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Radio-Frequency Identification (RFID)

A FOCUS ON INFORMATION SECURITY AND PRIVACY

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Working Party on Information Security and Privacy

RADIO FREQUENCY IDENTIFICATION (RFID): A FOCUS ON INFORMATION SECURITY AND PRIVACY

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FOREWORD

This report was prepared by the Secretariat with the assistance of Nick Mansfield, consultant to the OECD. The first draft benefitted from initial input from Francis Aldhouse, consultant to the OECD. It includes comments and suggestions from OECD member countries, business and civil society.

The report was discussed by the Working Party on Information Security and Privacy in October 2007 and declassified by the Committee for Information, Computer and Communications Policy on 17 December 2007. It is published under the responsibility of the Secretary-General of the OECD.

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RADIO FREQUENCY IDENTIFICATION (RFID): A FOCUS ON INFORMATION SECURITY AND PRIVACY

EXECUTIVE SUMMARY

The deployment of Radio Frequency Identification (RFID) in a large number of application areas is promising. This paper introduces the main characteristics of RFID technologies and focuses on the information security and privacy aspects of RFID in the short term. It will be complemented by an overview of RFID applications and an analysis of economic aspects of RFID carried out by the OECD Working Party on the Information Economy (WPIE).[1] Later on, and based on both sets of work, a common set of policy principles related to RFID will be developed.[2]

This report represents the first step of OECD work related to sensor-based environments. Follow-up work will address security and privacy issues raised by a number of possible longer-term trends such as the generalisation of object tagging (pervasive RFID), of open loop RFID and of other sensors and sensor networks that can monitor the environment.

A varied and complex technology

RFID is a convenient and popular term for a technology with **vague boundaries** and **many facets**. Radio-frequency identification is not always based on radio-frequency communications and identification is only one among the many functions RFID technology can perform. Rather, RFID enables data collection with contactless electronic tags and wireless transmitters (readers) for identification and other purposes. It can be seen as a first step towards sensor-based environments.

Understanding the capabilities and limitations of RFID technology is essential because the likelihood of several potential security and privacy risks varies according to the type of RFID technology used as much as according to the context in which RFID is implemented. The paper therefore provides **basic information** on RFID technology, including elements regarding standards, hardware and software components, frequency ranges, modes of operation (electromagnetic induction or radio-waves) and operation ranges.

Information security aspects

There are a **large number of potential risks** to RFID tags, readers and tag-reader communication that implicate each of the three classical dimensions of security: availability, integrity and confidentiality. Examples include denial of service, jamming, cloning, eavesdropping and skimming. Malware using tags as a vector for dissemination has also been identified as a potential risk. Tags and readers are not the only components of RFID systems that require security protection. Software (middleware), network and database components are also subject to information security risks. RFID security risks are not theoretical: a number of vulnerable security products and systems, sometimes deployed at very large scale, have been

1 . See OECD (2007b, c).

2 . DSTI/ICCP/IE/REG(2007)1.

discovered by researchers or reported in the press. However, many of these potential risks are more or less likely to occur depending on the type of RFID technology used (*e.g.* eavesdropping is less likely when magnetic induction is used because the operation range is very short).

Ensuring RFID security requires a mix of technical and non-technical controls to prevent and mitigate risk. A number of **technical controls** are available. However, their degree of sophistication, robustness, complexity and cost varies. As a result, there is no one-size-fits-all RFID security measure that would efficiently address a given class of risks in all possible situations and at low cost. The development of well tailored and innovative technical security safeguards for RFID may therefore be a critical success factor for large scale deployment of RFID in many areas.

As mentioned above, not only do risks to RFID systems vary considerably according to the technology used, they also vary depending on the application contexts and scenarios. Consistent with the OECD *Security Guidelines*, risk assessment and risk management can help address the security of RFID systems. A **holistic approach** to risk (*e.g.* carefully considering each stage of the system's life – planning, deployment, operation, data processing and end of life – and each component of the system – tags and readers, middleware, databases, back-end and network components) is required to develop an overall security strategy. The risk evaluation and management strategy help identify the necessity to strengthen specific parts of the system in order to compensate for some weaknesses that cannot be addressed directly.

Like any technology, adjusting RFID security to the appropriate level requires striking the right balance between the **value of the assets to protect,** the possible damages an attack could generate, and the risks. Key factors to consider include the potential impact on privacy when information related to individuals is used. Strategies to enhance the level of security include investing in more secure RFID, associating RFID with non-RFID security controls or using other technologies than RFID.

As RFID technology is still young and evolving, innovative and unpredicted cracking techniques are likely to emerge. **Review and reassessment** of RFID systems is key for deciding where security investments should be made to deal with evolving risks.

Privacy aspects

Potential risks to privacy are generally **important concerns** for individuals and organisations. Key characteristics and functionalities of RFID technologies have the potential to offer benefits (*e.g.* convenience, expediting processes) as well as to foster misperceptions and to impact privacy. RFID systems that collect data related to identified or identifiable individuals raise specific privacy issues that should be considered as a priority challenge to the adoption of the technology in a large number of areas. In most cases, the potential invasion of privacy through the use of RFID depends on both the technology used and the context.

Invisibility of the data collection may be the primary characteristic of RFID that raises concerns. It is also a risk multiplier for the potential privacy challenges associated with the use of the technology. RFID might reveal to third parties information about objects carried by individuals without their knowledge. It might allow inferences enabling links to more information on the individual and more precise **profiling**: for example inferences made from multiple tags carried by an individual or from sensitive data, such as biometrics in an unsecure RFID passport, or from tagged medicines. Such a scenario would require the presence of readers in the tags' environment as well as the capacity for the third party to convert the objects' tag information into meaningful data.

Likewise, **tracking** in real time or after the fact may be the primary functionality of RFID that raises concerns. In particular, because of the invisibility of the technology, tracking of individuals could happen

without their knowledge, if they are provided with hidden tags or tags that are not sufficiently secured. In other cases, tracking people could also be the objective of the RFID application (*e.g.* tracking children in an amusement park).

Another concern is that interoperable ("open loop") RFID technologies facilitate and therefore multiply the collection and processing of personal information. Pervasive RFID taking advantage of **interoperability** and ubiquitous Internet connectivity is often described as an inevitable future, though there are currently few examples of open loop systems.

In cases where RFID systems collect data which is associated with an identified or identifiable individual, the **OECD *Privacy Guidelines*** provide a useful framework.

When an RFID system processes personal data, **transparency** of the purpose of the processing and **consent** of individuals are essential. Beyond basic data protection information, privacy notices may usefully include further information such as *i)* the existence of the tags, *ii)* their content, use and control, *iii)* the presence of readers; *iv)* the reading activity, *v)* the ability to disable tags and *vi)* where to obtain assistance. Innovative means of informing individuals efficiently could be explored. Continued stakeholder dialogue between stakeholders, across sectors and in each of the specific application areas, would help clarify or reach a consensus on what information to provide to individuals, the best means to communicate it to achieve efficient transparency, as well as the cases where consent should be or not be required.

Naturally, **security safeguards** are essential for the protection of privacy in RFID systems.

The wide variety of technical configurations and use scenarios make **privacy impact assessments** a good practice for identifying and understanding privacy risks and best strategies to mitigate them in a given system. As for security, because RFID systems are often components of broader information systems, it cannot be expected that all privacy challenges can be solved at the RFID level. A holistic approach to privacy management may be highlighted as a good practice. Such an approach would consider all the components of the information systems involved, besides the core RFID components as well as the whole life cycle of the tag when it remains functional beyond the reach of the data controller.

The choice of the RFID technology to be used in a system influences the protection of privacy just as it impacts the security of the system. **Privacy by design** or embedding privacy in the design of the technology and of the systems can significantly facilitate the protection of privacy and foster trust in RFID systems. Efforts to develop **RFID privacy enhancing technologies** are ongoing and could be encouraged. Techniques such as data minimisation and anonymisation can be applied to RFID. Strategies to provide incentives to industry and business for designing and using RFID technologies that include sufficient privacy protections could be pursued. Nevertheless, as for security, privacy protection should not solely rely on technical measures but rather on a mix of technical and non-technical safeguards.

Some parties do not associate tag data with individuals yet provide them with consumer goods tagged with functional RFID tags that they or third parties could later read. It could be suggested that such parties take responsibility for either deactivating the tag or providing information to individuals regarding the presence of the tags, the privacy risks associated to them and the means to prevent or mitigate such risks.

Finally, and more generally, RFID is not well understood by individuals. Increasing the level of **awareness and understanding** about RFID, its possibilities and limitations as well as benefits and risks, can contribute to reducing this perception issue. It may also help individuals make appropriate choices and support efforts by organisations to deploy privacy friendly systems.

Conclusion

Security and privacy issues in relation to RFID infrastructures and related software should be addressed by all stakeholders before widespread deployment of the technology.

The OECD *Security Guidelines* provide a framework for developing a culture of security for RFID systems whether they process or not personal data. The OECD *Privacy Guidelines* also provide a useful framework for guiding the implementation of RFID systems that collect or process personal data.

However, dialogue is still necessary to clarify or to reach a consensus on a number of points, such as *i)* how to apply the concepts of personal data and data controller, *ii)* the nature of the information to provide to individuals and the best means to communicate it to achieve efficient transparency and *iii)* the cases where consent is needed.

Several concepts and approaches reflected in the 2002 *Security Guidelines* could be adapted to support the implementation of the OECD privacy principles, reinforce their effectiveness and help develop a culture of privacy for RFID systems. They include awareness raising initiatives, risk reduction methodologies (*e.g.* privacy impact assessments) and initiatives to integrate security and privacy protections in the design of RFID technologies and systems.

INTRODUCTION

Background

The OECD Information, Computer and Communications Policy (ICCP) Foresight Forum on "Radio Frequency Identification (RFID) Applications and Public Policy Considerations" in October 2005, highlighted the economic potential of RFID technologies as well as new privacy and information security challenges associated with these technologies. It also signalled that RFID could be seen as the first illustration of intelligent networked sensor technologies that would enable the creation of an "Internet of things". The use of RFID is expected to foster the convergence of communications technologies and ultimately contribute to realising "ubiquitous network societies" through which almost every aspect of an individual's life and work environments would be linked to an omnipresent, 24/7 global network.

Building on the interest generated in the ICCP Forum, further research on RFID was included in the OECD 2007-2008 programme of work:

- The Working Party on Information Security and Privacy (WPISP) undertook work on RFID and sensor-based computing within the broader context of pervasive sensors and networks with a view to exploring whether OECD Security and Privacy Guidelines would be challenged by these new technology trends, and

- The Working Party on Information Economy (WPIE) undertook work on the economic aspects of RFID.[3]

In October 2006, the WPISP discussed a preliminary report by the Secretariat exploring information security and privacy issues raised by RFID, sensors and pervasive networks technologies. It recognized that RFID and sensors are at two different stages of development and deployment. Though RFID technologies are evolving and progressing at a fast pace, they have already reached a certain level of maturity and are being deployed at small, medium and large scales in many countries, in several sectors and for various applications. They already raise security and privacy issues. Other sensor and sensor network technologies that monitor environmental parameters and communicate sensed data to other connected devices are less mature and generally deployed on a much smaller scale for applications that rarely affect individuals. Their widespread adoption is still to come, the applications and sectors that will drive that adoption are unknown, and the specific privacy and security issues they could raise are speculative. Specific privacy and security issues raised by pervasive RFID are also yet to come. Therefore, the WPISP agreed that work in 2007 would address issues raised by the use of RFID in the short term. Issues raised by pervasive RFID and other sensor-based technologies in the longer term would be addressed at a later stage.

This report on RFID, Information Security and Privacy underscores the important cross-cutting nature of the security and privacy work of the WPISP. Identity management, authentication and malware all have implications for RFID and other similar technologies. For example, RFID tags can store important personal data and be linked to databases holding personal data. RFID tags are increasingly used to

3. OECD, 2007b and 2007c.

authenticate people and can include biometrics or other authenticating information in large scale identity systems such as passports or national identity cards. Furthermore, RFID tags could well be used as attack vectors for malicious software or "malware". This illustrates the continued importance of addressing security and privacy issues jointly and in close connection with the evolution of new communications technologies and applications.

Although their creation dates back to the Second World War, RFID technologies have in a few recent years experienced a rapid evolution and broad implementation throughout the economy. As intelligent sensor technologies continue to develop and may, in conjunction with RFIDs, create an "Internet of things", it is important that the impact of these technologies on the Internet and society be recognised. In this context, the findings of this study will also inform the 2008 OECD Ministerial on "The Future of the Internet Economy".

Objectives and scope

This paper seeks to clarify the capabilities of RFID in the short term and to identify the information security and privacy challenges raised by this technology, the implications of which may not always be reflected in existing instruments or policies. The OECD *Guidelines for the Security of Information Systems and Networks: Towards a Culture of Security (Security Guidelines*) and the *Guidelines on the Protection of Privacy and Transborder Flows of Personal Data (Privacy Guidelines*) serve as a reference point throughout the analysis. This paper aims at informing the further development of policy guidance by the WPISP in this area, that will be provided in a separate document, jointly with conclusions of the paper developed by the WPIE on business and government applications of RFID, economic impacts, and government policies to develop and diffuse RFID and related technologies.[4]

The first section of this paper aims to provide an understanding of RFID which is a broad and somewhat vague concept used to refer to technologies that enable data collection, through use of contactless electronic tags and wireless transmitters (readers), for identification and other purposes. The second section focuses on information security and privacy issues related to RFID that are already present or likely to be raised in a three to four year time-frame as well as on possible solutions to address them.

Although RFID is seen as a subset of sensor-based computing, this paper does not address this broader category that also encompasses other technologies collecting information from the environment without tag devices. Nor does the paper examine issues that may arise when RFID becomes ubiquitous, is used in a manner that is not anticipated today, or in connection with other sensor-based technologies. These issues will be a topic for future work.

4 See DSTI/ICCP/IE(2007)6 and 7 presented at the WPIE meeting in May 2007.

1. UNDERSTANDING RFID

RFID has been described as the "world's oldest new technology". Its invention can be traced back to the 1940s with applications related to the "friend or foe" identification of military aircrafts. The first commercial applications appeared in the 1960s in the area of electronic article surveillance to fight against product theft; an application that is still very much used today. Advances in semiconductor technologies led to significant improvements of the technology. Within the same time-frame, commercial success of the marketed applications generated a dramatic reduction of cost and an ever-increasing interest from businesses.

There are many indications that the proliferation of applications using RFID technology is only at its beginning. Figures provided by market analysts predict a huge market increase over the coming decade. According to a Gartner study (2005), the RFID market's revenue (hardware and software spending) grew over 33% between 2004 and 2005 (representing USD 504 million in 2005) and will be worth USD 3 billion by 2010. Research firm IDTechEx (2006a) predicts a global market for RFID including systems and services of USD 26.23 billion in 2016 (compared to an estimated USD 2.71 billion for 2006) and a total number of tags delivered of 585 billion, 450 times the amount of 2006. Benefits of RFID technology for business and individuals are very promising (OECD, 2006a).

One important driver for market growth today is that of improving traceability of goods in the supply chain in order to increase supply chain efficiency, reduce theft and fraud, and realise significant cost savings. In addition, many other types of RFID applications have been reported, and the use of RFID technology is now common in areas including passports, hospitals, transportation, ticketing, libraries, museums, counterfeiting, baggage tracking in airports and livestock tagging. With such widespread adoption, it is likely that RFID will affect business and government processes, as well as the lives of individuals and consumers. As stated by the European Article 29 Working Party[5] (2005), "the specific functions that RFID tags can deliver in different sectors is also increasing and its possibilities are just beginning to emerge".

The use of RFID in the global supply chain requires a high degree of reengineering of complex business processes and it is not expected that RFID will become ubiquitous in the short-term at a level that would considerably impact society (*e.g.* item-level tagging or generalised usage of RFID after the point of sale, etc.). However, it is likely that the number of RFID applications will increase in many different areas, as the aforementioned figures suggest, and that the technology will evolve, enabling new applications.

One of the main findings of the ICCP Foresight Forum on RFID in October 2005 was that privacy and security are key challenges to the widespread adoption of RFID that need to be addressed. Understanding the technology, its capabilities and limitations, helps prevent understating or overestimating these risks.

5 . The Article 29 Working Party is the independent advisory body on data protection and privacy in the European Union. It gathers representatives from European data protection authorities. It was established by the Article 29 of the European Directive 95/46/EC.

This section provides a general and conceptual overview of the technology, the characteristics of tags, readers and the environment in which RFID technologies operate.[6]

1.1. A broad concept for a complex technology

RFID is a convenient and popular concept to qualify a technology with many facets. The expression "Radio-Frequency Identification" refers to two dimensions of the technology: *i)* a technical aspect: radio-frequency and *ii)* a particular function enabled by the technology: identify objects, animals or people carrying or embedding a tag. In so doing, the term RFID can be misleading: RFID communication is not always based on radio-frequency communications – it can use electromagnetic induction – and RFID can be used in contexts in which identification is just one function among others. For example, RFID enables tracking, a function that has considerable economic and social implications. Further, some RFID tags can write data received from a reader onto their memory, as do some tags equipped with sensors to monitor environment conditions such as light, sound or temperature.

RFID would be better described as a technology that enables data collection with contactless electronic tags and wireless transmitters (readers) for identification and other purposes. Such a broad definition does not necessarily reflect the terminology used in international standards. Nonetheless, it grasps the breadth of RFID technologies.[7]

As described below, other factors cloud a clear definition of RFID. For example, different types of technologies may be called RFID, either because they are based on radio communications, or operate in the usual RFID frequency range, or perform similar functions. Sometimes, businesses associate the technology, products or services they implement with the "RFID" acronym for marketing or public image purposes and this can skew public perceptions.

Understanding technology capabilities or limitations helps avoid unreasonable fears or unrealistic expectations.

RFID includes a software dimension with, for example, middleware components, back-end applications, communication protocols, etc. This dimension should not be neglected for a good understanding of the technology. However, the specificity and novelty of RFID lies in its hardware component (*e.g.* RFID tags, readers and electromagnetic communication) which are governed by the laws of physics, like any other hardware components. This is a major difference with software technologies, such as data mining for example, which are governed by rules developed by engineers in the form of standards and as such, are mostly limited by their imagination.

The experience of information technology has been that many limitations are transient and overcome through new technological developments. For most information technologies, engineers have not yet approached theoretical limits, as exemplified by the Internet. This suggests that RFID technologies will also experience technological progress, that the current limitations of RFID technology will diminish and that some technology features that are limited and therefore acceptable today will, sooner or later, face technological breakthroughs that will remove these limitations. Tag and reader size, along with communication range are typical examples. Admittedly, technologies will continue to evolve, but the laws

6. For a more detailed understanding of how the technology works, see, for example, Finkenzeller, 2003 and Lahiri, 2005.

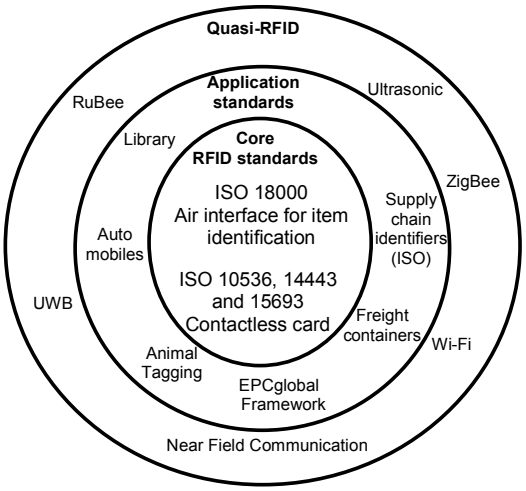
7. For example, systems based on ISO 14443 standards are often not called RFID systems by experts but "Contactless integrated circuit cards", which is the ISO standard's terminology. However, what everybody calls today an "RFID passport" is based on ISO 14443. Such distinctions are very subtle for the general public.

of physics will also continue to set theoretical limits on what the technology can and cannot perform. It is therefore important to understand where these boundaries set by laws of physics lie. Clarifying what characteristics of RFID are subject to technological evolution or not helps define adequate policy and may remove obstacles to acceptance by individuals without impeding innovation.

For scientists and other technical experts, RFID is an information technology defined in many standards. For example, the set of standards adopted by the International Organization for Standardization (ISO) is considered by some to be RFID's main reference.[8] Several other standards apply to RFID, the list of which evolves continuously.[9]

Some technologies are occasionally presented as alternatives to RFID. One could view these as variations of the concept, or "quasi-RFID". They include Near Field Communication (NFC), RuBee, ZigBee, Wi-Fi, Ultra Wide Band (UWB) and innovations such as HP's "Memory Spot". Some of these technologies (*e.g.* RuBee) are not fully standardised. Others (*e.g.* NFC) are not identified as RFID by their promoters for reasons that may include public perception considerations. Yet others (*e.g.* Wi-Fi) are related to RFID from a functional perspective rather than a technical one.[10]

Figure 1. RFID standards, from the core to the boundaries of the concept
See Annex I and II for the references of the standards



1.2. Hardware components

Tags and readers are core hardware components of an RFID system.

8 . ISO standards include the air interface standards for item identification (ISO 18000 series) and the close-coupled, proximity and vicinity contactless cards standards (ISO 10536, 14443 and 15693). Several other ISO standards are application-specific, such as animal tagging standards (ISO 11784, 11785 and 14223) or the automatic freight container identification standard (ISO 10374). ISO standards often relate to different data structures used, such as the "data model for use of radio frequency identifier (RFID) in libraries", currently under development (ISO/NP 28560), or ISO 15963, "unique identification for RF tags" and other supply-chain related ISO standards (Oehlmann, 2006; Rees, 2004).

9 . Annex I provides a brief non-exhaustive overview of RFID standards.

10. Annex II provides an overview of the capabilities of these technologies.

1.2.1. Tags

Tags, also called transponders, can be classified according to a number of characteristics. A distinction is usually made between passive and active tags. Memory capacity and read-write capability are also useful distinguishing factors. Tags of the future will certainly introduce new possibilities. Tags should not be confused with the objects to which they are attached or in which they are embedded.

1.2.1.1. Passive or active tags

Passive tags do not have an internal source of power and cannot send outbound signals without receiving energy from a reader. They use an incoming radio frequency signal to power up an integrated circuit and transmit a response. Their antenna must be able to both receive power from an incoming signal and transmit an outbound signal (see below). They can be as small as 0.15 mm (Figure 2, picture on the right) and as large as a postcard, depending to a large extent on the size of their antenna. Their lifetime is almost unlimited: they can be reactivated years after being manufactured. Systems operating in the Low Frequency (LF) and High Frequency (HF) bands are passive systems. Systems operating in the Ultra-High Frequency (UHF) and microwave frequency bands can be passive or active systems.

Figure 2. RFID tags
Left: Item level passive tag
Right: Hitachi µChip compared to grains of salt (0.15 x 0.15 x 7.5 micrometers without antenna)

Source: Left: Metro Group Future Store website, right: Hitachi. [11]

Unlike passive tags, active tags have their own energy source, to power the integrated circuit, which generates an outgoing signal. Compared to passive tags, this additional energy provides active tags with several advantages and has several consequences, in particular (QED Systems, 2002):

- *Signal strength*: active tags can receive very low power signals from the reader. Passive tags require very strong signals from the reader, up to 1 000 times the power level necessary for active tags, and the strength of the signal they return is very low.
- *Initiation of the communication*: passive tags require a reader to first send a signal in order to communicate. Active tags can initiate the communication. For example, active tags can be programmed to send data (*e.g.* environmental sensor data) at specific times or when external events occur.
- *Tag-reader distance* is shorter for passive tags than for active tags. Tags can be read from a few centimetres away, to a few meters for passive tags, and up to hundreds of meters for active tags. Reader distance depends on various factors including the antenna's size. In order to double the reading distance of a passive tag, 16 times more power is required from the reader. By contrast, doubling the reading distance of an active tag only requires four times the power, since active tags benefit from their onboard battery.

11. The Hitachi chip is capable of transmitting a 128 bits (1038) unique ID number. It was used in the 22 million tickets issued for the 2005 World exposition with a 0.001% incidence of ticket recognition error. See www.hitachi.com/New/cnews/060206.html.

- *Environmental sensors*: passive and active tags can be associated with sensors to monitor the environment. However, passive tags can only use their sensor capability when a reader is sending a signal. By contrast, active tags can continuously monitor the environment, regardless of the presence of a reader field, store sensor data and timestamp information, and send it to a reader at a specific time or when requested.
- *Read/Write capacity*: technology is available to enable passive and active tags to store information sent by the reader. However, energy constraints typically limit data processing features for passive tags which, in addition, do not usually feature large memory space. Data processing capabilities for active tags can include the use of more complex protocols, which limits, for example, transmission errors.

On the other hand, active tags' *lifetime* is limited to that of their battery, which itself depends on how often the tag is requested to process and/or send information.[12] Last, but not least, active tags are *larger* and *more expensive* than passive tags.[13] It is anticipated that in order to realise the full potential of item-level tagging, and thus enabling RFID to become more widespread, tags must become much cheaper than the current pricing. Some experts estimate cost-effective tags will enter the market in a couple of years, and will have a major impact on the efficiency and economy of the retail industry.

1.2.1.2. Tag Memory capacity

Another distinction between different types of tags can be made according to the memory capacity of the tag's chip. Typical memory capacity of a cheap passive identification tag is 64 bits to 1 kilobyte. More expensive tags, typically active tags, can hold more than 128 kilobytes.[14] Basic item-level tags used for item-level retail tagging usually hold 96 bits (12 bytes) of data used just to contain the product's unique identifier.[15] Passport RFID tags typically store the traveller's biometric (face image and, optionally, iris data and/or fingerprint) and passport data into a 32 kilobytes memory chip.

1.2.1.3. Tag memory capability

Read-only tags are "burned" once with information that can be accessed afterwards by readers but cannot be overwritten or erased. However, data stored in read-write tags can be read, modified and erased by readers. Some critics find this to be a mislabelled term as readers have in this case the capability to both read and write.

Read-only passive tags with low memory capacity are well-suited for item, case or pallet-level tagging of goods. When the chip only stores a unique identifier, all other information associated with the item can be stored in databases. Therefore, this solution does not require being able to write onto the chip, but instead, requires a connection to the database when information beyond an item number is needed at a given collection point in the supply chain. Different chips used in different contexts can have much more memory capacity and read/write capacity. This can be useful, for example, when no connectivity to a database is possible or desirable, when the tag is re-used, or for applications with purposes beyond simple identification (FTC, 2005, p.7). For example, to contain an up-to-date history of a patient's body temperatures, hospital wrist bands would need to have read/write capability. Finally, some chips may be hybrid, offering some memory space for read-only operations and some memory space for both reading and writing.

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12 . In some configurations, an active tag could live up to 10 years on its battery.

13 . EUR 5 to hundreds of EUR versus under EUR 0.50 for passive tags (IDTechEx, 2005).

14. 128 kilobytes may seem very small compared to today's basic gigabytes USB key or mp3 players. However, the first version of the IBM PC launched in 1981 was shipped with only 16 kilobytes memory expandable to 256.

15. See Annex IV for a description of EPCglobal electronic product code structure.

1.2.1.4 Auto-ID Labs/ EPCglobal classification of tags

The Auto-ID Labs and EPCglobal have developed a tag classification. This classification has been refined with time (Table 1) and is often referred to in literature on RFID.

Table 1. Auto-ID labs RFID tags class structure

Class	Description
0	ID only, programmed at fabricator; read-only in the field
1	ID only, Write Once, Read Many (WORM) in field
2	Class 1, plus additional user memory and/or encryption
3	Class 2, plus battery-assist and sensors
4	Active (battery-powered) tags
5	Class 4, plus reader capability

Source:. EPCGlobal

Table 2. Differences between Active and Passive RFID technologies

	Passive RFID	**Active RFID**
Tag Battery	No	Yes
Tag Power Source	Energy transferred from the reader	Internal to tag
Availability of Tag Power	Only within the field of an activated reader	Continuous
Required Signal Strength from Reader to Tag	High (must power the tag)	Low (only to carry information)
Available Signal Strength from Tag to Reader	Low	High
Communication Range	Short or very short range (3m or less)	Long range (100m or more)
Tag lifetime	Very long	Limited to battery life (depends on energy saving strategy)
Typical tag size	Small	Large
Multi-Tag Collection	- Collects hundreds of tags within 3 meters from a single reader - Collects 20 tags moving at 8 Km/h or slower	- Collects 1000s of tags over a 28 000 m^2 region from a single reader - Collects 20 tags moving at more than 160 km/h
Sensor Capability	Ability to read and transfer sensor values only when tag is powered by reader; no date/time stamp	Ability to continuously monitor and record sensor input; data/time stamp for sensor events
Data Storage	Small read/write data storage (Bytes)	Large read/write data storage (KBytes) with sophisticated data search and access capabilities available
Typical applications	Rigid business process, constrained asset movement, basic security and sensing. Simple cargo security (one time tamper event detection), substantial business process impact. Individual item tagging, luggage, boxes, cartons, pallet, printed labels	Dynamic business process, unconstrained asset movement, security/sensing, data storage/logging Intermodal container, rail car Area monitoring, high speed multi-tag portals, sophisticated cargo security applications (continuous tamper detection, date/time stamp), electronic manifest
Cost	Low (below 0.5 EUR)	High (above 5 EUR, up to hundreds)

Source: adapted from QED Systems, 2002.

1.2.1.5 Future tags

Research continues in the area of RFID tags. For example, some analysts predict large success for chipless RFID tags, which do not contain a silicon chip and can be printed directly on products and packaging at very low cost (IDTechEx, 2006b).

1.2.2. Readers

Readers, which are often called "interrogators", are complementary to tags and can be as technically diverse as tags. In a basic scenario, a reader sends a pulse of energy "to the tag and listens for the tag's response". The tag detects this energy and sends back a response that contains the tag's serial number and possibly additional information. In simple RFID systems, the reader's energy pulse functions like an on-off switch. In more sophisticated systems, the reader's radio-frequency signal can contain commands to the tag, instructions to read or write tag memory, and even passwords."[16] The reader can emit the signal permanently, thus always searching for tags present, or the signal can be triggered by an external event such as an operator switch, to save energy and minimise interferences.

Readers' sizes depend on many parameters and vary from the size of a coin to that of a personal assistant or personal computer (Figure 3). Readers can embed GPS capabilities and connectivity to information systems and networks. The cost varies from USD 100 to USD 1 000 for readers of passive tags to USD 1 000 to USD 3 000 or more for readers that communicate with active tags over long distances (RFID Journal, n.d.).

Figure 3. RFID readers

Handgun type reader (left), computer style reader (centre) and ultra small RFID reader (12 mm x 12 mm x 2 mm) (right)

Sources: Intermec (left), Alien Technology (center) and Innovision (right).

1.3. Electromagnetic communication

The transmission of information between tags and readers relies on the laws of electromagnetism. The laws of physics that apply to RFID are the same as those that apply to any radio system: to operate, the receiver on the tag and reader must be able to detect a signal transmitted by the respective reader or tag above the level of background environmental noise.

Designers, developers, vendors and operators of RFID systems must contend with a large number of parameters for the systems to be operational. Frequency of operation and the physics of energy and

16. Garfinkel, 2005, p.20.

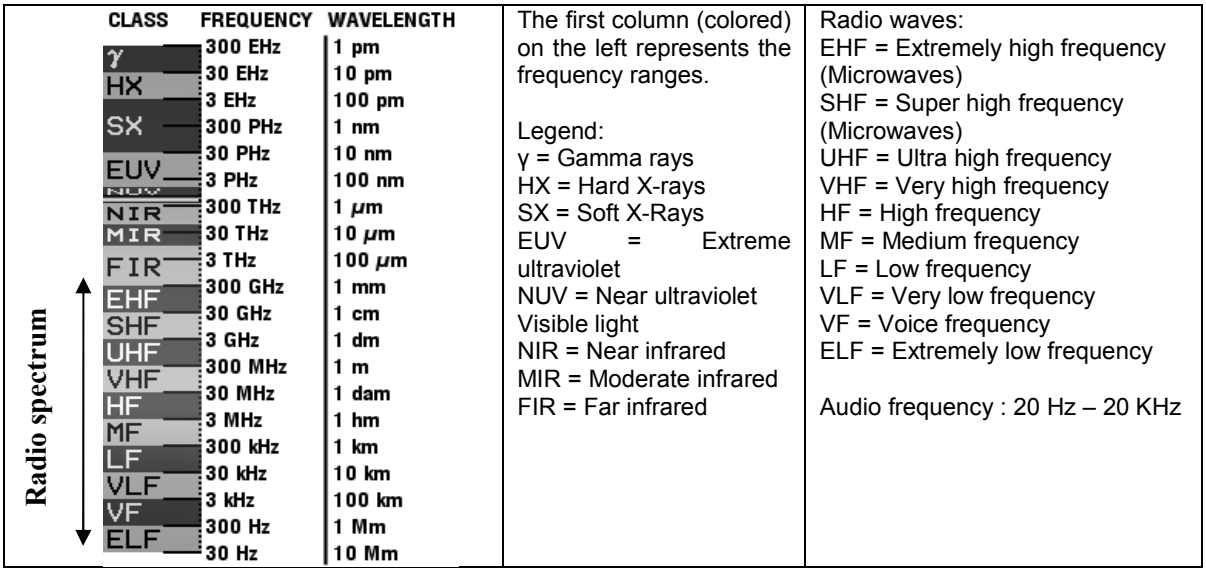
information transmission are critical to RFID systems' functioning. Other important factors include power level, antenna, interferences, reflection, absorption and mode of communication (half or full duplex). All these elements determine the range of operation of a system.

1.3.1. Frequency range

Each RFID system operates within a given frequency range. The frequency range in which a RFID system operates determines key capabilities and limitations in the system, summarised in Table 4 below. For example, the higher the frequency, the shorter the wavelength and the harder for a radio signal to go around or through obstacles to reach a receiver. Some of these limitations are interwoven with other technical characteristics introduced below.

The term "Radio-Frequency" used in RFID refers to the emission of energy within the radio frequency spectrum.[17]

Figure 4. Electromagnetic Spectrum Ranges, Frequencies, Wavelengths and energies



Note: EHF and SHF are sometimes considered to be not part of the radio spectrum and form their own microwave spectrum. The radio spectrum is between 9 KHz and 300 GHz.

Source: Wikipedia, "Electromagnetic Spectrum".

Governments have regulated and managed radio spectrum use in terms of operating frequency and power since the early days of radio communications.[18] One objective of such regulation is to share limited radio spectrum resources. Another is to minimise the interference that may be caused by one radio system

17. The electromagnetic spectrum is the range of all possible radiations (see Figure 4). The radio frequency spectrum is a portion of the electromagnetic spectrum in which electromagnetic waves can be generated by alternating current fed to an antenna. Radio or electromagnetic waves consist of oscillating electric and magnetic fields generated by an antenna supplied with electric current. The distance between two consecutive waves is called the wavelength. The number of complete oscillation of wavelength (cycle) in a second is represented by the frequency, measured in hertz (Hz), kilohertz (KHz), megahertz (MHz) and gigahertz (GHz). For example, 132 KHz = 132 000 cycles per second.

18. The first international discussions on the regulation of radio communications took place in 1903 in Berlin. The first radio conference took place in Berlin in 1906.

to another. For example, it is important that RFID systems do not interfere with radio and television, mobile radio services (police, security and emergency services), mobile phones, as well as marine and aeronautical communications. As noted below (1.3.3), for health and safety reasons, regulation also limits power levels.

Table 3. Frequencies and regions

Low Frequency (LF) 30-300 kHz	125 – 134 kHz in Canada, Europe, Japan, and the US
High Frequency (HF) 3-30 MHz	13,56 MHz in Canada, Europe, Japan, and the US
Ultra-High Frequency (UHF) 300 MHz-3GHz	433.05 – 434.79 MHz in most of Europe, US, and under consideration in Japan 865 – 868 MHz in Europe 866 – 869 and 923 – 925 MHz in South Korea 902 – 928 MHz in the US 918- 926MHz in Australia 952 – 954 MHz in Japan, for passive tags starting in 2005
Microwaves 2-30 GHz	2400 – 2500 and 5.725 – 5.875 GHz in Canada, Europe, Japan and the US

Source: US Department of Commerce, 2005b.

RFID systems operate at Low Frequency (LF), High Frequency (HF), Ultra High Frequency (UHF), and Microwave frequency ranges. Unlike some radio communications systems that operate at licensed frequencies (such as mobile telephony or television), RFID systems operate at specific unlicensed frequencies that are not fully harmonised internationally, in particular in the UHF and microwave ranges. Different frequencies for RFID in different regions can be challenging for those who advocate the deployment of global RFID applications, although technical solutions can cope with a certain level of divergence of frequencies (See Table 3).

1.3.2. Electromagnetic induction and radio waves

A conductor supplied with electric current radiates energy in the form of radio waves. It also produces a magnetic field around it that can be used to generate electricity by induction. Induction is the creation of electric current in a conductive material (usually a coil) presented within a changing magnetic field. To transmit energy and information to a remote device, RFID systems operating at Low Frequency and High Frequency rely on electromagnetic induction (or "inductive coupling") and RFID systems operating at UHF and microwave frequencies rely on radio waves (or radio communications).[19]

19. Induction provides for the operation of electrical generators, induction motors and transformers. The *induction* phenomenon appears in the area between a reader antenna and less than one wavelength of the radio-frequency wave emitted by a reader antenna. In the RFID context, this region is often called "near field". By contrast, energy transfer in a *radio communication* system takes place using propagation of radio waves, just like for a television, mobile phone, radar, and other radio communications. The region in which such propagation happens is often called "far field" (as opposed to the "near field" region where a magnetic induction phenomenon would take place). Consequently, induction RFID is sometimes termed "near field technology" and radio RFID is sometimes called "far field technology". However, contrary to what this terminology evokes, the primary distinguishing factor is not the range of operation, but instead, the physical phenomenon that is taking place. Neither does it mean that communication based on electromagnetic induction can take place in the whole "near field" area. Many additional factors limit the actual communication range of electromagnetic induction systems to a much shorter subset of the theoretical "near field". More on the differences between electromagnetic induction and radio waves RFID in Langheinrich, 2007.

Induction and radio waves are two radically different, but related, physical phenomenon that were discovered by a number of scientists in the 19th century. For RFID engineers, they correspond to two very different engineering areas with different capabilities, limitations (*e.g.* operation range) and challenges to address (*e.g.* interferences, absorption, health issues, etc.). A communication system based on induction cannot be transformed into a radio communication system just by changing the frequency of operation and the size of the antenna. There is no simple method to go from magnetic induction to radio wave propagation without reengineering the whole system. In the same way, there is no technological link between an oil lamp and an electric lamp, even though they perform the same function of providing light. They are not the same technology; they face different constraints and do not produce the same light.

1.3.3. Power level

The signal transmitted by readers and tags using radio waves is transmitted at a certain power level, measured in watts. The higher the transmitted signal power in the direction of the receiver, the greater the probability that the receiver will be able to detect it against "background noise". However, higher transmission powers may pose increasing threats to human health: radar, for example, usually operates at very high energy levels and can be dangerous to a person directly in front of an antenna. High power levels also increase the risk of interference with other radio-sensitive equipment. Government regulation in all countries imposes limitations on power levels to safeguard people's health and prevent interferences. Magnetic induction systems obey the same rules, although in practice short operating distance compensates low power coils on readers.

1.3.4. Antenna

Tag and reader power level can be considerably enhanced by the nature of their antenna and in particular its design and orientation. Low gain[20] antennas emit radiations in all directions equally (omnidirectional). High gain antennas radiate in particular directions (unidirectional) with a longer range and better signal but must carefully be aimed towards a particular direction. When either the transmitter or the receiver is in movement, it may not be practical to use directional antennas at both ends of the communications link. Antenna design and orientation also influences tag and reader sensitivity.[21]

Tags' and readers' antenna sizes are also a key difference between induction and radio wave RFID systems.[22] In general, electromagnetic induction tags require a smaller antenna[23] than radio wave systems. In some cases, radio tags are sold without an antenna and the size indicated by the manufacturer does not always reflect the size of the actual complete operational tag on an object.[24]

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20 . Gain, measured in decibel or db, is a measure of performance of an antenna in a given direction. It is expressed as a value relative to a theoretical reference antenna called "isotropic antenna".

21. Receiver sensitivity depends on the antenna gain and orientation, as illustrated by "fishbone" and parabolic dish antennas used in television reception. Orientation of the tags (and importantly their relatively small antennas) is sometimes more difficult to control than that of a television antenna. Often, tag and reader form factor is designed so that the user orientates the tag or the reader properly (*e.g.* tags in smart card and gun type readers) to compensate reading difficulties in basic systems.

22 . Radio wave propagation requires antenna systems that are typically half a wavelength of the operating frequency in size: 150 cm at 100 MHz, 15 cm at 1 Ghz, 5 cm at 2.5 GHz, 2.5 cm at 5.8 GHz.

23 . The "antenna" of an inductive coupling communication system is in fact a coil that generates a magnetic field, as in a wire electrical transformer.

24. The Hitachi μChip tag in Figure 2 (pictured on the right) does not include an antenna (Hitachi, 2003).

1.3.5. Interferences, attenuation and reflection

As noted above, communications of RFID systems can interfere with other RFID systems, in particular when the transmission power is high. Inductive coupling systems are less susceptible to interference because of higher signal attenuation (see below 1.3.7).

Low frequency signals penetrate liquids more easily because longer wavelength is less susceptible to attenuation. Therefore Low Frequency and High Frequency systems are better suited for tagging objects in environments containing water (like humans or animals). Metal stops radiofrequency signals and reflects them, creating interferences. Progress is being made regarding the management of interferences created by metallic environments. Low frequency magnetic coupling systems can communicate in a metallic environment under certain conditions.[25]

A wide variety of error-correcting coding techniques can be employed to try to mitigate the effects of noise. The greater the complexity of noise avoidance, mitigation and reduction techniques in data channel engineering, the greater the cost.

1.3.6. Half or full duplex communication

The level of sophistication of the communication depends on whether it is happening in half duplex or full duplex mode. In half duplex, the sender transmits a complete message and does not know if the message has been received until the receiver switches over and replies. In full duplex, both ends of the communication channel are sending and receiving at the same time, enabling real-time communication channel management and more sophisticated protocols. However, sophisticated protocols require more data processing capabilities on the tag side, which implies an increase in power consumption and a higher cost.

1.3.7. Range of operation

Two sets of laws limit the operation range of RFID systems: laws of physics and laws of governments (frequency and power regulations). Laws of physics can be expressed according to: *i)* the physics theory as expressed in mathematical equations; *ii)* experiments made in laboratory conditions and *iii)* experiences in an uncontrolled, real life environment. Depending on which of these three frames of reference is used, assessment of the operating range of RFID systems can be very different.

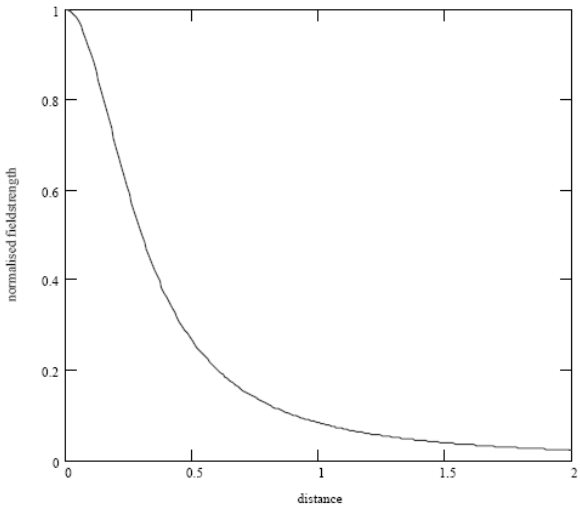
Ranges of operations resulting from controlled laboratory conditions are typically larger than ranges obtained in real life conditions. But they sometimes require settings that would be practically difficult to deploy in real life conditions. For example, an unrealistically heavy and large coil would be necessary to generate a large magnetic field capable of activating a High Frequency tag placed only a few meters away. In addition to complex engineering challenges, cost considerations play also a key role in the availability of equipment operating at enhanced operation ranges. Research is making progress and cost is evolving so that one may expect operation range to improve with time, within the boundaries set by the laws of physics.

The main factor to consider with regard to the range of operation of RFID systems is the type of technology used: communication based on electromagnetic induction is associated with a shorter read

25 . Information regarding the use of UHF tags in water and metal environments can be found in Desmons, 2006.

range compared with radio communication.[26] In addition, the range of operation of RFID systems depends on a number of factors including transmission power, receiver sensitivity, antenna gain and orientation, and interference. Natural and man-made "noise" interference plays an important role in radio communications: when distance increases, the level of natural noise remains stable, while the signal strength diminishes. Eventually, the overall noise level prevents detection. The communication range can be further shortened by additional man-made noise in the vicinity of the receiver.

Figure 5. Typical behaviour of the magnetic field strength versus distance (example), for a transmitting antenna with a diameter of 0.8 m.



Source: AIM Frequency Forum, 2000.

Following ISO standards terminology, inductive coupling systems are sometimes divided into proximity and vicinity systems. Proximity cards[27] are intended to be used in the 10 cm range (*e.g.* for use with a vending machine) and vicinity cards[28] inside the 1 m range (*e.g.* for opening a parking door without rolling down the car window; ICAO standard for biometric passports mandates the use of ISO proximity cards standard).

Figure 6. Range of operation

Frequency Band	System type	Communication range: 3 cm	10 cm	30 cm	1m	3m	10m	> 10m
LF	Passive	■	■	■	■			
HF	ISO 14443	■	■					
	ISO 15693	■	■	■				
UHF	Passive	■	■	■	■	■		
	Active	■	■	■	■	■	■	
Microwaves	Passive	■	■	■	■	■		
	Active	■	■	■	■	■	■	

Typical versus theoretical range attainable in a controlled environment

Source: *Atmel Applications Journal*, 2004.

26. Radio signal strength quarters every doubling of the distance travelled. The signal strength in magnetic induction is divided by eight every doubling of the distance travelled. See Langheinrich, 2007.

27. ISO 14443.

28. ISO 15693.

Active UHF and microwave tags have a considerably longer range of operation than passive tags, since the battery provides more power than what can be drawn from the radio wave signal.

In passive radio systems, the reader to tag signal is usually more powerful than the tag to reader one and can be detected or received over longer distances (see section 2.1. Information Security).

1.3.8. Summary table

The table below summarises and compares the limits of RFID according to frequency range. It also provides examples of different application areas in which either electromagnetic induction, or radio wave RFID, is likely to be found, as a consequence of the characteristics of each technology.

Table 4. Characteristics of RFID technologies

Parameter	Low frequency (LF)	High frequency (HF)	Ultrahigh frequency (UHF)	Microwave
Frequency range (see Table 3 for precise range per country)	30-300 kHz	3-30 MHz	300 MHz-3GHz	2-30 GHz
Transmission of energy and data	Electromagnetic Induction	Electromagnetic Induction	Radio Waves	Radio Waves
Reading range for passive tags (approx)	Typical : 20 cm. Maximum: 1.2 m	Typical : 20cm Maximum: 1.2 m	433 MHz : 100 m max 865-956 MHz : 0.5 to 5 m	Typical: 3 m Maximum: 10 m.
Moisture	no effect	no effect	negative effect	negative effect
Metal	negative effect	negative effect	no effect	no effect
Aiming of transponder during reading	not necessary	not necessary	sometimes necessary	necessary
Typical transponder shapes	glass tube transponders, transponders in plastic housings, smart cards, smart labels	smart labels, industrial transponders	smart labels, industrial transponders	large-format transponders
Typical application areas	access and route controls, brakes, laundry cleaners, gas readers, animal ID, car immobiliser	laundry cleaners, asset management, ticketing (ski, events, public transport), tracking and tracing, multi-access, library management, passports, payment card	palette tracking, container tracking	road pricing, container tracking, production control

Note: the influence of metal and liquids varies depending on the product. Reading range for active tags varies considerably according to the technology used.

Sources: adapted from BSI, 2005, p.23; Dressen, 2004; Metro Group RFID@Metro web site; Ward, 2006.

1.4. Software and network components

RFID tags and readers are often components of a broader RFID system, which, in turn, is a component of an enterprise information technology infrastructure, often interconnected with other information systems and networks, including via the Internet. Three types of RFID systems can be considered according to their level of connectedness with other systems:

- Standalone systems, not connected to other information systems and networks, including within the organisation.
- Closed-loop systems that track objects that never leave the company or organisation.
- Open-loop systems that involve multiple partners, like a retail chain and its suppliers.

As mentioned in the OECD paper on "RFID: Drivers, Challenges and Public Policy Considerations"[29], the information infrastructures associated with RFID, in particular with UHF RFID, will increasingly be accessed across IP networks, private intranets and the public Internet.

The notions of "RFID system" or "RFID network" do not imply that all the components included in such systems and networks are RFID specific. While tags and readers are obviously core RFID components, some of the other components are actually pre-existing, non-RFID technologies, systems, applications or protocols that either support RFID or are combined with RFID. At this early stage of the RFID policy debate, it is important to clarify which components are actually RFID or RFID specific and which components are not.

The efficiency of RFID systems within the broader IT infrastructure of an organisation depends on the capacity of an organisation's network to transport the flows of RFID information efficiently. Middleware components connect the core RFID elements to the enterprise back-end. They enable information to flow from the tagged object to the heart of the company information infrastructure. The proper implementation of middleware components sometimes represents considerable investment and efforts.

Standardisation and interoperability factors also play a key role in the implementation of RFID systems. This is important to recognise in a globalised economy where the supply chain spans across a range of partners who may be spread all over the globe. As noted above, considerable efforts have been made to leverage existing RFID and Internet technologies to create the standards and components for a global architecture capable of conveying object information in real-time as these objects progress through the production supply chain and beyond.

For example, the EPCglobal Architecture Framework includes a set of inter-related standards for hardware, software and data interface for improving the efficiency of supply chains through the use of Electronic Product Codes (EPCs). The EPCglobal Framework enables the sharing of tagged objects' information among trading partners in the global supply chain and tracking individual products in real-time. The Framework includes five categories of components: *i)* the Electronic Product Code (EPC), which identifies the tagged product,[30] *ii)* tags and readers, *iii)* middleware, which communicates the information that is read to EPC information services, *iv)* EPC Information Services[31], that allow trading partners to

29 . OECD, 2006a, p.18.

30 . See Annex IV.

31 . EPCglobal has recently ratified its open standard for EPC Information Services. See www.epcglobalinc.org/standards/EPCglobal_EPCIS_Ratified_Standard_12April_2007_V1.0.pdf

exchange EPC-related data through the EPCglobal network, and *v)* discovery services, including, but not limited to, the Object Naming Service (ONS), which can be queried with an EPC contained in an RFID tag to return the specific address of the application associated to the product code.[32] The EPCglobal Architecture Framework also includes the security framework for the system's authentication, data protection, and access control.

Other numbering schemes have been proposed for identifying objects, including the IPv6 numbering scheme, which is large enough to handle as much as 430 quintillion identifiers.[33]

32 . The ONS is a mechanism to discover information about a product and related services. The architecture and functioning of the ONS is very similar to that of the Internet's Domain Name System (DNS). When queried with an EPC code, the Root ONS directs the query to the servers of the EPCglobal Network member associated to the EPC code. The querying party can subsequently – and independently of the Root ONS – get the requested information from the EPCglobal Network member's server. The data that the Root ONS maintains is limited to *i*) an EPCglobal issued number (EPC Manager ID) that identifies an EPCglobal Network member and *ii*) the server identifier for that EPCglobal Network member. EPCGlobal contracted VeriSign to operate the authoritative root for the EPC network on behalf of EPCGlobal. See EPCglobal, 2005b, Section 7.3.

33 . 3.4 x 1038 addresses. On the use of IPv6 as a numbering scheme for RFID, see *RFID Journal*, 2003; Vadhia, 2004; Le Pallec, 2005.

2. INFORMATION SECURITY AND PRIVACY

RFID technology is at a stage of development where privacy and security have been identified as challenges for its widespread adoption.

Many RFID experts acknowledge that widespread deployment of RFID will take time but that applications that are being deployed and standards that are being designed and adopted are likely to influence the infrastructure to be in use in the next decades.[34] For security expert Ari Juels[35], "the RFID designs of 2005 – with all of their features and drawbacks – may be the predominant ones in 2020." Similarly, participants in the OECD ICCP Foresight Forum recognised that privacy and security should be integrated in the RFID infrastructure before widespread deployment of the technology, rather than having to deal with it afterwards, as has been required for the Internet. It was highlighted that for the Internet, security was "bolted on" afterwards instead of being "baked in" and that history should not be repeated with RFID. Such a consideration holds true also with regards to privacy protection.

There seems to be an agreement among experts that RFID security and privacy should be an urgent priority for all stakeholders in order to prevent large scale opposition by consumers and individuals, and facilitate the successful roll-out of future RFID systems. "The collection and use of personally identifiable information through RFID technologies represents a key public policy challenge to the deployment and use of RFID technologies."[36] As stated by the European Commission in its Communication on RFID in Europe, "a clear and predictable legal and policy framework is needed to make this new technology acceptable to users." Some consumer organisations consider that, in areas such as retail, there is a potential for public backlash regarding RFID and draw a parallel with such a backlash that happened in the area of genetically modified food.[37] At stake is the capacity of these frameworks to remove obstacles to the acceptance of RFID technology by individuals and to ensure privacy and security in new environments.

2.1. Information security

Academic researchers and security experts, often quoted by the press, have highlighted both theoretical and concrete security weaknesses discovered in some already widespread RFID systems. Annex III provides a selection of exploits which suggest that RFID systems can be vulnerable to security attacks, like other information systems, and also that RFID technology is still in its early days.

Some successful attacks targeted RFID products or applications deployed on a large scale[38] and/or could harm businesses and individuals (*e.g.* hotel keys, implantable chips). However, they relate mostly to lower cost RFID products that include either limited or no security feature at all. There are fewer reports of successful attacks against higher cost RFID products that contain sophisticated security features. Therefore it would be misleading to make general statements about the security of all RFID technologies based

34. US FTC, 2005, p.11, 15; EPCglobal, 2004a.

35. Juels, 2005b.

36. US Department of Commerce, 2005b.

37. Lace, 2004.

38. *E.g.* Texas Instrument "Digital Signature Transponder".

essentially on experiences with the use of low cost RFID products. To come to any conclusion, a more specific and detailed assessment is necessary.

This section provides a general overview of RFID security challenges and possible solutions. It is not intended to be detailed or comprehensive. In this section, threats are described in very general terms with a few specific examples detailed in Annex III and general risks associated with RFID systems, as well as some of the general security weaknesses that RFID systems might have and that might be exploited, are described in business terms.

2.1.1. Typology of risks

Risks result from threats posed by vulnerabilities or weaknesses that can be exploited and cause adverse effects. There are many ways to describe risks to RFID systems. For example, the US National Institute of Standards and Technology (NIST) Guidelines for Securing RFID Systems (2007) consider risks related to business process, business intelligence, privacy and externality risks (Table 5).

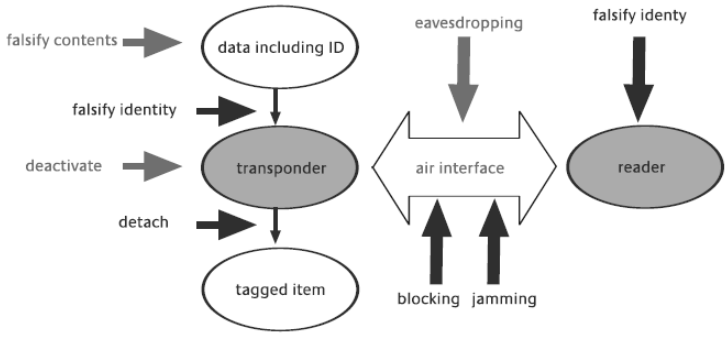
Table 5. Typology of risks by the US National Institute for Standards and Technology

Business process risks	Direct attacks on RFID system components potentially could undermine the business processes the RFID system was designed to enable.
Business intelligence risks	An adversary or competitor potentially could gain unauthorized access to RFID-generated information and use it to harm the interests of the organisation implementing the RFID system.
Privacy risks	Personal privacy rights or expectations may be compromised if an RFID system uses what is considered personally identifiable information for a purpose other than originally intended or understood. The personal possession of functioning tags also is a privacy risk because it could enable tracking of those holding tagged items.
Externality risks	RFID technology potentially could represent a threat to non-RFID networked or collocated systems, assets and people.

Source: NIST, 2007.

The German Federal Office for Information Security (BSI) classifies basic types of attacks based upon the data/tag relationship, tag/tagged item relationship and tag/reader relationship (see Figure 8).

Figure 7. Basic types of attacks relating to data/tag relationship, tag/tagged item relationship and tag/reader relationship



Note: transponder can be used as a more technical term for a tag.

Source: BSI, 2005.

BSI also presents types of attacks according to their purpose: spying, deception, denial of service, protection of privacy[39] (Table 6).

Table 6. Types of attacks according to their purpose

	Spying	Deception	Denial of Service	Protection of privacy
Falsifying content		■		
Falsifying tag identity		■		
Deactivating		■	■	■
Detaching		■		■
Eavesdropping	■			
Blocking		■	■	■
Jamming		■	■	■
Falsifying reader identity	■			

Source: BSI, 2005.

Security challenges raised by RFID can also be structured according to the traditional dimensions of information security: loss of availability, integrity and confidentiality.[40] Examples below help understand the nature of the general risk associated with each of these security dimensions and illustrate the potential consequences of attacks. Examples refer to transportation systems (*e.g.* subway access cards), supply chains (*e.g.* tracking of containers, pallets and goods), retail (*e.g.* inventory management, check out, warranty services, medicine tagging), identity documents (*e.g.* passports) and vehicle access or ignition. These applications were not chosen because they are more risky than others but rather because they are common and easy to understand.

Many of the threats and vulnerabilities to RFID systems are common to all information systems. The main component in RFID systems that distinguishes them from others is the transmission of information between tags and readers. But risks related to other, more traditional, components of the system should not be omitted. It is important to note that many security risks become privacy risks when information related to identified or identifiable individuals is involved.

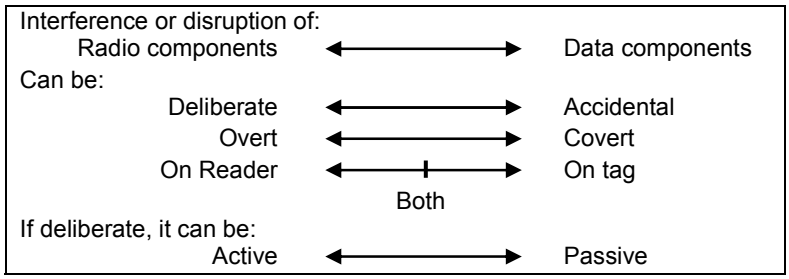
2.1.1.1. Risks related to tags and readers

Many events can disrupt a RFID system. They can be categorised as interference or disruption of either the hardware, or the radio, or the data components of the system. Interference or disruption to the physical components of readers and tags can be deliberate or accidental, overt or covert. Accidental or deliberate disruption of the radio components can be of the reader or tag or both. Deliberate attacks can be

39 . According to BSI, an attack aiming at protecting privacy could be carried out by an individual believing that his privacy is threatened by the RFID system. Presumably, such an attack would target the RFID system and not the information that may be contained within that system. The RSA Blocker Tag (Juels, 2003) may be an example of a means to perform such an attack.

40. Availability, integrity and confidentiality are useful conceptual distinctions but, in reality, the separation is often artificial: a failure in one dimension can have consequences in another and therefore the concepts are interdependent and overlapping. Accountability and audit are often associated to these dimensions. They ensure allocation of responsibility for a security control and provide means for monitoring and measuring its effectiveness.

active or passive. Interference or disruption on the data components can be of the tag or reader data or both.



As mentioned earlier, RFID systems, as any information system, include software and hardware components. However, their main specificity lies in the hardware components, namely the tags and readers as well as the methods of energy exchange they use to communicate.

- Availability

Availability is the assurance of timely and reliable access to data services for authorised users. It ensures that information or resources are available when required. For instance, Denial of Service (DoS) attacks target the availability of a system. Consequences of disruption of availability of typical RFID systems could be, for example, delays in processing identity documents (*e.g.* disabled RFID passports) thus possibly disturbing airport border control processes, preventing individuals to access public transportation systems (*e.g.* subway access card) or work premises (*e.g.* access control cards), preventing an owner to access his/her vehicle (*e.g.* RFID car keys), preventing automatic processing of medicine information in a health context leading to dangerous errors for patients (*e.g.* medicine tagging).

Threats to the availability of the physical components of a RFID system can be overt or covert. Overt attacks on tags include cutting the electrical circuit on the tag, detaching the tag from the tagged item, discharging the battery of an active tag, or masking the antenna (shielding) with a conductive material or paint. Such strategies could be pursued to evade anti-theft RFID systems in stores. They could also be used for privacy protection purposes: companies have developed RFID blocking wallets (for RFID credit cards) and passport cases that are presented as privacy protective apparel.[41]

Covert attacks can be conducted by overloading receiving components to stop them from functioning or to destroy them, for example by subjecting a passive tag to a high energy field in close proximity. Hackers have demonstrated that a strong energy field generated by an inexpensive, modified, single-use camera flash light can produce this result.[42]

A RFID system can also be compromised by overwhelming the wanted signal at the receiver side (blocking), by preventing the receiving device from decoding the signal (masking) or by disrupting the data communication (jamming). For example, creating an unwanted signal noise in one or all of the RFID system receiver circuits could prevent the wanted reader signal being detected by the tags. A signal can also be tailored to prevent the reader or tags from synchronising with other transmitters, therefore

41. For example, see DIFRwear website.

42. RFID Zapper, see https://events.ccc.de/congress/2005/wiki/RFID-Zapper(EN).

disrupting the wanted signal decoding process.[43] Jamming noise sources can be accidental man-made interferences caused by machines and other electrical equipment. An attacker can also deliberately create jamming noises. In such cases, an unwanted signal competes with a wanted signal so that it is the relative power and geometry (obstacles, distances and orientation) of the wanted transmission versus the unwanted one that determines the degree of disruption. The complexity of this situation is such that a deliberate attack can be difficult to detect. Therefore it might be carried out covertly and be undetected by the RFID system. Both RFID systems using active and passive tags are susceptible to these threats.

- Integrity

Integrity is the underlying assurance that data has not been altered during a transmission from the point of origin to the point of reception. Consequences of loss of integrity in common RFID systems could include, for example, delays and misdirection in the supply chain or confusion in retail operations due to corrupt or erroneous information. In some cases, loss of integrity generates loss of availability. For example, corrupt access cards would not enable individuals to access the transportation system. If car ignition key information is altered, then it is likely that access to the car will be impossible.

A man-made unwanted signal can also be used to inject a false signal, compromising the system's integrity. Reader identity could be falsified to access, modify or kill a tag. For example, a "kill" command could be sent before the tag is read by the legitimate reader and lead to fraud in a retail context, or disrupt supply chain information. Tag cloning and emulation could be used to falsify the identity of goods, and, for example, replace them with cheaper item identifiers. Automobile thieves could clone car keys. Cloned credentials could enable individuals' identity to be stolen to enable access to restricted areas in the work environment. Cloning could lead to identity theft if the cloned credential can be used as a proof of identity.

Attacks based on deception can take advantage of cloning and emulation techniques. In 2005, researchers demonstrated the feasibility of a cloning attack of the "Digital Signature Transponder" chip, which secures over 6 million ExxonMobil SpeedPass payment transponders and over 150 million automobile ignition keys. They cloned the chip using relatively cheap equipment, purchased gasoline at an ExxonMobil station multiple times and disarmed a Ford car immobiliser system. A security consultant successfully cloned Philips Electronics' Mifare contactless smart card chip, which is the most commonly used key-access system. The implantable RFID "Verichip" tag was cloned in less than 10 minutes by a 23 year-old Canadian hardware developer for the purpose of an article in the magazine *Wired*. The tag, implanted in the journalist's arm for the purpose of the article, featured no security at all.[44]

A read-write tag can be subject to unauthorised modification of tag data or falsification of tag content to deny availability, or change the identity or information details of goods or people. According to the same *Wired* article, 5 millions RFID tags have been sold to libraries in an unlocked state to "make it easier for libraries to change the data." Unfortunately, these tags also enable anyone with the right software and hardware to write on the tag as well.

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43. Decoding is an essential element of signal processing. Detection is a simple matter of receiving a signal above the noise threshold. The decoding process extracts the intelligence from the detected signal. To start decoding, the decoder must first synchronise with the incoming signal. This usually entails recognising a string of decoded bits as the point to start decoding. Not doing this prevents from knowing when one bit word (byte) begins or ends. An intelligent jammer could send a very short signal to disrupt this process using a blocking bit without disrupting the whole signal. The decoder then would go around a cycle and try to start again. The intelligent jammer knows this cycle and repeats the disruption to stop the receiver decoding the signal even though the receiver can detect it. This decoding should not be confused with cryptographic deciphering/decryption.

44 . See Annex III.

- Confidentiality

Confidentiality is the assurance that information is accessible only to those who are authorised to have access. When the data relates to an individual, loss of confidentiality results in data protection violations. Consequences of loss of confidentiality in typical RFID systems could include, for example, stealing competitor information in the supply chain or in the retail environment, stealing a vehicle by gaining access to electronic key information and cloning the chip. According to a Japanese newspaper, data about passengers' latest entry and exit stations stored in a Japanese public transport access card (Suica card) can be read by basic RFID readers, such as the one embedded in Sony Clié PDA. A journalist claimed that the possibility to read such information at a distance could potentially facilitate stalking. The vulnerability of passport information (including biometric data) has been pointed out as a possible source of fraud or crimes involving identity theft (see Annex III). Unauthorised remote access to data is sometimes also called "skimming".

Any system based on radio technology is susceptible to eavesdropping of the radio signal between transmitter and receiver, thus raising confidentiality challenges (as well as integrity challenges if the data can be reinjected). RFID systems based on magnetic induction also generate radio waves that an attacker equipped with the appropriate radio equipment could, in theory, intercept. However although theoretically possible, it is practically improbable because the energy levels would be relatively low and would be covered by noise, forcing the attacker to operate at short distance of the tags and reader (likely, in an overt manner).

RFID eavesdropping can be both passive and active. The attacker (or "interceptor") may actively send a signal to the tag to get a response, or simply passively listen to the response prompted by a reader activating the tag. Some tags can only reply with data (*e.g.* an identification number). More "intelligent" tags can send back a processed response akin to being actively interrogated with the objective of exploiting a vulnerability.

Eavesdropping on the transmission can reveal the existence of a communication between RFID devices potentially leading to the disclosure of valuable information for the attacker (*e.g.* the number of goods arriving in a warehouse or the presence of an individual in a given area). It enables tracking of the tag and the attached object. It can also reveal the content of the communications thus enabling unauthorised access to potentially valuable business, competitive or personal information and also enabling other attacks such as unwanted modification of the data or "man in the middle attack" (where the interceptor modifies the data exchanged between the tag and the reader). Other elements regarding privacy risks related to loss of confidentiality are provided in the privacy section below.

- Considerations regarding the type of technology used

Risks vary according to the type of technology used to perform a specific function. As highlighted earlier, RFID is an umbrella concept for a variety of technologies with different characteristics. The risks mentioned above are theoretically applicable to all RFID systems. However, on a continuum of risks, the likeliness of certain risks is higher in some technical configurations than in others. Parameters such as the use of passive or active tags, of electromagnetic induction or radio-wave communications, of read only or read-write capable memory influence the degree of likeliness that certain risks materialise. The table below highlights some of these elements in a very general manner, but it is important to note that only a detailed consideration taking into account all the characteristics of a given system can provide relevant conclusions relative to the potential risks to the different systems. At a general level, the table shows that technology choices that do not take into account security considerations have an impact on the level of security risk.

Table 7. Risk comparison on a risk continuum

Risk	Risk continuum: Lesser risks ← → Greater risks	Explanations
Eavesdropping	Induction ← → Radio waves	The attacker needs to be in the operating range[45]
Jamming	Induction ← → Radio waves	Idem
Covert tracking	Induction ← → Radio waves	Idem
Radio noise interference	Induction ← → Radio waves	Electromagnetic induction is not subject to radio interferences
Tag cloning	Authentication on tags ← → Data only on tags	Authentication prevents unauthorised access
Tag data integrity attack	Read only memory ← → Read-write memory	Read only memory cannot be modified (but, the chip could be destroyed)
Denial of service attack by tag blocking	Active tags ← → Passive tags	Active tags can include smarter communication protocols to defeat attacks

Operating ranges discussed in the first section can be considered in relation to the type of attack that is anticipated, as highlighted in box 1 below.

Box 1. Operation ranges from a security perspective

According to NIST "Guidelines for Securing Radio Frequency Identification Systems" (2007), six different operation ranges can be distinguished:

- **Nominal operating range**: the distance, often specified by standard, over which authorised transactions are expected to occur. This is the "official" operating range.
- **Back channel eavesdropping range**: the distance over which a rogue receiver can reliably interpret a tag's response to a legitimate reader.
- **Forward channel eavesdropping range**: the distance over which a rogue receiver can reliably listen to the transmissions of an authorised reader. Both back channel and forward channel eavesdropping can be considerably greater than the official operating ranges. Cover-coding technique, which has been included in EPCglobal class-1 Generation 2 specification, prevents a rogue receiver from deciphering exchanged data if it is not capable of eavesdropping also on the tag responses (the communication is encrypted using a key sent by the tag to the reader). This forces the eavesdropper to operate within the back channel eavesdropping range in order to decipher the communication.
- **Rogue skimming or scanning range:** the distance over which a rogue reader operating above the regulated power limits can reliably communicate with a tag.
- **Rogue command range**: the distance over which a rogue interrogator can execute a tag command that does not require the reader to successfully receive information from the tag.
- **Forward channel traffic analysis range**: the distance over which a rogue receiver can detect the presence of a reader's signal without having to interpret its content. Traffic analysis could enable the arrival of a shipment and possibly count the number of items. Such an attack can be performed over much longer distances than eavesdropping.

Source: Adapted from NIST, 2007, p. 2-13.

45. As noted in the first section of this paper, the law for radio waves signal propagation is different than for electromagnetic fields. Thus the operating range of radio waves tags (at UHF and microwave frequencies) can be much longer (meters) than that of electromagnetic induction systems (centimetres).

2.1.1.2. Risks related to other components

Other components of RFID systems present security risks too. In particular, database security has been identified as a serious and sometimes underestimated concern, since databases containing information associated to tags are likely to be accessed by different enterprises and, sometimes, will be maintained by third parties.[46]

Likewise, RFID systems relying on the transmission of information over the Internet are exposed to the same variety of attacks as other information systems. For example, some academic researchers[47] have pointed out potential confidentiality / privacy, availability and integrity concerns relative to the Object Naming Service (ONS) designed by EPCglobal as a component of the EPCglobal network architecture, mentioned earlier. EPCglobal considers that although security risks need to be addressed, they are limited and not greater than the ones that exist today on communications over the Internet or other information systems.

Academic research has also demonstrated that classic Structured Query Language (SQL) and script injection attacks are capable of significantly damaging an RFID system through the use of just one infected RFID tag.[48] RFID tags' data could include unexpected code or instructions designed, for example, to damage the back-end database of an RFID system, compromise the whole system and/or self-replicate inside the system. In such scenarios, the exploits are not inherently linked to the RFID technology but rather to the quality of the design and coding of the middleware software components, which interact with the RFID devices. Researchers highlighted that RFID applications are potential candidates for exploitation by malware: they involve complex applications with a large amount of source code, rely on generic protocols and facilities as well as back-end databases, they process and store high-value data and, since nobody expects RFID malware yet, they convey a false sense of security.[49]

2.1.1.3. "Expect the unexpected"

Tag technology is still relatively young. Therefore, innovative and unpredicted cracking techniques could emerge. As stated by the authors of the book "RFID. Applications, Security and Privacy": we should "expect the unexpected. If there is one thing that's clear about this new world of RFID, it's that there are both big changes ahead and surprises in store."[50] For example, in February 2006, professor and well-known cryptographer Adi Shamir "used a directional antenna and digital oscilloscope to monitor power use by RFID tags while they were being read. Patterns in power use could be analysed to determine when the tag was receiving correct and incorrect password bits". Shamir stated that "a cell phone has all the ingredients you need to conduct an attack and compromise all RFID tags in the vicinity."[51]

The demonstration of the feasibility of such an attack scenario in laboratory conditions needs to be balanced against the cost of deploying the scenario in real life conditions and the benefits or limitations of such an attack. However, this example stresses that it would be good practice to consider technology

46. US FTC, 2005, p. 16.

47. Fabian, 2005.

48. Rieback *et al*., n.d.

49. On Malware, see "Analytical Report on Malicious Software", OECD, 2007a.

50. Garfinkel, 2006, p. xliv.

51. Oren, n.d., Merrit, 2006. Security experts have noted that such "side-channel attacks" are not a new type of data attack and that RFID could benefit from mitigation techniques that have been used to protect contact-based smart cards, *e.g.* by masking the spikes in power consumption. See O'Connor, 2006.

evolution when defining a security strategy, to assess risk at the system design stage, and to periodically reassess it as in any security life cycle process.

2.1.2. Security controls[52]

Security is implemented through a combination of management, operational, and technical controls to mitigate risk. RFID systems vary considerably according to the technology used, the application contexts and scenarios. Effective security strategies rely on a mix of security controls that balance cost, performance and convenience for a given system within a given regulatory environment. Risk assessment is a key requirement to determine the threat and vulnerability level at a given time along with the appropriate combination of controls to mitigate them. In this respect, RFID is no different from any other information system.

Management controls include the policies, procedures and standards in relation to the oversight of the system. They detail how a business is run and how day-to-day operations are conducted. Management controls include IT security policies covering access control to RFID information, perimeter protection, password management, etc.; RFID usage policy that describes the authorised and unauthorised uses of RFID technologies; agreements with external organisations when data associated with RFID systems are shared across multiple organisations; and strategies to minimise the information stored on chips (*e.g.* in the case of personal information).

Operational controls correspond to actions performed by users of the system. They include physical access control (*e.g.* surveillance cameras, gates, walls, etc.); the appropriate placement of tags and readers (*e.g.* to minimise interference); training of personnel; use of identifier formats that do not reveal any information; etc.

Technical controls correspond to technology measures to monitor and restrict access to the information and the system. They include:

- Controls to protect the tag data: a feature which disables all the tag's functionalities when it receives a specific "kill" instruction; cryptography;[53] access control mechanisms, such as password protection to protect from anyone using the kill command in EPC Class-1 Generation 2 tags; authentication mechanisms where the tag authenticates the reader and/or the reader authenticates the tag; tamper resistance mechanisms to prevent the tag from being removed from the object to which it is attached.
- Controls to protect the radio-frequency interface: the use of a frequency which avoids specific interference (*e.g.* liquids); adjusting the power level to mitigate the propagation of radio-waves and risks of eavesdropping; shielding of the tag when it is not supposed to operate, to protect against unauthorised access, or shielding of the environment to protect against eavesdropping; and temporary deactivation of active tags[54].

52 . This paper does not aim to provide a detailed inventory of existing risk controls. Such more detailed inventories can be found in NIST, 2007 and BSI, 2005.

53 . Where cryptography is used a number of key management techniques such as key diversification can be used to limit the damages of a successful attack.

54 . Another technical control is cover coding, which takes advantage of the fact that a passive tag's signal power level is lower than that of a reader: a password is sent by the tag with which the reader encrypts the communication. A potential eavesdropper located beyond the tag operating range but within the reader's operating range would possibly intercept encrypted data but would not be able to capture the cryptographic key. This technique is included in the EPC Class 1 Generation 2 standard.

Many technical security controls are available in various degrees of sophistication and robustness. However, complexity often increases with sophistication. For example, strong cryptography often involves key management processes and techniques that are not easily compatible with lightweight turnkey solutions. Chips embedding more processing power required by security features are also likely to require more energy, thus adding new constraints such as shorter reading range, larger form factor, need for batteries, shorter life span, etc. In the longer run, it is possible that some of these constraints can be minimised. Cost of RFID devices is also likely to be proportional to their level of sophistication, including to the robustness of their security feature. Eventually, market forces will play a role in the reduction of such cost.

Important research efforts are currently underway to develop innovative technical security measures[55] in areas such as authentication, cryptography, blocking, and policy embedded devices (trusted computing)[56]. Data-minimisation techniques are also being explored: the unique identifier data (*e.g.* the EPC number, cf. Annex IV) could be erased, either automatically or via active participation by the individual, which means that only data that corresponds to the product class would remain accessible, like today's bar codes. Therefore the tag would not uniquely identify a specific object anymore but only a product class. Another technique consists in adding distance measurement capability to the chip and to vary the granularity of the information transmitted according to the computed distance of the reader. In this case, while a tag attached to a bottle of water might reply to a reader located far away, it might provide the brand only if the reader is closer and its actual identification number only if it is very close. None of these research efforts constitute a silver bullet, but they are useful and confirm the very large potential for security to be "baked" into the technology in the coming years.

There is no one-size-fits-all security measure that would efficiently address a given class of risks in all possible situations. The appropriateness of each security control depends on various factors: not all controls are available for all types of RFID. For example, data encryption helps protect sensitive tag data but, as noted in NIST Guidelines,[57] it is not available on EPC and ISO 18000 standards systems. Similarly, all controls have benefits and weaknesses: password protection enables restricting access to tag information but password length is often very short;[58] data encryption on tags requires power for computing cryptographic functions, and it may introduce an unacceptable delay in systems that require fast reading/writing operations between reader and tag.

It has been noted that open standards for classifying and rating the security features of RFID cards and tags are virtually nonexistent. As a consequence, assessing the security of RFID systems may be a difficult task for RFID operators and even manufacturers.

Technical measures cannot mitigate all risks to a system. Operational and management controls are also essential. For example, security tools, such as encryption, are only useful if part of a wider framework of controls supporting a comprehensive security policy.

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55. For example, the European Commission (2007a, p.10) "will stimulate research on security of RFID systems, including light-weight security protocols and advanced key distribution mechanisms, with a view to preventing direct attacks on the tag, the reader and the tag-reader communication."

56. For a detailed overview, see Juels (2005a). See also Gildas Avoine's "RFID, Security and Privacy" website which lists hundreds of research articles related to RFID security and privacy. See also BRIDGE's "Security Analysis Report" (2007) which focuses on security requirements for open loop systems.

57. NIST, 2007, p. 5-17.

58. *e.g.* EPC Class-1 Generation 1 tags provide 8-bit passwords, *i.e.* only 256 possible passwords; Class-1 Generation 2 tags provide 32 bits passwords, *i.e.* 4 294 967 296 possible passwords.

Table 8 below provides a summary of security controls for RFID security developed by the US National Institute for Standards and Technology.

Table 8. RFID Controls Summary

Controls	Business process risks	Business Intelligence Risks	Privacy risks	Computer Network attacks
Management controls				
RFID Usage Policy	■	■	■	■
IT Security Policies	■	■		
Agreements with External Organizations:	■	■	■	
Minimizing Data Stored on Tags	■	■	■	
Operational controls				
Physical Access Control	■	■		■
Appropriate Placement of Tags and Interrogators	■	■		■
Secure Disposal of Tags	■	■	■	
Operator and Administrator Training	■	■		■
Separation of Duties	■	■		
Non-revealing Identifier Formats		■	■	
Technical controls				
Tag Access Controls	■	■	■	
Kill Feature			■	
Data Encryption	■	■	■	
Fallback Identification Technology	■			
Authentication	■	■	■	
Tamper Resistance	■	■		
Radio Frequency Selection	■			■
Transmission Power Adjustment		■		■
Electromagnetic Shielding		■	■	■
Cover-Coding				
Temporary Deactivation of Active Tags		■	■	

Note: in the NIST Guidelines, computer network attacks are included in the "externality risks" category that also includes hazards of electromagnetic radiation.

Source: NIST, 2007.

2.1.3 A holistic approach

Security controls can be applied at any and all stages of the deployment of an RFID system. In particular, many technical controls are likely to be most effective if introduced at the earliest stage of development of the system. The controls in place before tag deployment can broadly be considered as pro-active and preventative whilst the controls in the environment and in the system beyond (including the readers) can be broadly described as reactive and limiting risk. To control the inherent openness of the RFID component of the system, it is necessary to take a holistic view of the system with regards to time and space when assessing and managing risks: *i*) at all stages of the system, including planning,

deployment, operation, data processing and disposition (end of life),[59] *ii*) considering the RFID system in its broader sense, including both RFID specific and unspecific components, avoiding a focus only on the tag-reader relationship, and considering the system as part of a broader infrastructure of information systems and networks. A narrow approach focusing only on the tag/reader operational relationship would not capture all the controls that could be placed before and after that point to both prevent and limit damages. A narrow approach would also fail to detect potential risks related to the network, middleware, and back-end components that are key to the efficiency of an RFID system. It could also lead to an underestimation of the cost and overestimation of the effectiveness of the security controls that could be applied.

Technologies used and participants in RFID systems are complex and dispersed. Consequently, it is impossible to conform to a closed and rigidly controlled security model. The many interconnections and interdependencies combined with the complexities between the different components of technology, organisations and business processes make a physical and logical security perimeter for any RFID system a difficult task. Further, many security variables are beyond the control of some of the individual participants. Thus, one could argue that achieving security requires adopting a holistic approach that would consider all of the individual components within an overall security picture, accepting that there may be weaknesses in some of the individual components but that these weaknesses would be compensated for elsewhere in the design.

In some cases, controls, by way of policy and regulation, are already in place, and the introduction of RFID technology will have no impact on existing security models. In other cases, the introduction of RFID technology may necessitate new risk assessments that could lead to a conclusion that existing controls, including security policy and regulation, need to be strengthened.

2.1.4 Adjusting security level to what is at stake

Information security management requires controls to be balanced in terms of risk, cost and effectiveness. The cost/benefit ratio of security controls cannot be expressed in an absolute manner. Rather, it depends on the application context and, in particular, the value of the assets or business process that need to be protected. An RFID tag can be likened to a token carrying information. Its security value depends on the asset it is attached to (*e.g.* a car key) and the purpose for which it is being used (*e.g.* verifying identity, providing access to restricted areas, paying goods, etc.). If RFID tags are used as an electronic wallet or tickets in a subway card or to open doors, criminals may be interested in stealing, copying or modifying them. When RFID is used for access control to other systems and networks, a successful attack could compromise not just the RFID system itself but also all systems and networks it was supposed to secure.

Risk increases when the benefits of an attack outweigh its costs. Before committing crimes, even criminals perform risk assessments of existing systems to identify whether and how they could exploit weaknesses. They also perform a cost/benefit analysis to determine which attack strategy is the best for reaching a given objective. Criminals will for example decide whether cloning an RFID hotel door tag is easier than bribing the domestic staff or breaking in via a window. Appropriate security controls can boost the cost of a possible attack so the cost outweighs the benefits. Insufficient security controls with regards to the value of the asset to protect will likely trigger the interest of a potential attacker. A set of efficient security controls will likely not suppress the intention of an attacker to commit a crime, but it may force him or her to use another technique or to target other less-protected systems or victims, or to take more risk.

59 . Although the "end of life" or disposition stage of a system is often associated with the destruction of information, for example, when it is no longer required, it may also involve activities such as the archiving of information or the transfer of information to a successor system.

When the information stored in a tag can be related to an identified or identifiable individual, the protection of the information should be regarded from the double perspective of security and privacy. In some cases, the stored data can be sensitive: information identifying a medicine taken or carried by an individual can reveal personal health data; medical data recorded in a patient RFID wrist band can lead to life threatening situations if lost or corrupted; unauthorised access to biometric data in a passport or identity document can lead to identity theft. Some sensitive personal data, such as biometrics, require more sophisticated protections than others, such as the use of effective encryption and electronic authentication mechanisms. Even though security risk assessment can be considered similar to privacy impact assessment in terms of methodology, its scope is different: an organisation performs a risk assessment to protect its assets and business processes. When it carries out a privacy impact assessment, it needs to take into account any possible loss of privacy for the individuals concerned by the data processing, including when such loss would not directly impact the organisation. The use of RFID for human identity verification provides a good example of a case where extensive security and privacy assessment is required before the decision is made to adopt RFID technology (US Department of Homeland Security, 2006).

It is possible that, in a given scenario, a risk assessment concludes that the level of risk and the cost of the necessary security controls to cope with the risks versus the benefit of using RFID technology is not worth deploying the system or requires a partial or complete re-evaluation of the project. In a given context, one particular affordable RFID technology may appear to be insufficiently protected against a certain class of risks but sufficiently against another. A decision could be made to invest in a more secure type of RFID technology, or to associate the initial low-cost RFID technology with non-RFID security controls (*e.g.* video surveillance, human monitoring, etc.), or to use other technologies than RFID.

2.2. Privacy

Privacy ranks as concern number one in consumer surveys[60] regarding RFID as well as in comments received by consumer protection agencies such as the US Federal Trade Commission.[61] Several well-known public campaigns featuring anti-"spychips"[62] groups halted companies' RFID trials and raised business awareness of the need to address public perception of privacy to enable widespread adoption of the technology. As one observer notes,[63] RFID was born in a technical environment, is designed, used and understood mainly by technical people. Originally designed for the supply chain, it is now extended to consumers and individuals but can be invisible, remains opaque and often unexplained. Perception issues cannot simply be dismissed as irrational fears. These concerns should be addressed by all stakeholders in a responsible manner in order not to jeopardise potential benefits for both the industry and the individuals.

In fact, surveys also highlight that consumer awareness regarding RFID is still relatively low. While some consider that privacy issues threaten to overshadow the benefits of RFID,[64] others question whether perceived benefits of the technology in some areas outweigh possible risks, in particular as some of these risks would not be immediately visible. More generally, the US National Research Council (2004, p. 28) recognised that "given the vast differences in individual preferences regarding privacy, along with a range

60. According to Cap Gemini (2005a), Privacy-related issues are the most significant concern about RFID among European consumers. US consumers expressed greater concern than Europeans about privacy-related issues, possibly as a result of the higher visibility of consumer advocacy groups' activities regarding RFID in the United States.

61. FTC, 2005, p.12.

62. See "Spychips" by Katherine Albrecht and Liz McIntyre (2006) and the website www.spychips.com

63. Pradelles (customer privacy manager, HP), 2006.

64. Cap Gemini, 2005b.

of social norms, the establishment of public trust with respect to RFID technology will be a complicated, long-term undertaking […]."

Several authors and public and private sector organisations have already performed privacy analyses of RFID and have issued reports and even guidance or principles to help stakeholders apply existing privacy frameworks. A list of references can be found in Annex V. This material forms a very useful basis on which the following elements are partly based. The following sections discuss privacy challenges RFID may raise as well as possible safeguards. The OECD *Privacy Guidelines* have been used to guide the discussion of privacy challenges.

2.2.1 Overview of privacy challenges

There is a broad variety of RFID hardware and software configurations deployed in many different contexts. RFID technology does not systematically or inherently generate privacy issues and, when it does, the nature, scope and extent of these issues vary according to both the technology and the use context.[65]

In most cases, the potential invasion of privacy through the use of RFID is likely to be proportionate to several interrelated parameters including: *i)* a tag's capacity to be read at a distance without the participation of the individual; *ii)* the possibility to reveal intrusive or sensitive information about individuals through inferences and profiling; *iii)* the degree of interoperability (who can read the tags, who can access the full information about the product); and *iv)* the tracking capabilities of RFID.

2.2.1.1 Invisibility of the data collection

An important characteristic of RFID is that the collection of data can happen without the knowledge of the individual: electromagnetic communication happens invisibly, it does not "touch the senses", it penetrates obstacles such as bags or clothes, the size of RFID tags and readers can be very small, and there may be no sign that they are in operation. This leads to both security concerns (*e.g.* jamming, eavesdropping, and replay attacks can be performed remotely) and privacy concerns.[66] Invisibility generates uncertainty and may lead individuals to think that "something might be happening behind their back", and thus constitutes an obstacle to a broad acceptance of the technology. However, what may lead to fear perceptions in some contexts may also foster usability in others: the possibility to automatically establish a communication between the reader and the tags, through obstacles, without direct line of sight is also the main advantage of RFID in supply chains, access control and other contexts. It can also bring convenience and choice to consumers when they shop.

2.2.1.2 Profiling

Access to tag information in objects owned or carried by individuals can reveal private elements of their life, such as interest in specific topics (tagged books), or holding of cash (in the case of RFID in banknotes) or other valuable objects. For example, unlike a fully random unique number and in addition to the object's serial number, EPC data structure contains elements that identify the manufacturer of the product ("EPC manager number") as well as the product code ("object class"), similar to the barcode system. If accessed by a third party, the information in the tag could reveal details about the object itself and thus sensitive information, *e.g.* "This person carries Prozac, is likely to be depressive or in contact with

65 . According to Ontario Information and Privacy Commissioner Ann Cavoukian (2006a), principles for RFID should "focus on RFID Information Systems, not Technologies".

66. Covert collection and transmission of personal data is not a new topic in the privacy realm. For example, it has been raised regarding the use of biometric technologies. See OECD, 2005.

a depressive patient",[67] etc. However, prior to performing such an inference, the third party would need to read the content of the tag and convert the product code into the actual product name. It might already know the relationship between the code and the product from a previous search. Or it might send the EPC manager number to an Object Naming Service (ONS) in order to retrieve the network address of the manufacturer of the product. Then, to retrieve the actual name of the product, it would have to send a query to this address with the product code.[68] Finally, it would need to perform the inference mentioned above. It is worth noting at this stage that such a scenario remains speculative as item-level tagging is still limited.

Revealing the type of soap or toothpaste bought in a supermarket may not be considered as a real privacy issue. But, in some cases, profiles and inferences that could be made from a cluster of RFID tags carried by an individual could become very precise and reveal much more intrusive information, including identifying him/her. Sensitive information such as individuals' nationality or biometric information could also be revealed by unprotected biometric passports.

Making inferences from available data to enhance existing profiles is not new. Credit companies, banks and insurance companies have long been using profiling techniques to associate a level of risk to customers. Popular websites such as Amazon suggest books and DVDs to returning customers based on their buying and browsing habits. Often, this leads to increased convenience and options for consumers, and enables companies to provide better, and sometimes more tailored services at a customer's request. RFID does not substantially modify profiling technologies but: *i)* the invisibility of the technology would enable such profiling to happen covertly[69] and *ii)* if widespread, it could make profiling technologies more accurate and efficient by providing more data to be processed.

2.2.1.4 Tracking

Tracking of objects, goods, cases, pallets and animals is a key functionality of RFID. Tracking of people is possible if they carry or wear objects that include RFID tags. For example, RFID is used in amusement parks to enable parents to find their children. It is used in ski resorts to help friends find each other, in hospitals to keep track of patients, and in prisons to track inmates throughout the facility.

Tracking is enabled by the collection or processing of location and time data and can be performed either after the fact with data already stored in a database, or in real time.

After the fact tracking can result from bringing together location, time and other information previously stored in one or several databases, thus acting as "digital footprints". For example, RFID tickets for sports games or cinema can record the time and place corresponding to when the buyer entered the stadium or the theatre. Badges used for access control in a work environment help restrict access to certain premises to authorised people and often keep track of employee presence and work hours. Subway RFID cards like the Parisian Navigo Pass, the London Oyster Card or the Tokyo Suica Card allow only individuals who have paid the fee to enter in the transportation system and take the journey they have paid for. All these RFID systems need to process location information in order to perform their access control feature but if such information is stored and can be linked to the individual, it could then be used for broader tracking purposes.

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67. Stapleton-Gray, n.d.

68. It is likely that the manufacturer's system would require appropriate authentication if it is deployed in a B2B context.

69. One often cited hypothetical example of covert basic inference is related to criminals accessing information about objects carried by a person in order to select that person as a target for a crime (*e.g.* a person wears a designer suit and is therefore likely to have other valuable objects on or with him/her).

According to privacy protection frameworks, personal data should not be disclosed, made available or otherwise used for purposes other than those originally specified except with the consent of the data subject or by the authority of law. Digital footprints are not a new concept in the online environment and have long been used for criminal investigation purposes. One objective of privacy protection is to prevent the generalisation of their use. Privacy impact assessments can help detect system functionalities that would enable breaching Privacy principles such as "use limitation" and determine which technical or functional alternatives can prevent function creep, like privacy-enhancing technologies, data minimisation and anonymisation strategies.

Real time tracking typically involves monitoring the movements of an identified person, but RFID might also be used to track an unidentified person, *i.e.* distinguishing an individual in a group and monitoring his/her behaviour without knowing the person's name or identity. However, such scenarios would require first that individuals be provided with functional (neither deactivated nor blocked) tags that can be read later on, and that the trackers deploy readers at appropriate locations, taking into account the operation ranges of the RFID technology used and other technical constraints. Whether the tags would later be readable by the original party that provided them to the individual, by a larger number of parties, or by anyone with the appropriate equipment, would depend on the nature of the security measures embedded in the tags and on the degree of tags' interoperability. The possibility for such real time tracking to happen in a covert manner, or for criminal purposes have been expressed by opponents to RFID chips but few cases have actually been reported yet.

The challenges raised by the operation of an open infrastructure that could be used for tracking objects as well as individuals are not in the scope of this paper, as such an infrastructure is not envisioned in the short term. Similarly, the hypothetical generalisation of ubiquitous sensor equipped environments where all objects would embed tags that can be read by anyone and interact with the environment (smart office, smart home, smart streets, etc.) might also raise real time and after the fact tracking concerns. However, being a speculative long-term scenario, it falls outside of the scope of this paper. Both topics could be monitored in relation to the broader issue of infrastructures of surveillance.

2.2.1.3 Interoperability

The context in which the collection of RFID data and its association to individuals may occur is important. In a closed loop context, where tag data is essentially read and modified by the organisation which originally deployed it, it is not clear whether the use of RFID would lead to substantially different outcomes than those occurring with the use of non-RFID systems, such as contact cards or barcodes. Barcodes already enable the collection of information on what individuals buy and its association with names or other personal data (with *e.g.* credit cards, cheques or loyalty cards). This information enriches profiles and is widely used for optimising marketing campaigns. Existing privacy protection frameworks can be applied and RFID, though adding a level of convenience at the data collection stage, would not add more information to the organisation's database. However, some stakeholders consider that RFID would enable more information to become available, such as real-time location data or product history.

The situation is likely to be different in an open loop context, where RFID data potentially related to identified or identifiable individuals could be accessed or read by many actors due to interoperability, and mass aggregation of such personal data would become possible. Although currently most RFID applications are not taking advantage of interoperability and standardisation, those features may be attractive for those seeking large-scale RFID applications. Some stakeholders consider that interoperability might enable broader dissemination of personal data (a collection, purpose and use limitation issue). For example, if interoperability of tags carried by individuals would result in tags being readable by anyone with the appropriate equipment, it might encourage some actors to collect personal data that they would not

otherwise collect. Progressively, personal data collection could become the default instead of being an exception.

Interoperability might also facilitate the adoption of data protection requirements. For example, the proposal made by academic researchers to incorporate explicit privacy policies based on the OECD principles into the standard of the reader-to-tag ISO protocol (Floerkemeir, 2004) shows both that privacy-friendly RFID devices can be envisioned and suggests that standardisation bodies and process could facilitate their generalisation. In another example, at the policy level, the European Commission (2007a) called upon the European standardisation bodies to ensure that international and European standards meet European requirements in particular as regards privacy and security, to identify gaps and to provide the appropriate framework for the development of future RFID standards.

While interoperability may bring benefits to business and remove a technical obstacle to the dissemination of personal information, there are many cases where business may consider that RFID data is too strategic to be shared. "Wal-Mart does not want its competitors to read tags that are from Wal-Mart stores. Wal-Mart probably does not want its suppliers to read information about its other suppliers. They want to control that information for competitive reasons".[70]

Finally, another issue often mentioned with regards to RFID and large-scale implementation is the creation of an additional pillar supporting the emerging infrastructure of surveillance, *i.e.* a global and fully interoperable RFID infrastructure that might enable tags provided to individuals to be read by anyone operating the appropriate connected equipment. While this is not likely to happen in the short term and therefore is not in the scope of this paper, it is important to keep in mind that any exploration of the concept of infrastructure of surveillance should attempt to grasp the measure of convergence of several potentially surveillance-enabling technologies and processes, including RFID and sensor-based networks, biometrics, digital identity management, etc.

2.2.2 Possible safeguards

The 1980 *OECD Privacy Guidelines* represent international consensus on general guidance concerning the collection and management of personal data. However, their implementation in the context of RFID may raise a number of questions. Furthermore, a number of concepts and policy tools may facilitate their implementation.

2.2.2.1 Privacy principles

"When is RFID in the scope of the *OECD Privacy Guidelines*?" may be the first basic question raised when considering using the *OECD Privacy Guidelines* for protecting privacy in the context of RFID. The next two sections attempt to address this question by analysing when RFID data may be considered personal data and when an RFID operator is a data controller. The following section discusses questions raised by the invisibility of RFID and in particular issues related to knowledge and consent. Naturally, and consistent with the Security Safeguards Principle of the *Privacy Guidelines*, the security safeguards discussed in the security section of this report are essential for the protection of privacy in RFID systems.

2.2.2.1.1 When is RFID in the scope of the *Privacy Guidelines*?

According to the *OECD Privacy Guidelines*, "personal data means any information relating to an identified or identifiable individual". Since the *Privacy Guidelines* only apply to personal data, when RFID technologies are used in contexts where RFID data is not related to an identified or identifiable

70 . US FTC, 2005, p.15.

individual, privacy principles do not apply. However, as we will see below, there may be privacy risks if the RFID data is associated to an individual even when the possibility to identify that individual is low. In any case, as acknowledged by the explanatory memorandum of the OECD *Privacy Guidelines* "the precise dividing line between personal data in the sense of information relating to identified or identifiable individuals and anonymous data may be difficult to draw and must be left to the regulation of each Member country."[71]

In some cases, RFID data is personal without ambiguity (*e.g.* in many access control applications). In other cases, RFID data may become personal data when it is possible to relate it to an identifiable individual. For example, when RFID is used in supply chain systems, the unique number stored on an RFID chip attached for example to a box of medicine to identify and track it, is not personal data. But the same RFID data can become personal data if it is collected or processed in such a manner as to enable a party to associate it with another set of information relating to an individual, *i.e.* by a nurse to track which patient has been provided with which medicine or by a drugstore to provide assistance services to patients.

Therefore, while some data are personal by nature (*e.g.* a name), other data can become personal once related to an identified or identifiable individual, which depends on context. One consequence is that parties who implement RFID systems are not systematically subject to data protection frameworks. A careful analysis of the nature and use of the RFID data at each step of its lifecycle is needed to help determine whether it should be considered personal and avoid turning it into personal data when it is not necessary for the purpose of the system.

One grey area still being debated relates to the possibility to use RFID unique data to distinguish an individual from other members of a group. This type of usage is in fact very similar to an HTTP cookie, with the difference that a cookie can be read only by the server that sent it to the client machine while RFID interoperability could, if enabled, allow for store A to read the RFID tags of objects sold by store B. The customer could benefit from such recognition, but could also in some cases consider the data collection an invasion of privacy; *a fortiori* where one of the stores would link the RFID data to the customer.

The European Article 29 Data Protection Working Party takes the view that the collection of a unique set of data, included in one or several RFID tags, which could be related to a specific individual, makes the information personal data within the scope of European data protection law. This view has been challenged by industry representatives who consider that data protection frameworks should apply only in cases where data processed through the use of RFID technology either contains personally identifiable information such as name, account or registration number or is combined with other personal data (*e.g.* personal data stored in a database or smart card).[72]

Privacy advocates argue that the capacity to determine that a set of characteristics belongs to a unique person can lead in some cases to damaging that person's privacy independently of whether the person can be named or not. From the individuals' perspective, inferences can lead the operator of RFID systems to a sufficiently high level of identification probability to raise privacy issues, even when the person cannot be formally identified. The risks associated to techniques that enable picking individuals out in a crowd relate to potential discrimination, dynamic pricing schemes or criminal activities. However, some businesses

71. Explanatory memorandum of the *OECD Guidelines on the Protection of Privacy and Transborder Flows of Personal Data*, paragraph 41.

72. International Chamber of Commerce *et al*., 2005, section 4.2; EPCglobal, 2005a, section 3.1; EPCglobal, 2007.

stress that considering RFID data as personal data in such cases would make some obligations such as the right of individuals to access the data related to them impossible to fulfil.[73]

At this stage, and while the debate is still ongoing,[74] one may consider that the ability to treat an individual uniquely is likely to raise privacy issues in some contexts, the level of privacy risk being proportional to several factors: *i)* the uniqueness of tag data (*e.g.* EPC numbers are fully unique. Proprietary numbers may not be as unique. Encrypted unique numbers are still unique numbers) or the number of tags carried by an individual (the more tags, the higher the probability of uniqueness), *ii)* the probability that the tag(s) will or will not be shared with other persons and *iii)* the capacity to read the tag at a sufficient distance without the actual participation and knowledge of the individual.

Another key question is whether any RFID operator is a data controller.

The effectiveness of privacy and data protection frameworks relies to a great extent on the ability to assign responsibility to an entity for complying with data protection rules and being held accountable for failures in compliance. The notion of data controller was defined with this objective in mind and, in particular, to avoid imposing liability on organisations and individuals acting as agents for others. It is therefore, as mentioned in the *OECD Privacy Guidelines'* explanatory memorandum, "of vital importance".

According to the *OECD Privacy Guidelines*, a data controller is someone who is "competent to decide about the contents and use of personal data".[75] As stated above, whether RFID data is related to an identified or identifiable individual depends on the context: the identification number of a box of medicine is not personal data. But it becomes personal data if it is collected with the purpose of associating it with other information relating to an identified or identifiable individual.

A narrow interpretation of the definition of data controller is likely to lead to difficulties in the RFID context because deciding about the content of the RFID data is not the same as deciding about the content of personal data. In most cases, the manufacturer of a good will be competent to decide about the content of the RFID data but will not know whether it will ever be associated with individuals. Conversely, a store that implements RFID can decide to use the tag data on the goods to profile its customers. Therefore, in the context of RFID, the notion of data controller could be interpreted keeping in mind that deciding about the content of personal data will most often be closely related to deciding about the association of the tag data with individuals. To some extent, it is the use of the tag data that makes the data personal or not.

As a result, when a party reads an RFID tag and associates its data with an individual buying, carrying or wearing the tag, this party may be viewed as a data controller, taking over all the corresponding responsibilities derived from the Privacy Guidelines. But when a party provides an individual with a functional (not deactivated) tag and does not collect or store any RFID data associated with that individual,

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73. If person A is requesting access to his/her personal data, how would the data controller decide which record in its database corresponds to him/her? Person A would need to provide the tag(s) that have been associated to that person by the controller in order for the controller to retrieve the data in its system and give access. But nothing would prove that the tag(s) really belong to person A and therefore that the profile that would be accessed would not in fact be disclosed to another individual impersonating Person A.

74. A key document in this debate is the recent Article 29 Working Party "Opinion 4/2007 on the concept of personal data" (June 2007).

75. "Data controller" means a party who, according to domestic law, is competent to decide about the contents and use of personal data regardless of whether or not such data are collected, stored, processed or disseminated by that party or by an agent on its behalf in *Guidelines Governing the Protection of Privacy and Transborder Flows of Personal Data*, paragraph 1.

that party may be viewed as not subject to any obligation under the existing privacy protection frameworks. It would not be considered as a data controller, although providing functional tags to individuals would possibly enable a third party to track the individual in real time, potentially in a covert or illegal manner.

This case raises the question of whether or not this party would nevertheless have a responsibility to remove or deactivate the tag before passing the item to the individual or *i)* inform the individual that the good includes a functional tag that may be read by a third party at a distance and *ii)* provide him or her with information on the content of the tag, and how to prevent distance reading, or other intrusions. This is not to suggest that such parties should be considered "data controllers" and be responsible for other duties assigned by the *Guidelines* to data controllers such as individual participation or purpose specification.

One approach to solving this question is that taken by the Ontario Privacy Commissioner who states that "organisations that typically have the most direct contact and primary relationship with the individual should bear the strongest responsibility for ensuring privacy and security, regardless of where the RFID-tagged items originate or end-up in the product life-cycle." Measures such as the appointment of an "information administrator" by retailers, from whom individuals can seek information, advice, assistance and remedies, have also been proposed. The "Privacy Best Practices for Deployment of RFID Technology" developed by the US-based Center for Democracy and Technology (CDT) state that "responsibility for providing notice lies with the company having the direct relationship with the consumer." Interestingly, the document notes that the company having the closest relationship with the individual may not know that the products they receive contain RFID tags. Therefore, it recommends that "a commercial entity incorporating RFID systems within its products should give notice to its direct purchasers of that fact, and to the extent practicable encourage its direct purchasers to give similar notice to their purchasers, and so on, with the objective of enabling the company having the direct relationship with consumers to give proper notice of the use of RFID technology".[76]

In considering the disclosure responsibilities of parties providing tags to individuals, examination of other policy frameworks may be instructive. For example, the OECD's 1999 *Guidelines on Consumer Protection in the Context of Electronic Commerce* provide guidance on disclosure to consumers, calling on businesses to provide "accurate and easily accessible information describing the goods or services offered; sufficient to enable consumers to make an informed decision about whether to enter into the transaction." These guidelines are limited in scope to transactions occurring electronically. However they are based on established consumer laws and policies governing fair commercial conduct applying both online and offline. It may therefore be useful to adapt this general information disclosure principle to all parties involved in the provision of RFID tags to individuals.[77] Another parallel could be drawn with the example of product safety and consumer information on risks.

2.2.2.1.3. Knowledge and consent

The invisibility of the technology discussed above is a key characteristic of RFID and also acts as a risk multiplier for other potential privacy challenges such as profiling and tracking. For example, RFID-enabled profiling might be a less acute problem if deployed in a fair and transparent manner where individuals would have been informed and have agreed to it.

76. See CDT, 2006. The Best Practices have been developed by a group of representatives from software and hardware vendors, organisations that use the technology, and industry and consumer organisations.

77. Although organisations that do not collect personal data from individuals do not have a disclosure obligation, many consider that informing individuals that they do not collect their personal data creates a trustworthy climate with potential benefits for the individuals, the company, and the general perception of the information technology involved, thus facilitating the adoption of the technology.

When RFID data is related to an identified or identifiable individual, several privacy principles reinforce each other to address the invisibility problem as well as most of the challenges mentioned in the previous section, such as tracking and profiling. In the *Privacy Guidelines*, the "collection limitation" principle requires "the knowledge or consent of the data subject where appropriate." This principle is reinforced by the requirement to specify the purpose of the collection by the time data is collected ("purpose specification" principle). The data collected must then be used and disclosed only for that purpose and compatible purposes except with the consent of the individual or by the authority of law. According to the "openness principle", there should be no secret data processing on individuals and this approach is strongly supported by the "individual participation" principle, which provides individuals with the means to "access and challenge personal data".

While the need for knowledge or consent is reflected in most stakeholders' RFID guidance, the interpretations vary regarding what and how information should be provided, and when consent is appropriate.

There appears to be an emerging consensus among several consumer and privacy bodies as well as some industry stakeholders[78] that the provision of information to individuals is a fundamental requirement[79] and helps address the psychological challenge related to the invisibility of the technology by making it more visible.

While there may also be a consensus with regards to the necessity to inform individuals about the existence of data collection using RFID technologies, the issue of the content and effectiveness of information is a matter for discussion. A number of information elements might be included in RFID notices, beyond information about the purpose of the collection and the right of access. They include further information such as *i)* the existence of the tags, *ii)* their content, use and control, *iii)* the existence of an RFID environment; *iv)* the reading activity, *v)* the ability to disable tags and *vi)* where to obtain assistance.

The importance of privacy notices has long been recognised by the OECD, in particular in the online context.[80] However, research suggests that the efficacy of online notices is inversely proportional to the quantity and complexity of the information to be conveyed (OECD, 2006b). In the case of RFID, providing full notification to consumers may not be feasible when items do not have sufficient space to accommodate detailed text and when data collection and sharing may be happening in real time.[81] One can expect that developing effective RFID privacy notices may be a greater challenge than in the case of online privacy notices that could take advantage of interactivity, hypertext links and the overall information driven nature of the web medium. Finally, it is unclear whether individuals would have the interest and capacity to understand and digest technical information related to RFID prior to making choices.

78. Including the International Chamber of Commerce and EPCglobal Guidelines on EPC for Consumer Products. EPCglobal Guidelines state "Consumers will be given clear notice of the presence of EPC on products or their packaging and will be informed of the use of EPC technology. This notice will be given through the use of an EPC logo or identifier on the products or packaging."

79. "Notice is an essential element of responsible EPC deployment and operation."

80. OECD work on online privacy recognises the need for online privacy notices and OECD guidance (2003, p.29) encouraged business and government to develop such notices and post them on their websites.

81. See CIPL (Center for Information Policy Leadership), 2007.

More research may be necessary to address this challenge. Possible solutions include innovative means of notifying people, such as audio, video alerts and the use of a universal symbol.[82] However, further work remains to be done to generate a consensus on the essential information to be delivered and effective means of conveying it.

When RFID data is related to an identified or identifiable individual, the opportunity for the individual to consent to the collection of personal RFID data and to the association of RFID data to his/her personal data is an important parameter both from the privacy/data protection and from the psychological (or trust) perspectives. The difficulty of providing efficient notices in RFID contexts may make consent an even more important consideration.

The explanatory memorandum of the *OECD Privacy Guidelines* suggests that, in general, knowledge should be the minimum requirement and recognises that consent is sometimes not practical or may be contrary to the public interest. The examples provided to illustrate cases where knowledge or consent cannot be considered necessary suggest, however, that they should remain a minority: routine updates and law enforcement.[83]

For the Article 29 Working Party consent is almost always appropriate unless the RFID system is authorised by law or is in the vital interests of an individual, as is the case for some health applications. Some businesses, official privacy bodies, and representatives from civil society also agree that consent is sometimes not necessary, but their views diverge regarding the criteria for dropping the need for consent.[84] Further work upon the consent issue might be necessary to narrow this difference.

Overall, knowledge and consent may be interpreted as a condition for individuals to make appropriate choices. However, one may argue that, sometimes, the individual has no real choice but to accept the collection of data in order to benefit from an associated service. For example, it is likely that public transportation systems that have started to deploy RFID systems for controlling access will ultimately remove the infrastructure for delivering and processing paper tickets. Individuals' choice will then be reduced to either accepting the collection of personal data or not using the transportation system. When the alternative to consenting to the collection of personal data is extremely costly for the individual, then the value of consent can become meaningless. Knowledge and consent are not a panacea for privacy protection.

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82. The Center for Information Policy Leadership launched an initiative to develop such an RFID Transparency Symbol. See CIPL, 2007.

83. Paragraph 52: "The knowledge or consent of the data subject is as a rule essential, knowledge being the minimum requirement. On the other hand, consent cannot always be imposed, for practical reasons. In addition, paragraph 7 contains a reminder ("where appropriate") that there are situations where for practical or policy reasons the data subject's knowledge or consent cannot be considered necessary. Criminal investigation activities and the routing up-dating of mailing lists may be mentioned as examples".

84 . According to the Trans Atlantic Consumer Dialogue, "RFID must be used transparently, so that consumers know (and can choose) when RFID is being used". The Privacy Rights Clearing House recognises that, for some applications, it would be sufficient to inform individuals but that individuals should be able to disable tags, and calls for the prohibition of tracking without consent. For the International Chamber of Commerce, "consumer choice, where possible and appropriate, is an essential element in developing consumer trust and acceptance." The EPCglobal Guidelines for Consumer Products (2005d) also recognise Choice as one core principle and calls for additional efficient, cost effective and reliable alternatives to further enable customer choice.

2.2.2.2 Other safeguards

The following measures are not explicitly part of the OECD *Privacy Guidelines*, but may be useful to support or facilitate their implementation.

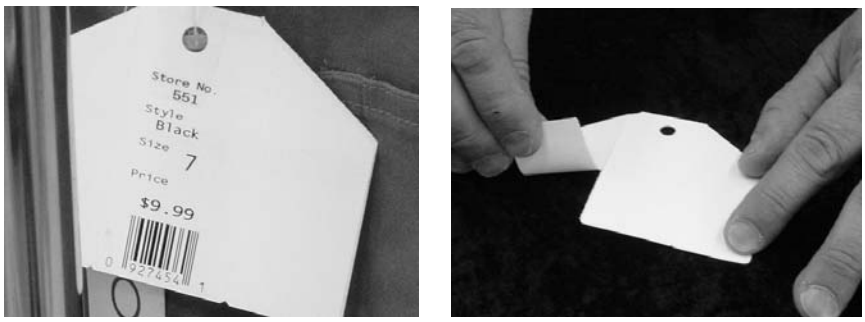
2.2.2.2.1. Technical measures

Generally, it may be worthwhile to consider using technical measures to prevent RFID information from being used in contexts where it could be linked to individuals. Privacy can be embedded in the design of RFID products and of RFID systems.

For example, specific data minimisation or aggregation/anonymisation techniques may help remove risks of function creep. The collection of the serial number segment of EPC numbers could for example, be technically prevented when it is not necessary for the purpose of the application. Generally, removing the possibility of linkage between the RFID tag data and individuals may be an efficient way to keep RFID data in the "non personal" data category and thus to protect privacy. Minimising, anonymising and unlinking RFID data to individuals can also be performed at the back-end level.

Technical measures that empower both operators of RFID systems and individuals to control the technology may also help prevent or mitigate the risks. A number of research programmes are exploring technical means to protect privacy[85] but some mechanisms are already available. For example, the EPCglobal Class 1 Generation 2 protocol "kill" command can be initiated at the point of sale to deactivate the tag permanently.[86] The tag antenna of the IBM Clipped Tag can easily be removed by the customer or by the merchant thus turning a long distance (10 m) UHF tag into a short distance (2 cm) tag for warranty, traceability or other services (See Figure 8). Reducing the read range to a few centimetres can make participation by the individual to data collection a prerequisite and, in some cases, may mitigate – if not eliminate – the privacy risks in an innovative manner. However, as for security, given the complexity and variety of RFID technology and possible use scenarios, there is no one-size-fits-all perfect technical solution to protect privacy.

Figure 8. IBM Clipped Tag



Note: The UHF RFID tag can be read at a distance of 10 meters until the consumer tears it apart, removing the antenna. The RFID tag remains functional but can only be read at a distance of a few centimetres.

Source: Markowitz, 2006.

85. "In response to the results of the European Consultation, the European Commission will support further development of privacy-enhancing technologies as one means to mitigate privacy risks." (European Commission, 2007a). For examples of RFID privacy technical research, see Juels (2005a) and Gildas Avoine's "RFID, Security and Privacy" website.

86. Consumer groups endorse the automatic deactivation of RFID tags at the point of sale, unless the consumer expressly agrees otherwise. See ANEC/BEUC, 2007.

In addition, it should be noted that technical measures always have a cost that, in some cases, may discourage RFID manufacturers to embed privacy protection in the design of tags and RFID operators to include them in the design of their RFID systems. Moreover, in a competitive environment, it is unclear whether higher product prices (or a reduction in business profit margins per product) due to the use of privacy-friendly technologies can be easily converted into a market advantage for a given company and product. Strategies to provide incentives to businesses for designing and using RFID technologies that include sufficient privacy protections may be pursued.

Minimisation of data collection, anonymisation and the use of technical measures embedding privacy in the design of a system should not however prevent data controllers from providing individuals with notice to seeking their consent or active participation. And reciprocally, providing notice and requiring consent should not prevent data controllers from using privacy friendly technologies.

2.2.2.2.2. Privacy impact assessment

Because of the wide variety of technical configurations and use scenarios, there is no "one-size-fits-all" technical solution that would compensate for the lack of consent in all situations and balance adequately privacy, cost, convenience and usability. In-depth examination of whether and to what extent the use of the technology actually gives rise to privacy concerns in a given system may be required. Such analysis would involve examining the RFID application, the kind of data collected, the nature and technical specification of the RFID technology used and the potential that the collected data will be related to an identified or identifiable individual.

Approaches that include an assessment, at design stage, of the impact on privacy of an RFID system enable identifying and understanding privacy risks and best strategies to mitigate them. They may be considered good practice. Echoing a consideration mentioned above regarding security risk management, the need for a holistic approach for privacy management may be considered as a good practice, considering each stage and each component of the overall system. In particular, the whole lifecycle of the RFID data within the organisation's broader information system should be considered. When considering the deployment of systems using interoperable RFID tags, the scope of such assessment may expand beyond the boundaries of the initial information system to include privacy risks associated with the whole life cycle of the tag.

As indicated in the section on security challenges, not all RFID technologies are equal regarding the likeliness of certain risks and, depending on the context in which they are used, some pose little or no specific risk at all. The choice of one RFID technology over another may have important consequences on privacy. A typical example is the operation range of radio wave systems compared to that of some magnetic induction systems that operate only at very short range, sometimes requiring individuals to actively take part in the reading process. One may suggest, as a good practice, to include privacy protection as one of the criteria for determining the characteristics of a planned system.

2.2.2.2.3. Awareness and understanding

Research in the United States and Europe[87] indicates that there is very limited public awareness of RFID and its implications but that consumers are looking for information.[88] The US FTC, the Ontario

87. Nearly two-thirds of the responses to the online public consultation carried out by the European Commission in 2006 indicated that, thus far, the information available is insufficient to allow the public to come to an informed judgement on the balance of risks of RFID (European Commission, 2007a). Cap Gemini's survey (2005a and 2005b) notes that although a bit higher in the United States, general awareness regarding RFID was low in both the United States and Europe.

Privacy Commissioner, and European Commissioner Viviane Reding, to name a few, have called for greater efforts to increase public understanding of the benefits and risks of the technology. Increasing the general level of awareness and understanding about the possibilities and limitations of the technology may contribute to alleviate perceived or real psychological obstacles and may increase the efficacy of relevant privacy notices. It may help individuals differentiate among RFID technologies, understand how the technology is implemented where they interact with it, and ask the right questions with respect to security and privacy.[89] Beyond the legal obligation to provide notice to individuals, policy makers may want to consider the encouragement of operators to provide open, comprehensive, transparent and educational descriptions of RFID systems, with a view to providing essential information on how they work and how privacy has been taken into account.

Efforts to enhance the general level of awareness and understanding of the technology could also aim at using simple language and avoid the confusion that technical jargon may generate as the technology becomes more widespread and reaches out to the general public. Using RFID vocabulary with educational needs in mind, in particular with a clearly defined and understood terminology, may certainly help in this respect. For example, as mentioned earlier, the very acronym RFID is itself misleading and terminology like "near field" and "far field", though certainly meaningful technically, is likely to create confusion for the general public.

Another source of confusion might come from generalisations regarding the level of risk associated with RFID, either to highlight or to downplay the risks, that may easily be inappropriate in specific situations and likely to create confusion. Debate over the risks and benefits of the technology frequently features scenario-specific examples leading to inaccurate generalisations. There are different RFID technologies with different properties and a large variety of ways to implement RFID systems. Sometimes, there may be compelling reasons for concern regarding privacy protection; sometimes the impact on privacy might be considered non existent. It is therefore important to avoid drawing general conclusions from specific examples: the drawbacks or the advantages of one implementation do not necessarily apply to another. Instead of focusing on the technology itself as being good or bad for privacy in general terms, a more balanced approach could consist in focusing on how it is implemented and whether and how risks are managed.

Efforts towards awareness and education may play an important role to reduce confusion and facilitate the deployment of RFID technologies for the benefit of business and individuals. However, as illustrated by the first section of this paper, RFID is a complex technology and will likely remain so. Therefore, there is a limit to the results that awareness and education can achieve. It cannot be expected that the average individual understands the ins and outs of RFID security and privacy prior to buying groceries at the supermarket, taking the subway, using a company badge, or his/her passport. Like for all information technologies that reach the general public, education is part of the answer to privacy and security issues, but cannot be the only answer.

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88. Cap Gemini (2005a).

89 . Awareness campaigns instructing individuals how to shield RFID tags so that they only expose personal data to those who need it could also be considered.

CONCLUSION

RFID technologies are often presented by their advocates as the "next big IT revolution" and are subject to a considerable amount of communication and publicity, sometimes drifting to technology and marketing "hype" or sensationalism. This phenomenon may increase the visibility of a technology with significant potential benefits to business and individuals. But it may also be counterproductive. The complexity of RFID technologies, their technical variety, and the very large range of possible applications they enable make them prone to being misunderstood. Like any information technology, if RFID were implemented without appropriate consideration of how to address privacy and security risks, it might damage the organisation that has deployed it, and cause harm to the individuals involved. Should significant risks be detected in existing or planned sensitive (*e.g.* passports, credit cards), large-scale (*e.g.* transportation systems) or striking (*e.g.* RFID implants) RFID systems, there would be a risk that RFID "hype" becomes RFID fear, damaging the perception of the technology by the general public and handicap its promising future. Such a scenario has already arisen. A number of RFID systems have been deployed without sufficient consideration for security and privacy, have been the target of severe criticisms by privacy and consumer organisations and have led to the creation of opposition or anti-"spychips" groups. On the other hand, the industry, public and privacy and consumer organisations have initiated a dialogue towards the development of privacy and security best practices.

Transparency requires that individuals understand what the technology can do and cannot do. Raising awareness about technology capabilities and limitations may be essential to prevent individuals and organisations deploying RFID from perceiving risks that do not exist or neglecting risks that actually exist, and to help them make appropriate choices.

The OECD *Security Guidelines* provide a flexible and technology-neutral framework that can be applied to RFID systems and networks. All the principles of the *Security Guidelines* are relevant in the RFID context.

The OECD *Privacy Guidelines* are also applicable to RFID systems when personal data is involved. The paper suggests that dialogue is still necessary to clarify or to reach a consensus on a number of points, such as *i)* the notion of personal data and data controller, *ii)* the nature of the information to provide to individuals and the best means to communicate it to achieve efficient transparency and *iii)* the cases where consent should be or not be required. Transparency, both from the data controllers and from organisations providing tags to individuals without being considered as data controllers has been pointed out as a key notion.

Although the OECD *Privacy* principles provide an essential framework for privacy protection including for RFID systems, the report also highlights other practices and measures that are incorporated into the 2002 *Security Guidelines* and could support the implementation of the privacy principles and reinforce their effectiveness.

Echoing the essential requirement for security risk assessments, methodologies such as privacy impact assessment may help identify privacy issues from the outset of a project and select the most appropriate and cost-effective prevention and mitigation measures. They may prevent the development of systems that can breach privacy and that would be extremely costly to turn into "privacy friendly" systems afterwards. As it cannot be expected that RFID security and privacy issues be solved totally at the RFID level, a

holistic approach to security risk assessment, privacy impact assessment and their management has been highlighted throughout this paper as essential. It results from the variety of RFID technologies, possible applications and uses, from the constantly evolving nature of technologies and risks and from the interdependencies between RFID systems and the other systems they are connected with.

The availability and adoption of cost-effective and convenient technical safeguards for privacy protection and security might be key success factors for the successful deployment of the RFID. A number of such technical security and privacy controls are already available. Still, cost and technical complexity may remain an obstacle to their deployment in some application areas. Research is ongoing but efforts to foster it and initiatives to provide incentives for the adoption of such technical safeguards could be welcomed. Nevertheless, security and privacy should not solely rely on technical measures but rather on a mix of management, operational and technical safeguards. Finally, building privacy into the technology rather than bolting it on afterwards has been identified by several technical and policy experts as one potentially efficient method to protect privacy. So called "Privacy by design" approaches or Privacy Enhancing Technologies, at the tag/reader or backend levels, could be encouraged.

Overall, RFID concerns a wide variety of stakeholders, from technologists and system designers to those who purchase the technology and their customers, including individuals who can carry tagged objects. Some stakeholders (*e.g.* on the supply side) are more likely to focus on preventive measures to reduce risk while others may focus on measures to mitigate the consequences of failures (*e.g.* on the use side). Effective communication and close co-operation by all stakeholders, including individuals, can help achieve increased security and privacy in RFID systems.

This report is the first step in OECD work to address security and privacy issues in the context of sensor based environments.[90] The findings and the present conclusions of this report are related to current and short-term uses of RFID technologies. But RFID technologies and uses evolve rapidly. It is therefore essential to monitor this evolution and detect potential new trends that would require further analysis and, possibly, modify these findings and lead to other conclusions. In particular, a number of anticipated developments are likely to raise challenges that are not addressed in this paper. These developments include for example the generalisation of objects tagging and open loop RFID applications processing personal data. The creation of an "Internet of things" and the development and pervasiveness of other sensor-based technologies, ultimately blurring the boundaries between the virtual and the physical worlds could modify the nature of privacy and security challenges in the longer term and remain to be analysed and addressed.

90. It is complemented by work carried out by the Working Party on Information Economy (WPIE). See OECD 2007b and 2007c.

ANNEX I. EXAMPLES OF RFID STANDARDS

RFID standards include (AIM, n.d. 2006):

- A number of standards developed and adopted by national and regional standardisation organisations such as the American National Standards Institute (ANSI), the European Telecommunication Standards Institute (ETSI) and the European Committee for Standardization (CEN).

- Standards and specifications adopted by sector specific standards organisations, such as the specification for RFID biometric passports adopted by the International Civil Aviation Association (ICAO) which defines how ISO 14443 standard on contactless smartcards should be implemented for travel documents (ICAO, 2004) and the Automotive Industry Action Group (AIAG) "Application Standard for RFID Devices in the Automotive Industry" (ARF-1) or "Tire and Wheel Identification Label Standard" (B-11); and

- The MIT Auto-ID Center (now Auto-ID Labs)[91] specifications related to the Electronic Product Code (EPC), now included in the work of GS1/EPCglobal,[92] as well as EPCglobal Architecture Framework which includes a collection of interrelated standards for hardware, software, and data interfaces, with core services for enhancing the supply chain. EPCglobal/GS1 Class 1 Generation 2 standard has been ratified by ISO in July 2006 as ISO 18000-6C.

91. The Auto-ID Center, created in 1999 was replaced in 2003 by the Auto-ID Labs which is a network of academic research labs.

92. EPCglobal is a joint venture between GS1 (former EAN International) and GS1 US, former Uniform Code Council, both bodies regulating barcode in Europe and in the United States respectively.

The table below highlights the main international RFID standards.

Table 9. Main International RFID Standards

ISO 10536	Identification cards – Contactless integrated circuit(s) cards (cards operating at very short proximity, < 1cm)
ISO 14443	Identification cards – Proximity integrated circuit(s) cards (cards operating at 10 cm distance and include a microprocessor). For example, this is the standard chosen by ICAO for passports (ICAO, 2004)
ISO 15693	Identification cards – contactless integrated circuit(s) cards – Vicinity cards (cards operating at 1 meter and usually not containing a microprocessor)
ISO 18000	RFID for Item Management - Air Interface (description of the standard air interface operating below 135 KHz, at 13.56 MHz, 2.45 GHz, 860 MHz to 960 MHz, 433 MHz)
ISO 10374	Freight containers -- Automatic identification (includes a container identification system, data coding systems, description of data, performance criteria and security features)
ISO 11784, ISO 11785, ISO 14223	Animal tagging
ETSI TS 102.190, ISO 18092, and ECMA 340	Near Field Communications Interface and Protocol-1 (NFCIP-1)
Standards directly related to Electronic Product Codes (EPC):	
Auto-ID Center Specifications	• 900 MHz Class 0 Radio Frequency (RF) Identification Tag Specification (communications interface and protocol, RF, and tag requirements, operational algorithms for 900MHz communications) • 13.56 MHz ISM Band Class 1 Radio Frequency (RF) Identification Tag Interface Specification (communications interface and protocol, RF, and tag requirements). • 860MHz -- 930 MHz Class 1 Radio Frequency (RF) Identification Tag Radio Frequency & Logical Communication Interface Specification (defines communications interface and protocol, RF, and tag requirements). • Conformance Requirements Specification v. 1.0.4 for Class-1 Generation2 UHF RFID (compliance for physical interactions (the signaling layer of the communications), operating procedures, and commands; between interrogators and tags for 860 MHz – 960 MHz communications.)
EPCglobal Architecture Framework	A collection of interrelated standards for hardware, software, and data interfaces, with core services for enhancing the supply chain through the use of Electronic Product Codes (EPCs). Includes standards for : • Tag Data • EPC Tag Data Translation • Class 1 Generation 2 UHF Air Interface Protocol (“Generation 2”), approved as ISO 18000-6C in July 2006 • Reader Protocol • Reader Management • Application Level Events • Object Naming Service (ONS) • Certificate Profile • Drug Pedigree • EPC Information Service version 1.0, approved on 12 April 2007

Sources: Pedris-Lopez, 2006; RFID Association Australia website (www.rfidaa.org/standards) ; EPCglobal website (www.epcglobalinc.org/standards/);

ANNEX II. NFC, UWB, ZIGBEE, RUBEE, WI-FI, ULTRASONIC TECHNOLOGIES

Near Field Communication (NFC): is a short-range technology that enables two devices to communicate when they are brought into actual touching distance. Sponsored by the NFC Forum which groups more than 100 companies including Sony, NXP (Philips) and Nokia, NFC enables sharing power and data using magnetic field induction at 13.56MHz (HF band), at short range, supporting varying data rates from 106kbps, 212kbps to 424kbps. A key feature of NFC is that it allows two devices to interconnect. In reader/writer mode, an NFC tag is a passive device that stores data that can be read by an NFC-enabled device (*e.g.* smart poster, for which a technical specification was developed). In Peer-to-Peer mode, two NFC devices can exchange data. For example, Bluetooth or Wi-Fi link set up parameters can be shared using NFC and data such as virtual business cards or digital photos can be exchanged. In Card Emulation mode, the NFC device itself acts as an NFC tag, appearing to an external reader as a traditional contactless smart card. This enables contactless payments and e-ticketing, for example. NFC is backed by 14 mobile operators representing 40% of the global mobile market.[93] NFC standards are acknowledged by major standardisation bodies and based on ISO/IEC 18092.

NFC mode	Applications
Peer to peer mode	Connect electronic devices
Read/Write mode	Access digital content (*e.g.* poster)
Card emulation mode	Make contactless transactions

ZigBee[94]: developed and promoted by the association of companies called "ZigBee alliance", the ZigBee specification adds application profile, security and network layers to IEEE 802.15.4 standard for wireless low-rate personal area networks. It operates in the UHF/microwave bandwidth with battery powered tags that communicate with each other. ZigBee adds to IEEE 802.15.4 the option of AES-128 encryption security. ZigBee protocols are intended for use in embedded applications requiring low data rates and low power consumption, enabling devices to form a mesh network of up to 65 000 nodes, covering a very large area.[95] It targets general-purpose, inexpensive, self-organising, mesh networks that can be used for industrial control, embedded sensing, medical data collection, smoke and intruder warning, building automation, home automation, domotics, etc. The resulting network will use very small amounts of power so individual devices might run for a year or two using the originally installed battery.

RuBee is a commercial name for a peer to peer communication protocol designed for active or passive tags operating at Low Frequency (using magnetic induction), suitable in environments containing water and/or metal. It is being standardised by IEEE as P1902.1 "IEEE Standard for Long Wavelength Wireless Network Protocol ". According to IEEE, the standard "will offer a "real-time, tag searchable"

93. "Mobiles Hope to be 'smart wallet'", BBC News website, International version, 21 November 2006, http://news.bbc.co.uk/2/hi/technology/6168222.stm.

94. See the Zigbee Alliance web site: www.zigbee.org. The name ZigBee comes from the zigzag path of bees which serves to signal new food location to other members of the colony, an analogy of mesh network topology.

95. « So, Who Needs ZigBee?" 8 November 2005, http://rfdesign.com/next_generation_wireless/who-needs-zigbee/ See also www.zigbee.org/en/press_kits/092706/Documents/ZigBeeTutorial.pdf.

protocol using IPv4 addresses and subnet addresses linked to asset taxonomies that run at speeds of 300 to 9 600 Baud. RuBee Visibility Networks are managed by a low-cost Ethernet enabled router. Rubee enables tag networks and telepresence applications. Individual tags and tag data may be viewed as a stand-alone, webserver from anywhere in the world. Each RuBee tag, if properly enabled, can be discovered and monitored over the World Wide Web using popular search engines (*e.g.* Google).[96]

Wi-Fi and **Bluetooth** communication protocols are usually not considered as RFID or sensor technologies since they were originally designed for connecting devices such as PCs, laptops and printers. They are commercial names for communication protocols IEEE 802.11 and IEEE 802.15.1. Both operate in the same frequency range (near 2.4 GHz). Bluetooth is a building block for personal area networks (PAN) or short distance wireless networks which connect together devices such as PC, Personal Digital Assistants (PDA), peripherals (keyboard, mouse…), cell phones, pagers, etc. Wi-Fi was developed to be used for laptop connectivity to local area networks but is now increasingly used for more services, including Internet and voice over IP, and connectivity of computer devices such as printers, webcams, DVD players, etc. However, several vendors have developed Wi-Fi active tags that allow for the use of existing Wi-Fi coverage and access points instead of deploying a specific RFID communication infrastructure. They are being used for example for asset tracking in power plants and hospitals, by theme amusement parks such as in Legoland (Denmark) to help parents find their children or to keep track of automotive vehicles in Venice (Italy) Port's visitor parking facility (Malykhina, 2005; Collins, 2004; Aeroscout, 2005).

Ultra Wide Band[97] can enable wireless connectivity at very large bandwidth for very close electronic devices (*e.g.* computer and monitor). UWB technology transmits information spread over a very large bandwidth (25% or more of the center frequency or at least 500 MHz)[98] but at very low power levels thus not interfering with other narrower band devices nearby. The receiver translates the pulses into data by listening for a familiar pulse sequence sent by the transmitter. As the data is moving on several channels at once, it can be sent at high speed, up to 1 gigabit per second. It also has the ability to penetrate walls. Frequency regulations limits UWB to low power levels in order to keep interferences at or below the level of noise produced unintentionally by electronic devices such as TV sets. As a consequence, UWB is limited to short-range applications, enabling wireless connectivity (*e.g.* wireless monitors, camcorders, printing, music players), home or office networking, automotive collision detection systems, medical imaging, etc. It is promoted by two industry associations, the WiMedia Alliance and the UWB Forum.[99] UWB is a fairly new technology that was regulated in 2002 by the US Federal Communications Commission (FCC), in 2006 in Japan and in 2007 in Europe (Yomogita, 2006; Holland, 2007). As it has been regulated only recently, the type of innovative applications it will enable in the future is still unclear.

Ultrasonic (based on ultrasound waves) technology enables tags to transmit unique 20 kHz to 40 kHz acoustic signals to a receiver. The signal does not require a line of sight between the reader and the tag, but

96. "IEEE Begins Wireless, Long-Wavelength Standard for Healthcare, Retail and Livestock Visibility Networks", 8 June 2006, IEEE, http://standards.ieee.org/announcements/pr_p19021Rubee.html.

97. Elements of information about UWB come from the following sources: Ultrawideband planet, FAQ, www.ultrawidebandplanet.com/faq/. "An introduction to Ultra Wide Band (UWB) wireless", Rafael Kolic, 24 February 2004, Deviceforge.com, www.deviceforge.com/articles/AT8171287040.html. "Intel and UWB", www.intel.com/standards/case/case_uwb.htm.

98. "A UWB signal centered at 2 GHz would have a minimum bandwidth of 500 MHz and the minimum bandwidth of a UWB signal centered at 4 GHz would be 1 GHz. The most common technique for generating a UWB signal is to transmit pulses with durations less than 1 nanosecond". UWB resource center, Palowireless; "Ultra Wide Band Tutorial", www.palowireless.com/uwb/tutorials.asp.

99. See www.wimedia.org and www.uwbforum.org.

it does not penetrate solid walls and the receiver has to be located in the same room. It is not subject to electromagnetic interferences and does not create such interferences. Tags are battery powered. This technology has been tested and deployed in the hospital environment.[100]

Hewlett Packard's (HP) experimental "Memory Spot" chip (see Figure 9 below) suggests that technological innovation is likely to force us to review today's concepts and definitions of RFID. About the size of a grain of rice, the "Memory Spot" chip can broadcast data at 10 megabit per second, has a built-in antenna and a storage capacity ranging from 32 kilobytes to 512 kilobytes. It uses microwaves (2.45 GHz) but needs to be positioned very close (1 mm) to the reader for the communication to take place. It has read/write capacity and enables cryptography. These chips, which could reach the market within two or three years, can store large amounts of text, sound, pictures and even video clips. For example, they could enable adding a video clip to a postcard, a medical record to a patient's wristband, "adding voice instructions to a consumer medicine bottle, storing a document electronically on the printed copy […] attaching a copy of the manual to every piece of equipment so you always know where to find it". As noted by a journalist, with this type of memory capacity, processing and networking capability, memory spots "will function like mini-computers rather than like passive tags". The memory spot prototype demonstrates that the differences between a tag and a computer are decreasing. (Kanellos, 2006; Krill, 2006; HP, 2006; Taub; 2006)

Figure 9. HP Memory Spot

"Attach a chip to the prints of photographs and add music, commentary or ambient sound"

Source : HP Memory Spot.

100. "Testing Ultrasound to Track, Monitor Patients", Mary Catherine O'Connor, *RFID Journal*, 15 March 2006, www.rfidjournal.com/article/articleprint/2199/-1/1/. See www.sonitor.com.

ANNEX III. SECURITY EXPLOITS

This Annex provides a list of security exploits found in the literature.

Lack of basic security:

- Of the ten different types of RFID systems used in hotels, a hacker found that none used encryption. He also found out that many systems which use encryption failed to change the default key set by the manufacturer, or that they used sample keys provided in user manuals sent with the cards. He created a database of such sample keys to conduct dictionary attacks and was able to open about 75% of all the cards collected. In addition, he created a master key card to open every room in a hotel, office or other facility. He cloned Philips Electronics' Mifare, the most commonly used key-access system. To create a master key he simply needed two or three key cards for different rooms to determine the structure of the cards. (Zetter, 2006)
- The same hacker was also able to crash RFID-enabled alarm systems designed to sound when an intruder breaks a window or door to gain entry. Such systems require workers to pass an RFID card over a reader to turn the system on and off. The hacker found that by manipulating data on the RFID chip, he could crash the system, opening the way for a thief to break into the building through a window or door.
- According to a Japanese newspaper, data about the passenger's latest entry and exit stations stored in the Suica card[101] can be read by basic RFID readers, such as the one embedded in Sony Clié PDA. The journalist claimed that the possibility to read such information at a distance could facilitate stalking.[102] Similarly, a British newspaper reports that access to data corresponding to "every journey taken in the past 10 weeks" in the London Oyster card is possible by keying in its serial number on a website or taking the card to a reader machine in the underground. The journalist reports that this information can be used in divorce procedures.[103]
- The implantable RFID "Verichip" was cloned in less than 10 minutes by a 23 year old Canadian hardware developer for the purpose of an article in the magazine *Wired*. The tag, implanted in the journalist's arm for the purpose of the article, featured no security at all (Newitz, 2006).
- According to the same *Wired* article, 5 million RFID tags have been sold to libraries in an unlocked state to "make it easier for libraries to change the data". Unfortunately, these tags also enable anyone with the appropriate software and hardware to write on the tag as well.

101. 10 million Suica cards were issued between 2001 and 2004. See www.jreast.co.jp/e/press/20041003/.

102. http://kodansha.cplaza.ne.jp/digital/it/2003_08_27/content.html, article in Japanese.

103. "How an Oyster Card can Ruin your Marriage", *The Independent on Sunday*, reproduced at www.theabi.org.uk/press/p0602.htm

Insufficient security

- Texas Instrument "Digital Signature Transponder" which secures over 6 million tags ExxonMobil SpeedPass payment transponders and over 150 million automobile ignition keys has been cloned in 2005 by RSA Laboratories using inexpensive off-the-shelf equipment. The team purchased gasoline at an ExxonMobil station multiple times with the cloned pass and spoofed a Ford car immobiliser system (Bono *et al*., 2006).
- Electronic passports have been under intense scrutiny since their announcement:
  - A German computer security consultant successfully cloned an ICAO compliant RFID electronic passport using an off-the-shelf RFID reader and software tools (Zetter, 2006).
  - The same consultant conducted a successful attack against RFID passport readers by cloning a passport chip and modifying the image it contained to exploit a known vulnerability in the software library used to decode the image (Zetter, 2007).
  - A shielding solution planned for the US e-passport that is aimed at preventing remote reading of the passport when the document is not open was found to allow such reading when the booklet is only a half inch open, such as in a pocket or handbag (Flexilis, 2006). The prototype Dutch RFID passport, featuring the Basic Access Control[104] protection, was cracked by security specialists and they claimed that the attack was possible at a 10m range (Lettice, 2006).
- Expensive cars secured by software methods can be stolen using a simple laptop: "The expert gang suspected of stealing two of David Beckham's BMW X5 SUVs in the last six months did [used] software programs on a laptop to wirelessly break into the car's computer, open the doors, and start the engine" (Leftlane News, 2006).

104. Basic Access Control is an optional feature which unlocks the RFID chip only if the passport's machine readable zone has been read by an optical reader, and encrypts the data exchanged using information derived from the content of that zone.

ANNEX IV. THE ELECTRONIC PRODUCT CODE (EPC) NUMBER STRUCTURE

01	0000A89	00016F	000247DC0
Header 8 bits	EPC manager 28 bits	Object class 24 bits	Serial number 36 bits

"The EPC is a generic, universal numbering scheme for physical objects, similar in scope to the barcode numbering scheme (UPC). However, […] the EPC has the capability to identify every single, individual product item. […] The manager number identifies the company involved in the production of the item (manufacturer) and the object class defined 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 millions companies (2^{28}). Each manufacturer can have 16 million (2^{24}) object classes and 68 billion serial number (2^{36}) in each class."

(*Source*: JISC Technology and Standards Watch, May 2006).

"The structured hierarchy of EPC numbers nests identification information onto distinct segments of the EPC string (*i.e.* the EPC Manager Number segment identifies who, the Object Class segment identifies what, and the Serial Number segment identifies which). As a result, each segment conveys a different level of information about the item to which the EPC is attached."

Source: EPCglobal, EPCglobal Position Paper, Implementation of the EPCglobal Network Root ONS, Release 1, 2005.

ANNEX V. EXAMPLES OF PRIVACY REFERENCES

A large number of resources related to RFID privacy are available. This list reflects only a subset of the documents that the Secretariat has gathered to date. It only contains documents with a policy guidance dimension, issued either by governmental bodies or by organisations with a public policy focus or international orientation. It is complementary to the bibliography.

A. RFID in general

DPAs and other official bodies

International
25th International Conference of Data Protection and Privacy Commissioners – Sydney – "Resolution on Radio-Frequency Identification", 20 November 2003
www.cnil.fr/fileadmin/documents/uk/Resolution_RFID-VA.pdf

Regional
Article 29 Working Party – "Working Document on Data Protection Issues Related to RFID Technology", 19 January 2005
http://ec.europa.eu/justice_home/fsj/privacy/docs/wpdocs/2005/wp105_en.pdf

European Commission's RFID consultation website
www.rfidconsultation.eu

Canada
Ontario - Information and Privacy Commissioner
"Privacy Guidelines for RFID Information Systems", June 2006
www.ipc.on.ca/images/Resources/up-rfidgdlines.pdf
"Practical Tips for Implementing RFID Privacy Guidelines", June 2006
www.ipc.on.ca/images/Resources/up-rfidtips.pdf

Germany
Resolution of the 72nd German Data Protection Conference of the Federation and the Länder held in Naumburg from 26 to 27 October 2006, "Binding rules for the use of RFID technologies"

Federal Commissioner for Data Protection and Freedom of Information
"RFID Radio Chips for Every Occasion"
www.bfdi.bund.de/cln_029/nn_672292/EN/Topics/technologicalDataProtection/Artikel/RFID_E2_80_93RadioTagsForAllOccasions.html

Italy
GarantePrivacy
"Smart (RFID) Tags: Safeguards Applying to Their Use", 9 March 2005
www.garanteprivacy.it/garante/doc.jsp?ID=1121107

France
CNIL
Address by Philippe Lemoine relating to Radio-Tags (RFIDs), 2003
www.cnil.fr/fileadmin/documents/uk/CNIL-lemoine-RFID_102003_VA.pdf

Japan
"Guidelines for Privacy Protection with Regard to RFID tags", 8 July 2004
www.rfidconsultation.eu/docs/ficheiros/JP_RFID_PrivacyGLsRev_METI.pdf

Korea
"RFID Privacy Protection Guideline" (unofficial translation)
www.worldlii.org/int/other/PrivLRes/2005/3.html

Netherlands
Minister of Economic Affairs,
"RFID in the Netherlands", 25 September 2006 (document transmitted to the Parliament)

United Kingdom
ICO – "Data Protection technical guidance", 9 August 2006
www.ico.gov.uk/upload/documents/library/data_protection/detailed_specialist_guides/radio_frequency_indentification_tech_guidance.pdf
www.rfidconsultation.eu/docs/ficheiros/RFID_Ofcom_statement.pdf

United States
« The use of RFID for Human Identification» (Draft Report),
Department of Homeland Security
www.dhs.gov/xlibrary/assets/privacy/privacy_advcom_rpt_rfid_draft.pdf

"RFID applications and implications for consumers", March 2005
Federal Trade Commission
www.ftc.gov/os/2005/03/050308rfidrpt.pdf

Business

Enterprise Privacy Group – A privacy code of conduct for RFID technologies – 3 May 2005
www.rfidconsultation.eu/docs/ficheiros/EPG_RFID_Privacy_Code_of_Conduct.pdf

EPCglobal – Guidelines on EPC for consumer products
www.epcglobalinc.org/public/ppsc_guide/

EPCglobal – "EPCglobal Submission to the Article 29 Working Party in Response to its Working Document 10107/05 WP 105 of 19 January 2005 on Data protection issues related to RFID Technology"
http://ec.europa.eu/justice_home/fsj/privacy/docs/rfid/epcglobal_en.pdf

EPCglobal – "EPCglobal Response to the EU RFID Online Consultation"
www.rfidconsultation.eu/docs/ficheiros/EPCglobal_Response_to_EU_RFID_Online_Consultation.pd

EuroCommerce Position paper
www.rfidconsultation.eu/docs/ficheiros/EuroCommerce_Position_on_RFID.pdf

International Chamber of Commerce – "ICC principles for responsible deployment and operation of electronic product codes"
www.iccwbo.org/home/statements_rules/statements/2005/EPC_principles.asp

UK RFID Council - UK Code of practice for the use of RFID in retail outlets
www.rfidconsultation.eu/docs/ficheiros/code_release_1_0_120406__logos.pdf

Civil Society

Center for Democracy and Technology Working Group on RFID: "Privacy Best Practices for Deployment of RFID Technology"
www.cdt.org/privacy/20060501rfid-best-practices.php

EPIC Guidelines on Commercial Use of RFID Technology
www.epic.org/privacy/rfid/rfid_gdlnes-070904.pdf

Privacy Rights Clearinghouse - "RFID position statement of Consumer, Privacy and Civil Liberties Organisations"
www.privacyrights.org/ar/RFIDposition.htm

Trans Atlantic Consumer Dialogue – "Resolution on Radio Frequency Identification", April 2005.
www.tacd.org/docs/?id=274

B. RFID in specific areas

Libraries
"Privacy and Confidentiality Guidelines" (American Library Association)
www.ala.org/ala/oif/statementspols/otherpolicies/rfidinlibraries.pdf

Ontario Information and Privacy Commissioner
"Guidelines for using RFID tags in Ontario Public Libraries"
www.ipc.on.ca/images/Resources/rfid-lib.pdf

Drugs & healthcare
RFID Feasibility Studies and Pilot Programs for Drugs / Compliance policy guide
www.fda.gov/oc/initiatives/counterfeit/rfid_cpg.html

Workplace
UNI "RFID in the Workplace – UNI code of Good Practice"
www.union-network.org/uniindep.nsf/2702f48e48fad7dac125718e0034fd79/$FILE/RFIDdraft.pdf

"Pervasive Computing: Trends and Impacts", 2006
www.bsi.de/literat/studien/percenta/Percenta_eacc.pdf

BIBLIOGRAPHY

Aeroscout (2005), *Port of Venice Deploys Aeroscout Visibility System for Vehicle Inventory Management*, Aeroscout, San Mateo, www.aeroscout.com/viewItem.asp?type=press&itemId=23.

AIM (n.d.), *RFID Standards*, AIM website. www.aimglobal.org/standards/rfidstds/RFIDStandard.asp, accessed 8 June 2007.

AIM (2001), *Shrouds of time. The history of RFID,* AIM, Pittsburg. www.aimglobal.org/technologies/rfid/resources/shrouds_of_time.pdf

AIM Frequency Forum (2000), *Draft paper on the Characteristics of RFID systems*, Version 1.0. www.aimglobal.org/technologies/rfid/resources/RFIDCharacteristics.pdf

Alberganti, Michel (2007), *Sous l'oeil des puces*, Actes Sud, Paris.

Albrecht, Katherine and McIntyre, Liz (2005), *Spychips*, Plume.

ANEC/BEUC (2007), *Consumers' scenarios for a RFID policy - Joint ANEC/BEUC Comments on the Communication on Radio Frequency Identification (RFID) in Europe: steps towards a policy framework COM(2007) 96*, Bruxelles, www.anec.org/attachments/ANEC-ICT-2007-G-059.pdf.

Article 29 Working Party (2005), *Working Document on data protection issues related to RFID technologies*.

Article 29 Working Party (2007), *Opinion 4/2007 on the concept of personal data*.

Avoine, Gildas (n.d.), *RFID Security and Privacy*, website. http://lasecwww.epfl.ch/~gavoine/rfid/.

Australian Government, Department of Communications, Information Technologies and the Arts (2006), *Getting the most out of RFID. A starting Guide to Radio Frequency Identification for SMEs*, www.dcita.gov.au/__data/assets/pdf_file/41249/Getting_the_most_out_of_RFID.pdf

Bacheldor, Beth (2006), "Hospital Tries ZigBee to Track Patients", *RFID Journal*, 21 July 2006, www.rfidjournal.com/article/articleview/2509/.

BMWi (German Federal Ministry of Economics and Technology) (2007), *European Policy Outlook RFID*, Berlin, www.nextgenerationmedia.de/Nextgenerationmedia/Redaktion/en/PDF/Final_20version_20European_20Policy_20Outlook_20RFID,property=pdf,bereich=nextgenerationmedia,sprache=en,rwb=true.pdf

Bono, S., Green, M., Stubblefield, A., Juels, A., Rubin, A. and Szydlo, M. (2006), *Security Analysis of a Cryptographically-Enabled RFID Device*, in "Proceedings of the 14th Usenix Security Symposium", p. 1-16. https://db.usenix.org/events/sec05/tech/bono.html.

BRIDGE (Building Radio Frequency Identification for the Global Environment) (2007), *Security Analysis Report*, BRIDGE, www.bridge-project.eu/data/File/BRIDGE%20WP04%20Security%20Analysis%20Report.pdf

BSI (Bundesamt für Sicherheit in der Informationstechnik) (2005), *Security aspects and Prospective Applications of RFID Systems,* BSI, Bonn, www.bsi.bund.de/fachthem/rfid/RIKCHA_englisch_Layout.pdf

Cap Gemini (2005a), *RFID and Consumers. What European Consumers Think About Radio Frequency Identification and the Implications for Business*, Cap Gemini, Paris. www.capgemini.com/news/2005/Capgemini_European_RFID_report.pdf

Cap Gemini (2005b), *Consumer education is key to boosting awareness and overcoming misconceptions about RFID*, Cap Gemini, Paris, www.capgemini.com/news/2005/0209RFID.shtml

Cardullo, Mario, "Genesis of the Versatile RFID Tag", *RFID Journal*, www.rfidjournal.com/article/articleview/392/1/2/.

Cavoukian, Ann (2004), *Tag, you're it: Privacy Implications of Radio Frequency Identification (RFID) Technology*, Information and Privacy Commissioner/Ontario, Toronto, www.ipc.on.ca/images/Resources/up-rfid.pdf.

Cavoukian, Ann (2006a), Privacy Guidelines for RFID Information Systems (RFID Privacy Guidelines), Information and Privacy Commissioner/Ontario, Toronto, www.ipc.on.ca/images/Resources/up-rfidgdlines.pdf.

CDT (Center for Democracy and Technology) (2006), *CDT Working Group on RFID: Privacy Best Practices for Deployment of RFID Technology*, www.cdt.org/privacy/20060501rfid-best-practices.php

CIPL (Center for Information Policy Leadership) (2007), *RFID Transparency Symbol Project*, Hunton & Williams, www.hunton.com/files/tbl_s47Details/FileUpload265/1948/RFID_Two-Pager.pdf.

Collins, Jonathan (2004), "Lost and Found in Legoland", *RFID Journal*, www.rfidjournal.com/article/articleview/921/1/1/.

Desmons, Dimitri (2006), *UHF Gen 2 for Item-Level Tagging*, Impinj Inc, www.impinj.com/files/Impinj_ILT_RFID_World.pdf

DIFRwear website, www.difrwear.com, accessed on 11 July 2007.

Dressen, David (2004), "Considerations for RFID selection", *Atmel Applications Journal*, www.atmel.com/dyn/resources/Prod_documents/secrerf_3_04.pdf.

Dutch DPA (Data Protection Authority), R. Beugelsdijk, (2006) RFID, *Promising or Irresponsible? Contribution to the Social Debate about RFID*, Dutch DPA, The Hague, www.dutchdpa.nl/documenten/en_rap_2006_rfid.shtml

Engels, D.W. and Sarma, S.E. (2005), *Standardization requirements within the RFID class structure*, Auto-ID Labs, MIT, January 2005, Cambridge MA, USA. http://autoid.mit.edu/CS/files/11/download.aspx.

EPCglobal (2004a), *The EPCglobal network: Overview of Design, Benefits, & Security*, EPCglobal Inc., www.epcglobalinc.org/news/EPCglobal_Network_Overview_10072004.pdf.

EPCglobal (2004b), *EPCglobal Object Name Service (ONS) 1.0*, EPCglobal Inc., www.epcglobalinc.org/EPCglobal_ONS_1.0.pdf.

EPCglobal (2005a), *Submission to the Article 29 Working Party in Response to its Working Document 10107/05, WP 105 of 19 January 2005 on Data Protection issues related to RFID Technology*, EPCglobal Inc., http://ec.europa.eu/justice_home/fsj/privacy/docs/rfid/epcglobal_en.pdf.

EPCglobal (2005b), *The EPCglobal Architecture Framework*, EPCglobal Inc., www.epcglobalinc.org/standards/Final-epcglobal-arch-20050701.pdf.

EPCglobal (2005c), *EPC Radio-Frequency Identity Protocols Class 1 Generation 2UHF RFID. Protocol for communications at 860 Mhz -960 Mhz. Version 1.0.9*, EPCglobal Inc., www.epcglobalinc.org/standards/Class_1_Generation_2_UHF_Air_Interface_Protocol_Standard_Version_1.0.9.pdf.

EPCglobal (2005d), *Guidelines on EPC for Consumer Products*, EPCglobal Inc., www.epcglobalinc.org/public/ppsc_guide/.

EPCglobal (2007), *Position Paper on the Definition of Personal Data in the Context of RFID/EPC Technology Applications*, EPCglobal Inc.

EPIC (Electronic Privacy Information Center) (n.d.), *RFID Privacy Page*, www.epic.org/privacy/rfid/.

European Commission (2007a), *Radio Frequency Identification (RFID) in Europe: steps towards a policy framework. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of Regions*, European Commission, COM(2007)96 final, Brussels. http://ec.europa.eu/information_society/policy/rfid/doc/rfid_en.pdf.

European Commission (2007b), *The RFID Revolution: Your voice on the Challenges, Opportunities and Threats. Commission Staff Working Document. Results of the Public Online Consultation on Future Radio Frequency Identification Technology Policy*, European Commission, SEC(2007)312, http://ec.europa.eu/information_society/policy/rfid/doc/rfidswp_en.pdf.

European Commission (2007c), Communication from the Commission to the European Parliament and the Council on the Follow-up of the Work Programme for Better Implementation of the Data Protection Directive, COM(2007)97 final, European Commission, Brussels. http://ec.europa.eu/justice_home/fsj/privacy/docs/lawreport/com_2007_87_f_en.pdf

European Parliament (2007), *RFID and Identity Management in Everyday Life. Striking the balance between convenience, choice and control*, IPOL/A/STOA/2006-22, PE 383.219, www.europarl.europa.eu/stoa/publications/studies/stoa182_en.pdf.

Fabian B., Olivier, G. and Spiekermann, S (2005), *Security Analysis of the Object Name Service (ONS) for RFID,* International Workshop on Security, Privacy and Trust in Pervasive and Ubiquitous Computing, SecPerU'05, IEEE, http://lasecwww.epfl.ch/~gavoine/download/papers/FabianGS-2005-sptpuc.pdf.

Finkenzeller, Klaus (2003), *RFID Handbook: Fundamentals and Applications in Contactless Smart Cards and Identification*, 2nd Edition, Wiley & Sons.

Finkenzeller, Klaus (2006), *Standardization of RFID*, RFID Handbook website, www.rfid-handbook.de/rfid/standardization.html.

Flexilis (2006), *RFID E-Passport Vulnerability*, Flexilis, www.flexilis.com/epassport.php

Floerkemeir, C., Schneider, R., Langheinrich, M. (2005), *Scanning with a purpose – Supporting Fair Information Principles in RFID Protocols.,* 2nd International Symposium on Ubiquitous Computing Systems, UCS 2004, 8-9 November 2004, Tokyo, Japan.

Garfinkel, Simson and Holtzman, H. (2005), *Understanding RFID Technology*, in Garfinkel Simson. and Rosenberg Beth, "RFID Applications, Security, and Privacy", Addison-Wesley Professional, Boston.

Gartner (2005), *Gartner Says Worldwide RFID Spending to Surpass $3 Billion in 2010*, Gartner, Stamford, www.gartner.com/press_releases/asset_141469_11.html.

HP (Hewlett-Packard) (2006), *HP Unveils Revolutionary Wireless Chip that Links the Digital and Physical Worlds*, HP, www.hp.com/hpinfo/newsroom/press/2006/060717a.html.

Hitachi (2003), *Hitachi to Sell Inexpensive μ-Chip Inlets at Fraction of the Cost of Existing Inlets, Open the Way to Use in Various Applications*, Hitachi press release, www.hitachi.com/New/cnews/031204.html

Holland, Colin (2007), *Europe approves UWB regulations*, EETimes Europe, http://eetimes.eu/showArticle.jhtml?articleID=197800214.

IDTechEx (2005), *Active RFID - A profitable business*, IDTechEx, www.idtechex.com/products/en/articles/00000396.asp

IDTechEx (2006a), *RFID Market $2.71Bn in 2006 to $12.35Bn in 2010 – RFID Forecasts 2006 to 2016: The latest research from IDTechEx*, IDTechEx, www.idtechex.com/products/en/articles/00000409.asp.

IDTechEx and Das, Raghu (2006b), *Chipless RFID – The End Game*, IDTechEx, www.idtechex.com/products/en/articles/00000435.asp.

ICC (International Chamber of Commerce), EICTA (European Information, Communications and Consumer Electronics Technology Industry Association), ICRT (International Communications Round Table) and JBCE (Japan Business Council in Europe) (2005), *European Commission DG Internal Market – Art.29 Data Protection Working Party Working Document on data protection issues related to RFID technology – WP 105/ Response by ICC, EICTA, ICRT and JBCE to the public consultation,* ICC, EICTA, ICRT and JBCE, http://ec.europa.eu/justice_home/fsj/privacy/docs/rfid/eicta_en.pdf.

ICAO (International Civil Aviation Organisation) (2004), *Annex I - Use of Contactless Integrated Circuits in Machine Readable Travel Document. Version 4.0*, ICAO, Montreal. http://mrtd.icao.int/component/option,com_remository/Itemid,32/func,fileinfo/id,2/

ITU (International Telecommunication Union) (2005), *The Internet of Things*, ITU, Geneva. http://mrtd.icao.int/component/option,com_remository/Itemid,32/func,fileinfo/id,2/.

Kanellos, Michael (2006), *HP's Memory Spot puts video, audio into photos*, CNET News.com, http://news.zdnet.com/2100-1040_22-6094586.html.

Krill, Paul (2006), *HP hails Memory Spot chips to extend content access*, Infoworld www.infoworld.com/article/06/07/17/HNmemoryspotpalo_1.html,

Juels, A., Rivest, R. and Szydlo, M. (2003), "The blocker Tag: Selective Blocking of RFID Tags for Consumer Privacy", in V. Atluri, ed. 8th ACM *Conference on Computer and Communications Security*, pp. 103-111. ACM Press.

Juels, A. (2005a), *RFID Security and Privacy: A Research Survey*, RSA Laboratories, www.rsasecurity.com/rsalabs/staff/bios/ajuels/publications/pdfs/rfid_survey_28_09_05.pdf

Juels, A. (2005b), *RFID Privacy: a technical primer for the non-technical reader*, RSA Laboratories, www.rsasecurity.com/rsalabs/staff/bios/ajuels/publications/rfid_privacy/DePaul23Feb05Draft.pdf.

Lace, Susan (2004), *Calling in the chips? Findings from the first summit exploring the future of RFID technology in retail*, National Consumer Council, London, www.ncc.org.uk/technology/calling_in_chips.pdf.

Lahiri, Sandip (2005), "RFID: A Technology Overview", *RFID Sourcebook*, IBM Press.

Langheinrich, Marc, (2007), "RFID and Privacy", in Milan Petkovic, Willem Jonker (Eds.), *Security, Privacy, and Trust in Modern Data Management*, Springer, Berlin Heidelberg New York, www.vs.inf.ethz.ch/publ/papers/langhein2006rfidprivacy.pdf.

Le Pallec, Sophie (2005), *La convergence des identifiants numériques,* CGEMP, Université Paris Dauphine, http://2005.jres.org/resume/70.pdf.

Leftnane News (2006), *Gone in 20 minutes: using laptops to steal cars*, Leftlane news, www.leftlanenews.com/2006/05/03/gone-in-20-minutes-using-laptops-to-steal-cars/

Lettice, John (2006), *Face and Fingerprints Swiped in Dutch Biometric Passport Crack*, The Register, www.theregister.co.uk/2006/01/30/dutch_biometric_passport_crack/.

Malykhina, Elena (2005), "Active RFID Meets Wi-Fi to Ease Asset Tracking", *InformationWeek*. www.informationweek.com/story/showArticle.jhtml?articleID=57701494.

Merritt, Rick (2006), *Cellphone could crack RFID tags, says cryptographer*, EEtimes online, www.eetimes.com/showArticle.jhtml?articleID=180201688.

Moore, Bert (2006), *RFID: A Plethora of Standards*, AIM, Warrendale, Pennsylvania. www.aimglobal.org/members/news/templates/aiminsights.asp?articleid=1615&zoneid=43.

Moskowitz, P., Lauris, A. and Morris, S. (2006), "Privacy-Enhancing Radio Frequency Identification Tag: Implementation of the Clipped Tag", *RFID Journal Live*, www-03.ibm.com/solutions/businesssolutions/sensors/doc/content/bin/Clipped_Tag_White_Paper.pdf?g_type=hpfeat.

National Research Council, Committee on Radio Frequency Identification Technologies, (2004), *Radio Frequency Identification Technologies: a Workshop Summary*, National Research Council, Washington.

Newitz, Analee (2006), "The RFID Hacking Underground", *Wired*, www.wired.com/wired/archive/14.05/rfid.html

NIST (National Institute of Standards and Technology) (2007), *Guidelines for Securing Radio Frequency Identification (RFID) Systems*, Special publication 800-98, NIST, Gaithersburg, http://csrc.nist.gov/publications/nistpubs/800-98/SP800-98_RFID-2007.pdf

O'Connor, Mary Catherine (2006), "EPC Tags Subject to Phone Attacks", *RFID Journal*, www.rfidjournal.com/article/articleview/2167/1/1/

O'Connor, Mary Catherine (2007), "Building Automation Will Drive ZigBee Adoption", *RFID Journal*, www.rfidjournal.com/article/articleview/2943/1/1/.

OECD (1980), *OECD Guidelines on the Protection of Privacy and Transborder Flows of Personal Data*, OECD, Paris.

OECD (1999), *OECD Guidelines for Consumer Protection in the Context of Electronic Commerce*, OECD, Paris.

OECD (2002), *OECD Guidelines for the Security of Information Systems and Networks: Towards a Culture of Security*, OECD, Paris.

OECD (2003), *Privacy Online. OECD Guidance on Policy and Practice*, OECD, Paris.

OECD (2005), *Biometric Based Technologies*, OECD, Paris

OECD (2006a), *Radio Frequency Identification (RFID): Drivers, Challenges and Public Policy Considerations*, OECD, Paris.

OECD (2006b), *Making Privacy Notices Simple: an OECD Report and Recommendations*, OECD, Paris.

OECD (2006c), Foresight Forum *"Radio Frequency Identification (RFID) Applications and Public Policy Considerations":* Proceedings, OECD, Paris.

OECD (2007a), *Analytical report on Malicious Software*, DSTI/ICCP/REG(2007)5/FINAL (forthcoming), OECD, Paris.

OECD (2007b), *RFID: Challenges and Benefits in Technology Implementation*, DSTI/ICCP/IE(2007)6/FINAL, OECD, Paris.

OECD (2007c), *RFID: Outline of Further Work*, secretariat working paper, OECD, Paris.

Oehlmann, H. (2006), ISO RFID application standards published in 2006, Odette.se, www.odette.se/files/seminariet%202006-04-11/Oehlmann.pdf.

Ohkubo M., Suzuki K., Kinoshita S., (2003), *Cryptographic Approach to "Privacy-Friendly" Tags*, Paper presented at the RFID Privacy Workshop at MIT 2003, www.rfidprivacy.us/2003/papers/ohkubo.pdf.

Oren, Y. and Shamir, A. (n.d.), *Power analysis of RFID*, Yossi Oren's website, www.wisdom.weizmann.ac.il/~yossio/rfid/.

Peris-Lopez, P., Hernandez-Castro, J.C., Estevez-Tapiador, Juan. and Arturo Ribagorda (2006), *RFID Systems : A Survey on Security Threats and Proposed Solutions*, http://lasecwww.epfl.ch/~gavoine/download/papers/PerisHER-2006-pwc.pdf.

Pradelles, Daniel, *RFID & Privacy. Perception of Reality?*, Presentation at the European Commission Consultation on RFID Workshop on 17 June 2006, www.rfidconsultation.eu/docs/ficheiros/Daniel_Pradelles.pdf.

QED Systems (2002), *Part 1: Active and Passive RFID: Two Distinct, But Complementary, Technologies for Real-Time Supply Chain Visibility*, QED Systems, www.autoid.org/2002_Documents/sc31_wg4/docs_501-520/520_18000-7_WhitePaper.pdf.

Rees, Richard (2004), *ISO Supply chain RFID Standards*, Presentation at the "RFID and Telecommunication Services Workshop", ETSI, http://portal.etsi.org/docbox/ERM/open/RFIDWorkshop/RFID_20%20Richard%20Rees_BSI.pdf.

Resolution of the 72nd German Data Protection Conference of the Federation and the Länder held in Naumburg from 26 to 27 October 2006 (2006), *Binding Rules for the Use of RFID Technologies*.

RFID Journal (n.d.), *Frequently asked question. The cost of RFID equipment*, *RFID Journal*, www.rfidjournal.com/faq/20/86, accessed on 23 May 2007.

RFID Journal (2003), *Military's RFID Alternative: IPv6*, *RFID Journal*, www.rfidjournal.com/article/articleprint/609/-1/1/.

Rieback, M., Crispo, B. and Tanenbaum A. (n.d.), "Is your cat infected with a Computer Virus?", Vrije Universiteit, Amsterdam, www.rfidvirus.org.

Simpson, Richard and St. Arnaud, Bill (2007), Position paper on *"Social and Economic Factors Shaping the Future of the Internet for the Workshop"* hosted by the NSF and the OECD.

Song, Jieun *et al* (2005), *Security Enhanced RFID Middleware system, "*Transactions on Enginering", Computing and Technology, v10, p.79-80.

Stapleton-Gray, Ross (n.d.), *RFID, Surveillance and Privacy: The Sorting Door Project*, Stapleton-Gray & Associates, Inc.

Swedberg, Claire (2006), *Chicago Fire Dept. Tests ZigBee-based RFID System, RFID Journal*, www.rfidjournal.com/article/articleview/2717/1/1/.

Taub, Howard and Genuth, Iddo (2006), *HP's Memory Spot Chip is Spot On*, The Future of Things website, www.tfot.info/content/view/79/59/.

US Department of Commerce (2005a), *RFID in 2005: Technology and Industry Perspectives – Workshop Summary – Wednesday 6 April 2005*, US Department of Commerce, Washington DC, www.technology.gov/Events/2005/RFID/0406_Summary.pdf.

US Department of Commerce (2005b), *Radio Frequency Identification. Opportunities and Challenges in Implementation*, Department of Commerce, Washington. www.technology.gov/reports/2005/RFID_April.pdf.

US Department of Homeland Security, Data Privacy & Integrity Advisory Committee (2006), *The Use of RFID for Human Identify Verification*, www.dhs.gov/xlibrary/assets/privacy/privacy_advcom_12-2006_rpt_RFID.pdf.

US FTC (Federal Trade commission) (2005), *Radio Frequency Identification: Applications and Implications for Consumers. A workshop report from the staff of the Federal Trade Commission*, FTC, Washington, www.ftc.gov/os/2005/03/050308rfidrpt.pdf.

Vadhia, D. and Gupta, R. (2004), *IPv6 vs EPC,* Silicon Valley World Internet Center. www.worldinternetcenter.com/Pubs/Pubs2004/feb05/IPv6vEPC.pdf

Ward, Matt and Kranenburg, Rob van (2006), *RFID: Frequency, standards, adoption and innovation*, JISC Technology and Standards Watch, London. www.jisc.ac.uk/uploaded_documents/TSW0602.pdf

Yomogita, Hiroki (2006), *Japan's UWB Finally Takes off with Upcoming UWB-Enabling Devices*, Nikkei Electronics, http://techon.nikkeibp.co.jp/english/NEWS_EN/20060803/119881/.

Zetter, Kim (2006), "Hackers Clone E-Passports", *Wired*, www.wired.com/news/technology/1,71521-0.html.

Zetter, Kim (2007), "Scan This Guy's E-Passport and Watch Your System Crash", *Wired*, www.wired.com/politics/security/news/2007/08/epassport.