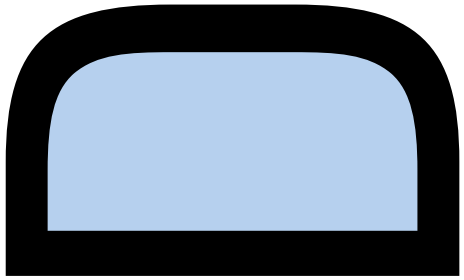
WHITE PAPER SERIES / EDITION 1



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Radio frequency identification: technology, applications and impact

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AUTO-ID LABS

1. Introduction

Radio Frequency Identification or RFID has sprung into prominence in the last five years with the promise of providing a relatively low cost means for connecting non electronic objects to an information network. In particular, the retail supply chain has been established as a key sector for a major deployment of this technology. This short report provides a background to the technology and its position with regard to competing technologies. A range of applications is reviewed and we conclude with some comments on the likely societal impact of RFID and potential barriers to deployment. This report is aimed at a non-technical audience, namely senior staff from a spectrum of areas, such as insurance, banking, telecommunications, government institutions and academia. The report does not cover any technologies other than RFID, in particular those that may be candidates for tracking people.

2. Technology

In this section we review the background to and operations of RFID systems [20]. We also review the networking implications of having ubiquitous RFID data available and finally contrast RFID to other comparable technologies.

2.1 Introduction to radio frequency identification (RFID)

At its most simple, a radio frequency identification (RFID) system consists of two components, namely a tag (also called a transponder) and a reader (also called an interrogator). The tag is designed to be small and cheap – perhaps the size of a credit card or smaller – whilst the reader is more expensive and larger – typically around

the size of a laptop computer. The RFID tag contains a small amount of memory for holding data, and whenever that tag comes into proximity with the RFID reader, the reader will detect the tag's presence and can read the data from the tag.

A real-world RFID application will typically make use of many RFID tags, which are attached to physical objects. When one of these objects comes into proximity with the RFID reader, date from the associated tag can be read – this may be used to identify that specific object or to provide information about it. Similarly, real applications of RFID technology often make use of several RFID readers, so that the tagged objects can be identified in different locations.

Performa Tag

Performa Slimline RFID Reader

Performa Portable Reader

Performa Long Range Reader

There are many different types of RFID system that vary in their exact mode of operation and operating performance. With 'active' RFID systems, the tag contains a small battery that enables it to control communication with the reader. A completely 'passive' RFID tag, however, has no battery but instead harvests power for its operation from the reader's radio communication signal. This means that the reader has to drive communication, but it makes the tag much cheaper.

Examples of an RFID tag, real size around 5cm by 5cm (top left), and a number of different types of reader, manufactured by Checkpoint Systems [21]. The slimline reader is around 35cm by 25cm.

2.2 Overview of the operation of RFID

RFID relies on radio frequency communication. The RFID reader emits energy, in the form of a radio wave at a particular frequency, which is used to power and to communicate with the RFID tags. As the radio waves propagate through the environment, their energy gradually dissipates – so a tag that is beyond a certain distance from the RFID reader will not be able to pick up enough signal to operate reliably. In other words, the maximum operating distance between the RFID reader and a tag (also known as the range) is limited. The exact range depends on a great many factors, including the radio frequency being used for communication, the power emitted by the RFID reader, sources of radio interference and objects in the environment that are likely to reflect or absorb radio waves. A typical range for a passive RFID system will be anywhere between a few centimetres and a few metres. If a battery is incorporated into the tag, the range is increased dramatically, to many tens of metres or more.

Since the communication mechanism is based on radio wave propagation, a direct 'line of sight' between the reader and the tag is not required. (Contrast this with barcode systems where the

reader must be able to 'see' the barcode label.) This means that tagged objects may be identified even if the tag or even the entire object is not in direct view of the reader – for example they may be inside packaging or hidden behind other objects. Also, most modern RFID systems can identify multiple tags in very quick succession (from tens to hundreds per second). This means that many tagged objects can be read in effect 'simultaneously' as they pass by an RFID reader, something that is not easily achievable with other technologies such as barcodes. Although the relative orientation of the tag and the reader does alter the operating range to some extent, it is often possible to set up an RFID system so that this effect is not important – in other words, tagged objects may pass by a reader with little constraint on their orientation or alignment, another big advantage over many other identification technologies.

RFID systems rely on the use of a radio communication channel for their operation. This has a number of implications relating to the security of system operation. The most fundamental consideration is that the channel is by is very nature, shared within any given vicinity.

This means that

- any transmissions that occur may be detected by any other equipment within range
- any other equipment may also make transmissions – which will potentially interfere.

The former of these two observations is often considered to be a significant security risk, especially given the non line-of-sight operation of the system that may make it relatively easy for an eavesdropper to remain hidden. However, the signals that emanate from the tag are incredibly weak, so an eavesdropper would need to be quite close by (certainly no further from the tag than the genuine reader). It is possibly to design an RFID system that uses completely secure communications, where the information that is communicated is encrypted, but this will impact the cost of the tags and the performance of the system (range, communication speed etc.) and is not currently seen to be commercially viable.

The latter of the issues above is perhaps more interesting. For one, it means that a unauthorised reader is a liberty to communicate with tags. But it also means that any equipment that generates radio communication signals at the same operating frequency as the RFID system will interfere with the RFID operation, reducing performance and potentially rendering it inoperable. This is unlikely to occur by chance – it would mostly likely be due to the malicious (and illegal) operation of interfering equipment.

There are a number of aspects to the security of RFID systems, such as anti-counterfeiting, privacy, detection of communication errors, reliability of communication.

2.3 History of RFID up to current state-of-art

The concepts behind RFID were first discussed in the mid to late 1940's, following on from technical developments in radio communications in the 1930's and the development of radar during World War II [1]. An early published work exploring RFID is the landmark paper by Harry Stockman, "Communication by Means of Reflected Power" [2]. Stockman stated then that "Evidently, considerable research and development work has to be done before the remaining basic problems in reflected-power communication are solved, and before the field of useful applications is explored."

The 1950s were an era of exploration of RFID techniques – several technologies related to RFID were developed such as the long-range transponder systems of "identification, friend or foe" (IFF) for aircraft [3]. A decade of further development of RFID theory and applications followed, including the use of RFID by the U.S.

Department of Agriculture for tracking the movement of cows. In the 1970's the very first commercial applications of the technology were deployed, and in the 1980's commercial exploitation of RFID technology started to increase, led initially by small companies.

In the 1990's, RFID became much more widely deployed. However, these deployments were in vertical application areas, which resulted in a number of different proprietary systems being developed by the different RFID solutions providers. Each of these systems had slightly different characteristics (primarily relating to price and performance) that made them suitable for different types of application. However, the different systems were incompatible with each other – e.g. tags from one vendor would not work with readers from another. This significantly limited adoption beyond the niche vertical application areas – the interoperability needed for more widespread adoption could not be achieved without a single standard interoperable specification for the operation of RFID systems. Such standardisation was also needed to drive down costs.

The drive towards standardisation started in the late 1990's. There were a number of standardisation efforts, but the two successful projects were:

- the ISO 18000 series of standards that essentially specify how an RFID system should communicate information between readers and tags
- the Auto-ID Centre specifications on all aspects of operation of an RFID assettracking system, which has subsequently been passed onto EAN.UCC (the custodians of the common barcode) for international standardisation

It is quite possible that these two standards will merge in the future, to create one single specification of interoperable RFID system operation, which will promote larger-scale adoption of the technology and help to drive down costs. This means that passive RFID tags and readers, which in the past cost in the region of US$0.50-1.00 and US$1000-2000 respectively, are now heading towards US$0.05-0.10 and US$200-400.
The particular RFID based Automated Identification system specifications being developed by the Auto-ID Centre [13] have particularly focussed on establishing global, open specifications for very low cost tags and readers.

2.4 The Auto-ID Centre

The Auto-ID Centre is a university-based organisation that was formed in 1999, initially by the MIT, the Uniform Code Council (UCC, the 'custodians' of the barcode in North America), Gillette and Procter and Gamble. The motivation of the Centre was to develop a system suitable for tracking consumer packaged goods as they pass through the supply chain in order to overcome problems of shrinkage and poor on-shelf-availability of some products. The Centre quickly expanded, and by October 2003 it had over 100 member companies, all with a common interest in either deploying such a technology in their companies or in supplying these technology components.

Early on in the life of the Centre, it became clear that RFID would form a cornerstone of the technological solution, and along with the help of some end-user and technology companies, the Centre was instrumental in driving down the cost of RFID to a point where adoption started to become cost-effective in some application areas. Part of the solution to keeping costs down is a single-minded drive to reduce RFID tag complexity, and one approach to this advocated by the Auto-ID Centre is to store as little data about products as possible actually on the tag. Instead, this information is stored on an organisation's computer network, which is much more cost-effective. Hence, an RFID-based Auto-ID system gener-

ally comprises the following elements

- A unique identification number which is assigned to a particular item (the so-called electronic product code, or EPC).
- An identity tag that is attached to the item with a chip capable of storing—*at a minimum*—a unique identification number. The tag is capable of communicating this number electronically.
- Networked RFID readers and data processing systems that are capable of collecting signals from multiple tags at high speed (100s per second) and of pre-processing this data in order to eliminate duplications and misreads.
- One or more networked databases that store the product information.

With this approach, the cost of installing and maintaining such systems can be spread across several organizations while each is able to extract its own specific benefits from having uniquely identified items moving in, through and out of the organization's operations.

2.5 Comparison with other technologies

The most obvious technology that is comparable to RFID for many application areas is barcoding. Both these technologies involve the addition of a 'tag' or 'label' to an item that contains information about that item which allows it to be identified by a computer system.

A system designed to identify objects based on RFID tags has two advantages over conventional bar code systems:

- Barcodes are fixed once they have been created, whereas the data contained within an RFID tag can typically be augmented or changed as appropriate [4]. This means that
  - It is possible to separate the time at which an object is tagged from the time at which information is stored on the tag – it may be advantageous, for example, to apply the tag at some point in an item's manufacturing process, before the information to be associated with the tag is known. This is not possible with a barcode.
  - Information can be updated as a tagged item moves through a process, keeping the important information with the tag (and the item) and so making it available at any point in its life [4].
- Barcodes have to be scanned deliberately by a person in a process that is difficult to automate. RFID tags, on the other hand, can be readily scanned automatically without human involvement. This means that:
  - The data can be obtained continuously and thus they are more up-to-date then data obtained only at specific intervals (like inventory counts) and specific points in the supply chain (like shipping or receiving)
  - Not involving a human in the process means that the readings can be less expensive and generally more accurate – incremental readings are virtually cost-free once the system has been set. It also means that there may be fewer misreads.
  - Speed – many tags can be read simultaneously into a computer, rather than reading a single tag at a time
- Barcodes require line-of-sight to read, while RFID tags can be read (in any orientation) as long as they are within the reader's range. This implies that:
  - The content of various conveyances (such as trailers, cases, pallets, shopping carts) can be read automatically without opening and sorting the conveyance
  - Barcodes do not work well when exposed to weather elements, when dirty, or if damaged in any way that interferes

with clear line-of-sight reading. RFID is much more suited to operation in harsh environments [4]. The RFID tag can be hidden from view if this is beneficial, whereas a barcode is very obvious.

In addition to RFID and barcoding systems, there are also a number of other technologies that may be used in similar ways for storing information with an object or for identifying that object. These include magnetic stripe and contact systems, where information is stored on a magnetic stripe or in a chip (accessed by electrical contacts) and computer vision systems that identify objects based on their visual appearance. The relative merits of all these different technologies are summarised in the table below.

Characteristic	Tagging technology					
	Passive RFID	1-D barcode	2-D barcode	Magnetic stripe	Contact memory	Vision systems
Data capacity	High	Low	Medium	Low	High	Low
Data nature	Re-writeable	Read only	Read only	Re-writeable	Re-writeable	Read only
Human visibility/ readability	Hidden	Visible, may be readable	Visible	Stripe visible	Contacts visible	No specific tag!
Simultaneous identification	Yes	No	No	No	No	Possibly
Robustness	High	Medium	Low	Medium	Medium	
Operating distance	High	Medium	Medium	Low	Low	High
Line of sight needed?	No	Yes	Yes	No	In effect	Yes
Problematic objects (e.g. metal)	Yes	No	Not	Yes	Possibly	Yes (hard to see)
Tag cost	€0.1-1	<€0.01	<€0.01	<€0.1	€0.1-1	€0 (n/a)
Reader cost	High	Low	Medium	Low	Low	Very high

3. Applications

In this section we provide an insight into the nature of the applications that have attracted RFID deployment to date and also provide a window into future uses. As emphasised earlier, this review focuses solely on the application of tags to inanimate objects.

3.1 Applications: past, present and planned

Direct sensing of product identity is important in environments in which it is too complex, uncertain or expensive to extract information about product movement via indirect methods – generally these involve computer tracking models and simple proximity sensing devices of some form. Following the contrast between bar coding and RFID systems in Section 2, it is clear that when an easily automated, wireless, non-line of sight system is required and where multiple simultaneous reads is preferred then RFID has significant attractions.

These characteristics are reflected in applications of RFID to date such as supply chain management; anti theft systems, electronic tolling, facilities management (e.g. libraries); airline baggage handling, asset tracking. The table below compares the nature of these different applications, indicating that in many ways, supply chain applications are – at least at present – rather different to most other existing applications.

	Tolling	Library	Asset	Airline	EAS	Supply Chain
Complexity of the Information on Tag	M	L	H	L	L	L
Single or Multiple Applications for Each Tag	S	S	S	S	S	M
Volume of Tags	L	L	L	M	M	H
Expected Life of Tag	H	H	H	M	M	L

This difference highlights the impact of the Auto ID Centre's work which has shifted the paradigm of RFID from low volume, high cost applications to those where high volume is critical, where costs must be as low as possible and benefits from a single tag must be achieved across multiple applications. The following table – extracted from [6] – indicates the range of applications potentially achievable across the retail supply chain in which reduction of variabilities and uncertainties is of prime importance

Supply Chain Area	Description	Variabilities / Uncertainties	RFID Applications
Shipping	shipment consolidation, contract compliance, routing optimization, tendering and other transportation management functions associated with getting shipments out the door.	late orders, emergency shipments, lack of transportation capacity, lack of inventory visibility for order completion, misplaced and mis-picked items, etc.	Upstream visibility increasing planning options, simplified optimisation of trailer contents, speeding loading processes
Transportation process	all the processes and activites performed by the carrier, logistics company or whomever, in connection with the transportation process.	delays, misrouted packages in terminal operations, last minute diversion of conveyances,[1] dynamic trucking operations, wrong drop-off and pick-up operations, pilfrage during transit, spoilage, etc.	Increased speed, simplicity and accuracy in tracking: Order tracking, sub conveyance tracking of part loads/individual pallets, speeding of tracking of individual items
Receiving process	verification, acknowledgement, pairing and put-away activities associated with receiving shipments at the buyer location.	item shortages, wrong items, wrong quantities, deliveries to the wrong location (or receiving door within a location), put-away in wrong locations, wrong data entry, etc.	One touch verification, automated proof of delivery processing, accurate/fault tolerant locating of items
Internal processes	Includes all the processes taking place within the buyer's facility. These may include transformation in a factory, storage in a warehouse, display in a store and all the processes around these activities.	errors in determining product state during processing, quality problems, raw material stockouts, inventory mismatches, unknown location of product within the facilty, etc.	Manufacturing: raw material, sub assembly tracking, asset tracking Warehousing: inventory management, spare part management Retail: shelf level monitoring, automated reordering, auto check out

3.2 More detailed case studies

In order to provide insight into the way that RFID solutions are being deployed we now present a number of short application "case studies". These are intended to be illustrative but not comprehensive.

Inventory control

Companies are starting to use RFID technology for warehouse applications which range from inventory counting of tagged products to product location and picking.

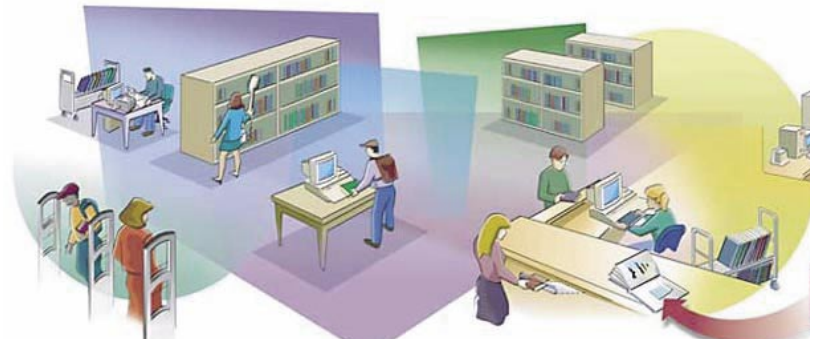
Figleaves, a U.K. online retailer of ladies' underwear tags totes with RFID transponders and places readers in bays, so workers can correctly identify the location of a particular tote. The system saves the company time and labour in not having to double-check orders before shipping. The system enables staff to pick 60,000 items a month with an error rate of less than 0.1 percent. But he would like to eliminate all failed picks by also using RFID to make sure bins are where they are supposed to be. Today, if a bin is not in the right location, it's very hard to find because it could be almost anywhere in the facility. Figleaves hopes to install tags on shelf edges and on the bins that carry products, and even on all items in a bin when the cost of tags drops further. Figleaves would like to install RFID tags on the shelf edges and on the bins. That way, staff could stroll through the warehouse, scan the shelves with a handheld scanner and make sure every bin is in the right location. That would mean that when staff pulled up with a cart, they would be virtually guaranteed to find the right product right away. Figleaves have established a business case for item level tagging provided the tag price falls below US$0.10.

Grocery distributor Associated Food Stores in Salt Lake City uses an RFID-based, real-time locating system at its distribution centre. The system enables Associated managers to know when

trucks enter or leave the distribution yard and their exact location. RFID also can measure certain performance levels, such as detecting an increase in temperature, which would indicate a refrigerator truck door was left open.

Library systems:

RFID technology is well-suited to material management in a library setting. RFID tags can easily be incorporated into books and other library media. The tags may be applied at source (at the time of publishing) or after manufacturing, for example by the library staff as items are acquired.



The self-checkout system developed by Checkpoint [19] allows patrons of the library to check-out materials themselves, saving staff time and providing privacy. All types of library cards can be used, including those using traditional bar-codes, magnetic strips or smart cards. Receipts are provided automatically. A user-friendly touch screen monitor guides the patron through the checkout process. Sensors automatically guard the library entrances and exits. They constantly query materials that pass through the sensors for proper checkout. Materials are verified against the library circulation system. If a person attempts to steal books, the system can alert staff. It is also possible to identify stolen items should they later be returned, and to highlight items that need to be replaced. A portable hand-held wand can be used to inventory materials in a library very quickly, and can assist in the location of mis-shelved materials.

Toll collection:

Electronic payment systems, enabled by RFID technology are becoming increasingly popular for road toll collection. An RFID tag (typically an active or semi-passive tag) is carried by the vehicle and a reader is deployed at each toll collection point. Whenever a tagged vehicle passes through a collection point, it can be detected and identified, and this information is used to levy the appropriate charge for the journey, electronically. The advantages of electronic tolling are clear from the driver's point of view – there is no need to slow down significantly at the toll booths, no need to have the correct change to hand, no queuing. Similarly, costs of collecting tolls are significantly reduced by reducing staffing levels, cash handling and so on.

Tagging in the Automotive Industry

Enormous efforts in the automobile industry are being expended in ensuring the tracking and traceability of all parts is in place for warranty purposed. Applications are being developed for tagging of car bodies (even at extremes of temperature), metallic parts, seats and tires. We examine the latter two here for illustration.

Working with the Automotive Industry Action Group, Intermec [7] has developed a UHF read/write tag that can be placed inside a car tire and includes a unique serial number and a US Department of Transport coding number. The two numbers together can point

to the exact location, time and conditions of manufacture of the tire. The tag is placed during the manufacture of the tyre and is written to at the point of manufacture before distribution.

The tagging of car and truck seats is also receiving significant attention:

Johnson Controls [8] has deployed a 13.56MHz tagging solution from Escort Memory Services for tagging all pallets used to convey the car and truck seats they produce. This was done primarily to improve tracking errors: specifically errors in delivery sequence and content for customers such as Daimler Chrysler, Ford Motor Co. and General Motors. RFID was chosen because of the harsh environments and the need to have very accurate identity readings. Bar codes were considered unsuitable because of line of sight restrictions and the likely replacement requirements over the pallet life. This is despite the US $60 cost to place 4 tags onto each pallet Most interestingly, Johnson has been able to use this same system as a means of improving processing procedures in their own production plant. Their production lines are inherently flexible in terms of dealing with small batches of multiple product types. However limitations in material handling systems require generation of inventory at the end of production which in the past has lead to the mixing of orders of seats with slightly different specifications. They can now produce multiple types of 1seats on a single production line without fear of confusion arising, and hence not only deliver but also produce to order in a flexible, Just in Time manner.

A wide range of RFID solutions have developed specifically for this industry which is in many ways the leader in the field, primarily because of the combination of relatively high volumes and item prices which provides an attractive business justification for both the end user and the solution developer.

3.3 Potential future applications

In addition to offering improvements in many existing processes, Auto ID systems will in the future enable fundamentally new service and business offerings which may have widespread ramifications. While the applications discussed so far are primarily based on a cost reduction justification, future applications might rather be seen as value adding. We emphasise that the following discussion is in part speculative, and is simply intended to outline examples of fundamentally new applications being considered.

Retail Stores of the Future

The “holy grail” in retail is to reduce customer queues at check out without increasing staffing levels. Many retailers are exploring options for “check out free” stores, in which RFID scanners either in doorways or on board trolleys provide a self check out service that is hassle free to the customer. Also, continuous shelf inventory checking using RFID and the addition of more frequent replenishments mean that shelf space for each item can be reduced substantially while increasing level of service and reducing out of stock levels. The result may be smaller supermarkets and other retail outlets while the number of SKUs offered remains constant.

Procter and Gamble in Ohio, Phillip Morris in New York State, Sainsbury’s in the UK and MGI (Metro) of Germany have opened Future Stores as a means of demonstrating the type of facilities that might be expected in an Auto ID-enhanced retail outlet. Applications range from smart – anti theft – shelves, to wireless and automated ordering systems, dynamic use by dates, to intelligent trolleys which scan items as they are collected and update an electronic shopping list accordingly. Personalized advertising systems have also been tried.

RFID Systems in the Home

One of the first applications in the home may be continuous inventory. RFID, however, may give a new generation of home appliances the ability to know their content and act on it. Such actions may include cooking (in case of a microwave oven reading imbedded instructions on a package); a refrigerator and a cupboard ordering automatically from a store when the inventory level reaches a predetermined reorder point; and a refrigerator or medicine cabinet letting the owner know about the expiration date of content.

Product Visibility Over the Entire Life Cycle

Today the supply chain for retail goods effectively ends at point of sale. Auto ID can enable applications in the usage phase (e.g. in the home) and at the end-of-life phase (e.g. disposal/recycling/reuse application) through information preservation. Keeping product information by connecting the RFID tagged product to a networked data base infrastructure through the usage and disposal processes means that information about the item is known throughout their lifecycle. Figure 7 is derived taken from McFarlane and Sheffi [4], illustrating the current typical information profile of items as they go through a supply chain. The networked RFID-enhanced case is shown by the dashed line in Figure 7.

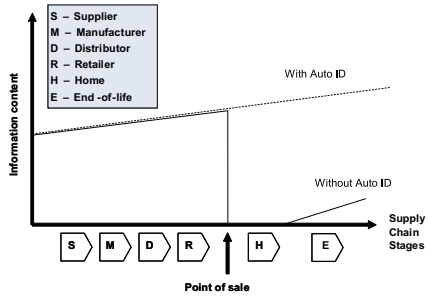


Fig. 7 Product Information Content along the Supply Chain

One of the benefits of the extension of the visibility into the home or workplace is in terms of more efficient end-of-life operations. Being able to detect which parts are contained, for example, in a discarded appliance and how that appliance was used at home, can aid in the decision of where to send it for processing, allowing recycling centres to specialize. In the recycling centres RFID information can help automate the sorting process, which is the Achilles' heel of most recycling processes. It can help decide what parts to recycle, what can be used in remanufacturing and what should be discarded and where.

4. Drivers and Effects

4.1 Commercial drivers for RFID

A large number of consumer packaged goods (CPG) manufacturers and retailers have been exploring the potential benefits of RFID for tracking and identifying their products as they pass along the supply chain for a number of years. Whilst the most significant potential benefits of deploying such technology may differ from company to company, if a common, standardised, interoperable RFID system is deployed by all the trading partners in the supply chain, then the cost of deploying the technology can be amortised across the entire chain.

The recent technological developments in RFID that have brought down tag cost, especially when considering the very high volumes of tags that will be needed by the CPG industry, coupled with recent progress in global standardisation, mean that RFID is now much more cost-effective in this application area. As a result of this, leading retailers are beginning to think very seriously about deploying the technology, and the world's largest retailer

Wal-Mart has recently announced that by January 2005 its top 100 suppliers must use RFID technology to label all cases of products supplied. This requirement will be extended to all its suppliers in time. The so-called 'Wal-Mart announcement' is incredibly significant given the size and power of Wal-Mart – it will clearly drive the adoption of RFID in the CPG supply chain.

The US Department of Defence has issued a similar mandate, relating to the RFID tagging of items that it purchases, and the leading UK retailer Tesco is already using RFID in one of its distribution centres and with some of its suppliers. Tesco plans to extend its deployment of RFID significantly over the coming year. These plans will also force the product manufacturers to deploy RFID, thereby driving adoption of the technology significantly.

4.2 Legislative drivers for RFID

In addition to commercial factors, legislation can also be a big technology driver. There are a number of areas in which new legislation may well drive the adoption of RFID in certain industries and for certain application areas.

The European Waste Electrical and Electronic Equipment (WEEE) Directive[10] became European law in February 2003, setting collection, recycling and recovery targets for all types of electrical products. The Directives must be implemented in European Member states by August 2004, although there is an additional two-year period before full compliance must be demonstrated. Of particular relevance to RFID is the compulsory producer responsibility for financing the management of consumer electronic and electrical waste. This means that producers need to be able to identify the electronic and electrical equipment that they originally produced (because they will not want to incur the cost of disposing of another manufacturer's equipment). Also, they would benefit from being able to identify their own products accurately, in order to recycle the sub-components as effectively as possible. Similarly, the EU Directives On Packaging And Packaging Waste and the Management Of End-Of-Life Vehicles Legislation place further pressures in the areas of packaging and motor vehicles.

Legislation regarding the tracking of medicines and foodstuffs in order to ensure human health and safety is another driver for the adoption of RFID technology. In some cases, existing or proposed legislation requires quite onerous audit trials of such products to be maintained by manufacturers and retailers. In these cases, whilst a number of different technologies might be used to meet the guidelines, RFID is an obvious choice for costeffective implementation. However, in some instances RFID is being explicitly recommended or mandated. For example, the Healthcare Distribution Management Association (HDMA), a nonprofit organization for distributors, has recently recommended that manufacturers and wholesalers of pharmaceutical drugs and other healthcare products begin putting RFID tags on cases beginning in 2005 and deploy related infrastructure needed to take advantage of those tags [14]. Additionally, in the food industry, food traceability enabled by RFID is a major topic for discussion, prompted by

4.3 Social impact of RFID

Here we briefly review the possible social impact of RFID, examining the individual, society as a whole and the environment.

Impact on the Consumer

- Consumer benefits – Identified benefits to the consumer from RFID range from those in a retail store (reduced queuing, fresher goods, increased product availability), to the home (automated product checking, drug authenticity and dosage monitoring, home security systems) to travel (improved airport luggage management), to simpler access and borrowing

systems for public services such as libraries. There has been little attempt thus far to quantify the benefits of RFID to the consumer as much of the industrial focus recently has been in the business supply chain, and in the media on concerns over potential privacy infringements …

- Consumer privacy concerns - RFID has received a lot of attention in the world-wide press in recent months due to consumer privacy concerns, raised by a relatively small number of privacy advocates [15][16]. Whilst consumers are genuinely concerned, in most cases the worries are based on a lack of understanding on exactly what the technology is capable of and how it can be used. The Auto-ID Centre has put forward a list of guidelines about best practice for addressing public concerns [17]; these include visually marking products or packaging that contains an RFID tag, giving consumers the option to have the tag destroyed at the point of sale, and guaranteeing the anonymity of data collected regarding any tagged items.

Impact on Society

- Healthcare - RFID Developments for assisting hospital based and in-home healthcare have the potential to improve quality and reduce costs of hospital treatment and contribute significantly to the management of Europe's aging population. Applications ranging from life cycle tagging of drugs [11], to intelligent medicine cabinets which can check user ID and drug ID to ensure each is authorised appropriately.
- Food Safety – the food tracing legislations discussed in the previous section are intended to secure the entire food chain and to ensure a safe and effective supply of foods to consumers, as well as the ability to trace and recall quickly and accurately if required.

Impact on the Environment

- Recycling And Reuse Of Materials – the legislative requirements in this area are discussed above. In addition, it is noted that the effective deployment of RFID in the Endof- Life management of goods may in fact help these activities to become profitable, providing a positive feedback loop for further developments in the area
- Energy Management - the use of RFID based circuitry in electrical goods is being explored within a EU research project as a means of monitoring and analysing the performance of equipment while in use. [12] Data is extracted periodically and used to review energy consumption amongst other variables. Up to 50% of all energy expended on many electrical products over their life cycle is during their usage phase.

4.4 Potential barriers to success of RFID

Technological challenges include the following:

- Data storage and access – tracking every object at the individual item level will generate enormous amount of data that will have to be stored (probably using distributed data bases) and accessed quickly. The Auto-ID Centre has developed migration strategies but this done only at the cost of reducing the fidelity of the data.
- Accuracy – As operations and their underlying information systems grow to rely more and more on real time, automated product identity data, the specifications placed on the identification system will tend towards absolute accuracy of location information generated. This will place new challenges on the engineering and production of the tags and readers.
- Interference – with the proliferation of wireless devices (cordless and mobile phones, PDAs, consumer electronics devices, etc.), there is the potential for electromagnetic interference

with RFID systems. This may be particularly important since RFID does not have its own dedicated frequency band in most jurisdictions, but rather operates in a band that is shared with other users.

- IT integration – companies typically have a number of legacy IT systems. Whilst some IT systems providers will provide off-the-shelf solutions to address such implementation issues, it is likely that integration of RFID systems with existing systems may be difficult, time consuming and expensive. The real-time nature of the item-level information that can be generated using an RFID system will place significant challenges on the IT infrastructure.
- Difficult-to-tag items – the performance of an RFID system is very-much dependent on the type of object being tagged and the environment in which that object needs to be identified. For example, objects with a high metal or liquid content typically absorb the RF energy emitted by a reader significantly, thereby reducing the range of an RFID system dramatically.
- RF legislation – RFID systems traditionally operate in regions of the radio spectrum that are unlicensed. This means that, as long as the RFID reader follows some basic operating principles, it can be operated without the need for a special radio transmission licence. National governments are typically responsible for defining which parts of the radio spectrum are unlicensed and of these, which are suitable for RFID systems. Unfortunately, due to historical reasons, not all governments have the same allocations – North America, Europe, South Africa and Australia have slightly different allocations and operating principles, for example. Over time, these differences are gradually being aligned, but this is a long-term process and in the shorter term there may be interoperability issues.
- Recycling of tags – if an RFID tag is truly embedded into an item (rather than attaching it to the packaging of that item, for example), then there may be an issue with subsequently recycling that item. The materials used to form the RFID tag (silicon chip, metallic antenna) may not be compatible with the recycling process for the item, thereby reducing the effectiveness of the recycling operation.

Other challenges include:

- Health and safety issues – In the past, RFID reader deployment has not been particularly widespread. However, as this changes, and workers and the general public increasingly come into contact with the technology, concerns about the health and safety impact of exposure to the radio waves generated by readers are likely to be raised. There is currently no evidence of potential harm to human health, but just as with exposure to mobile telephone radiation, it is important to continue to improve understanding in this area.
- Criminal activity – As technology develops, there is a trend away from physical operations and processes to electronic ones. One downside of this is that these operations and processes may become more open to abuse in certain respects. One example is the proliferation of unwanted ‘spam’ email and computer viruses, which are transmitted relatively easily and cheaply through the electronic media that have replaced the physical communications mechanisms of previous generations. Similarly, it is possible to imagine scenarios where the electronic systems that rely on RFID generated information to manage company operations may be abused to the detriment of that company. This might be due to malicious computer network traffic, or it could be due to intentional manipulation of the radio spectrum that prevents RFID information from being collected or even generates misleading RFID information [18].

Such criminal activities might be motivated by an intellectual challenge (as with many computer viruses), by commercial gain or by terrorism.

- The cost of RFID components – RFID tags and readers will most likely continue to fall as the technology and the associated production processes improve. However, in the near term, costs are likely to limit adoption of the technology to the tagging of more expensive objects, such as pallets and cases of goods and higher-value items such as consumer electronics devices.
- The cost of integration – In addition to the direct deployment costs of RFID technology, there will be a big cost associated with IT systems integration. As indicated above, traditional IT systems are not designed to deal with the real-time generation of item-level information, and adding this capability will be costly.

5. Conclusion

This report has described the fundamentals of operation of radio frequency identification technology and the application areas in which such systems have traditionally been used. As the sophistication of the technology increases, and the component costs drop, there will clearly be an increasing number of application areas in which the technology is cost-effective. Additionally, the standardisation of a number of aspects of RFID implementation means that systems deployed in different industries and by different companies will be interoperable, which further increases the cost-effectiveness of RFID deployment because the same infrastructure can be shared.

The most immediate expansion of RFID deployment is likely to be in the consumer packaged goods supply chain, so that product manufacturers, logistics companies and retailers can monitor the movement of goods much more accurately. By doing this, they hope to reduce shrinkage, mis-deliveries, diversion of goods and so on. The largest supermarket chain in the world, Wal-Mart are actively moving to RFID for this application on a very aggressive timescale, and are therefore driving their suppliers to adopt the technology too. Other retailers and also government organisations are also moving in this direction that will again drive adoption of RFID in the CPG supply chain.

Recent and planned legislative changes in a number of areas are likely to further drive adoption of RFID technology – either because the use of this specific technology is mandated or recommended, or because RFID is simply the most cost-effective way to comply with the new legislation. Whilst there are factors that may act to slow the technology adoption, such as the concerns of consumers or the cost of systems integration, it currently looks like there will be a significant adoption in certain application areas in the relatively near term.

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