2. RFID TECHNOLOGY IN DETAIL

The radio frequency part of RFID is the communication medium between tags and readers. With passive RFID tags, radio frequency is also used to deliver power to the tag, as they do not have on-board power systems.

RFID systems are designed to be asymmetric: readers are expensive and power hungry, whilst tags are cheap and require comparatively low levels of energy. In addition, there are three key elements that need to be borne in mind in any discussion of RFID systems: energy source (which determines if a tag is passive or active), frequency and memory.

2.1 Energy Source: Passive or active?

RFID tags come in a variety of different types according to their functionality, and these types have been defined in an RFID Class Structure by the Auto-ID Center (and later through EPC Global) (Engels and Sarma, 2005), which has been subsequently refined and built on. The basic structure defines five classes in ascending order as follows:

Table 1: RFID class structure.

Class	*Class Layer Name*	*Functionality*
1	Identity Tags	Purely passive, identification tags
2	Higher Functionality Tags	Purely passive, identification + some additional functionality (e.g. read/write memory)
3	Semi-Passive Tags	Addition of on-board battery power
4	Active *'ad hoc'* Tags	Communication with other active tags
5	Reader Tags	Able to provide power for and communicate with other tags i.e. can act as a reader, transmitting and receiving radio waves

It is worth noting that the nomenclature for the classes has changed over time (RFID Journal, 2006) and older documents and specifications also refer to a Class 0 tag. This is a simple, passive tag which has had its ID programmed in *at the time of manufacture*. A Class 1 device (under this older scheme) is the same as a Class 0, but it can have its ID programmed into the tag at a later date, *after* manufacture. Both of these tags are read-only, in the sense that the ID can only be programmed in once. Later specifications work by EPC Global has clarified this by merging Class 0 and Class 1 into a new superseding Class 1 (Traub et al., 2005). However, there is still a considerable body of literature, specification documentation and manufacturer's material that refers to Class 0 tags and some tag manufacturers still offer a Class 0+ in which the ID is added at manufacture but can be altered later. For the purpose of this report we will consider Class 0 as absorbed into Class 1. It should be noted that Class 1 to 5 terminology is only used by EPC Global, and is not generic to RFID.

Each successive class builds on functionality provided by the lower layers and in order to understand how this works it is helpful to look at what is meant by passive, semi-passive, and active. i.e. the use of harvested (or what is sometimes termed 'reflected') power and on-board power sources (Cheekiralla and Engels, 2005).

- *Passive Tag Systems* do not have an on-board power source so they have to 'scavenge' power from the reader in order to run the digital logic on the chip and issue a response to the reader. They can therefore only operate in the presence of a reader. The communication range is limited by the need for the reader to generate very strong signals to power the tag, which therefore limits the reader-to-tag range. In addition, the small amount of energy that the tag is able to harvest in order to power its response to the reader, means that the tag-to-reader range is also limited (to around four or five metres in UHF). However, as passive tags do not require a continuous power source they have a much longer lifecycle, and because of their minimal on-board circuitry they are much cheaper to produce. This means that passive RFID tags are more suitable for tagging individual product items for applications such as supermarket checkouts and smart cards.

- *Semi-passive Tag Systems* require the tag to use battery power for the digital logic on the chip, but still use harvested power for communication. Semi-passive tags are far more reliable and have greater read ranges than purely passive tags, but they also have shorter lives (due to their reliance on battery power), are more fragile, and are significantly more expensive.

- *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). Read range increases (up to several kilometres) and reliability improves; 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. Active tags can also be equipped with built-in sensors e.g. for monitoring temperature control and reporting unacceptable fluctuations on refrigerated products whilst in transit, although this does increase the cost even more – to over £55 (around $100 or €80) per tag (IDTechEx, 2005). They also have a much larger memory than passive tags and, due to their higher processing capabilities, are also more secure.

2.2 Frequency

RFID is fundamentally based on wireless communication, making use of radio waves, which form part of the electromagnetic spectrum (i.e. frequencies from 300kHz to 3 GHz). It is not unlike two other wireless technologies, WiFi and Bluetooth. The three technologies are all designed for very different uses and therefore have different functionalities but there is shared ground between the three, with some hybrids starting to appear. RFID systems can utilise both WiFi and Bluetooth and need not see them as competitors.

RFID operates in unlicensed spectrum space, sometimes referred to as ISM (Industrial, Scientific and Medical) but the exact frequencies that constitute ISM may vary depending on the regulations in different countries[3]. These operating frequencies are generally considered to be organized into four main frequency bands and the table shows these different radio wave bands and the more common frequencies used for RFID systems (IEE, 2005).

Table 2: RFID operating frequencies and associated characteristics.

Band	LF Low frequency	HF High frequency	UHF Ultra high frequency	Microwave
Frequency	30–300kHz	3–30MHz	300 MHz–3GHz	2–30 GHz
Typical RFID Frequencies	125–134 kHz	13.56 MHz	433 MHz or 865 – 956MHz 2.45 GHz	2.45 GHz
Approximate read range	less than 0.5 metre	Up to 1.5 metres	433 MHz = up to 100 metres 865-956 MHz = 0.5 to 5 metres	Up to 10m
Typical data transfer rate	less than 1 kilobit per second (kbit/s)	Approximately 25 kbit/s	433–956 = 30 kbit/s 2.45 =100 kbit/s	Up to 100 kbit/s
Characteristics	Short-range, low data transfer rate, penetrates water but not metal.	Higher ranges, reasonable data rate (similar to GSM phone), penetrates water but not metal.	Long ranges, high data transfer rate, concurrent read of <100 items, cannot penetrate water or metals	Long range, high data transfer rate, cannot penetrate water or metal
Typical use	Animal ID Car immobiliser	Smart Labels Contact-less travel cards Access & Security	Specialist animal tracking Logistics	Moving vehicle toll

N.B. Within a given frequency band the actual, real-world communication range will vary widely depending on factors such as the operating environment, the detail of the antenna design and the available system power (Dressen, 2004; Paret, 2005).

[3] Due to the value of communication in the EM spectrum, most of it is controlled by both national and international regulation. In Europe, RFID is the driver behind a re-think of EM spectrum regulation (European Commission, 2006) but it seems unlikely in the current climate that this will be replicated at a global level. It is therefore important that RFID systems and applications allow for multiple frequency tags and readers.

There are two types of RFID system, each using different physical properties to enable communication between the reader and the tag (Thompson, 2006). The physics employed can become complex, but it is important to realize that it partly determines the operating range of the systems. RFID systems based on LF and HF frequencies make use of **near field** communication and the physical property of *inductive coupling* from a magnetic field. The reader creates a magnetic field between the reader and the tag and this induces an electric current in the tag's antenna, which is used to power the integrated circuit and obtain the ID. The ID is communicated back to the reader by varying the load on the antenna's coil which changes the current drawn on the reader's communication coil; further detail of the physics of the operation can be found in ACM Queue's RFID special edition (Want, 2004). RFID systems based on UHF and higher frequencies use **far field** communication and the physical property of *backscattering* or 'reflected' power. Far field communication is based on electric radio waves: the reader sends a continuous base signal frequency that is reflected back by the tag's antenna. During the process, the tag encodes the signal to be reflected with the information from the tag (the ID) using a technique called modulation (i.e. shifting the amplitude or phase of the waves returned).

2.3 Memory

Tags come in a variety of forms with varying types of on-chip memory capability. Tags can be read-only (the unique ID code is permanently stored on the tag – also known as WORM: Write Once Read Many), read/write (allowing a user to change the ID and add additional data to the tag's memory), or they can be a combination, with a permanent tag ID and some storage space for the user's data.

Passive tags typically have anywhere from 64 bits to 1 kilobyte of non-volatile memory. Active tags tend to have larger memories with a range of, typically, between 16 bytes and 128 kilobytes (Dressen, 2004; Zebra website[4]).

2.4 Standards

The number and use of standards within RFID and its associated industries is quite complex, involves a number of bodies and is in a process of development[5]. Standards have been produced to cover four key areas of RFID application and use: air interface standards[6] (for basic tag-to-reader data communication), data content and encoding (numbering schemes), conformance (testing of RFID systems) and interoperability between applications and RFID systems (RFID Journal, 2006).

There are several standards bodies involved in the development and definition of RFID technologies including:

- International Organisation of Standardisation (ISO)

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[4] http://www.zebra.com/id/zebra/na/en/index/rfid/faqs/rfid_tag_characteristics.html

[5] A more detailed explanation of standards can be found at RFID Journal's website (www.rfidjournal.com)

[6] Air interface standards cover the Physical and Data Link layers of the basic OSI communications model (i.e. the lowest layers of a communications protocol)

- EPCglobal Inc™[7]
- European Telecommunications Standards Institute (ETSI)
- Federal Communications Commission (FCC)

2.4.1 Air interface (frequency) standards

RFID frequencies (as outlined in table 2) are governed by the ISO 18000–RFID Air Interface family of standards, and a complete set of standards was released in September 2004:

ISO 18000-1 – Generic Parameters for the Air Interface for Globally Accepted Frequencies
ISO 18000-2 – for frequencies below 135 kHz
ISO 18000-3 – for 13.56 MHz
ISO 18000-4 – for 2.45 GHz
ISO 18000-6 – for 860 to 960 MHz
ISO 18000-7 – for 433 MHz

There are also earlier standards relating to, for example, cattle tracking systems (ISO 11785), tag-based payment "proximity" cards (ISO 14443) and electronic toll collection "vicinity" cards (ISO 15693). ISO 14443 and ISO 15693 both operate at 13.56MHz (HF), but the first standard has a read range of about 10cm whereas the later has a read range of 1 to 1.5 metres.

The situation regarding frequencies is somewhat confused by the introduction, by EPC Global, of a separate air interface standard for UHF frequencies (covered by ISO 18000-6) for their early class 0 and class 1 tags. These tags are not interoperable with each other, nor are they compatible with ISO's air interface standards (RFID Journal, 2006). EPC Global has subsequently developed a second generation of protocols (GEN 2) that merge the old Class 0 and Class 1 passive tags and should be more closely aligned with the ISO, although disagreements remain between the two organisations at the time of writing. Obviously, supply chain managers and equipment vendors would like to see an agreed, international standard.

2.4.2 Data content and encoding

As supply chains involve moving goods between large numbers of disparate organisations and locations, there is a requirement for all parties involved to use a standardised form for the identification of products. The Auto-ID Center at MIT was responsible for much of the development of recent RFID technology and standards work, particularly around supply chain management. Some of this work has now been transferred to the EPC Global[8] organisation (as the Auto-ID Center closed in October 2003, although some of the more research-based work is continued through a network of Auto-ID labs in universities across the world[9]).

EPC Global has defined standards for a range of features of global RFID systems

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[7] EPCglobal describes itself as a neutral, consensus-based, not-for-profit standards organisation which is owned jointly by GS1 and GS1 USA (two members-based organisations for the supply chain industry)
[8] http://www.epcglobalinc.org/
[9] http://www.autoidlabs.org/

including unique identification system protocols (the Electronic Product Code, or EPC™) for tag to reader communication, specification of middleware systems to handle EPC codes, a mark-up language (Physical Mark Up Language) and the Object Naming Service (ONS)[10]. These are described in detail below:

2.4.2.1 Electronic Product Code

A crucial component in the development of RFID was the introduction of the Electronic Product Code (EPC™). In short, this is the unique code number that is embedded into the RFID tag's memory. It is a generic, universal numbering scheme for physical objects, similar in scope to the barcode numbering scheme (UPC). However, there is one fundamental difference between the EPC and the UPC: the EPC has the capability to identify every single, individual product item. Whereas the barcode on a tin of baked beans will provide a codification for the manufacturer and the product (e.g. a 12 oz tin of beans), it does not provide for identifying a *particular* tin of beans. The Auto-ID Center's numbering system provides much greater scope for identification than barcodes, and consists of a 96-bit number, structured as follows:

01.	0000A89.	00016F.	000247DC0
Header 8 bits	EPC Manager 28 bits	Object Class 24 bits	Serial Number 36 bits

It is in fact not a single numbering system, but a "federation" of several naming structures (Traub et al., 2005). The Header bits define which of several coding schemes is in operation with the remaining bits providing the actual product code. The scheme is designed, in part, to accommodate existing global numbering systems such as the Global Trade Identification Number (GTIN), Serial Shipping Container Code (SSCC), and the Global Location Number (GLN). The Manager number identifies the company involved in the production of the item (manufacturer) and the object class defines the product itself. The Serial number is unique (within the scope of the other numbers) for an individual product entity. The 96-bit code can thus provide unique identifiers for 268 million companies (2^{28}). Each manufacturer can have 16 million (2^{24}) object classes and 68 billion serial numbers (2^{36}) in each class (Moroz, 2004).

2.4.2.2 Alternatives to EPC: IPv6

Some researchers believe that the architecture of the Internet offers a clear series of principles for developing the new communication capability for individual physical items and devices.

IPv6 is a network layer standard that governs the addressing and routing of data packets through a network. It is a numbering scheme large enough to give 430 quintillion addresses for every square inch of the world's surface, in comparison to IPv4 (the current system), which has the capacity to support 4 billion addresses[11].

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[10] http://www.nje.ca/Index_RFIDStandards.htm

[11] http://en.wikipedia.org/wiki/Ipv6 [last accessed 10/04/06].

It has been suggested that IPv6 could be used in conjunction with RFID, leaving the EPC™ redundant, and the US Department of Defense has already mandated that its battlefield network should use IPv6 by the end of 2006 (RFID Journal, 2003). However, Daniel Engels of the Auto-ID Center (2002) believes that 'the requirement to interpret an IPv6 identifier as an address for IP communication prevents its use as a permanently assigned identifier on mobile objects' (p. 6). In addition, due to the development of standards and the fragmentation of the RFID market (in terms of both technologies and applications) it is unlikely that IPv6 currently holds a direct threat to the adoption of the EPC™.

2.4.3 ISO Testing and Conformance

Standards for testing the conformance of RFID equipment to the operating standards and for measuring the performance of equipment are covered by ISO 18047 and ISO 18046 respectively.

2.4.4 Interoperability between applications and RFID systems

The EPC Network Architecture

RFID tags and interrogators are rarely used in isolation; they form part of a supply chain, or a logistics, library or other system. The key concept is that the ID code embedded on an RFID tag can provide what database designers call a 'primary key' into a database of products. All additional data associated with that item can be stored in back-office databases and systems. The Auto-ID Center has developed an architectural overview and vision for the use of the EPC™ unique identifier in supply chain systems, known as the EPC Network Architecture. The architecture is layered, with tags and their associated readers operating at the bottom of an integrated system that is linked to database and manufacturers' back-office enterprise systems.

The exact operational details of this complex architecture are beyond the scope of this report, however, we will note of some key components and related standards. Those interested in a more detailed examination of the network architecture, see Synthesis, 2004.

Savant

Savant is the middleware software system that links reader devices and processes the information streams from tags. It acts as the gateway to the enterprise systems and database applications, providing filtering, aggregation and counting of tag-based data.

ONS

The Object Naming Service (ONS) is 'the 'glue' that links the EPC™ with the associated data file' (Brock, 2001, p.1). Working much like the current Domain Naming Service of the World Wide Web it provides a look-up table for translating a unique EPC code into a Uniform Reference Locator (potentially a webpage) where additional information can be stored. The ONS system is built on the same technology used in the Internet's Domain Name Service (DNS) (Brock, 2001).

Physical Mark Up Language

The Physical Markup Language (PML) is an XML-based common language designed to provide standardised vocabularies for describing a) physical objects, b) observations made by sensors and RFID readers about these objects and c) the observers (the sensors and readers) themselves and exchanging this data between entities operating within the EPC™ network architecture. PML uses the W3C XML Schema language (XSD) for its definition. Full details can be found in (Floerkemeier et al., 2003).

The difficulty in describing physical objects is acknowledged by the Auto-ID Center (Brock et al., 2001), but the intention of PML is to give a structure to agreed object characteristics such as volume, mass, temperature, owner, location etc.

3. RFID APPLICATIONS IN EDUCATION

It is clear that the majority of envisaged commercial applications for RFID revolve around improving the supply chain, stock control and logistics and that as consuming entities universities and colleges will increasingly be handling and working with physical equipment and resources that involve RFID labelling and tagging (for example, expensive medical equipment is beginning to be tagged in large hospitals to allow tracking and prevent loss). It should be noted that, although it is beyond the scope of this report, there are health and safety implications for workers using RFID equipment, especially those with active, implanted medical devices such as cardiac pacemakers (HSE, 2003). The EU Directive 2004/40/EC (due to be implemented from 2008) sets out to provide a minimum level of protection for workers, but its scope is limited (in terms of the health issues it covers) and its focus has changed since its original inception. These issues are complex and work is ongoing; interested readers should investigate the work of the Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR)[12] and EMF-NET[13], the EU's Co-ordination Action that aims to provide a framework for the co-ordination of the results of the research activities related to the biological effects of electromagnetic fields, including occupational exposure.

3.1 RFID in Libraries

For many years, libraries have used a combination of technologies to reduce the likelihood of theft, improve stocktaking, and speed up issue and return procedures. The advantage of using RFID is that it is capable of incorporating and improving upon existing systems within one technology. For example an RFID reader does not need a direct line of sight, which means that books do not have to be tipped out or even pulled out completely as with barcode scanners, so inventory checking is faster and can be done more frequently. Also, RFID tags do not need to be read individually as barcodes do as RFID scanners can read stacks of books at a time, saving time, and potentially reducing health problems caused by RSI. Other benefits of RFID include simplified and faster issuing of books, self-return (the 'ATM approach' to returning books), and rapid location checking of books (Gilbert, 2004b).

There are two main types of system that can be used in libraries, both of which involve each book being tagged with an RFID chip which either contains bibliographic data (bibliographic method) or a simple reference to detailed bibliographic information held off-chip in the library databases ('name plate' or 'licence plate' systems). At the moment, the bibliographic system is not used very much in the UK, although there are discussions taking place around possible data objects for encoding selected bibliographic data within library tags (Praxis, 2006). These systems allow a self-checkout process when books are borrowed: as the books pass a special RFID reader at the check-out desk the tag is scanned and the item is recorded as borrowed by the identified student or staff member. Apart from being faster, this system also frees up library and information staff from carrying out more mundane checkout tasks.

[12] http://europa.eu.int/comm/health/ph_risk/committees/04_scenihr/docs/scenihr_q_005.pdf
[13] http://www.jrc.cec.eu.int/emf-net/index.cfm

So libraries have become early adopters of RFID, and in the US more than 300 public and college libraries have adopted RFID (Gilbert, 2004b). In fact, library implementations are important test-beds for the technology. They have discovered that the 'tuning' of the RFID interrogator's detection field can be critical in a system's security as leaving tagged items in close proximity to an issue/return station can result in them being discharged or issued unintentionally; in some instances, incorrect tuning of the detection field also meant that it was possible to evade the field completely (Marsterson, 2006).

There is also a strong economic argument in favour of tagging valuable items such as library books. To date, uptake of RFID in general has been limited because even passive tags are still relatively expensive to produce (around 27 pence or 50 American cents, although this is continually reducing), so it makes no economic sense to tag inexpensive items (such as individual tins of baked beans). Within libraries, where individual books and journals can be worth hundreds of pounds, and will be borrowed and returned hundreds of time, the one-off cost of a tag is more than off-set by cost savings and efficiency gains.

In the UK, Glasgow University Library was the first university library to install RFID (in 2002) and has been joined subsequently by a small number of university libraries including Middlesex and Nottingham Trent University. Similar systems are also being introduced in public libraries such as Norwich, Essex, Haringey, Somerset and Sutton, and CILIP – the library professionals association - recently held their first major conference on the subject and have subsequently produced an RFID implementation checklist[14]. Standardisation work has also been strong in the library sector: in the UK the BIC/CILIP RFID in Libraries Committee has been working on possible data objects for library RFID systems and in Denmark, the national library authority developed a Working Group to bring together interested parties in the development of an RFID data model for libraries that has fed into the ISO TC46/sc4 work on the standardisation of protocols, schemas and related models and metadata.

This position as early adopters, who also have a considerable amount of group bargaining power and a strong interest in developing standards, puts libraries in an interesting position. It could be argued that libraries are uniquely placed to have a positive impact on the development of RFID technology and that this influence could extend beyond current efforts to develop interoperability and data standards, to addressing more general issues that are 'in the public good' such as privacy concerns (see section four). Issues such as whether or not RFID tags are implemented in students' library cards and the frequencies that RFID interrogators operate at (i.e. open or regulated) are simple, but important starting points. It should also be noted that Danish libraries are generally accepted to be at the forefront of library-based RFID development, and that JISC's collaboration with the Danish National Library Authority along with the recent instigation of the Knowledge Exchange provide a timely opportunity for international collaboration and good practice sharing.

[14] Available from BIC (Book Industry Communication) by e-mail: rfid (at) bic.org.uk.

3.2 Asset Location Management

Hospitals around the world are starting to use RFID tags to track and manage assets, particularly expensive or critical items of equipment such as ventilators, electrocardiogram devices and infusion pumps. These systems, known as Real Time Location Systems or Enterprise Asset Visibility systems, tag physical items of equipment and make them 'visible' to hospital managers via the hospital's WiFi network. This means that hospital staff can always locate valuable or important equipment very quickly, which increases efficiency (one hospital in America estimates savings of nearly 8,000 minutes per month) and can even save lives (Wexler, 2005). Such systems may well be introduced into UK university medical schools and the same technology could be used for tracking highly mobile equipment (such as laptops, projectors, research monitoring equipment etc.) within UK academic environments.

The use of RFID technology is also starting to have implications for document tracking and business process workflows, an important issue in college and university administration departments and for registrar activities (e.g. tracking of completed exam papers). RFID tags in the form of labels that can be written on can be attached to paper documents. The tag's unique ID can be scanned by readers as the document passes through the administration system. By referring the tag ID back to a database of other information such as the document's history and expiration date, the document's status can be tracked. As readers can then obtain information from the label without line of sight scanning it would be easy to locate a mis-placed document simply by scanning a shelf of papers and books, and this would be particularly useful for university paper archiving systems.

3.3 People tracking and tagging

There could be a number of applications for RFID within education related to security and the identification of staff and students, but this, of course, is controversial as there are serious concerns over privacy. RFID technology can be used for the identification and location tracking of a person carrying the tag (which can be embedded into an identification card) and can be used to verify a person's right to enter a particular building or even to access a service. For example, in the US, RFID-enabled cards are used to automatically register students at lectures, and in China, nearly 3,000 universities have installed RFID tag readers, for use with RFID-enabled student identification cards, contactless library applications, and to reduce train travel fraud (Collins, 2003).

Subcutaneous RFID tags, about the size of a grain of rice, have also been approved for use by the US Food and Drug Administration (Gilbert, 2004a). The tags are injected into the fatty tissue of the arm and provide an ID that can be linked to a patient's hospital records.

3.4 Intelligent Buildings and disabled access

RFID tags are being increasingly used as one tool in the development of a more user-focused experience for visitors to museums, galleries and similar spaces. For example, at the Exploratorium, a science museum in San Francisco, visitors wear an

RFID-enabled card through which they interact with networked RFID readers, which are mounted on museum exhibits. The exhibits are hands-on experiments which visitors take part in (for example, a heat camera that shows a thermal image of the body). As the visitor takes part in an exhibit experiment their RFID tag is read and this triggers a camera to record the experiment. The results of these experiments are automatically uploaded to a personalised webpage for the visitor, which provides a record of their visit (His and Fait, 2005). Museums and galleries have also used RFID tracking when moving art works and other expensive pieces (Katz, 2005).

Researchers at the University of Florida are developing a system to help blind students make their way around campus. The Drishti project makes use of various technologies including an information 'grid' based on passive, low-cost, high frequency RFID tags installed under the flooring which is used to convey precise location and detailed attributes about the surrounding areas. RFID tags are placed along corridors, inside rooms and even outside, and store information about their immediate surroundings. An RFID reader is incorporated into a walking cane and shoe and uses sound to deliver directions (Willis and Helal, 2005).

3.5 Research applications – Equipment and Activities

Research Equipment

Products are becoming available that incorporate RFID into laboratory equipment for research and medical work. The use of RFID tagging on, for example, test tubes, is designed to reduce human error. In addition, processes are much faster because RFID tags can be read in large quantities and data can be synchronised with client databases.

Research activities

RFID tagging is being increasingly used as a research tool in experiments and investigations. This is particularly true in biology and ecological studies where tagging of wildlife and monitoring of feeding and migration has been carried out for some years using forms of remotely monitored tag[15]. One example of this type of use is Digital Angel's RFID system in Colombia, Ohio (USA) to monitor the movement of salmon within the river system and at dams[16].

In addition, RFID tags with in-built temperature monitoring systems have recently been proposed for monitoring the health of large numbers of farm poultry with a view to early detection of avian flu symptoms (Using RFID, 2005). A handheld RFID reader can take in the ID and temperature of large numbers of birds at a very fast rate.

A number of research projects are also being undertaken within computer science and healthcare that explore the activities of daily living in order to infer information about daily human activity through monitoring the objects that people make contact with and handle. Within community medicine this enables homes to be more 'helpful' to individuals by, for example, providing enhanced facilities for the elderly that allow them to remain in their own homes (Philipose et al., 2004).

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15 http://www.biomark.com/
16 http://www.digitalangelcorp.com/about_pressreleases.asp?RELEASE_ID=211

3.6 RFID in new Learning Environments

RFID tags are an increasingly important component in the toolkits that are being developed for exploring new learning environments through the use of gaming, location-based services, tangible interfaces and augmented reality (see Benford (2005) and O'Malley and Stanton (2005) for a general overview, and the NESTA Teaching with Games project http://www.futurelab.org.uk/research/teachingwithgames.htm for specific insight into the ways in which commercial games might be implemented in a formal educational setting). In these types of contexts, children or students enter the RFID-enabled environment with RFID reader devices and interrogate RFID-enabled 'objects' (physical entities in the environment such as toys, the flash cards used in games etc.) in order to control the flow of events and initiate their own access to information. In this way, RFID tags are used as a way of embedding user control within learning and gaming environments.

Although to date these environments have been explored in the context of younger, school-aged children it is likely that more sophisticated versions of such environments will be introduced into Higher and Further education in coming years. These new learning environments are providing important test-beds for developing these ideas within an educational context.

4. SOCIO-CULTURAL IMPLICATIONS

4.1 RFID and privacy

The introduction of RFID tags, particularly into the consumer supply chain, has not been without controversy, although the US has borne the brunt of this so far. There has been considerable concern about the implications for individual privacy, especially with the recent publication, by the IEEE, of a paper concerning RFID viruses (Rieback et al., 2006). As it is likely that HE and FE will increasingly be using RFID in libraries, administration and research it is worth being aware of the nature of the controversy and some of the implications.

Most of the concerns stem from the fact that once individuals move around in a world of widespread tagging, the products they buy, wear and consume will be capable of being identified and recorded by a widespread network of readers. Such information could provide a great deal of intelligence on a person, their habits, likes and dislikes and movements. In essence this is an aspect of a person's individuality and the right to privacy should be paramount. The argument is that by mining the data about the position and movement of 'things' one can obtain information about people, forming knowledge from 'the collection of diverse data from everyday life' (Hennig et al., 2004, page 5).

In the case of passive tags, a signal from an RFID reader causes the tag to beam back its unique ID along with any other information it has been programmed to relay. In this scenario there are two types of potential privacy infringements that could take place. Firstly, bearing in mind that the transponder and interrogator are connected to an 'intelligent' back-end system that stores information related to the unique ID, there is the potential for privacy infringement or identity theft either through poor information management, poor system security, or virus attack. The second type of infringement is related to the nature of the 'other information' that is programmed into the tag. As an example, the use of bibliographic tags within library RFID systems, whilst useful to libraries because they help to alleviate potential vendor lock-in and facilitate services such as inter-library loans, have been the subject of concern by privacy activists since by programming bibliographic information onto the tag, there is the potential for a privacy infringement from non-library interrogators. Bearing in mind that RFID readers are now starting to appear in mobile phones, it is possible for a borrower's books to be interrogated whilst still in their bag or rucksack (although the interrogator would have to be very close – say on a crowded tube train). The owner of the RFID interrogator would then be privy to information about the library user's reading habits, which, in itself, would be a breach of the library user's privacy. However, the concern is that information gleaned from this type of privacy attack may then be used more widely for impersonation or identity theft.

4.1.1 RFID and the surveillance society

Within consumer scenarios, concerns have been raised about the capability to use RFID to track a customer's movement around a shop. This concept is not a new one for consumers, as most people are familiar with CCTV tracking, but RFID tracking logs are significantly smaller than CCTV output and are machine-processable

(Engberg et al., 2004). To some people this may in itself be considered an invasion of privacy, but additional problems occur when shops keep persistent records that are traceable to identifiable customers. This problem is compounded when, for example, the RFID tag's unique ID can be obtained by any reader and that reader can also connect to the back-end RFID infrastructure (either through legal or illegal means), linking the unique ID to detailed tag information and even the purchase transaction.

Some authors have argued that these problems are issues of RFID system security: if RFID systems were better designed, and had security at the heart of the design, then these kinds of privacy invasion would not be possible (Engberg et al., 2004). However, this assumes that there is a sufficiently robust legal system in place to redress the issue of people or organisations that do not deploy these 'secure' tags, and further, that the victim of the privacy invasion or identity theft is aware of when an 'illegal' RFID-enabled transaction is taking place. This means that ordinary consumers would need to be aware of issues such as when data collection is taking place, the potential use this data may be put to, and the potential consequences of both of these.

An example used by anti-RFID campaigners provides a case in point for some of these issues. In Germany, the METRO Extra Future Store was set up as a test-bed for new 'intelligent' technologies, including a small selection of RFID-tagged items (Weber, 2004). Without going into a detailed description of what the campaigners found[17] it appears that there were significant breaches of policy, resulting in 'hidden' tagging of customers through the shop's loyalty card. In addition, the shop's deactivation technology, designed to disable the passive RFID tags attached to individual items, was not completely successful, leading to some tags remaining 'live' even after customers had left the shop. Activists point to a scenario where a passive RFID tag, embedded in a new shoe, could be providing information to tag readers wherever the person walks: this information could then be combined to form a picture of a person's movements.

These examples demonstrate several factors that can be extrapolated to give a more conceptual picture of the potential for privacy invasion: the ubiquity of RFID readers and tags and the fact that they can be hidden; the linking of a unique ID to other information contained in a database or other storage system; security and privacy risks that are created either maliciously or through neglect.

4.2 Approaches to Privacy Protection

In a consumer scenario the most obvious solution to the RFID privacy problem is to disable the tag at the point of sale. However, this is meaningless if the deactivation system is not completely reliable. Also, while it may be appropriate to disable some tags at the point of sale, other tags, e.g. passive tags in library books or active tags used in road toll systems have to remain 'live' while in the possession of the customer.

Disabling RFID tags in consumer environments at the point of sale also means that the tag cannot be used by consumers as an enabling technology for ambient intelligence applications, for example, in advanced recycling applications where the

[17] more information can be obtained from the Spychips website: http://www.spychips.com/metro/scandal-payback.html

tag's unique ID could be used to automatically sort recyclable material and could also be used to levy waste charges on the manufacturer based on the nature and volume of rubbish collected. Passive RFID tags used in consumer environments could also be used to deliver after sales services for product service records or to provide warranties.

In order to try to address these issues there have been proposals for 'secure' tags equipped with 'handover protocols' to facilitate the transfer of ownership of the unique ID (so that different sets of readers would be able to read the tag at certain points in time) and systems that support 'multiple authorisations', where readers belonging to several authorised 'actors' may be able to read the tag at the same point in time (e.g. the consumer and the after sales service provider may both access the tag while the product is under warranty). However, it should be noted that solutions based on consumer consent offer no guarantee of privacy protection and may turn into some sort of advanced blackmail, where consumers have the impossible choice of not getting a service (e.g. warranty protection) unless they agree to the collection of personally identifiable information (Engberg et al., 2004). In addition, these types of advanced systems assume that the owner is capable of managing the technology and actually 'trusts' it to work as described.

4.3 Trusted computing, beta culture and the DIY culture

In order for RFID to be widely adopted it needs to be accepted as credible and trustworthy. This is an area of computing that is growing in importance, especially in a world where the speed of technological innovation and route to market of new technology products is challenging the historical view of computers as being highly credible (Fogg, 2003). Part of the reason why RFID is perceived as not being trustworthy is due to a lack of belief, on the part of the consumer, in their ability to have any control over the technology. Whatever the truth may be about the actual control they can exercise over the technology, their perception is that they in fact have very little control, and that is why it is not seen as either credible or trustworthy.

Other developments, such as releasing software products 'in beta' are also acting to further undermine the trustworthiness of computers. This is often regarded as a 'new model for how software companies can get new products or features out into the marketplace quickly, then improve them as they're used' (Carr, 2006) but it is also (cynically) seen as a way of potentially avoiding lawsuits or as a lazy approach to product development.

As a response to this, increasing numbers of technology consumers who have grown up with digital technologies and who are not afraid of taking them apart are modifying or 'modding' them to their own requirements. Web-based magazines such as Makezine.com and Zapped! (www.zapped-it.net) explain how to create RFID-enabled front doors and RFID blockers, and report on keyring devices for detecting nearby RFID readers. In addition, sites such as RFDump (www.rf-dump.org) have developed tools designed to demonstrate the vulnerability of RFID readers and the data they process, whilst in Korea, people have been melting the plastic cover of smart cards in order to retrieve the RFID chip inside in order to incorporate it into their portable gadgets or handbags (Jin-seo, 2005). It is important to note that many of these activities stem from the view of RFID as a 'participatory' technology and that in the future this 'can do' group of technologically savvy people may be able to address their privacy concerns directly by taking matters into their own hands.

4.4 Privacy legislation and regulation

These issues have not gone unnoticed. In 2004 the National Consumer Council held a summit in the UK driven by the feeling that 'this technology is being developed and implemented without the knowledge or participation of consumers more widely' (Lace, 2004, p. 1). There were a number of recommendations from the summit, including:

- Review data protection laws and regulations
- Fund further research into consumer's perceptions of RFID technology
- Improve dialogue with consumers over the benefits and risks of RFID
- Explore these issues in the wider context of the information society and the increasing amount of data gathered on individual consumer's behaviour
- Build privacy protection into the technology

Similarly, in the US, the National Research Council's Committee on Radio Identification Frequencies Technologies held a workshop that observed that:

> 'on the consumer and regulatory side, there are many concerns and unanswered questions about the technology—for example, what are the ramifications for personal privacy of embedding RFID tags in consumer products? Indeed, more than one company has had to change or rethink its plans for RFID technology because of the concerns of consumers and privacy advocates about how the technology would be used.'
>
> (NAP, 2004, page vii).

Closer to home, the European Commission has just launched a public consultation on RFID, following on from the RFID inter-service group established last year to co-ordinate the gathering, analysis and internal dissemination of information concerning RFID technology and its uses. Outputs from the public consultation will be published as an online consultation document in September 2006 before the preparation of a Commission Communication on RFID, which is expected to be adopted before the end of the year. The Communication will also address the need for other legislative measures for RFID, such as decisions on allocation of spectrum and could lead to amendments of the e-privacy-Directive, which is up for review (European Commission, 2006).

The Commission is also planning to support, in the forthcoming Seventh Framework Programme for Research and Technological Development, technology and innovative applications that bring us a step closer to the 'Ambient Intelligent Society'.

There is no doubt that there are serious issues that will have to be dealt with seriously. Technologists, proponents of RFID and privacy experts are beginning to debate and address the issues raised by consumer groups, civil liberties groups etc. The issues that are engaging these groups include debating what privacy means in a technologically rich world, developing models of privacy threat, how to determine whether a proposed technology can be adjusted in order to meet concerns and detailed technical solutions to situations.

5. THE IMMEDIATE FUTURE: THE FIVE-CENT TAG

The potential of RFID ubiquity through item level tagging has hinged around some technical and economic challenges. For global RFID adoption, systems will have to be interoperable (therefore reliant on protocol standards) and economically viable. In 1995 Noel Eberhardt (Motorola) and Neil Gershenfeld (MIT Media Lab) started collaborating in order to achieve a cost effective design for an RF tag, where the goal was to design the 'penny tag' (i.e. one American cent) (Schmidt, 2001). Eleven years later the industry is still struggling with the technical challenges this problem presents. In recent years, the goal has been set a little lower – the hunt for the 5¢ tag is on.

Whenever the 5¢ tag is achieved, it is important to understand the most likely characteristics and functionalities of the tag. In short, the tag will need to be passive (manufacturing and component costs means active and semi-passive tags are unviable), with low memory (in the region of 64 bits - smaller memory means less silicon and therefore lower costs) and no re-write functionality.

6. THE FUTURE AND THE BIGGER PICTURE: TOWARDS AN INTERNET OF THINGS

> *"Conceptualizing them simply as ID tags greatly underestimates their capabilities, considering some have local computing power, persistent storage, and communication capabilities"*
>
> Vince Stanford, 2003, p. 9.

RFID systems are part of a bigger picture and are potentially a key stepping-stone in the development towards the vision of ubiquitous computing. In the ubiquitous (ubicomp) or pervasive computer vision there will be a multitude of computationally capable, small - sometimes invisible to the human eye - devices that will be scattered throughout our environments, operating silently and largely unseen as they go about their individual tasks to support our daily activities. This will be a device-centric future with highly distributed network control.

In a step-change that will be orders of magnitude greater when compared to today's computing power, a bewildering population of heterogeneous sensors, computers and actuators will be operating. Often, these devices will operate with self-awareness (being 'conscious' for example, of their physical location and their immediate surroundings) and be widely networked together. In order to realise this vision a comprehensive jigsaw of technological 'pieces' needs to come together and converge as technology develops over the next few years. The RFID piece of the jigsaw is the ability for individual (physical) items to be able to identify themselves to the network.

A key concept in this development trajectory is the **Internet of Things**. A term first coined by RFID developers in the Auto-ID Center in the late 1990s, it is also sometimes referred to as the Product Internet, T2T (Thing to Thing) network, or the M2M (Machine to Machine) network. In this vision, increasingly large numbers of our everyday objects and gadgets will have some kind of simple communication technology embedded into them, allowing them to be connected to each other within local networks and, ultimately, connected to the wider network of networks – the Internet. In a sense this is a process of extending the Internet beyond computational devices down to a lower layer in the hierarchy of machines – to that of simpler devices and individual items (Krikorian and Gershenfeld, 2004). In order to facilitate this process, three areas need to be developed. Firstly, each of these items must be able to *identify* itself to other items and to the network in general. This is provided for by the introduction and development of RFID technology. Secondly, these items should include some element of embedded computational power in order to act with some level of 'intelligence'. Thirdly, they will need to have some sense of their physical environment and geographical location. Continuing developments in computational science and electronics, particularly work on miniaturisation, tiny operating systems and wireless communication will make this vision increasingly realistic (International Telecommunication Union, 2005). The basic RFID system of transponder and interrogator is an important starting point in the process.

6.1 From identification to Wireless Sensor Networks

At the lower (passive) end of RFID technology the systems simply provide a tag that can remotely identify an object by returning an ID when interrogated over short ranges. As RFID systems are introduced and find acceptance in business and other environments the functionality provided by these low cost tags will be increasingly seen as insufficient as new applications are developed (Engels and Sarma, 2005). There is likely to be a natural progression for RFID that includes the widespread incorporation of sensor functionality (Jarosik, 2005). Such devices will be able to make measurements concerning their surroundings and physical location about such variables as pressure, temperature, flow rate, speed, vibrations etc. (Allan, 2005). They will be networked either through RF technologies or through other wireless communications systems and these developments are often referred to as sensor nets, integrated on-chip radios, or wireless networked sensors (WNS). These types of networked, RFID-enabled objects will become similar to what Bruce Sterling (2004) calls 'spimes'. They will have histories (e.g. every time they are accessed they will record the details of that access), they will be 'precisely located in space and time' and they will become 'protagonists of a documented process' (Sterling, 2004).

These RFID-based sensors will need to communicate in order to participate in the network of things. However, other computational devices within the likely ubicomp jigsaw will not necessarily be using radio frequency for communication. Other protocols currently proposed or developed include ZigBee, Near Field Communication Technologies (NFC), Bluetooth and Wifi – all systems that offer local and personal area networks (LANs and PANs).

Zigbee is focused on individual devices (such as smoke alarms, lamps and consumer electronics) that need a robust, low bandwidth, low cost, low power, peer-to-peer communication. NFC is designed for very short-range communication (devices have to almost touch for the signalling systems to work). The applications being developed for NFC to date revolve around situations where it is intuitive for devices to touch in order to communicate e.g. allowing mobile phones to act as electronic tickets or electronic cash wallets when pressed against a suitable reader or kiosk device.

Some commentators see these developments as tending towards a form of ubiquitous wireless communications network which encompasses low-bandwidth systems such as RFID, computational and peripheral device networking through ZigBee, NFC and Bluetooth (e.g. digital cameras and printers), and higher bandwidth (telecommunication) devices through 4G cellular and WiMax (Cheekiralla and Engels, 2005).

6.2 Spatial identifiers – GPS

Such networking is part of a wider technological development as fixed networks move to wireless networks, *ad hoc* networks, and meshes (Mobile Ad-Hoc Networks, or MANETs). In the latter, mobile communicating devices form *ad hoc* networks (in a peer-to-peer fashion) with nearby devices to form meshes of communication that have varying topologies. The development of these kinds of networks will facilitate the increased use of spatial annotation (e.g. leaving personal messages or information within a given space). Most technological projects exploring spatial annotation use

GPS (Global Positioning System) and the use of RFID in conjunction with GPS could allow for another layer of context-specific information.

6.3 Miniaturization and motes

In the longer term, RFID tags (with some on-board computation) and wireless sensors might become so small as to be almost invisible, constituting a kind of 'smart-dust' (Rheingold, 2005). Research is being carried out into developing computational 'motes', which combine sensors, some element of communication (RF or optical) and the ability to float, even to fly. Such motes may be used in weather front analysis, or as remote sensors from dangerous environments (e.g. outer space, nuclear power plants, oceans etc.).

6.4 Technological implications – information overload

In an information-rich, digitally connected world, where much of the knowledge and tools that we make use of are outside our heads (our 'extelligence', see Stewart and Cohen, 1997) there will be a need to develop new communication 'senses' that allow us to manage and make use of the enormous amount of information we will be confronted by. This will lead to the development and adoption of new and different types of human-computer interfaces and different ways of communicating with technology.

Indeed, part of the ubicomp vision is of seamless interaction with devices, where computers become adaptive and perceptual in their interactions with users and the environment. In addition, communication between people and devices will become implicit (taking place incidentally, whilst the user is undertaking another task) and multi-modal (using all five of our senses). See, for example, The International Journal of Human-Computer Studies' special issue on information management (Zhang, 2005). In a ubiquitous computing environment, then, the user has to be not only textually, and visually literate, but also has to have 'corporal literacy', that is, an awareness of extelligence and a working knowledge of all the senses.

CONCLUSION

As a fledgling technology RFID is starting to make an impact on the core business of F&HE. Libraries are likely to initiate most of the activity over the next five years or so, but applications within administration and research are also likely to increase. It is, as yet, unclear to what extent RFID will impact on teaching and learning other than within specialist projects and it is probably more likely that these applications will develop alongside more general ubicomp developments.

RFID has the potential to be a hugely significant technology within the ubicomp vision. However, the benefits of a pervasive computing environment are unlikely to be realised unless the technology can be trusted. Where that trust does not yet exist, or is likely to be undermined by problems that may arise as the consequence of ill-considered or malicious implementation of parts of the technological 'jigsaw', the ubicomp vision will also be negatively affected. The F&HE community cannot rely on the relative ease with which RFID has so far been implemented in the UK – it is widely acknowledged that there are genuine concerns around the implementation of the technology and it would be wise for JISC to make good use of its position within the pan-European HE/ICT community to initiate a pro-active approach to developments that will impact positively on UK F&HE.

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Working Party on the Information Economy

RFID APPLICATIONS, IMPACTS AND COUNTRY INITIATIVES

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FOREWORD

This report was presented to the Working Party on the Information Economy at its meeting in December 2007 as part of its work for the 2008 Seoul Ministerial on *The Future of the Internet Economy.* It was recommended to be made public by the Committee for Information, Computer and Communications Policy in March 2008.

The report was prepared by Verena Weber, consultant, in conjunction with Graham Vickery, OECD Secretariat, as part of work on the economic and social impacts of ICTs and new technologies. It is published under the responsibility of the Secretary-General of the OECD.

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SUMMARY

Radio frequency identification (RFID) technology is currently one of the most promising and discussed auto-identification and data capture (AIDC) technologies. Although it is not a new technology, the range of applications is broadening rapidly and new applications which integrate other technologies such as sensors are developing. Eight major fields of application are analysed in this study, comprising: *i*) asset utilisation, where mobile assets are tagged for their use along the supply chain; *ii*) asset monitoring and maintenance, where mostly fixed and high value assets are tagged to store information, *e.g.* for maintenance purposes; *iii*) item flow control in processes, where RFID tags are attached to items which are moving along the supply chain; *iv*) inventory audit, for example in warehouses where pallets are tagged to improve the speed and efficiency of stock taking; *v*) theft control; *vi*) authentication to provide secure identification mechanisms for persons and objects; *vii*) payment systems to secure transactions; *viii*) automatic display of information where items are tagged to provide additional information on products and services when read.

It is difficult to quantify the impact of the technology, in part because most RFID applications are recent. Market analysis shows rapidly growing markets for RFID systems and, apart from very detailed mainly qualitative evaluations of particular applications, there are few aggregate impact studies. Available aggregate studies show large impacts in terms of benefit/cost ratios and productivity gains; however calculations are based largely on current good practice case studies, leading to a potential overestimation of aggregate benefits.

Country initiatives are divided into three main categories: *i)* the use of RFID by the public sector; *ii)* information, awareness and education programmes; and *iii)* incentives for business R&D and public funding of projects. The review of initiatives draws largely on replies to the *Information Technology Outlook 2008* policy questionnaire. This review suggests that government support for RFID technologies is focused on government applications for own use, often with a large demonstration component, and supporting multi-stakeholder projects to meet technological and industry needs, often to develop new technologies or applications. There are potentially large gains in innovation and efficiency from more widespread applications. Due to technological and business uncertainties education and awareness activities could be further emphasised, particularly for small businesses and more advanced applications where potential impacts are high, for example, those involving sensors.

INTRODUCTION

Radio frequency identification (RFID) technology is currently one of the most promising and discussed auto-identification and data capture (AIDC) technologies. It uses electromagnetic waves to transmit real-time data to identify specific objects (Garfinkel and Rosenberg 2005, p. xxvii). The technology is already in broad use in different fields of application such as toll collect systems, car keys and applications along the supply chain of companies.

There is high business and policy interest in this promising technology and the OECD has published a series of studies dedicated to RFID. The 2004 and 2006 editions of the *OECD Information Technology Outlook* as well as the Background report and Proceedings from the Foresight Forum on "Radio Frequency Identification (RFID) Applications and Public Policy Considerations" held in October 2005, give an introduction to the technology and its impacts. The Working Party on the Information Economy country study for Germany analyses in detail how companies use newer RFID applications along their supply chains [see "RFID implementation in Germany: Challenges and benefits", DSTI/ICCP/IE(2007)6/FINAL]. Studies by the Working Party on Information Security and Privacy summarised in "Radio Frequency Identification (RFID): A Focus on Security and Privacy" [DSTI/ICCP/REG(2007)9/FINAL] focus on trust-related challenges when deploying RFID systems.

Some of these studies briefly discuss possible roles of the public sector as well as touch on the economic impacts of the technology. As technological development has occurred at a rapid pace, estimates on the economic impact of the technology have varied and public sector projects have become more concrete. This document aims at addressing the following three questions:

What is the historical development of RFID technology and which fields of application in the public and private sector can be identified?

- What is the economic impact of RFID technology according to selected studies?
- What government RFID initiatives are there in OECD countries?

Section 3 on country initiatives is based in particular on 27 replies to the Information Technology Outlook Policy Questionnaire 2008.

1. DEVELOPMENT AND APPLICATIONS OF RFID

The first part of this section summarises the historical development of RFID, the second part gives an overview of different RFID fields of application in the public and private sector.

1.1 Historical development of RFID

RFID is not a new technology despite rapidly growing interest in RFID technology in recent years. The concept of the technology dates to "the mid to late 1940s, following on from technological developments in the 1930s and the development of radar during World War II" (Hodges and McFarlane, 2005). In the 1950s, several technologies related to RFID technology were developed. One prominent example is the "identification friend or foe (IFF)" system for aircraft which is a long-range transponder system. An active IFF system was first developed for British aircraft whereby each aircraft was equipped with a transponder. When radar stations emitted signals from the ground, the aircraft transmitted a signal back to identify itself as friendly (*RFID journal*, 2007).

The first commercial applications emerged in the 1960s and 1970s. The electronic article surveillance (EAS) equipment was developed by new companies such as Sensormatic and Checkpoints (Landt and Catlin, 2001) to prevent theft of goods at the point of sale. This system is currently in widespread use. With generally a 1-bit transponder, it is the most basic use. The data is sufficient to tell the reader whether a transponder is located in a certain area or not (Finkenzeller, 2006). Overall, this period was characterised by important further development of RFID technology. Research focused on applications for animal tracking, vehicle tracking, car keys, as well as process automation in production facilities (Landt and Catlin, 2001, *RFID Journal*, 2005).

Besides the development of these commercial applications, governments also began the development of RFID systems in the 1970s. For example, the US Department of Agriculture spurred the development of animal tracking and the US Department of Energy promoted the development of a system to track nuclear materials (*RFID Journal,* 2007) which was put in place in the mid-1980s.

In the 1980s, the "commercial exploitation of RFID started to increase, led initially by small companies" (Hodges and McFarlane, 2005). An important aspect for the expansion of the technology was the development of the Personal Computer (PC) facilitating data management.

Whereas the exploitation of RFID was a common point in different countries, the interest in special fields of application diverged. The main interests in the US were for applications including access control of persons and transportation. European countries were mainly interested in toll collection systems and industrial applications as well as short-range systems for the tracking of animals (Landt and Catlin, 2001). Overall, from a technological point of view, applications developed to this point were mainly operating at low-frequency and high–frequency ranges.[1]

In the early 1990s, applications operating at ultra high frequency (UHF) emerged (*RFID journal*, 2007). These systems attained a higher read range and faster data transmission than systems operating at lower frequency ranges. The very first pilot projects started in the retail sector for the tracking of consumer goods along the supply chain. However, due to low volumes, these RFID systems were expensive (*RFID Journal*, 2007). A further obstacle to widespread use was that applications to this date were niche applications. As a consequence, a large number of proprietary systems were developed which were incompatible with each other (Landt and Catlin, 2001). The development of standards was thus crucial both for price decline and the use of RFID technology beyond niche applications.

Standardisation activities emerged in the late 1990s. The International Organisation for Standardisation (ISO) developed several standards in the field of RFID. One example is the ISO 18000 series which defines the air interface for different frequencies, *i.e.* how readers and tags of an RFID system communicate with each other. Furthermore, in 1999, the Auto-ID Center at the Massachusetts Institute of Technology (MIT) was established "to develop an open standard architecture for creating a seamless global network of physical objects" (Auto-ID Labs, 2006). It was initially funded by the Uniform Code Council, European Article Numbering (EAN) International and industry. By the year 2003, the Center was supported by over 100 user companies, key RFID suppliers and the US Department of Defense and a federation of Auto-ID research institutes was created. Specifications developed by the Auto-ID Center focused on low cost tags for goods with the aim of tracking them along the supply chain. The results of the standardisation activities include two air interface specifications, the Electronic Product Code (EPC) numbering scheme as well as a network architecture (*RFID Journal*, 2007). These specifications were passed to EPCglobal for commercialisation purposes.[2]

Besides standardisation activities, the 1990s were furthermore characterised by an increased commercialisation of RFID systems. According to Landt and Catlin (2001), electronic toll collection systems were widely deployed both in the United States and Europe. For example, different regional toll agencies in the Northeast of the United States developed a regionally compatible toll system. Further important implementation projects included applications such as the tagging of over 3 million rail cars in the United States, access control applications (*e.g.* company badges and ski passes) as well as applications along the supply chains of companies. For example, in the late 1990s, European car manufacturers started RFID projects for asset tracking and tracking of parts along their internal supply chains. In addition, an RFID–based immobiliser system for cars was commercialised in the mid-1990s which authenticate car keys and is in wide use. With the broader deployment of these applications, multiple use tags arose *e.g.* for toll collection, access control and gated community access (Landt and Catlin, 2001).

The beginning of the 21st century is marked by *i*) a growing interest of industry, government and the media in RFID technology, *ii*) further technical development, *iii*) a first round of standards harmonisation, and *iv*) an increasing number of applications.

The impact of RFID is repeatedly discussed in mainstream media, and journals specifically devoted to RFID have been launched such as the *RFID Journal* in 2002. Technological development contributes to smaller tags, a reduction of costs and increased functionality. Concerning standardisation, a first harmonisation was implemented in 2006 when an ISO standard (ISO 18000-6) included the EPC Generation 2 UHF Air Interface Protocol and thus provided a broader technological basis for further RFID implementation in the field of passive, low cost RFID systems. There is a growing interest in RFID applications in different sectors, especially for applications along the supply chain. Important retailers such as Wal-Mart, Metro and Tesco conducted pilot projects and began to implement the technology in 2003 and 2004. Further sectors such as the aviation sector, the logistic sector and the pharmaceutical sector are also moving to wider implementation of RFID technology (*RFID Journal*, 2007). In addition, the public sector has important RFID implementation projects *e.g.* in the areas of defence, health, e-passports and identity cards. Overall, the range of different applications is broadening at a rapid pace and new applications which also integrate other technologies such as sensor technology are emerging. The following section provides an overview of different fields of application.

1.2 Overview of RFID applications

As discussed in the previous section, there is a large number of different RFID applications and the number is growing at a fast pace. To structure this range of applications, eight fields of application are described below.

- **Asset utilisation:**
  Mobile assets are tagged for their use along the supply chain. Typical examples are RFID–tagged containers which are used at different production stages. Companies rely on RFID technology in order to locate these assets and to monitor which departments use the assets how many times. The aim is to optimise processes and attain a more efficient use of capacity.

- **Asset monitoring and maintenance:**
  Mostly fixed and high–value assets are tagged to store information, *e.g.* for maintenance purposes. Examples include tagged machines where the maintenance history and information on replaced parts are stored on the tag. When data is stored directly on the tag and not on the companies' network, tags with high data capacity are needed.

- **Item flow control in processes:**
  For item flow control, RFID tags are attached to items which are moving along the supply chain. Often information going beyond a simple ID number is stored on the tag to control production processes. This is, for example, the case in the automotive industry where production information is stored on the tag which can be attached to car bodies or smaller parts. This mainly aims to avoid costly errors during the production process.

- **Inventory audit:**
  A prominent application is the use of RFID for inventory audit. Examples include retailers' warehouses where pallets and sometimes cases are tagged to improve the speed and efficiency of stock taking. In most cases, only an ID number is stored on the tag to minimise the cost of the tag.

- **Theft control:**
  Item level RFID tags are used to prevent theft along the supply chain or at the point of sale. A simple form is electronic article surveillance (EAS) which can be RFID-based. In this case, low-end RFID systems (*e.g.* 1-bit tags) are used which communicate when consumers leave the shop if they have not been deactivated (Finkenzeller, 2006, pp. 25, 32). Applications for theft control in mail order for high-value products such as mobile phones use more sophisticated tags.

- **Authentication:**
  For authentication purposes, RFID is used to provide secure identification mechanisms for persons and objects. Prominent examples of personal authentication are company entry badges, transportation system cards, electronic passports and identity cards. Current fields of application for object authentication include the tagging of drugs in the pharmaceutical sector and high-value goods in the luxury sector to prevent counterfeiting.

- **Payment systems:**
  RFID technology is used for payment systems to secure transactions. Safety requirements for tags are very high. The systems are further characterised by very low read ranges to avoid mixing different payment cards.

- **Automatic display of information:**
  In the emerging field of automatic display of information, items are tagged to provide additional information on products and services when read. Early applications can be found at the point of sale or in the public sector, for example, in museums.

Table 1 shows the first seven fields of application and gives application examples for the private and the public sector. However, as new applications are developed on a daily basis, the list of examples is non-exhaustive. Further application examples organised by different industry sectors are listed in Table 2 where fields of application and industry sectors are cross-tabulated.

Table 1: Overview of RFID applications in the private and public sectors

	Application examples in the **Private sector**	Application examples in the **Public sector**
Asset utilisation	• Container management (*e.g.* small load carriers in the automotive sector) • Loading equipment management (*e.g.* for gears in the automotive supplier sector) • Management of dollies at airports • Fleet management	• Waste management: Container management • Health: Location of medical equipment at hospitals
Asset monitoring and maintenance	• Machine maintenance • Tool box maintenance (*e.g.* for the maintenance of aircraft) • Maintenance of parts built in aircraft • Smart home applications	
Item flow control in processes	• Tagging of parts along the supply chain to correlate information on the tagged item to process steps • Goods movement control • Quality control of goods • Tracing drugs in the pharmaceutical value chain • Tracking finished goods for the purpose of diversion control	• Health: Tracking of medication from the pharmacy to the hospitalised patient • Health: Tracing blood bottles • Administration: Document management
Inventory audit	• Real-time location systems for finished vehicles in the automotive sector • Automation of warehouse management • Automated sorting and counting of inventory • Checking of ingoing and outgoing goods • Baggage handling at airports • Livestock tagging	• Defence: Ammunition management • Education: Lending system in libraries • Exhibition in museums • Science: Tagging animals and plants for research purposes
Theft control	• Car keys (immobilisers) • Electronic Article Surveillance (EAS) systems • Tracking products along the supply chain to minimise theft	

Authentication	• Persons:
	  ○ Company badges
	  ○ Ski passes
	  ○ Event ticketing
	  ○ Sports: recording time during a competition
	• Objects (counterfeiting control):
	  ○ Proof of authenticity of spare parts (*e.g.* in the aviation sector)
	  ○ Proof of authenticity of drugs
	  ○ Proof of authenticity of luxury goods
		• E-Passports, identity cards
		• Health: Patient authentication for the monitoring of medication in hospitals
		• Leisure/sports: recording time during a competition
		• Traffic: Tolling systems
		• Traffic: Speed control
		• Transport: Access control cards for public transport

Payment systems	• Tolling systems • Contactless cards for financial transactions	• Transport: Payment cards for public transport

Source: Authors' compilation.

Table 2: Overview of RFID applications by sector [Note: Includes government applications]

	Asset utilisation	Asset monitoring and maintenance	Item flow control	Inventory audit	Authenti-cation	Theft control	Payment systems
Automotive	• Container management • Loading equipment management • Truck control	• Machine maintenance	• Tagging body parts on the assembly production line • Tagging built-in parts	• Finished vehicles real-time location system		• Car keys combining automobile immobiliser systems and access control	
Automotive suppliers	• Container management • Loading equipment management			• Finished products identification • Automation of warehouse management			
Wholesale and retail trade			• Goods movement control from store warehouses to the sales area • Freshness control of goods	• Goods receipt checking and database entry in the warehouse • Automated sorting and counting of inventory • Checking shipments of outgoing goods		• Checking deliveries (in trucks) for theft prevention • Anti-theft systems at the point of sale (EAS)	• Contactless payment cards
Consumer goods			• Goods tracking along supply chain • Freshness control	• Checking outgoing shipments			
Aviation	• Container management	• Tool box maintenance • Aircraft main-tenance • Tagging built-in parts to avoid errors (wiring harnesses)			• Proof of authenticity (*e.g.* for spare parts)		
Airports	• Management of dollies	• Maintenance of fire shutters	• Baggage handling	• Equipment check	• Border control (e-passport)		
Pharma-ceutical industry			• Tracing drugs		• Proof of authenticity of drugs		

	Asset utilisation	Asset monitoring and maintenance	Item flow control	Inventory audit	Authenti-cation	Theft control	Payment systems
Agriculture and forestry			• Tracing of goods (*e.g.* for freshness monitoring)	• Inventory audit in forestry and animal-ID			
Logistics	• Container management			• Checking of shipments			
Tourism and leisure			• Competition time recording (*e.g.* tags in shoes)		• Ski passes • Event ticketing		
Financial sector							• Contactless payment cards
Luxury goods			• Tracking of finished products for diversion control		• Proof of authenticity of distri-buted goods	• Anti-theft systems at the point of sale • Tracking products from distribution centre to shop to minimise theft	
Public sector Educational institutions				• Lending systems in libraries • Exhibitions in museums			
Science				• Tagging animals and plants for research			
Public health	• Location of medical equipment and patient transport equipment		• Tracking medication from pharmacy to patient • Tracing blood bottles		• Patient authentica-tion for monitoring medication in hospitals		
Waste				• Waste management			
Border control					• e-passport		• Tolling systems • Public transport access and payment cards

Source: Authors' compilation

2. REVIEW OF ECONOMIC IMPACTS

Most RFID applications are still recent and it is very difficult to quantify the impact of the technology. In the recent past, market analysts have published projections on the growing RFID market, and studies are becoming available evaluating the economic impact for specific applications. Section 2.1 compares predictions from different market analysts. Section 2.2 focuses on selected aggregate impact studies for different applications; it does not look at micro-level impact studies.

2.1 RFID market estimates

In terms of technology application, RFID implementation is still at an early stage. For this reason, it is difficult to obtain market projections and a challenging task to evaluate the RFID market. Table 3 provides an overview of global market projections by different market analysts. When dealing with the notion "RFID market", projections usually cover whole RFID systems (*i.e.* readers, tags, RFID middleware). Only the study by IDTechEx analysts includes services.

Table 3: Estimates of the RFID global market (USD)

Market analyst	Date of release	2005	2006	2007	2010/2011	2015	2017
Gartner	2005	504 million	2.7 billion		3 billion (2010)		
RNCOS	2005	1.9 billion				26.9 billion	
BCC Research	2006	649 million	713.4 million		1.05 billion (2011)		
IDTechEx (Study includes systems and services)	2007			4.96 billion			27.88 billion

Source: Authors' compilation.

Overall, large differences between market estimates are observed. For example, whereas the market for RFID systems for 2006 was estimated at USD 2.7 billion by Gartner analysts, BCC estimated an RFID market of only USD 713.4 million in the same year.

There are various reasons for these large differences. Two important reasons are the early stage of RFID implementation in both public and private sectors and, as a result, divergent evaluations of the technology in terms of both coverage and evolution. According to the European e-Business Watch large-scale survey of RFID adoption strategies and impacts in four broad economic sectors,[3] 14% of the European companies interviewed were piloting, using or implementing RFID technology in 2007.[4]

Companies that were using RFID or planning to use RFID expected major effects on: *i*) inventory management (49% of companies using or planning to use RFID), *ii*) control and efficiency of inbound logistics (46%), and *iii*) merchandise management and reduced out-of-stocks (44%). These results correspond to those found in the WPIE qualitative country study for Germany [DSTI/ICCP/IE(2007)6/FINAL]. The major costs for those using or planning to use the technology were seen to be the costs of project implementation and system integration (39% of all companies using or planning to use RFID). Interestingly, for those companies *not* using or planning to use RFID technology, 64% stated that a relevant reason for not using it was the insufficient evidence of a strong return on investment (ROI).[5] To further examine this issue at a more aggregated level, the next section focuses on selected quantitative impact studies.

2.2 Selected studies on the aggregate economic impact of RFID

Whereas section 2.1 deals with market estimates at aggregate level, this section aims at assessing the impact of RFID at a more detailed aggregate level from a user perspective. Apart from studies of toll applications and access control, to date there are very few studies assessing the economic impact of RFID technology in business applications. Of these studies, the majority assess RFID benefits at a qualitative rather than a quantitative level resulting in an even lower number. Of the quantitative studies, we chose two selected impact studies which are based on a well-defined methodology and which outline their assumptions and calculations. The first study deals with global financial impacts in the retail and healthcare sectors. The second study assesses the financial impact of RFID technology at cross-sectoral level in one OECD country.

In their 2006 study Barua, Mani and Whinston focus on the "financial impacts of RFID technology in the retail and the healthcare sectors". Health care sectors include pharmaceutical companies, healthcare distributors and hospitals. They analyse both reduction of costs and the increase of revenues by relying on RFID technology. Calculations are made based on different sources such as case studies of RFID pilot and implementation projects, documents of government and industry associations as well as synthesised results from prior studies. Overall, according to Barua, Mani and Whinston, benefits have already amounted to a global cumulated USD 40 billion in the retail and healthcare sectors.

Out of these estimated USD 40 billion, the retail sector has cumulated benefits of USD 12.05 billion from RFID applications. Total cumulated spending on RFID systems from 2003 to 2006 amounted to USD 2.37 billion according to the authors, resulting in a ROI of about 500%.

This results from both the reduction of costs and increased revenues. On the cost reduction side, economies result from the reduction of labour costs, reduced losses during production and shipment ("shrinkage") as well as from reduced inventory write-offs and non-working inventory. On the revenue side, benefits result from increased product availability at the point of sale, a faster time to market and "providing ubiquitous access to customers across multiple channels" (Barua, Mani and Whinston, 2006). Based on expected adoption rates of pallet tagging (45%) and item-level tagging (25%) in 2011, the authors estimate that benefits will reach USD 68.55 billion in 2011.

Total cumulated benefits in the healthcare sectors have been estimated at USD 27.95 billion. Investments in RFID systems have been USD 2.03 billion, leading to a significantly higher ROI (over 1 300%) compared to the retail sector. According to the authors, this is due to higher RFID adoption rates for the health sectors than for the retail sector.

Pharmaceutical companies have realised these benefits due to "*i*) a reduction in counterfeit, shrinkage and parallel trade, *ii*) efficient product recall, *iii*) efficient sample management, *iv*) enhanced inventory turns, and also shorter clinical trial cycles and faster time-to-market" (Barua, Mani and Whinston, 2006). For healthcare distributors, the authors attribute the benefits to enhanced inventory turns on the one hand and a reduction in labour costs at distribution centres on the other hand. Finally, by relying on RFID technology, hospitals have benefited from *i*) better asset utilisation, *ii*) higher inventory turns, *iii*) increased healthcare access and *iv*) higher patient safety because of fewer errors.

Overall, the report by Barua, Mani and Whinston is one of the first to discuss in detail how RFID benefits can be quantified. This is not an easy task as RFID implementation in these sectors has only taken place recently and the authors admit that "it is not easy to quantify the challenges for a successful implementation". Furthermore, benefits are quantified in a rather optimistic way. Calculations are based on current case studies which are in general best practice examples and success stories of leading companies in these sectors. As a consequence, the results of successful projects have been taken to estimate economies and increased sales in a whole sector which may over-state total benefits across firms which are less efficient in implementation.

The study "RFID: Prospects for Germany" in 2007 focuses on a cross-sectoral analysis of RFID in Germany. Within this analysis, one part is dedicated to sales and productivity effects of RFID technology. Sectors assessed in the study include the consumer goods, retail, logistics and the automotive sector. Macroeconomic effects in Germany in 2010 are derived from sales and productivity effects of each of these sectors. Calculations for all sectors are based on sources such as preliminary case studies of RFID pilot and implementation projects. Overall, according to the study, sales and productivity gains amounted to EUR 3.24 billion in 2004 and are expected to rise to EUR 62.2 billion in 2010.

In **German retailing**, productivity effects are estimated at EUR 8.6 billion in 2010. Estimates are based on total retail sales and the estimation that companies having implemented RFID technology by 2010 will account for 40% of total retail sales. Moreover, the percentage of sales influenced by RFID is estimated at 30% and operational productivity effects (productivity gains from avoiding out-of-stock situations, less shrinkage, etc.) are estimated at 20%. Estimates on productivity gains are based on preliminary studies such as documentation of the Metro future store.

The model calculations for the **German logistics sector** differentiate between logistics and transport services only and auxiliary services in logistics (*e.g.* inventory management, order processing, logistics planning). In the logistics and transport services productivity effects will reach EUR 1.7 billion in 2010 according to the study. In the field of auxiliary services in logistics, RFID use will yield about EUR 4.3 billion in 2010.

Productivity gains in the **German automotive sector** are estimated at EUR 2.4 billion in 2010. Interestingly, these estimates are significantly lower than the estimated gains in the retail sector. This is explained by the estimates of the operational productivity effects directly attributable to adoption of RFID. In the automotive sector, the authors estimate these effects very conservatively at 2% by 2010. In the retail sector, however, these gains are estimated at 20%.

These sector analyses are the starting point for the macroeconomic assessments of RFID technology on the German economy. The calculation is based on the gross value added (*i.e.* the total value of goods generated in the production process minus inputs consumed during production). Industry subcategories were selected which will be influenced by RFID technology in the medium term. Table 4 shows that productivity gains triggered by the use of RFID will increase from EUR 3.24 billion in 2004 to EUR 62.2 billion in 2010.

Overall, the study "RFID: Prospects for Germany" is one of the first studies which analyses how productivity gains can be calculated for different industry sectors and how they can be aggregated to obtain gains at macroeconomic level. This is a demanding task as RFID implementation has only recently taken place. Furthermore, the authors estimate potential gains in a structured and logical way. However, in their penultimate step, the authors calculate the gains based on a percentage of the total output "influenced" by RFID technology rather than on a percentage of total (production) cost reduction. As a consequence, estimated gains are high. In addition, as in the report by Barua, Mani and Whinston, calculations are based on current case studies which in general tend to be success stories. This may be another factor leading to a potential overestimation of total benefits.

Table 4. Table 5: Model calculation: portion of value added due to RFID technology

	Year	Manufacture of transport equipment	Manufacture of textiles and textile products	Manufacture of chemicals and chemical products	Manufacture of machinery and equipment	Commercial agents/wholesaling	Retailing (except motor vehicles)	Transport, storage and communication	Health and social work	TOTAL
Gross value added (EUR, billions)	2004	73.1	37.4	45.6	67.2	89.5	84.0	116.4	141.2	654.4
	2010	71.4	34.4	55.4	85.5	133.5	88.1	148.1	148.1	764.5
Percentage of RFID pioneers	2004	10%	5%	5%	2%	10%	10%	7%	1%	--
	2010	40%	20%	15%	15%	40%	40%	25%	15%	--
RFID pioneers' value added (EUR, billions)	2004	7.3	1.9	2.3	1.3	9.0	8.4	8.2	1.4	39.8
	2010	28.6	6.9	8.3	12.8	53.4	35.3	37.0	22.2	204.5
Percentage of output "influenced" by RFID	2004	10%	5%	10%	2%	10%	10%	5%	1%	--
	2010	35%	30%	20%	20%	30%	30%	40%	20%	--
Portion of value added "influenced" by RFID (EUR billion)	2004	0.7	0.1	0.2	0.03	0.9	0.9	0.4	0.01	**3.24**
	2010	10.0	2.1	1.7	2.6	16.0	10.6	14.8	4.4	**62.2**

Source: OECD based on BMWi (2007).

3. REVIEW OF COUNTRY INITIATIVES

Country initiatives are divided into three main categories: *i)* the use of RFID by the public sector (section 3.1.), *ii)* information, awareness and education programmes (section 3.2), and *iii)* incentives for business R&D and public funding of projects (section 3.3). This categorisation is developed on the basis of literature review and the RFID country study in Germany.

3.1 The use of RFID by the public sector

The public sector is an important user of RFID technology in addition to rapidly increasing use of RFID in the private sector. Examples which are contributing to widespread use of the technology include using RFID technology in electronic passports (e-passports), and for tracking assets and items in the area of defence and equipment of hospitals.

Seven main application areas in the public sector are listed below:

- **E-passports and identity credentials**

  E-passports combine the traditional paper document with an RFID tag where the critical information is stored. The RFID tag often contains biometric data such as data for facial recognition and fingerprints. The format of the biometric data and communication protocols is defined in a standard adopted by the International Civil Aviation Organization to ensure international interoperability. The RFID tag runs on the standardised ISO/IEC 14443 communication protocol (Finkenzeller, 2006, p. 404). RFID technologies are also planned for national identity credentials or other official documents such as driving licences, residence permits, social security cards, etc.

- **Public services (*e.g.* waste management/waste control)**

  Public services include services such as the management of parking facilities and waste management. In waste management RFID is used for two main purposes: for tracking (hazardous) waste to protect the environment and to allocate costs according to the amount of waste. Currently applications can, for example be found in Korea where pilot projects in the field of hazardous waste tracking were conducted as well as in Germany where costs of waste are calculated according to the waste's volume or quantity.

- **Health (*e.g.* applications in hospitals)**

  A significant number of public sector RFID projects are implemented in healthcare. One area where multiple projects are already at the implementation stage is the hospital sector. RFID is used to track assets such as beds or containers, to identify patients for medication control and to track babies and dementia patients to increase their security. Other applications include health insurance cards which have already been introduced in Mexico, for example. Information such as username and prescribed drugs are stored on the embedded RFID chip.

- **Document administration/postal services**

  The public sector also uses RFID technology for the administration of documents. In this field, RFID tags are attached to documents to improve the location of documents and thus to increase process efficiency and quality. RFID is also used for postal services in distribution centres to facilitate the sorting of mail items.

- **Defence**

  RFID technology in the area of defence is mainly used to streamline supply-chains and procurement processes. The most prominent example of a department relying intensively on RFID technology is the US Department of Defense. Both active and passive tags are attached to inbound and outgoing shipments at the case and pallet level.

- **Education/Cultural institutions/Science**

  The public sector also relies on RFID at its cultural institutions. Examples include lending systems at libraries and newer applications can be found in museums where artworks are presented via RFID technology via automatic display of information.

- **Logistics/Transport (*e.g.* toll collect systems)**

  Finally, RFID is used by the public sector in the fields of logistics and public transports. Toll collect systems were early applications of RFID technology. Newer applications are access cards for public transport, RFID-based bus schedules as well as particular location-based services.

Table 5 gives a non-exhaustive overview of RFID applications used by OECD countries indicating that applications are very diverse. Many projects in the fields of e-passports, health, transport and defence are already at the implementation stage. Newer applications can be mainly found in the fields of public services and education.

Overall, governments are currently developing and using RFID in a variety of different areas. To be an important user of RFID technology has a number of important effects both for further RFID suppliers and users. On the supply side, government projects can have significant effects. Pilot projects contribute to further development and testing of different components of RFID systems, and are seen as an important means to spur innovation. Moreover, important implementation projects support the formation of an RFID market at national and international level. These effects on the supplier side enhance a more reliable and sophisticated supply of different components of RFID systems.

On the user side, pilot projects conducted by governments provide pilot experiences for new RFID applications. Both the public and the private sector profit from technology feasibility studies and testing results. A further characteristic of government projects is their ability to generate valuable experience and robust results on a large scale. Furthermore, many of the governments' RFID projects may trigger wider applications.

Government projects are usually designed to disseminate results widely. A wide range of stakeholders involved in RFID technology benefit from these projects and results are usually made broadly available. If this process is organised in a highly efficient way, spill-over benefits of public sector RFID projects can be considerable.

Table 6: Selected RFID applications in the public sector in OECD countries

Country	Project category	Project description
Austria	Health	Tests by the municipal administration of Vienna on the applicability of RFID in the health care system
	Public services	Tests in the Viennese parking facility management
Denmark	Education	Lending systems in libraries
	E-passport	E-passport available since mid-2006; biometric passport relying on RFID embedded fingerprint technology to be introduced mid-2009
Germany	E-passport	E-passport (available since the end of 2005), electronic ID card (to be introduced at the end of 2009)
	Public services	Waste management in different communities
	Education	Lending systems in libraries
Japan	Logistics/Transport	Set-up of the "Free Mobility Assistance System" based on ubiquitous network technology including RFID tags, to provide information for seamless movement (*e.g.* transfer routes and transport modes)
Korea	Public services, health, defence, logistics/transport	Pilot projects in the fields of procurement, baggage handling, container management, ammunition management, tracking hazardous waste, museums, air cargo, etc.
Mexico	Health	Health insurance card: RFID technology is integrated in the "popular insurance" card where the username, information on doctors as well as prescribed drugs are stored
Netherlands	E-passport	E-passport
	Health	RFID technology used in hospitals
	Education	Libraries
	Logistics/Transport	Payment cards for public transport
Portugal	E-passport	E-passport and e-passport control systems at Portuguese airports (*e.g.* Lisbon, Faro)
Spain	Document administration/ postal services	The Spanish postal service uses RFID technology in 15 distribution centres in different locations in Spain (*e.g.* Madrid, Barcelona)
United Kingdom	E-passport	Biometric passport relying on RFID technology
United States	Defence	Use of passive and active RFID tags for inbound and outgoing shipments along the supply chain
Singapore	Logistics/Transport	Nationwide Electronic Road Pricing (ERP) system to control and manage traffic volume; payment of road usage charges. The ERP is applied to all of Singapore's 840 000 vehicles
	Public services	RFID tags replace paper season parking tickets at car parks in public housing estates
	Education	Lending systems in all national and community libraries

Source: Compiled from replies to the IT Outlook Policy Questionnaire 2008 and case studies.

3.2 Information, awareness and education activities

Apart from being a user of RFID technology, another important role for the public sector is in providing and sharing information and in the education of stakeholders. Information and education activities include for example:

- Conferences on RFID technology and its impacts.
- Discussion forums and online dialogue platforms.
- Information (*e.g.* studies providing an introduction to RFID, its benefits and barriers and assessing current and future RFID markets).
- Publication of guidelines (*e.g.* how the private sector could assure data protection).
- Demonstration projects.

Table 6 illustrates different information, education and awareness activities in OECD countries. Activities in this category primarily focus on the publication of studies and demonstration projects. Most of the studies are either directed at consumers or companies. In the first case, studies are published aiming at increasing public awareness. One of the challenges of studies directed at consumers is a balanced presentation of potential benefits and potential risks as potential risks vary greatly according to specific RFID applications. Another major challenge is to distinguish between applications which do not have an impact on consumers and users and where privacy is not an issue (*e.g.* supply chain applications), and applications which directly concern consumers and where privacy is an issue. In the first case, studies provide an introduction to RFID technology and information on fields of application and benefits and challenges in technology implementation.

A significant number of these studies focus on small and medium-sized enterprises (SMEs). These companies often face important transaction costs, especially in the case of new RFID applications where few off-the-shelf solutions exist and where different technology providers supply different parts of the RFID system. Further, SMEs often lack the necessary R&D budget, economic capacity and time to take large risks with new technologies. As SMEs are potentially important users of RFID systems, information and awareness on prospective applications as well as showcases are important for diffusion of RFID technology and reducing unnecessary risk. Publications on best practices can further facilitate RFID diffusion among SMEs.

Some OECD countries (*e.g.* Finland and Korea) have provided showcases and demonstration projects which include demonstrations in application centres and implemented projects, for example in the field of baggage handling.

Overall, as RFID implementation projects are still at an early stage, lack of knowledge potentially hampers further development and implementation. Governments are experienced in raising awareness of and disseminating information on new ICT technologies and fields of application, often in collaboration with other stakeholders, and can help devise collaborative mechanisms to improve diffusion and uptake in generic technologies. Projects are usually characterised by being developed in close collaboration with other stakeholder groups including industry groups and academics and they try to give a comprehensive overview of the technology. In Germany, for example, the report "RFID – Security Aspects and Prospective Applications of RFID Systems" gave a detailed overview of benefits and challenges, thus helping German companies to reduce transaction costs by reducing the time spent searching for information on RFID technology. Further activities aiming at discussing different facets of RFID implementation and the broad dissemination of these activities could contribute to better understanding of RFID technology and applications and thus foster its broader acceptance and diffusion.

Table 7: Selected RFID information and education activities in OECD countries

Country	Project category	Project description
Australia	Information (guide)	Publication of a guide "Getting the most out of RFID – A starting guide to radio identification for SMEs[6]"
	Information (event)	Educative events such as the "RFID Executive Breakfast" to build awareness of opportunities and challenges presented by RFID technology
Canada	Information (study)	"RFID Technologies and Consumers in The Retail Marketplace" – Study update discussing RFID technology, pilots and deployment in Canada, consumer concerns and policy developments[7]
Denmark	Information (study)	"RFID possibilities in the value chain" – study, published by the Independent Technology Council[8]
Finland	Demonstration projects (application centre)	Partly publicly funded RFID application centre providing information and piloting facilities[9]
Germany	Conference	Expert conference "RFID: Towards the Internet of Things"[10] organised by the Federal Ministry of Economics and Technology
	Discussion forums	"RFID-Dialogplattform": Forum pooling information on activities and initiatives both administrated by the government and industry
		"RFID und Verbraucherschutz (RFID and consumer protection)" aiming at providing transparency and creating trust
	Information (online portal)	"Netwerk elektronischer Geschäftsverkehr (Electronic Commerce Network)": Online portal to support SMEs. Special part on RFID technology including studies and checklists
	Information (studies)	A number of studies issued by the government such as "Leitfaden RFID - eine Chance für kleine und mittlere Unternehmen (RFID guide – an opportunity for small and medium-sized enterprises)"[11], "RFID – Security Aspects and Prospective Applications of RFID Systems"[12] or "RFID-Prospects for Germany" (BMWi, 2007)
Italy	Information (study)	The "National Centre for IT in Public Administration" (CNIPA) is working on a study evaluating the use of RFID in public administration[13]
Japan	Guidelines	Modification of the document "Guidelines for Privacy Protection with Regard to RFID Tags" according to technological changes and usage in order to improve dissemination conditions of RFID
Korea	Information (studies, guidelines)	RFID technology feasibility studies, guides for companies based on conducted pilot projects (see Part 3.1)
Netherlands	Information	"The Netherlands Digitally Connected", Information on RFID directed at SMEs via generic ICT awareness and educational programmes
Switzerland	Discussion forum	Risk dialogue foundation[14] (dialogue between stakeholders from industry, science, public sector, consumer protection, data security amongst others)
	Information (study)	"The precautionary principle in the information society"[15]
European Commission	Information (communication)	Communication from the Commission to The European Parliament, The Council, The European Economic and Social Committee and The Committee of the Regions: "Radio Frequency Identification (RFID) in Europe - steps towards a policy framework"[16]
Singapore	Information (knowledge base)	Creation of a knowledge base by the National RFID Centre to shorten learning curves and deployment times across industries
	Discussion forum	Creation of an RFID focus interest group with linkages to a network of local and overseas RFID labs by the National RFID Centre
	Demonstration projects	Demonstration of novel RFID technologies and solutions at the National RFID Centre

Source: Compiled from replies to the IT Outlook Policy Questionnaire 2008 and case studies.

3.3 Incentives for business R&D and public sector project funding

Public sector project funding (either wholly or in part) is a third category of country initiatives . They include *i)* projects funded and conducted by the public sector for business sector applications, *ii)* funding of mostly collaborative projects between business, research and public groups, and *iii)* funding projects conducted by the private sector. Some of these funding schemes are specifically focused on RFID, in other cases R&D and new applications as well as the development of standards are funded via general national technology development and support funding mechanisms.[17] It should be further noted that RFID R&D and investment can benefit from general R&D tax incentives and investment incentives, but that there are no reported RFID-specific R&D or other tax incentives for their development in OECD countries.

Table 7 provides an overview of funding projects in selected OECD countries. Further projects with important funding volumes are conducted by the European Commission within the 6th framework programme (see Box 1). Overall, projects range from RFID projects in specific fields of application, the funding of selected projects between different stakeholder groups, to a wide range of tax expenditures via general tax incentives.

Table 8: Selected RFID funding projects in OECD countries

Country	Project	Description	Stakeholders
Australia	National EPC Demonstrator Project (2006/2007)	Funding two phases of the National EPC Demonstrator Project: RFID in (open circulation) supply chains; interoperability and integration requirements	Government and industry
Austria	FIT-IT – Programme line 'embedded systems'	Ministry for Transport, Innovation and Technology. RFID projects funded in the programme 'embedded systems'	Government, industry, academics. Funding cooperative industry/academic research projects
	Competition: Development and Application of RFID Technology	Project within the programme "Digital Economy/ICT". Funding of seven projects. Total funding volume provided by the Federal Ministry of Economics and Labour: EUR 400 000	Government, industry and academics
	'PROACT' initiative	Joint private-public initiative by the university of Graz and NXP (former Philips Semiconductors) for RFID R&D	Public sector and industry
Canada	McMaster RFID Applications Lab (MRAL)	Creation of an RFID lab at McMaster University in joint public-private initiative. Hub for RFID applications promoting RFID research, social and economic impact and policy issues	Industry and public sector
Denmark	Train travel card	Test of RFID technology based e-ticket by major Danish train operator	Government and industry
	BroBizz (Bridge toll)	Use of RFID technology for commuters for the toll system on the bridge between Denmark and Sweden, as well as toll on bridges in Denmark	Government
	Mail delivery and registration	Implementation of smart phones to combine road planning, RFID scans, payment and postal registration by the major Danish mail operator in 2007	Government and industry
Finland	GIGA[18]- Converging networks	TEKES (main government body for funding R&D programmes). Programme focus areas: wireless access (including RFID), seamless networking, network support, telecommunication business	The programme is a combination of research and industrial projects

Country	Project	Description	Stakeholders
Germany	-	Targeted support of projects developing pioneering RFID activities and producing show-cases	Government and industry
Korea	Airline Baggage Tracking and Control System	RFID tags attached to baggage of domestic flight passengers and RFID readers deployed in destination airports to secure baggage traceability	Jeju, Busan, Daegu, Gwangju and Chungju airports
Mexico	PROSOFT[19] fund	Programme for development of the software industry (PROSOFT), supports RFID-related projects. About one third of funding from the Ministry of the Economy	Government, industry and academics
Spain	Interference tests	Interference tests in several Spanish towns (*e.g.* Madrid) to test the compatibility of RFID with radio links	Government
Turkey	RFID Research and Test Centre	Established by Istanbul Technical University. Research projects RFID use, especially logistics and manufacturing	Public sector and industry
Singapore	National RFID Centre (September 2006)	Funding RFID industry pilot projects	Government and industry
		Training for potential solutions for companies and end users	Government and industry

Source: Compiled from replies to the IT Outlook Policy Questionnaire 2008 and case studies.

Government support promotes RFID technology on both supplier and user sides. The funding of projects with a wider scope (*e.g.* the Finnish GIGA project) has the particular advantage that these projects have the potential to trigger wider and future applications. Finally, funding of long-term projects allows development and testing of more future-oriented applications such as applications combining RFID technology with other promising technologies (*e.g.* sensor technology). At all funding stages, collaboration with different stakeholders and intense information exchange are crucial and help to maximise benefits.

Besides the projects described above, the public sector may also need to address environmental and recycling issues related to RFID technology. The technology can very effectively track, minimise and assist efficient waste and pollutant disposal. But in addition, environmental impacts associated with the technology itself will need to be addressed. As the number of RFID tags continues to rise, they will have to be separated from other materials during recycling processes. Government support could encourage research on the impact of RFID technology on the environment and especially on recycling issues.

Box 1: Selected RFID funding projects in the 6th Framework Programme

BRIDGE (Building Radio frequency IDentification solutions for the Global Environment):

- Three year RFID application research and development project. Funding: EUR 7.5 million.
- Objective: "To research, develop and implement tools to resolve barriers to the implementation of RFID and EPCglobal technologies (solutions for network(s), application software, security, hardware, implementation, increasing the influence of European organisations in global standard processes" [20]

SMART

- 30-month project.
- Objective: "aims to support intelligent business networking and consumer services based on effective and efficient information/knowledge sharing and collaboration across supply chain partners, capitalizing on the fact that products are uniquely identified with the use of smart tagging technology in the supply chain".[21]

StoP

- 30-month project
- Objective: "aims at developing ambient intelligence-based and network-oriented systems for the efficient and secure authentication of products".[22]

Indisputable Key

- Objective: resource optimisation in the timber industry.

CE RFID (Coordinating European Efforts for Promoting the European RFID Value Chain)

- Objective: "CE RFID aims at improving the conditions of competition for RFID technology and its further development in Europe and at reinforcing the political environment of RFID at European level".[23]

Source: Authors' compilation

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NOTES

1 For a discussion of different frequency ranges and further characteristics of RFID systems see the OECD RFID country study for Germany [DSTI/ICCP/IE(2007)6/FINAL].

2 EPCglobal Inc. is an industry standards group which establishes industry-driven standards in the field of supply chain management (see also http://www.epcglobalinc.org/about/).

3 European Commission, DG Enterprise and Industry: Sectoral e-Business Watch, Chart Report 2007. The final study by the Sectoral e-Business Watch is expected in June 2008. The e-Business Watch studies aim at analysing the impact of ICT and e-business on enterprises, industries and the economy in general.

4 The survey sample consisted of 434 enterprises from 4 sectors (manufacturing, retail distribution, transportation, hospital activities) and 7 EU countries (France, Germany, Ireland, Italy, Poland, Spain, and the United Kingdom). Quantitative interviews were conducted by phone relying on computer-assisted telephone interviews (CATI).

5 The survey question was stated as follows: "Please tell me for each of the following items whether or not this is a relevant barrier for an RFID project. Is this a relevant barrier for an RFID project or not? [...](c) There is not enough evidence of a strong return on investment (ROI)."

6 Small and medium-sized enterprises.

7 http://www.ic.gc.ca/epic/site/oca-bc.nsf/en/ca02287e.html.

8 English summary: http://www.tekno.dk/pdf/projekter/p06_rapport_RFID.pdf.

9 http://www.rfidlab.fi/?1;2;1200;1200;14.html.

10 http://www.nextgenerationmedia.de/Nextgenerationmedia/Navigation/en/rfid-conference.html.

11 http://www.ec-net.de/EC-Net/Redaktion/Pdf/RFID/rfid-leitfaden-mittelstand,property=pdf, bereich=ec__net,sprache=de,rwb=true.pdf (in German).

12 http://www.bsi.bund.de/fachthem/rfid/RIKCHA_en.htm.

13 http://www.osservatori.dig.polimi.it/dettaglioOsservatorio.php (in Italian).

14 http://www.risiko-dialog.ch/Themen/Kommunikationstechnologien/263 (in German).

15 http://www.ta-swiss.ch/a/info_perv/2003_46_pervasivecomputing_d.pdf (in German).

16 http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2007:0096:FIN:EN:PDF.

17 See for example the National Science Foundation (NSF) (http://www.nsf.gov/eng/iip/iucrc/directory/celdi.jsp) and the National Institute for Standards and Technology (NIST)