. / 2004	• Active tags come with an on-board battery which provides larger read ranges and memory sizes but also higher unit cost and size and a limited lifespan of typically 3-5 years (p. 1182, Introduction section, para. 3).	• Passive RFID tags require no on-board battery and can be read from a distance ranging from a few centimeters to a few meters (p. 1182, Introduction section, para. 3).	• RFID leads to cost reduction and additional business benefits like increased asset visibility, improved responsiveness and even extended business opportunities (p. 1182, Introduction section, para. 4).
Boushka, et al. / 2004	• Ongoing battery replacement for active tags should be factored into operations and maintenance costs (p. 25, Maintenance section, para. 1).		• The product being tagged greatly affects the costs; will the tag require a standoff (in the case of metal mounts)? Will the tag need to be concealed? Will the tag antenna be printed or metal coil? (p. 23, Tag Costs section, para. 4)
Corsette, et al. / 2005	• The active tag has the ability to store information and contains an internal power source as well (p. 6, What is It? section, para. 1). • Active tags are coin-sized RFID tags (p. 6, What is It? section, para. 1). • Active tags can be used in a variety of environments and are the most effective when dealing with long range (RFID) (p. 6, What is It? section, para. 1).	• Passive tags use the incoming signal as a power source instead of having an internal power supply. As a result, these tags are very small and are also a more economical option than their counterparts (p. 6, What is It? section, para. 1). • The primary limitation of a passive RFID tag is distance (p. 6, What is It? section, para. 1).	• There are very high costs associated with RFID use. Often times RFID process are dependant of the quantity purchased (p. 11, Privacy, security, and cost… Oh My! section, para. 2). • Firms must consider the large up front cost and the potential that the data collected from RFID will not be valuable enough to warrant the expense (p. 13, What are the potential uses for our company? section, para. 1).

Appendix C: Results of Content Analysis (*Continued*)

Table C- 2: **RFID Tag Type Factors (*continued*)**

Curtin, et al. / 2005	• Active tags have a battery used to broadcast the signal to the reader (pp. 4-5, The Technical Background of RFID section, para.1). • Active tags typically have internal read and write capability, their own batteries, and can transmit their signals over a longer distance (p. 6, The Technical Background of RFID section, para.1).	• Passive tags draw power from the reader and are cheaper and smaller than active tags (p. 5, The Technical Background of RFID section, para.1).	• Active tags are expensive – typically more than US $20 each (p. 40, Appendix 1). • Passive UHF tags have a per unit cost of under $0.50 when purchased in volumes of a million tags or more (p. 6, The Technical Background of RFID section, para.4).
Das / 2004	• One application of active RFID tags is the car *clicker* on key rings (p. 4, Commercial Success section, para. 1).	• Passive RFID tags have generally taken the form of contactless smart cards (p. 4, Commercial Success section, para. 1).	• Tag volumes – either active or passive – will be the determining factor on cost per tag (p. 3, Cost section, para. 5).
Dempsey / 2004	• Active RFID tags can provide location in addition to identification (pp. 295-296, Active RFID section, para. 1). • Active RFID solutions use an RFID tag that consistently transmits a known signal (pp. 295-296, Active RFID section, para. 1). • Active tags' performance is not driven by antenna size (p. 296, Active RFID section, para. 1). • Active tags don't typically use time to determine location – the precise timing that is required in RF triangulation systems (and its associated cost) is not necessary (p. 296, Active RFID section, para. 1).	• Location of passive RFID tags must be surmised from the location of the transponder used to read the tag; since transmit distances are smaller (compared to active tags) more readers are needed to provide location (triangulation) of the passive tag (p. 293, Passive RFID section, para. 2).	• Active tag costs are approximately $0.23 per year (p. 26, Table 1). • Average active tag battery life is 2-6 years (p. 26, Table 1).

Appendix C: Results of Content Analysis (*Continued*)

Table C- 2: RFID Tag Type Factors (*continued*)

Dinning, Schuster / 2004	• Active tags are typically used for capital asset tracking and management. For example, rail cars and steamship containers are tracked through switching rail yards and holding terminals at ports (p. 2, Introduction section, para. 2).	• The energy needed to power passive tags is drawn from electromagnetic fields created by readers that also serve a dual purpose of gathering the signals emanating from the passive tag (p. 3, Introduction section, para. 3). • A passive RFID tag has four components (a) the integrated circuit (IC); (b) the antenna; (c) the connection between the IC and the antenna; and (d) the substrate on which the antenna resides (p. 6, How Auto-ID Works section, para. 1).	• A common price for active tags is $2 or more (p. 3, Introduction section, para. 2). • Because passive tag cost is significantly less than active tags, passive tags hold a greater potential in a far greater number of applications (p. 3, Introduction section, para. 3). • As costs decrease, passive tags will selectively replace bar codes as a means of gathering information within supply chains (p. 3, Introduction section, para. 3).
Gambon / 2006		• Passive tags have shown great success in asset real-time locating systems (RTLS) because of the cost savings (p. 2, para. 4).	• Passive tags used for RTLS cost $6 to $7 each, compared to $50 per active tag (p. 2, para. 4).
GAO / 2006	• The Department of Defense has been using active RFID technology since the early 1990s to help with in-transit visibility of shipments (p. 3, Background section, para. 1).	• In January 2005, the Department of Defense officially began to implement the use of passive RFID (p. 1, para. 1).	• Active tags used by the Department of Defense cost around $100 each and are reusable (p. 3, Background section para. 1).
Maloni, DeWolf / 2006	• Active tags have their own power source (usually battery based) and transmitter, enabling them to remain active and broadcast when no reader is present (p. 9, Tags – Passive, Active, Semi-Active section, para. 3). • Active tags are able to retain more memory than passive tags, support longer read ranges (30+ meters), and also include input/output sensors (p. 9, Tags – Passive, Active, Semi-Active section, para. 3).	• Passive tags only use backscatter modulation to power the tag and reflect RF signals, so they can only broadcast when awoken by a reader (p. 9, Tags – Passive, Active, Semi-Active section, para. 3). • Passive tags have limited data storage, usually 96 bits of user programmable data, and limited read range (3-5 meters) (p. 9, Tags – Passive, Active, Semi-Active section, para. 3).	• The cost of active tags is significantly higher than that of passive tags, reaching from $20 to $80 each (p. 9, Tags – Passive, Active, Semi-Active section, para. 3). • Passive tag prices are currently declining below 15 cents each (p. 9, Tags – Passive, Active, Semi-Passive section, para. 2). • Industry analysts caution that tag costs should be at five cents or even below two to three cents to remain economically viable (p. 9, Tags – Passive, Active, Semi-Passive section, para. 2).

Appendix C: Results of Content Analysis (*Continued*)

Table C- 2: RFID Tag Type Factors (*continued*)

Ward, Van Kranenburg / 2006	• Active tag systems have an active radio frequency (RF) transmitter (i.e. they are capable of peer-to-peer communication) and the tags use batteries to power the logic chip and to communicate with the reader (i.e. they do not use harvested power) (p. 9, Energy Source: Passive or Active section, para. 6). • Active tags can be read while moving at up to 100 miles an hour (e.g., in automatic toll-road payment systems) and the readers are capable of reading up to a thousand tags per second (p. 9, Energy Source: Passive or Active section, para. 6). • Active tags can be equipped with built-in sensors (e.g., for monitoring temperature control and reporting unacceptable fluctuations on refrigerated products while in transit (p. 9, Energy Source: Passive or Active section, para. 6). • Active tags have larger memory than passive tags and due to their higher processing capabilities, are also more secure (p. 9, Energy Source: Passive or Active section, para. 6). • Active tags have memories with a range of, typically, between 16bytes and 128 kilobytes (p. 11, Memory section, para. 2).	• Passive tags are currently the most widely deployed as they are the cheapest to produce (p. 4, The Tag section, para. 1). • When a passive tag is within range of a reader, the tag's antenna absorbs the energy being emitted from the reader, directs the energy to *fire up* the integrated circuit on the tag, which then uses the energy to beam back the ID number and any other associated information (p. 5, The Reader section, para. 1). • With passive RFID systems radio frequency is used to deliver power to the tag as passive tags do not have on-board power systems (p. 8, RFID Technology in Detail section, para. 1). • Passive tags can only operate in the presence of an RFID reader (p. 9, Energy Source: Passive or Active section, para. 4). • Passive tags have a much longer life cycle when compared to active tags and, because of their minimal on-board circuitry they are much cheaper to produce (p. 9, Energy Source: Passive or Active section, para. 4). • Passive tags typically have anywhere from 64 bits to 1 kilobyte of non-volatile memory (p. 11, Memory section, para. 2). • The five-cent tag, or less, of the future will most likely be passive, with low memory and have no re-write functionality (p. 26, The Immediate Future: the Five-Cent Tag section, para. 2).	• One of the areas where RFID has been a cost effective deployment is within library systems, where, due to the high volume and high value of individual books and journals and the many ways in which each tag can deliver value (e.g., issue/returns, stocktaking, etc.), the one-off cost of a tag is easily offset by overall cost savings and efficiency gains (p. 3, Executive Summary section, para. 3). • The cost of active tags with sensors increases the cost to around $100 per tag (p. 9, Energy Source: Passive or Active section, para. 6). • The reuse of RFID tags (active or passive) more than offsets the onetime costs (p. 17, RFID in Libraries section, para. 4).

Appendix C: Results of Content Analysis (*Continued*)

Table C- 3: **RFID Configuration Factors**

Source Author / Date	RFID Configuration: Fixed	RFID Configuration: Portable	Factors Determining Cost
Anusha / 2005	• Covering a large geographic area requires a large number of fixed readers (p. 5, Fixed Reader section, para. 1).	• …where complete coverage is required… using mobile readers instead of fixed readers is a cost-effective option (p. 8, Mobile Readers section, para. 5).	• Using a fixed placement of readers to guarantee complete coverage at all times increases the deployment costs (p. 5, Fixed Reader section, para. 1) • .…providing complete coverage of an area, the number of mobile readers needed is much less than the number of fixed readers (p. 8, Mobile Readers section, para. 5).
Asif, Mandviwalla / 2005	• Readers come in many form factors from huge frames covering an entire entrance to the size of a US quarter (p. 400, Readers [a.k.a. Interrogators] section, para. 4). • Some readers can only read tags while others can read and write tags (p. 400, Readers [a.k.a. Interrogators] section, para. 4). • The accuracy of some readers is well below 90 percent (p. 410, Accuracy section, para. 1).		• A [fixed] reader today costs $1000 on average yet some may cost as high as $3000 (p. 408, Hardware and Software are a Significant Expenditure section, para. 1).
Barker, Mahedevan / 2004	• Installing readers at transition points will reduce the cost of replacing missing and lost items by 95 to 98 percent (p. 11, Asset Management Utilization section, para. 1).		

Appendix C: Results of Content Analysis (*Continued*)

Table C- 3: **RFID Configuration Factors (*continued*)**

Gambon / 2006		• Mobile RFID readers mounted on a vehicle provide flexible solutions for asset tracking (p. 4, para. 1). • Using mobile RFID readers attached to forklifts, operators can be instantly alerted if they attempt to pick the wrong asset. Additional benefits are seen for receiving RFID enabled assets via forklifts equipped with mobile RFID readers (p. 4, para. 4).	• Portable RFID readers provide greater flexibility and reduced costs when compared to stationary RFID readers covering the same area (p. 2, para. 1).
Maloni, DeWolf / 2006	• Basic equipment consists of a tag on the item itself and a reader and antenna combination to “interrogate” the tag (p. 7, RFID Technology section, para. 1). • An RFID reader consists of a transmitter, receiver, and microprocessor that function to read the information contained on RFID tags (p. 7, Reader section, para. 1). • Some readers have tag writing capability (p. 7, Reader section, para. 1).	• RFID readers can be either fixed or mobile (p. 7, Reader section, para. 1).	• Companies considering RFID should realize that the true costs of RFID solutions extend well beyond tags and readers (p. 27, Costs and ROI Models section, para. 1). • Current per unit costs range from $100 up to $1,000 for high end and handheld models (p. 7, Reader section, para. 1).
Prabhu, et al. / 2005	• Using an RFID reader, the data on the tag can be read wirelessly, even without line-of-sight access, even when tagged objects are embedded inside packaging or even when the tag is embedded inside an object itself (p. 3, Radio Frequency Identification (RFID) System section, para 3). • RFID reader can read multiple RFID tags simultaneously (p. 3, Radio Frequency Identification (RFID) System section, para 3).	• Many mobile RFID terminals operate Windows CE or Pocket PC and communicate over 802.11b and Bluetooth wireless connections (p. 15, Reader Web Service section, para 3).	

Appendix C: Results of Content Analysis (*Continued*)

Table C- 3: RFID Configuration Factors (*continued*)

Pradhan, et al. / 2005	• Fixed readers are designed to operate at fixed locations as they require wired connections (p. 7, Platforms and Networking section, para 1).		
RFID Journal / July 21, 2003	• Fixed readers can be as simple as a single fixed reader and antenna (p. 1, para. 8).	• Inventory with portable RFID readers allows operators to move from location to location (pp. 2-3, para. 10).	
Ward, Van Kranenburg / 2006	• Fixed readers interrogate nearby RFID tags and obtain their ID numbers using radio frequency (RF) communication without requiring line of sight of contact with the RFID tag (p. 5, The Reader section, para. 1). • Many fixed RFID readers cover doorways or gateways or even hidden areas (p. 5, The Reader section, para. 2).	• Portable RFID readers can be incorporated into handheld devices such as PDAs (Portable Digital Assistants) and mobile phones (p. 5, The Reader section, para. 2).	
Wilding, Delgado / 2004	• Fixed readers provide visibility of assets through fixed points within the organization (p. 36, Woolworths, UK section, para. 4).	• Many handheld RFID readers incorporate bar code reading capability and thereby expand flexibility (p. 36, Woolworths, UK section, para. 4).	

Appendix C: Results of Content Analysis (*Continued*)

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Asset Visibility

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NCR Corporation improves asset management through use of RFID technologies.

Michael, K., & McCathie, L. (2005). *The pros and cons of RFID in supply chain management*. Retrieved February 6, 2007, from http://ieeexplore.ieee.org/servlet/opac?punumber=9999

This paper presents the pros and cons of using radio-frequency identification (RFID) in supply chain management (SCM). While RFID has a greater number of benefits than its predecessor, the bar code, it currently comes at a price that many businesses still consider prohibitive. On the one hand, RFID is advantageous because it does not require line-of-sight scanning, it acts to reduce labor levels, enhances visibility, and improves inventory management. On the other hand, RFID is presently a costly solution, lacking standardization, it has a small number of suppliers developing end-to-end solutions, suffers from some adverse deployment issues, and is clouded by privacy concerns. Irrespective of these factors, the ultimate aim of RFID in SCM is to see the establishment of item-level tracking which should act to revolutionize SCM practices, introducing another level of efficiencies never before seen.

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Auto-ID Labs (2006). (http://www.autoidlabs.org/)

The Auto-ID Labs are the leading global network of academic research laboratories in the field of networked RFID. The labs comprise seven of the world's most renowned research universities located on four different continents. These institutions were chosen by the Auto-ID Center to architect the Internet of Things together with EPCglobal.

ISO: Information Technology Standards – SC31 "Automatic identification and data capture techniques" (http://isotc.iso.org/livelink/livelink?func=ll&objId=327946&objAction=browse&sort=name)

Standards based information on automatic identification, workgroups, and conferences.

RFID Technologies

RFID Journal (2005). *10 questions to ask RFID vendors.* http://www.rfidjournal.com/article/articleview/1330/1/129/

This article outlines important questions for RFID tag and reader providers that can help ensure a successful RFID project.

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EPCglobal is leading the development of industry-driven standards for the Electronic Product Code™ (EPC) to support the use of Radio Frequency Identification (RFID) in today's fast-moving, information rich, trading networks.

Roberti, M. (2005). *Developing an RFID strategy.* RFID Journal (http://www.rfidjournal.com).

The author details approaches companies take toward RFID deployment which can make the difference between disaster and profitability.