

The Future of Radio Frequency Identification

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Abstract

This study identifies the most important and unsolved issues that will determine the future of radio frequency identification (RFID). A review of the RFID business-oriented literature identified twelve issues related to the future of RFID. In the first round of the Delphi Method, a panel of RFID experts narrowed this list to the seven issues considered to be most critical to the future of RFID. In round two, the panel ranked the seven issues in terms of importance and likelihood of being solved within the next two years. A third round, with feedback from round two, was conducted to insure there was a consensus within the panel. Results indicate that standardization is the most important issue and standardization is also the issue most likely to be solved within the next two years. System costs, business process reengineering, and integration also ranked high in importance. Privacy, lack of RFID-skilled professionals, and data warehousing were viewed as of less importance to the future of RFID.

Key words: Radio Frequency Identification, RFID, Mobile Business, Delphi Method

1 Introduction

When you walk into a store and pick up any packaged product, what are you likely to see? A barcode. These barcodes hold information about the products in the form of the Universal Product Code. Barcodes are used to track items in the supply chain and to identify them at the point of sale. However, barcodes have certain limitations – they only contain a limited amount of information, require line-of-sight contact to work, and can easily become soiled, marked over or hidden by frost [2].

Radio frequency identification (RFID) is emerging as an improved and viable alternative to barcodes. A basic RFID system consists of (1) a transponder or radio frequency tag that includes an antenna and a computer chip with information about the item (e.g., product code, manufacturer, use-by date) and (2) a RFID reader that contains a radio wave transceiver. When the reader emits a radio signal, the chip in the tag is activated and the tag broadcasts its data, which the reader receives and records. The data collected by the reader are transferred to information systems for processing. Most RFID tags are passive, receiving their power supply from the radio signal generated from the reader. Active tags with an independent power supply have a greater range and can be used to record and transfer information continuously [3], [30].

RFID technology offers great promise in supply chain management and retail operations [7], [13], [17], [28]. Applications include warehouse management, supply tracking, theft control, and self-catered retail checkout [13], [33]. The greatest potential for RFID, and any identification technology, lies in tracking goods as they move through the supply chain. In addition, an RFID system offers a single platform on which users can implement several applications simultaneously. This versatility can benefit all parties involved in a commercial transaction: manufacturers, distributors, retailers, and consumers [25]. In the near future, advanced RFID systems will encourage the development of new business models and entirely new products and service offerings, based on emerging RFID applications [5].

However, for this potential to be realized there are a number of issues that have to be resolved in terms of RFID's future and implementation. Failure to address these issues could result in failure of an RFID implementation, which results in a waste of significant resources and potential loss of strategic opportunities.

The purpose of this research is to identify what experts think are the most important issues relating to the future of RFID and the likelihood of difficulties associated with those issues being resolved within the next two years. The focus of this research is on RFID applications in supply chain management and retail operations. In this context, the research questions that this study addresses are:

1. Which issues are the most important to RFID's future?
2. What is the likelihood of these issues being solved within the next two years?

This research will be of value to decision makers and innovators as it can help them to understand what issues need to be considered when using RFID by exploring the obstacles to RFID's implementation and its future.

2 Issues Related to the Future of RFID

Most research literature in RFID tends to be technical, not focused on the application of RFID in business, which is the focus of this study. Nevertheless, a comprehensive review of the RFID business-oriented literature found the following twelve issues to be related to the future of RFID, listed in alphabetical order. This paper includes a summarized description of the twelve issues; a more detailed exploration of this literature is included in [35].

Anti-collision: A passive RFID tag draws power entirely from the electromagnetic waves emitted by an RFID reader. However, a passive tag can respond only once for each RFID reader's signal, which limits the design of a wireless communication protocol when multiple readers are in simultaneous use. This limitation has become a crucial issue in environments in which a large number of tags should be identified almost simultaneously, thus leading to what is called an anti-collision problem [16].

Business process reengineering: Success in technology implementation frequently depends on how well it is integrated into daily operations. If businesses view RFID simply as a replacement for barcodes and do not change or redesign their business processes based on RFID's capabilities, the return on investment will be suboptimal [21]. The process challenge associated with RFID is for a company to leverage the technology to create strategic momentum by being the first in its industry to derive meaningful advantages from the adoption of RFID technology. It is only when a firm achieves a deep integration of the technology into its daily operations that significant cost savings can be achieved and business processes can be transformed into a hard-to-imitate strategic advantage [8].

Data warehousing: An RFID implementation can generate 10 to 100 times more information than traditional barcode technology, most of it of little business value. For instance, a mid-size retail chain may generate 100 terabytes of RFID information each week. Perhaps only half of one terabyte is important to understanding, managing, and

automating the supply chain [18]. Most companies will need new data warehousing systems to intelligently parse the usable data from the RFID stream to ensure reasonable data processing and storage costs [31].

Integration with other systems: In order to function appropriately, the RFID system must be integrated with other information systems. Internal integration requires that an organization's existing facilities, equipment, hardware, and software be examined in light of the proposed RFID system, then procedures put in place to insure a smooth implementation of the new RFID system [4]. If an organization's supply chain extends to suppliers and customers, then integration with their systems is also required to insure gains in terms of capacity planning and efficiency [15].

Lack of RFID-skilled professionals: A survey by the Computing Technology Industry Association (CompTIA), reveals that 80 percent of CompTIA member companies with active RFID plans or deployments believe there are insufficient numbers of professionals skilled in RFID available for hire today [22]. Two-thirds of the CompTIA respondents say training and educating their employees in the technology is one of the biggest challenges they will face in order to succeed in the RFID market, and more than half say the lack of professionals with knowledge in RFID will slow the adoption of the technology [22]. Professionals capable of integrating this new technology with business processes are especially hard to find and train [2].

Orientation: Although RFID tags do not need line of sight to be read, the reader cannot effectively communicate with a tag that is oriented perpendicular to it. For example, random placement of products in a customer's basket might render some tags invisible to the reader. One approach to solving this problem is to have multiple readers at different angles, but the information streams would have to be merged and sorted, a relatively expensive solution [32].

Performance: RFID readers can fail to read tags correctly for a variety of reasons. Distance and tag orientation to the reader can prevent a successful read. Radio-reflective metals and radio-absorbing liquids can distort or absorb RFID signals [11]. Packaging, the surrounding environment, and product handling may affect the read success rate [19]. Electromagnetic background noise generated by other equipment can also present problems. Even the speed that tags move past a reader impacts its ability to successfully read the tag [27]. Widespread adoption of RFID could affect the packaging used for products, including the development of material standards to combat this problem [32].

Privacy: A concern of many consumers is what happens when they leave the retail store? If the RFID tags on their purchases can still be read, then a person's clothes or accessories could identify them as they go about their business. Customers are concerned that stores would have the capability to recognize them as soon as they enter the store [12], [19], as illustrated in a recent *Harvard Business Review* case study [6] and also in the movie *Minority Report*, in which Tom Cruise is delivered customized advertisements when walking through a shopping center [14]. This privacy threat is more real with RFID than barcode because RFID tags can store a unique ID for each item and RFID does not require line-of-sight contact, so a tag can be read unobtrusively, without a person's consent or knowledge [10]. Of course the data from the tag would have to be linked to a customer database to insure identification. So the main threat to privacy lies in the combination of both technologies [9], [11].

Range: Most low frequency RFID systems can read tags from about a meter away. Ultra high frequency systems can extend this range up to 10 meters or more, depending on conditions [2]. These ranges could limit the size and application of an RFID system.

Security: As a wireless technology, RFID poses some potential security risks to users. In terms of RFID, security includes: (a) confidentiality or message content security, (b) integrity of message content, and (c) authentication of the sender and recipient. In contrast, privacy deals with anonymity and unlinkability [23]. The principal security threat is that the wireless communication between the tags and the reader is exposed to eavesdropping and traffic analysis. Thus, an RFID system is constantly under threat from man-in-the-middle attacks, whereby a third party may monitor a data stream between a tag and a reader to obtain sensitive information [11]. Illicitly obtained information may contain sensitive information stored on the tag, such as an authentication code. Additionally, the tags themselves can be reverse engineered to create fake tags or produced in large numbers to initiate a denial of service attack [23]. Finally, competitors of an organization may scan inventory labeled with RFID tags to obtain valuable information to ascertain the performance of its competitors [26].

Standardization: A significant benefit of RFID is being able to track items between partners in a supply chain. However, a critical requirement in this process is universally recognized standards [19]. Standards are essential in the air interface protocol (e.g., radio frequency, data signal strength, communication protocols), tag encoding format (e.g., writing and locking tag data, encryption), and the information service infrastructure (e.g., data structure for supply chain applications). For example, competing international standards between the ISO and EPCglobal are already a cause for concern [34]. The Physical Markup Language (PML) may offer a solution for describing data attributes that change constantly, such as temperature of a shipment of fruit or vibration levels of a machine (i.e., dynamic data), or slowly over time, such as the location of a cargo container (i.e., temporal data) [1].

System costs: In 2005, passive tags cost between US\$0.15 (fifteen cents) to US\$0.75 (seventy-five cents) each, with volume purchasing having a significant impact on the cost [19]. The average cost of readers was US\$1,000 each, but as much as US\$3,000 [2]. Given emerging standards, advances in micro-manufacturing, and the economics of competitive large-volume production, the RFID industry should approach its targeted price point of approximately

US\$0.05 (five cents) per tag, within the decade [24]. System costs also include applying tags to items, purchasing and installing readers, system integration (see above), implementing application solutions, redesigning work processes, and staff education and training. Integration throughout an entire supply chain will raise questions as to cost sharing, but this is not an issue in closed loop integration inside a company [15].

The identification of these twelve issues was the starting point for this research. Which ones will determine the future of RFID? How likely are the problems identified here to be solved in the next two years? The process used to answer these questions is described in the next section.

3 Methodology

The Delphi Method is a structured survey process for consolidating the opinions of a group of experts into a judgment on an issue, usually related to the future. Questions are asked of the experts and the information is then analyzed and fed back to each expert. Each round gives participants the opportunity to revise their views in light of the responses and comments of other panel members. This is done repeatedly until a consensus is reached on the particular question. To insure validity of the results, panelists do not directly interact with each another, thus avoiding the social processes and contaminations that can happen in a group situation [20].

For this study, a panel of experts was first asked to assess which issues are important for the future of RFID. Specifically, a list of twelve issues from a literature review (see previous section) was presented to the panel in the first round of the Delphi survey. The purpose of this round was to insure all issues critical to the future of RFID were included and to exclude any issues that were not considered to be important. In a second round, the panel was asked to rank the issues in terms of (a) which issues are the most important in determining the future success of RFID and (b) which of the issues will be solved within the next two years. In the third and final round panel members received ratings and feedback from the second round and were asked to reassess their viewpoint in light of other panelists' ratings and comments, in order to achieve a consensus.

The three rounds of the Delphi Method process ran from July to October 2005. The panel of experts was sought from a population comprising people who have knowledge and experience in the application of RFID technologies in retail operations and supply chain management. The panel included four experts, briefly described as follows:

- Panelist A: Supply chain manager in a major retail store chain in New Zealand
- Panelist B: RFID specialist in an international IT company in the United States
- Panelist C: Project manager in a RFID development company in New Zealand
- Panelist D: Development manager for an IT industry group in New Zealand

A larger panel would have been desirable, but only a limited number of professionals were qualified to sit on this panel and many of them cited pressing time commitments as the reason why they could not participate. However, the group does bring a variety of perspectives – retail, manufacturing and sales, research and development, and industry representation – to the panel.

4 Results

For round one of the Delphi survey, panelists were sent the list of 12 issues identified from the literature review and background information similar to that summarized earlier. Panelists were asked to (a) identify any issues that should not be on this list, (b) suggest any additional issues that should be on this list, and (c) provide comments to support their judgments about the issues.

The results of round one identified the following five issues as being inappropriate for this list: anti-collision, orientation, performance, range, and security. A full description of the panelists' comments is available in [35], but most comments suggested that the issue was either already resolved or a resolution was imminent. For example, an anti-collision protocol is written into the new generation of the Electronic Product Code (EPC) software, orientation-insensitive tags and rotating readers will virtually eliminate the orientation problem, close range scanning is sufficient and usually desirable, and the use of code logic in software can be used to encode and secure tag data.

The following seven items were formally entered into the Delphi survey in round two: business process reengineering, data warehousing, integration with other systems, lack of RFID-skilled professionals, privacy, standardization, and system costs.

In round two, the panel was presented with the seven issues and revised descriptions of the issues, descriptions that now highlighted comments from the panelists. Space limitations prevent a detailed explanation of panelists' comments, but representative comments include:

- *Business process reengineering*: The need for organizations to gain first-mover advantage is widely recognized, but a wait-and-see attitude can also be justified, especially in a maturing technology such as RFID.

- *Integration with other systems*: The key to successful integration is that the system software be evaluated for compliance with systems currently in place. Problems often occur in trying to alter the RFID system software package to fit in existing systems.
- *Lack of RFID-skilled professionals*: Education efforts at the university and trade school level are beginning to take shape to meet this demand, as well as programs that re-train telecommunications engineers to handle RFID system installation and maintenance.
- *Privacy*: This issue only applies to item-level tagging, which is years away.
- *System Costs*: Simple "slap-and-ship" compliance solutions can run from as little as \$15,000. On the other hand, many early adopters of RFID experience duplication of costs as new RFID systems are frequently implemented in parallel with current data capture and management applications. Another panelist pointed out that cost of service and maintenance was an important cost not included in the original description.

The panel was asked to (a) rank each item in its importance to the future success of RFID (1 = most important; 7 = least important) and (b) rank each item on the likelihood of the issue being resolved within the next two years (1 = most likely; 7 = least likely). Comments about these rankings were also solicited. The results of round two for each panelist (NR = no response) and the mean rank are shown in Tables 1 and 2.

Table 1: Round Two Rankings: The Importance of the RFID Issue

Issue	Mean Rank	A	B	C	D
Standardization	2.00	3	2	2	1
System costs	2.50	1	1	4	4
Business process reengineering	3.25	4	5	1	3
Integration	3.25	2	4	5	2
Privacy	5.25	7	3	6	5
Lack of RFID-skilled professionals	5.25	5	6	3	7
Data warehousing	6.50	6	7	7	6

Table 2: Round Two Rankings: The Likelihood of Solutions for the Issue Within the Next Two Years

Issue	Mean Rank	A	B	C	D
System costs	2.25	1	2	1	5
Integration	2.50	2	2	3	3
Standardization	2.67	NR	1	6	1
Business process reengineering	3.25	2	2	3	6
Lack of RFID-skilled professionals	3.50	2	6	2	4
Privacy	3.75	6	2	5	2
Data warehousing	7.00	NR	7	7	7

Some of the comments from the panelists help explain these rankings:

- *Standardization*: One panelist commented that their organization is currently testing RFID equipment and they are finding tags from different vendors respond differently. Hence, the level of consistent interoperability or standardization of tag performance is a real issue to them.
- *System costs*: This issue ranked high in both questions. Two of the panelists cited it as a major issue but also that tags could expect to reach a desirable price range within the next few years.

In round three this ranked set of issues and the panelists' comments were returned to the panel. Each panelist was asked to reconsider his or her own ranking in light of the second round results and to make a final ranking. The purpose of this feedback and review was to seek a consensus of opinion and/or confirm divergent views. The results are shown in Tables 3 and 4.

Table 3: Final Rankings: The Importance of the RFID Issue

Issue	Mean Rank	A	B	C	D
Standardization	1.75	2	2	2	1
System costs	2.25	1	1	3	4
Business process reengineering	2.75	2	5	1	3
Integration	3.00	4	2	4	2
Privacy	5.25	6	4	6	5
Lack of RFID-skilled professionals	5.75	5	6	5	7
Data warehousing	6.75	7	7	7	6

Table 4: Final Rankings: The Likelihood of Solutions for the Issue Within the Next Two Years

Issue	Mean Rank	A	B	C	D
Standardization	1.50	1	1	3	1
System Costs	2.50	2	2	1	5
Integration	2.75	2	2	4	3
Business Process Reengineering	4.25	4	5	2	6
Lack of RFID-Skilled Professionals	4.25	6	2	5	4
Privacy	5.00	7	5	6	2
Data Warehousing	6.25	4	7	7	7

One panelist (D) decided not to change any of his/her rankings in round three while the others did. Standardization remains the issue that is judged to be the most important and has taken over system costs as the issue that is most likely to be solved within the next two years.

5 Discussion and Conclusions

5.1 Discussion of the Findings

The results indicate that standardization is the most important issue in determining the future of RFID. This does not come as a surprise as RFID is mostly being used along the supply chain at the current time. The various organizations along the supply chain have to follow standards to ensure a smooth transition of products with RFID tags from manufacturers to distributors to retailers.

The results also indicate that standardization will be the issue that is most likely to be solved within the next two years. To support this optimism of having the most important issue being solved the earliest, there has been progress made by EPCglobal, an organization that is developing RFID standards. In particular, their Class 1 Generation 2 protocol will help solidify the adoption of RFID, with benefits including enhanced security.

It is also not surprising that the cost of RFID systems is one of the most important issues, second only to standardization. The organizations along the supply chain that use RFID are concerned with the costs of RFID implementation and the return on their investment. Organizations implementing RFID must be able to produce a business case that this new technology will reduce costs and increase efficiency enough to increase profits. The panelists are confident as well that this issue will be solved relatively soon, with economies of production in tag and reader production decreasing equipment costs and proliferation of compatible software reducing system integration costs.

Based on reports in the media and in some research (e.g., [29]), it might be surprising that privacy is not considered as one of the most important RFID issues. This is mostly attributable to the fact that organizations are using RFID technologies to track crates, pallets, and boxes; RFID is not in widespread use at an item level yet. Additionally, the panel did not have any members who could be said to represent a consumer perspective. If a panelist from a consumer organization had been included, this issue would undoubtedly rank higher.

The issues of system costs and privacy are related. It is not feasible at the moment to RFID tag individual items. However, if system costs reduce within the next few years, as the panelists have predicted, RFID tags will begin to appear on individual items and the privacy issue will probably receive more consideration.

Interestingly, according to the panel, the technical issues that had been identified from the literature review – especially anti-collision, tag orientation, performance, and range – already had solutions or were not all that

important. Anecdotal evidence suggests this can be attributed to the progress that organizations are making to improve the performance of RFID technologies.

5.2 Limitations of the Study

As noted in section 1, the focus of this research is the application of RFID in the retail sector, especially in supply chain management. Other uses of RFID (e.g., security, mobile payments) have not been explicitly addressed. A study focusing on these applications would produce a different set of results. Similarly, broader and more conceptual issues relating to RFID development (e.g., the role of innovation) have not been included.

A larger panel of more than four members would have been desirable. As noted earlier, aggressive attempts to recruit additional panelists were unsuccessful due to the lack of experts in this field and the busy schedules of the experts we contacted. This limitation was somewhat mitigated by the fact that all four panelists participated in all three rounds of the study. Panel drop out is common in Delphi Method studies, but this was not a problem in this study.

A panel of RFID experts from the business community was appropriate for this study. However, broader perspectives such as academics studying RFID and panelists with a consumer perspective could have produced different results.

A related limitation is that the study is limited to panelists from America and New Zealand. Due to differences in legislation and privacy concerns, a more international panel probably would have produced different results.

5.3 Suggestions for Further Research

This study has presented a broad overview of the issues concerning the future of RFID. Further research might include an in-depth case study of an organization that has recently implemented RFID, or a multiple case study approach along a supply chain to identify where costs and benefits are derived.

A comparative study might be conducted in other countries with a larger panel and more diverse panel, overcoming the main limitation of this study. Especially, organizations in different countries might be concerned with different issues, depending on the stage of RFID adoption.

Finally, because RFID is an emerging technology with progress being made regularly, a replication of this study should be done in about two to three years to determine if the issues identified in this study are still unsolved and to see if new issues have emerged.

5.4 Conclusion

RFID is a part of the future for most businesses. Successful adoption of RFID seems to be a question of when, not if, for most firms. Already, organizations are adopting RFID and we are confident that as the issues of RFID are solved, adoption will increase and RFID will become an integral technology in the supply chain.

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