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RFID IMPLEMENTATION IN GERMANY: CHALLENGES AND BENEFITS

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FOREWORD

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

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1. SUMMARY

Niche RFID applications have been in use for many years. Supply chain applications are increasing rapidly in parallel with ticketing and entry applications. Industry sector developments vary widely, with the choice between passive, low cost tags and sophisticated, high performance tags specific to sectors and applications. Benefits have focused on process optimisation rather than process change, and common barriers include standards and adoption uncertainties, suggesting a government information role.

Industry sectors differ widely in RFID development. The automotive sector has over ten years experience whereas forestry and large parts of consumer goods are only beginning implementation. Diffusion within sectors varies greatly, with many automotive companies and hospitals relying on RFID systems but there are only isolated applications in airports or forestry. Systems are application-specific. Passive, low cost tags have most data on the network with only small amounts of information on these tags, whereas sophisticated, high performance tags with high data capacity or read ranges can have considerable data on tags without network connection.

Business benefits are mainly sector-specific, but common benefits include process optimisation, increased process quality and security and improved inventory management. Most implementation projects are in their early stages and many businesses have not yet changed their processes to better capture benefits. Furthermore, most businesses initially aim at internal closed-loop benefits. A common barrier is standardisation where standards play a particularly important role, and there may be considerable uncertainty in optimal timing of RFID investment due to rapid evolution of standards, and related interference and commercial tag availability.

Applications are likely to increase in the short term in asset utilisation and maintenance and in the longer term in item flow control, and new applications will come from combining RFID with other technologies. There is a shift towards passive technology as performance improves and towards open-loop systems where overall benefits are higher because of improved control of distribution, better customer information and customer services among others. There is a general trend to item-level tagging, beginning with high-value goods or components, dependent on declines in tag prices. In the longer term whole sector value chain strategies are being considered.

Technological developments are focusing on increasing real-time information of business processes. These include improvement of specialised tags to operate in metallic environments and extreme conditions; better battery performance; greater read-ranges; increased tag storage capacity; development of polymer-based tags; and improved security and privacy. Combination with other technologies will be important in the longer-term. For example in communications technologies, personal digital assistants and mobile phones can be used by business to monitor production processes and stocks and by consumers for automatic release of information, including information on tagged products such as clothing, or on artworks or bus schedules. Sensor technology to measure temperature, pressure, vibration, humidity or gases can monitor the general environment as well as the tagged goods or be used in healthcare applications.

Government policy roles are directed at liberalisation of frequency ranges and some aspects of standards, as well as developing new public sector applications and being model users. Further activities include incentives for business R&D and new applications and information, awareness and education activities (*e.g.* studies and demonstration projects) to catalyse adoption and use, particularly by small businesses.

2. INTRODUCTION

Radio frequency identification (RFID) is a technology which is already in widespread use in a few applications (contactless travel passes, toll road payment, entry badges) but the range of potential applications is increasing rapidly. Besides new applications along the supply chains of companies, the public sector recently also intensively deals with RFID, *e.g.* for museum items or e-passes. This rapidly widening range of potential applications has captured the attention of the media, governments, companies and the general public. After the initial RFID hype, evaluation of the technological applications has been more mixed. On the one hand, there are early adopters of RFID who have already integrated the technology, some of them for years, with generally positive results. The main competitive advantages have been important time and cost savings along the supply chain due to improved tracking and tracing capabilities as well as an increased level of transparency and security. On the other hand, there are a significant number of critical reports, too, and a significant number of companies are reluctant to adopt the technology. They argue that cost savings are difficult to assess, that there are still significant technological challenges and that standardisation remains an issue to be solved. Overall, the RFID landscape is marked by a high level of uncertainty.

Existing studies on the implementation of RFID technology either assess related benefits and challenges on an aggregated level or focus on one sector or even one specific application. Few studies compare the use of RFID technology in different sectors.

This study aims to answer the following questions:

- What is RFID? What are the elements and varieties of RFID systems?
  (research objective 1)
- Why are companies in different industry sectors investing in RFID technology?
  (research objective 2)
- How do industry sectors differ in the implementation and the use of RFID?
  (research objective 3)
- What is the potential of RFID in the future?
  (research objective 4)

The study draws on in-depth interviews with early adopters of RFID technology, academics and research institutes as well as consulting companies. It follows the 2004 and 2006 editions of the *Information Technology Outlook* and complements the analysis of the Working Party on Information Security and Privacy issued in the document “Radio-Frequency Identification (RFID): A Focus on Information Security and Privacy” (forthcoming), and the Proceeding from the OECD Technology Foresight Forum on “Radio Frequency Identification (RFID) Applications and Public Policy Considerations” held on 5 October, 2005 [DSTI/ICCP(2006)7].

3. METHODOLOGY

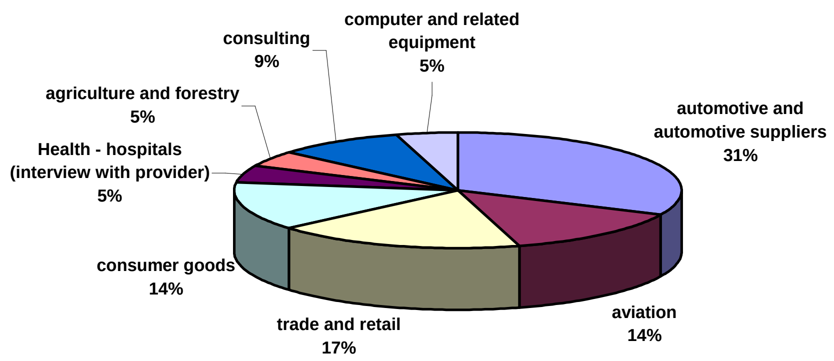
Given the aim to obtain a broad understanding of the reasons why companies are implementing RFID technology, and some of the impacts of these applications, the study relies on qualitative in-depth interviews. This qualitative research produces more in-depth knowledge as the research is based on open questions which allowed detailed analysis of particular issues. The questionnaire consisted of four main pillars:

- The current situation of RFID implementation.
- Factors affecting the decision making processes.
- The implementation process.
- The role of the public sector.

On the basis of this questionnaire, in-depth interviews were conducted by telephone and in certain cases on site interviews were undertaken.

The sample is based on leading companies in Germany which are early adopters of RFID technology and that are undertaking pilot or implementation projects. To compare different sectors, companies were selected from a broad range of industry sectors. Figure 1 represents the sector composition of the company sample. To get additional perspectives on RFID implementation in different sectors, leading academics in the field of RFID as well as consulting companies were interviewed. A total of 30 in-depth interviews have been conducted, 22 with company members in 8 sectors and 8 with academics and experts. The results of this study are only representative for the experts and sectors interviewed and portray the perspective of the sample.

Figure 1: Sector composition of the company sample



4. RESULTS - AN ASSESSMENT OF RFID TECHNOLOGY

4.1 Overview of assessment[1]

The analysis of available literature and of expert interviews conducted shows that the term RFID is used for numerous applications relying on diverse technological systems. When fields of application are described and assessed, studies do not differentiate unambiguously between fields of application and sectors. As a consequence, fields of application are blurred and the potential of RFID technology cannot be assessed in a satisfying way.

For this reason, and given research objective 1, the following section develops a framework mapping RFID technology and applications. It provides a classification of RFID technology, base functions, fields of application as well as sectors.

Based on this framework, section 4.3 provides a general assessment of factors driving and hampering the implementation of RFID technology to answer the question why companies are implementing the technology (research objective 2). As the added value of RFID is determined by alternative technologies, the first subpart gives an overview of alternative technologies and compares them to RFID. The second part discusses benefits and barriers of the technology on an aggregated, cross-sectoral level.

As the way RFID technology is used differs significantly from one industry to another, section 4.4 highlights the current situation of RFID in eight industry sectors and gives an outlook on future applications in these sectors (research objective 3). The discussion of each industry sector follows the same structure to allow for comparison.

Based on the outlook of future applications, sections 4.5 and 4.6 cover the future potential of RFID (research objective 4). Section 4.5 outlines a roadmap for future diffusion of RFID applications. As the potential of RFID also depends on future technological development, section 4.6 gives a prospect of the development of RFID technology as well as of the combination of RFID technology with other technologies.

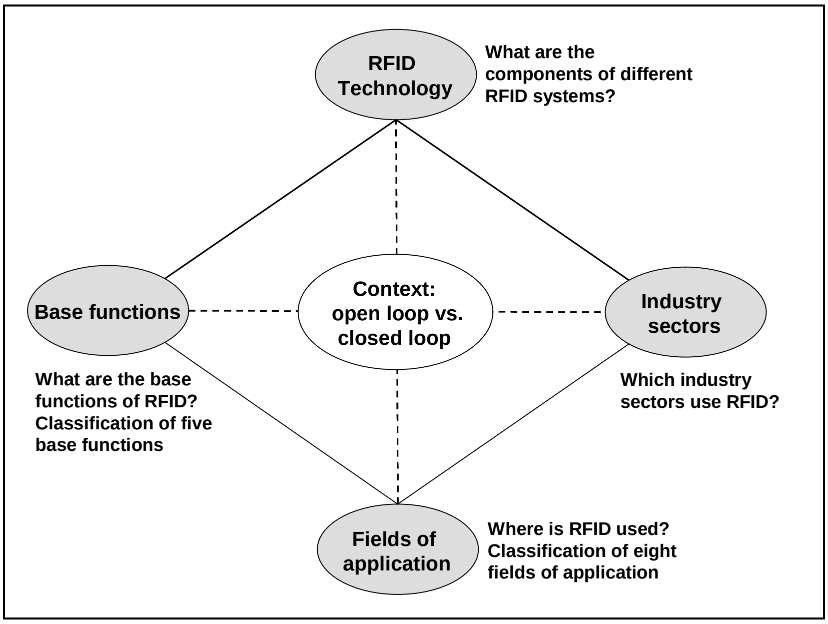
Finally, section 4.7 deals with the role of government and international organisations.

4.2 Mapping RFID technology and applications

As there are many different RFID systems and applications, RFID technology and applications need to be mapped carefully. Figure 2 provides a framework illustrating RFID technology, base functions, fields of application, sectors as well as contextual factors.

1 Our results draw on both literature review and the interviews with managers and experts from research institutes.

Figure 2: RFID framework



RFID technology and different technological systems provide the basis for this framework. Section 4.2.1 gives an introduction of RFID technology, different RFID systems and their characteristics. Base functions derive directly from technological characteristics of RFID and explain what the technology is used for. They are presented in section 4.2.2.

The next section illustrates how base functions are combined to form different fields of application and provides a classification of eight fields of application. Section 4.2.3 then shows which industry sectors rely on different fields of application.

Finally, section 4.2.4 deals with the context RFID systems are embedded in. It illustrates the characteristics of open-loop and closed loop-systems and provides examples of these systems.

4.2.1 RFID technology

RFID base functions and fields of application derive from the technological characteristics of RFID. For this reason, the following section provides an introduction to RFID technology. It gives an overview of the basic components of an RFID system and discusses principal differentiating factors of RFID systems.[2]

4.2.1.1 Components of an RFID system

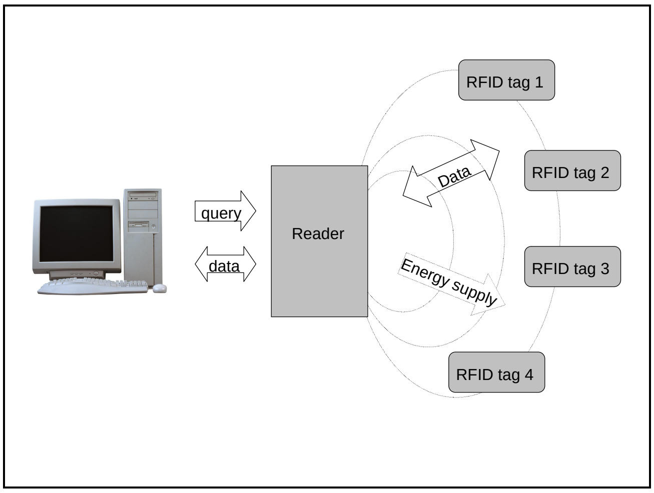
RFID technology belongs to the group of automatic identification and data capture (AIDC) technologies (NIST 2006, p. 2-1). It uses electromagnetic waves to transmit real-time data to identify specific objects (Garfinkel/Rosenberg 2005, p. xxvii).

An RFID system typically consists of three key elements: a reader, a transponder which is also called a tag, as well as a data processing and distribution system (OECD 2005, p. 4). The reader, a handheld or a fixed device, obtains data and queries from the data processing and distribution system via a serial

[2] For a comprehensive description of RFID technology see Finkenzeller 2006 (German) or Finkenzeller 2003 (English).

interface or a network connection (Lampe/Flörkemeier/Haller 2005, p. 70). It decodes the information received information and "transmits data via electromagnetic waves using air interface and data protocols" (OECD 2006a, p. 248) to RFID tags situated in the magnetic field of the reader. In case the RFID tags do not have their own energy supply, the reader also provides the necessary energy. The tags receive data and, if necessary, energy from the reader and send the requested data back (see Figure 3). Both the reader and the tags are equipped with a coupling element (antenna or coil) and are "capable of modulating and demodulating radio signals" (NIST 2006, p. 2-2).

Figure 3: Basic elements of an RFID system[3]



RFID tags which perform the data carriage consist of an antenna and a microchip which are packaged so that they can be attached to objects (Tellkamp 2006, p. 44). There are many different types of tags with various shapes. One important differentiator is the energy supply of tags. Four different types of tags can be distinguished (NIST 2006, p. 2-5):

- **Passive tags:** do not possess their own battery. They depend on the energy provided by the reader both for receiving and sending data. Due to power restrictions, the operating range is lower than for active tags but passive tags are significantly cheaper than active tags.

- **Active tags:** have their own internal battery which is used to power the microchip and to send data to the reader. They thus attain higher read ranges and can read weaker signals than passive tags. Furthermore, they are able to transmit data over long distances and face less interference problems (*e.g.* metal, water) than passive tags (OECD 2006b, p. 9). However, active tags are more expensive than passive tags and the life span of batteries is limited.

- **Semi-active tags**: remain dormant until they receive a signal from the reader. Therefore, they have a longer battery life than active tags (NIST 2006, p. 2-5). As active tags, semi-active tags can rely on their battery to transmit data to the reader.

- **Semi-passive tags:** also rely on a battery to power the microchip but use the energy provided by the reader to transmit data. Compared to passive tags, semi-passive tags have more power for internal functions. They are for instance used to power integrated sensors (see also section 4.6.2).

3 Based on Lampe/Flörkemeier/Haller 2005, p. 71.

4.2.1.2 Frequencies and power levels

RFID systems are also distinguished by their frequency ranges. Most RFID systems operate at the following frequencies in four main frequency ranges:

- 125; 134-135 kHz – Low Frequency (LF).
- 13.56 MHz – High Frequency (HF).
- 868 MHz (Europe); 915 MHz (US) – Ultra High Frequency (UHF).
- 2.4 GHz; 5.8 GHz – Microwave (MW).

The frequencies around 135 kHz, at 13.56 MHz as well as at 2.4 and 5.8 GHz are typically globally available. These four frequencies form part of ISM (Industrial Scientific and Medical) bands, *i.e.* they have been harmonised globally by the International Telecommunication Union (ITU) (Finkenzeller 2006, p. 169). This is not the case for UHF frequencies. Whereas UHF RFID systems in Europe operate at around 868 MHz, systems in the United States use the 915 MHz band. Furthermore, while RFID systems can transmit information at a transmission power of 4 Watt in the United States, the power is limited to 2 Watt in Europe resulting in a lower read range than in the United States.

4.2.1.3 Operating principle

Frequency ranges also determine the operating principle. There are two principal ways how energy is transmitted between RFID readers and tags: inductive coupling and backscatter coupling.

RFID systems operating at around 135 KHz and 13.56 MHz rely on inductive coupling for energy transmission (Lampe/Flörkemeier/Haller 2005, p. 74). The antenna coil of the reader generates a magnetic field. This field penetrates the antenna coil of the tag and generates a voltage by induction. The voltage is rectified to provide the tag with energy in passive RFID systems (Finkenzeller 2006, p. 44). Data is transmitted from the tag to the reader via load modulation: the switch-on and switch-off of a load resistance at the antenna of the transponder provoked by digital encoded data causes voltage changes at the antenna of the reader (Finkenzeller 2006, p. 47). In a following step, the reader demodulates, decodes and processes the data (Lampe/Flörkemeier/Haller 2005, p. 75).

RFID systems using UHF and microwave employ backscatter coupling. The reader generates an electromagnetic wave which reaches the tag and generates a voltage in the tag's antenna (Lampe/Flörkemeier/Haller 2005, p. 75). After rectification, the voltage can be used to power the tag in passive RFID systems. As for inductive coupling, digital encoded data provokes an activation and deactivation of a resistance. Resistance changes modify the characteristics of the reflected electromagnetic wave and thereby data is modulated on the signal reflected by the tag (Lampe/Flörkemeier/Haller 2005, p. 76, Want 2004, p. 44). The reader receives the modulated signal and decodes it to process the tag's data (Lahiri 2005, p. 31).

4.2.1.4 Interference problems

RFID systems are susceptible to various different types of interferences (Lampe/Flörkemeier/Haller 2005, p. 79). Analysis of the expert interviews conducted revealed two main sources of interference: metals and liquids in the environment and as parts of tagged objects. These sources are discussed in the following (for further discussion of other sources and interferences see Lampe/Flörkemeier/Haller 2005, p. 79-81).

A metallic environment or metallic parts of a tagged object typically produce interferences. There are considerable differences of opinion regarding at which frequency the level of interference is particularly high. This is partly due to the fact that specialised tags have been developed for isolated applications which are able to overcome interference problems. Additionally, the development pace is very high making it difficult to get a good overview of all specialised RFID solutions in different frequency ranges. Nonetheless, how metals influence RFID systems can be described for different frequency ranges. For inductive coupling systems at LF and HF, metals weaken the magnetic field and thus the coupling between RFID reader and tag (Jansen/Müller 2004, p. 34). RFID systems relying on electromagnetic waves (*e.g.* systems operating at UHF and microwave) face the problem that waves are reflected on metallic surfaces. The reflected waves can overlay the electromagnetic waves emitted by the reader but they can also intensify them and this makes it impossible to predict read ranges (Lampe/Flörkemeier/Haller 2005, p. 81).

Besides metals, liquids can also cause interferences since they can absorb the magnetic field or the electromagnetic waves between the reader and the tag. Generally, the ability to penetrate liquids decreases with higher frequencies (Engels 2004, p. 5, NIST 2004, p. 2-6). Therefore, RFID systems operating at UHF and MW show significant decreases in the read range (Engels 2004, p. 5, Lampe/Flörkemeier/Haller 2005, p. 81).

4.2.1.5 Read range

RFID systems can be classified into three classes according to their read range: close coupling, remote coupling and long range systems (BSI 2004, p. 39).

Close coupling systems operate at read ranges between 0.1 cm and a maximum of 1 cm (Finkenzeller 2006, p. 53) and at different frequencies (from LF up to 30 MHz) (BSI 2004, p. 40). They are used for applications with important safety requirements such as payments systems or access control (Engels 2004, p. 5, Lampe/Flörkemeier/Haller 2005, p. 79).

Remote coupling systems have a read range of about one meter and rely on inductive coupling. They usually operate at and below 135 KHz and at 13.56 MHz. Typical remote coupling applications include proximity cards with a maximum read range of 20 cm and vicinity cards with a read range of approximately one metre (BSI 2004, p. 40).

RFID systems with a read range of above one metre belong to the class of long range systems. Typically, they operate at UHF and MW. These RFID systems are used, for example, for asset tracking or the tracking of finished goods.

Generally, according to Lampe/Flörkemeier/Haller (2005), the effective read range of an RFID system is dependent on many different factors including:

- Tag-reader frequency.
- Tag energy efficiency.
- Alignment of the tag’s antenna with respect to the reader’s antenna.
- Coupling between the tag and the reader.
- Antenna design as well as the shape, size and quality of both the RFID tag and reader.
- Sensitivity of the reader.
- Transmitting power generated by the reader.

- RFID regulations in the country where the system is used.
- Environment (outdoor, indoor).
- Susceptibility to noise and interference from other radio devices.

As a result, it is very difficult to indicate effective read ranges of RFID systems. Read ranges in Table 3 at the end of the RFID technology section have thus to be considered as approximate values.

4.2.1.6 Standards

Standards are crucial to ensure the interoperability of various components of an RFID system that may be provided by different companies. Furthermore, standards enable the worldwide use of RFID technology. Several national and international standards organisations are currently developing RFID standards. The two main standards organisations on the international level include the International Organisation for Standardisation (ISO) and the industry standards group EPCglobal. The following paragraphs give an introduction to the two standards organisations and the developed standards whereby standards are clustered according to concrete applications to facilitate the reading (for a more detailed review on existing RFID standards, see Finkenzeller (2006), pp. 259-315).

The **International Organisation for Standardisation (ISO)** is "a network of the national standards institutes of 157 countries" (ISO 2006) which is based in Geneva. To this date, ISO developed separate standards for livestock tracking, contactless smart cards and supply chain applications. Table 1 gives an overview of published ISO standards in the field of RFID.[4]

The standards ISO 11785, ISO 11784 and ISO 14223 deal with livestock tracking. ISO 11784 defines the structure of the 64 bit code for animals (Finkenzeller 2006, p. 259). ISO 11785 covers the characteristics of the transmission protocol, *i.e.* how the tag is activated and how information is transmitted between the RFID tag and the reader (AIM Global 2006 a). Finally, ISO 14223 is an extension of the older standards ISO 11784 and 11785 and consists of three main parts. Part 1 of this standard covers the HF air interface (Finkenzeller 2006, p. 263); parts 2 and 3 will deal, *inter alia*, with the code structure and are still under development (AIM Global 2006 a). The shape of the RFID tag is not defined by any of the three standards to allow for suitable shapes for each animal species (Finkenzeller 2006, p. 259).

ISO 14443 and ISO 15693 are two important standards for contactless smart cards with different ranges. ISO 14443 deals with vicinity cards which have an intermediate range of 10 cm (NIST 2006, A-1) and which are mainly used for ticketing purposes (Finkenzeller 2006, p. 270). The standard consists of four parts defining the physical characteristics, the radio frequency power and signal interface, initialisation and anti-collision as well as the transmission protocol (AIM Global 2006 b). It is noteworthy to add that ISO 14443 has two variants, ISO 14443A and ISO 14443B, which differ in the interface. Readers that are ISO 14443 compliant have to be able to deal with both variants (NIST 2006, A-1). Smart cards defined by ISO 15693 are vicinity cards with a higher read range than proximity cards. Such cards can attain a read range of up to one meter (NIST 2006, A-1). Typical application examples include access control cards. The standard consists of three parts defining the physical characteristics, the air interface and initialisation as

4 Standards defining test methods for RFID systems are not analysed in these paragraphs as they are not relevant to companies using RFID technology but to technology suppliers that are not assessed in this study. They include ISO 10373 (test methods for identification cards), ISO 18046 (Radio frequency identification device performance test methods) as well as ISO 18047 parts 2, 3, 4, 6 and 7 (Radio frequency identification device conformance test methods). For further reading see Walk 2006, pp. 56-57, Finkenzeller 2006, pp. 293-297.

well as protocols (Finkenzeller 2006, p. 288). Both standards describe RFID systems operating at high frequency (13.56 MHz).

Table 1: Overview of ISO standards directly related to RFID technology

	Standard	Name
Live-stock tracking	ISO 14223	Radiofrequency identification of animals – Advanced transponders
	ISO 11784	Radio frequency identification of animals – Code structure
	ISO 11785	Radio frequency identification of animals – Technical concept
Contactless smart cards	ISO 14443	Identification cards – Contactless integrated circuit(s) cards – Proximity cards[5]
	ISO 15693	Identification cards – Contactless integrated circuit(s) cards – Vicinity cards
Supply chain applications	ISO 10374	Freight containers – Automatic identification
	ISO 15961	Radio frequency identification (RFID) for item management – Data protocol: application interface
	ISO 15962	Radio frequency identification (RFID) for item management – Data protocol: data encoding rules and logical memory functions
	ISO 15963	Radio frequency identification for item management – Unique identification for RF tags
	ISO 18000-1	Radio frequency identification for item management – Part 1: Reference architecture and definition of parameters to be standardised
	ISO 18000-2	Radio frequency identification for item management – Part 2: Parameters for air interface communications **below 135 kHz**
	ISO 18000-3	Radio frequency identification for item management – Part 3: Parameters for air interface communications **at 13.56 MHz**
	ISO 18000-4	Radio frequency identification for item management – Part 4: Parameters for air interface communications **at 2.45 GHz**
	ISO 18000-6	Radio frequency identification for item management – Part 6: Parameters for air interface communications **at 860 MHz to 960 MHz**[6]

ISO also developed various standards in the field of supply chain applications. ISO 10374 is focusing on one concrete application, while the other ISO standards are used in a wider context of item management along the supply chain. ISO 10374 is a standard for the automatic identification of freight containers and specifies a standard format for the transmission of the container's identity and related information (AIM Global 2006 d). Although this standard could contribute to increased security which is, in particular, emphasized since 9/11, it has not been recommended for use by the World Custom Organisation (WCO) and only a fraction of the world's containers are tagged with ISO 10374 compliant tags (Downey 2006).

5 ISO 10536 is also a standard for contactless smart cards operating at 4 9152 MHz and defined for close-coupling cards. As this operating frequency is not further discussed in this study and as contactless smart cards as defined in ISO 10536 are barely used due to high production costs and have no significant advantages compared to contact smart cards, the standard is not listed in the table (for further details, see Finkenzeller 2006, pp. 268-270).

6 The last part of the ISO 18000 family is ISO 18000-7 (Radio frequency identification for item management – Part 7: Parameters for active air interface communications at 433 MHz). The 433 MHz operating frequency is not widely used, is not discussed in section 4.2.1 and ISO 18000-7 is not listed in the table.

ISO 15961-15963 and the ISO 18000 family cover item management. ISO 15961-15963 are dealing with different aspects of data organisation and are independent of the technology in use (Franke/Dangelmaier 2006, pp. 39-41). ISO 15961 defines concrete commands and responses in the context of data transmission between the RFID tag and the reader (Finkenzeller 2006, p. 303). The way data is organised and processed in the tag is described in ISO 15962 (Franke/Dangelmaier 2006, p. 40). Furthermore, ISO 15963 specifies a unique numbering system for the identification, registration and use of RFID tags (AIM Global 2006 c) and thus represents a competing numbering system to the standard defined by EPCglobal which is discussed in the next paragraphs. To complement the discussed data standards, the ISO 18000 family defines the air interface for different frequencies. ISO 18000 part one (18000-1) deals with general parameters applying to all frequency ranges, parts 2,3,4,[7]6 and 7 describe specifics for different frequency ranges (see Table 1).

EPCglobal, Inc.,[8] the most prominent **industry standards group,** also establishes standards in the field of **supply chain management** (NIST 2006, p. A-2). The group relies on research conducted by the Auto-ID Labs, a federation of seven research universities,[9] which "has evolved from the Auto-ID Center" at the Massachusetts Institute of Technology (MIT), "initially founded in 1999 to develop an open standard architecture for creating a seamless global network of physical objects" (Auto-ID Labs 2006) for the Internet of Things. The work at these Auto-ID labs is characterised by a high involvement of major companies including (potential) end users and technology providers to ensure that standards are developed according to companies' needs.

The result, which has been transferred to EPCglobal, is the **EPC network** defined as "a method for using RFID technology in the global supply chain by using inexpensive RFID tags and readers to pass Electronic Product Code numbers, and then leveraging the Internet to access large amounts of associated information that can be shared among authorized users" (EPCglobal 2004, p. 5).

This definition refers to two important components of the network, the Electronic Product Code and inexpensive RFID tags, which are discussed in the following paragraphs. The network's key component is a single numbering system known as the Electronic Product Code (EPC). Contrary to the barcode, the EPC code not only contains numbers for manufacturer identification and product type, but also a unique serial number of the tagged item (Flörkemeier 2005, p. 88). For example, it is not only possible to differentiate between different models of MP3 players of a company, but every single MP3 player has a unique number. To date, tags specified by EPCglobal only carry the Electronic Product Code. Any additional information on the product has thus to reside in back-end systems (Lahiri 2005, p. 215).[10]. This approach allows using tags with little storage capacity (Sarma 2001, p. 6). As the storage capacity directly influences tag prices, prices can be kept at a relatively low level.

However, to provide tags with different capabilities and at different price levels, EPCglobal has produced a taxonomy of tag classes consisting of five classes (Lahiri 2005, p. 215) where each successive class is "more sophisticated than the one below it" (*RFID Journal 2006*, p. 2). An overview of tag classes is given in Figure 4. Currently, only tags belonging to Class 0 and Class 1 are fully developed. These classes are briefly discussed in the following.

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7 Part 5 (ISO 18000-5) should cover the frequency at 5.8 GHz but was withdrawn (NIST 2006, p. A-1).

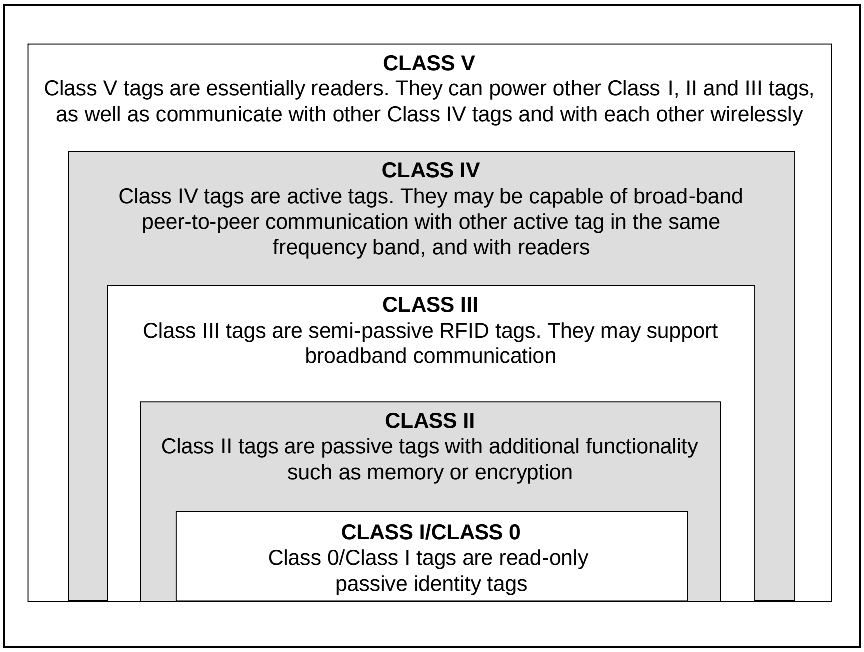
8 In the following referred to as "EPCglobal".

9 Participating universities include the MIT (US), University of Cambridge (UK), University of St. Gallen/ ETH Zurich (Switzerland), Fudan University (China), Information and Communications University (Korea), University of Adelaide (Australia), Keio University (Japan).

10 This approach is commonly referred to as "data on network" in opposition to "data on tag" where all important information is directly stored on the tag.

Class 0 and Class 1 Generation 1 tags are the most basic and thus the cheapest types of tags. Both are passive tags which are able to store either 64 or 96 bits (Finkenzeller 2006, p. 314). Whereas Class 0 is only defined for the frequency range 900 MHz (UHF), Class 1 Generation 1 is defined for RFID systems operating at 860-930 MHz and at 13.56 MHz (HF) (NIST 2006, pp. A-2 – A-3). To date, “Class 0 and Class 1 tags are not interoperable” (Lahiri 2005, p, 215) meaning that different types of readers are needed.

Figure 4: Overview of EPC tag classes[11]



Class 1 Generation 2 tags[12] operating at UHF frequency are expected to replace Class 0 and Class 1 Generation 1 (Finkenzeller 2006, p.315) as they have improved features. Regarding tag memory, for example, Class 1 Generation 2 tags “can have EPCs up to 496 bits in length” (Barber/Tsibertzopoulos 2005, p. 248). Additionally, there is an optional user memory and a kill command rendering tags inoperable. Class 1 Generation 2 tags are based on the UHF Air Interface Protocol which has been approved as a standard by EPCglobal as discussed below.

This taxonomy of tag classes provides a basis for the specifications and standards of the EPCglobal network. To date, EPCglobal has published four specifications and nine standards (see Table 2). EPC specifications mainly result from the work of the Auto-ID Center at the MIT and are fundamental to EPC technology (Finkenzeller 2006, p. 310). Standards are specifications that have been ratified by the EPCglobal Board of Governors and are the result of international standardisation work of multiple companies (Finkenzeller 2006, p. 310).

As Table 2 shows, the EPC has approved a document on the general structure of the EPC network, several air interface communications specifications and standards as well as data protocol standards. The architectural framework document describes and defines the overall architecture of the EPC network (EPC 2006 d).

11 Based on Sarma/Engels 2003, pp. 5-6.

12 The abbreviations Gen 2 tags or EPC Gen 2 tags are often used for Class 1 Generation 2 tags.

All air interface communications specifications and standards developed by EPC global to date are standards for Class 0 and Class 1 passive tags. They all operate at UHF and are often used to track inventory along the supply chain. Out of these four specifications, the only specification which has been approved by EPCglobal as a standard is the Class 1 Generation 2 UHF Air Interface Protocol in 2004 which was “long awaited by the industry” (OECD 2005, p. 17). The standard is currently used in the value chain of important retailers such as the Metro Group and consumer goods companies (see also sections 4.4.5 and 4.4.6). In mid 2006, ISO has approved the Generation 2 UHF Air Interface Protocol as part of its ISO 18000-6 standard, as amendment 18000-6C, which is the first common standard of ISO and EPCglobal. The inclusion of the EPC standard in the global ISO standard is seen as an important step towards a broad implementation of Class 1 Generation 2 RFID systems, in particular as “the World Trade Organisation (WTO) has guidelines about following standards endorsed by ISO” (O’Connor 2006, p.1).

Table 2: Overview of EPCglobal specifications and standards[13]

	Specifications	
	Name	**Brief description**
Supply chain applications	900 MHz Class 0 Radio Frequency (RF) Identification Tag Specification	Defines the communications interface and protocol for **Class 0** tags at 900 MHz
	13.56 MHz ISM Band Class 1 Radio Frequency (RF) Identification Tag Interface Specification	Defines the communications interface and protocol for **Class 1** tags at 13.56 MHz
	860 MHz – 930 MHz Class 1 Radio Frequency (RF) Identification Tag Radio Frequency & Logical Communication Interface Specification	Defines the communications interface and protocol for **Class 1** tags at 860 MHz – 930 MHz
	Conformance Requirements Specification v. 1.0.2 for Class-1 Generation 2 UHF RFID	Specifies compliance for physical parameters and commands for **Class 1 Generation 2** tags at 860 MHz – 930 MHz
	Standards	
	Name	**Brief description**
	Architectural Framework Document	Defines and describes the fundamental structure of the EPC network
	EPC Tag Data Standard	Defines the standardisation of EPC tag data
	EPC Tag Data Translation Standard	Deals with a machine-readable version of the EPC Tag Data Standards
	Class 1 Generation 2 UHF Air Interface Protocol Standard Version 1.0.9: "Gen 2"	Defines the communications interface and protocol for **Class 1 Generation 2 tags** at 860 MHz – 930 MHz
	Reader Protocol (RP) Standard, Version 1.1	Specifies the interactions between an RFID reader and application software
	Reader Management (RM) Standard, Version 1.0	“Defines Version 1.0 of the wire protocol used by management software to monitor the operating status and health of EPCglobal compliant RFID readers” (EPCglobal 2006 b, p. 10)
	Application Level Events (ALE) Standard, Version 1.0	Specifies an interface for the query of EPC data from various sources
	Object Naming Service (ONS) Standard, Version 1.0	Specifies the use of a Domain Name System to locate data associated with the SGTIN[14] portion of an EPC
	EPCglobal Certificate Profile Standard	Defines a special authentication framework for the authentication of entities such as subscribers, services or physical devices

13 Based on Finkenzeller 2006, pp. 310-311, EPCglobal 2006 a, p.10, EPCglobal 2006 b, EPCglobal 2006 c, EPCglobal 2006 d, p. 4, Walk 2006, p. 60).

14 SGTIN: Serialized Global Trade Identification Number which is a method to uniquely identify items. For further reading see Finkenzeller, pp. 312-313, Glover/Bhatt 2006, Appendix A, Section A-1.

Data protocol standards describe the specification and interchange of data. They have been developed for several parts of the RFID system (Walk 2006, p. 60): the EPC Tag Data Standard and Tag Data Translation Standard define how the data is encoded on the tag and how this data is translated into a machine-readable version. The reader management and reader protocol standard specify how the reader can be monitored and how it exchanges data with an application software (EPCglobal 2006 d). This application software is also the focus of the Application Level Events (ALE) Standard defining how the software can obtain filtered and consolidated data from diverse sources (EPCglobal 2006 d). The EPC document on the Object Naming Service (ONS) deals with the EPC information network and specifies how the ONS is used to identify the location of additional information and services linked to the EPC. Finally, the EPCglobal Certificate Profile Standards provides means to authenticate entities such as subscribers to secure network functions by relying on a special certificate (EPCglobal 2006 a, p. 4).

Overall, the review of these international standards shows that various standards are already developed. On the one hand, standard organisations partly deal with the same issue and compete with each other (Walk 2005, p. 53). On the other hand, a first harmonisation can be observed between EPCglobal and ISO which is further pursued by EPCglobal (O'Connor 2006, p. 1). One example for this harmonisation is the inclusion of the EPC Generation 2 UHF Air Interface Protocol in ISO 18000-6 providing a broad technological basis for further RFID implementation in the field of passive UHF RFID systems which are used for inventory tracking in the consumer good – retail value chain, for example for the tracking of pallets. However, standardisation is far from being completed. Especially in the fields of data standards and the integration of RFID technology in the existing technological infrastructure, work on new standards is still crucial (Walk 2006, p. 53). Furthermore, EPCglobal is currently working on industry-specific standards (Tsukada 2006, p. 60). However, there is also a downside to the fast development of new standards by these organisations: too many new standards which are developed to replace existing ones may provoke a high level of uncertainty among technology providers and users, especially when new standards are incompatible with established legacy systems.

4.2.1.7 RFID technology in summary

Table 3 summarises technological characteristics of RFID systems discussed in section 4.2.1 organised by frequency ranges.[15] In addition to the previous sections on RFID technology, it highlights two important facts:

- Currently, it is not always simple to install an RFID system due to interference problems. This does not mean that these problems are insurmountable but they should be kept in mind.

15 Only ISO standards which could be attributed to particular frequency ranges are represented in the table.

Table 3: Overview of typical RFID systems[16]

Typical frequencies	Low Frequency (LF)	High Frequency (HF)	Ultra High Frequency (UHF)		Microwave (MW)
	125, 134-135 kHz	13.56 MHz	865-868 MHz (Europe)	915 MHz (US)	2.4 GHz
Availability	Typically globally available		Not globally available (different frequencies in use)		Typically globally available
Operating principle	Inductive coupling		Electromagnetic coupling (backscatter)		
Energy supply	Typically passive		Active and passive		
Read range	≈ < 1 m	≈ < 1.5 m	≈ 3-6 m (passive)	≈ 6-8 m (passive)	≈ 2m (passive)
			Up to 100m (and more in isolated cases) (active)		Up to 100m (and more in isolated cases) (active)
Interference problems - Metal (for passive tags)	Attenuation of the magnetic field (typically less problems than in the UHF and MW frequency ranges)		Reflection on metallic surfaces		
Interference problems – Liquids (for passive tags)	No impact	Low impact	High impact (absorption)		High impact (absorption)
Available standards ISO	14223 11784/5 18000-2	15693 14443 18000-3	10374 18000-6		10374 18000-4 18000-5
EPC	--	Class 1 (Gen 1) HF	Class 0 (Gen 1) Class 1 (Gen1) UHF Class 2 (Gen 2)		--
Typical applications	Livestock tracking Access controls Car keys	Public transport Inventory management	Inventory management Container management Access cards		Finished products tracking Electronic toll collection

- There is not **the** off-the-shelf RFID system but there are many different RFID systems varying in technological characteristics. Sometimes, systems are even highly specialised. For example, it makes an important difference whether companies rely on a rather inexpensive RFID system operating with passive tags at low frequency with a short read range or use expensive active tags with high read ranges operating at microwave frequencies, which we will show in section 4.4.

16 Based on BSI 2004, pp. 27-37, Engels 2004, p. 6; Finkenzeller 2006, pp. 27-30/ 259-316; IEEE USA 2006, pp. 1-5; Jansen/Müller 2004, p. 34; Lampe/Flörkemeier/Haller 2005, pp. 72-77; NIST 2006, pp. 2-1 -2 -21; Terstegge 2005, p. 1; Walk 2006, pp. 54-61.

When looking at this second fact, one question immediately comes to mind: for which applications are companies using these RFID systems? In the next section, we identify five base functions of RFID technology. In a second step we illustrate how these base functions are combined to form eight fields of application.

4.2.2 Base functions and fields of application

To understand the variety of different fields of application, it is important to understand the underlying base functions. During our empirical research, we recognised for example that, both for the tracking of assets such as containers and the flow control of products along the supply chain, one important function of RFID was tracking and tracing. After having put all applications together, clustered and subsequently reduced them to generic functions, we obtained the following five base functions:

- **Gate monitoring**: The focus of gate monitoring lies on the entry and exit information, *i.e.* the information on whether a person or object passed or did not pass. For this purpose, readers are usually fixed. Gates are an example for this kind of readers. Application examples of gate monitoring are ski passes at ski resorts.

- **Content inventory:** In contrast to gate monitoring, content inventory concentrates on stock tracking, *i.e.* the information whether items are in a certain place or not (here/not here). Items are usually in a fixed place which also distinguishes this base function from gate monitoring where persons and objects are moving. The reading of received goods in a company's warehouse can be taken as an example.

- **Identification code storage:** This base function emphasises the one-time storage of a unique identification code on the tag to unambiguously identify persons and objects. Typical applications include the storage of a unique code programmed on access cards of employees as well as tags for high-value products to detect counterfeited goods.

- **Tracking and tracing:** This is probably the most commonly known application. It consists of tracking, monitoring and reconstructing the flow of items. When tracking and tracing items, objects are moving in most cases and the tracking and tracing usually occurs at different times. The observation is therefore dynamic.

- **Data storage and retrieval (information editing)**: The last base function highlights data processing on RFID tags for the purpose of monitoring and controlling items equipped with RFID tags. As opposed to the base function "identification code storage", data is modified on the tag which is a dynamic action. Often, features of the items or the stage of production is stored during this process at different times. To exemplify, companies store and retrieve maintenance information on tags for high-value assets such as machines.

Table 4: Description of RFID base functions

	Gate monitoring	Content inventory	Identification code storage	Tracking & tracing	Data storage and retrieval (information editing)
Description	Entry and exit registration (both of persons and objects)	Digital stocktaking of items in a delimited space	One-time storage of a unique identification number	Tracking, monitoring and reconstructing the flow of items	Data filing and processing on tags for monitoring and control of items
Kind of information	In/Out Passed/Not passed	Inside/outside Here/not here	Identification code	Location of items	Features, qualities of items
Reader	Fix	Mobile/fix	Fix	Fix	Fix/moving
Object	Mobile	Fix	Mobile	Moving/Fix	Fix/moving
Kind of observation	Static	Static	Static	Dynamic	Dynamic
Example	Ski passes	Bulk reading of received goods in a warehouse	Entry control systems for employees	Livestock tracking	Maintenance information storage on tagged machines

Table 4 compares the different base functions and distinguishes them by the information they provide, the mobility of the object and the reader as well as the kind of observation. Combining these base functions in different ways leads to several fields of application. Each field of application is composed of several base functions as indicated by the black dots in table 5.

Table 5: RFID fields of applications and underlying base functions

	Gate monitoring	Content inventory	Identification code storage	Tracking and tracing	Data storage and retrieval (information editing)
Asset utilisation	■	■	■	■	
Asset monitoring and maintenance			■		■
Item flow control	■	■	■	■	■
Inventory audit	■	■	■		
Authentication	■		■		
Theft control	■	■	■	■	
Payment systems	■		■		■
Automatic release of information	(■)				■

By the term **"asset utilisation"**, we define the use of assets of companies along the supply chain. We use it for mobile assets such as containers for different production processes. Companies rely on RFID tags in order to track these assets, for example, to monitor which departments use assets and how many times, aiming at optimising processes and thus attaining a more efficient use of capacity.

For the purpose of **asset monitoring and maintenance**, RFID tags are usually attached to high value assets in order to store information. Examples are tagged machines for maintenance purposes where the maintenance history and information on replaced items are stored. When data is stored directly on the tag and not on the companies' network, tags with high data capacity are needed.

For **item flow control**, RFID tags are attached to items that are moving along the supply chain. As Table 5 shows, it is the only field of application relying on all five base functions. Often, information that goes beyond a simple ID number is stored on the tag to control the production process. This is, for example, the case in the automotive industry where results of different production steps are stored on a tag which can be attached to a car body or even smaller parts.

RFID is also regularly used for **inventory audit**. Prominent examples are warehouses of retailers where pallets and sometimes cases are tagged to improve the speed and efficiency of stock taking. In most of the cases, only an ID number is stored on the tag to minimise the cost of a tag.

In the field of **authentication,** RFID is used to provide secure identification mechanisms of persons and objects. Prominent application examples are company entry badges and car keys. Newer fields of application include the tagging of drugs in the pharmaceutical sector and the tagging of high-value goods in the luxury sector to prevent counterfeiting. In addition, RFID technology is integrated in electronic passports.

Theft control is a further field of application where tags are used on the item level to prevent theft along the supply chain or at the point-of-sale. A very simple form is Electronic Article Surveillance which can be based on RFID technology. In this case, it is a low-end RFID system as 1-bit tags are in use which only communicate whether or not tags are still active when consumers leave the shop (Finkenzeller 2006, pp. 25, 32). New applications such as theft control in mail order businesses for high-value products such as mobile phones rely on more sophisticated tags (see also section 4.4.4).

To secure transactions, RFID technology in also used for **payment systems**. Safety requirements for tags are very high and the systems are characterised by very low read ranges to avoid mixing different payment cards.

Finally, in the field of **automatic release of information** items are tagged to provide additional product information. Currently, the first applications are used at the point-of-sale to provide customers with additional information.

Overall, the fields of asset utilisation and item flow control rely on most base functions; with the field of item flow control relying on all base functions. As a consequence, the question arises whether these two fields of application play a dominant role in RFID implementation in different sectors. To understand which industry sectors rely on which fields of application and to complement our framework (see Figure 2), we will compare the use of RFID in various industry sectors.

4.2.3 Overview of industry sectors

Table A-1 in Annex 1 illustrates the fields of application discussed above for different industry sectors. With this list, we intend to give an overview of the main applications in various industry sectors. As the implementation of RFID is relatively new in business and new applications are developed every day, the list is non-exhaustive.

As shown in the table, industry sectors often rely on more than one field of application. In particular, the automotive, retail, and aviation sectors are characterised by a broad use of RFID. However, the use of this technology significantly differs from one of these sectors to another as shown in section 4.4. The public sector also uses RFID in many different fields of application. Different institutions such as hospitals, libraries, museums and research institutes rely on specific fields of application as indicated in the table.

In this industry sector overview, the most commonly used fields of application are item flow control and inventory audit followed by authentication and asset utilisation. The latter field of application is predominantly relevant for technology related sectors such as automotive or aviation which are using an important number of specialised containers. However, the table does not give an indication of how widely RFID is used for the different fields of application in the industry sectors. For selected sectors, this will be discussed in section 4.4.

4.2.4 Open loop vs. closed loop RFID systems

The last, but important aspect in our RFID technology and applications map (see Figure 2) is the context in which the RFID application is embedded. Benefits and costs are highly dependent upon whether RFID is implemented in a closed-loop or in an open-loop system.

A **closed-loop** RFID system is normally set up within a company and RFID tags do not leave the internal supply chain. As a consequence, closed-loop applications often rely on proprietary RFID systems as no standardisation efforts are needed and include isolated RFID applications. Tags used to have long life spans and used to circle numerous times through the RFID system.

Closed-loop systems are often used in the fields of asset utilisation, asset monitoring and item flow control. Typical sectors relying on these systems to date are the public (*e.g.* tracking of medical equipment in hospitals) and the automotive sector. For example, car bodies are tagged in a closed-loop system along the production line to provide each working station with the required information. In terms of the stage of implementation, there are already numerous roll-out projects since closed-loop systems can be implemented rapidly and return on investment (ROI) can be determined in a much easier way than for open-loop systems.

In an **open-loop system**, multiple companies along the value chain rely on RFID technology in open supply chain applications. For these systems, standards are crucial. Tags are often not reused and thus are passive to minimise costs. Open-loop systems can be commonly found in the fields of item flow control and inventory audit. Sectors relying on open-loop systems include the luxury sector and the consumer goods – retailer value chain. In the latter value chain, for example, pallets and cases of consumer goods are tagged to speed up inventory auditing. In contrast to closed-loop systems, open-loop projects are in large parts still at the pilot stage as the implementation is much more complex than for closed-loop applications.

4.2.5 Mapping RFID technology and applications in summary

What is RFID and what are the elements and varieties of an RFID system? To answer research objective 1, section 4.2 developed a framework for mapping RFID technology, base functions and derived fields of application, industry sectors as well as the difference between a closed and open-loop system.

Overall, the section showed that RFID is comparable to a craggy landscape:

- On the technological level, there are many varieties of RFID systems.
- There are large numbers of fields of application.
- On a sector level, the overview showed that different sectors already use RFID and that some sectors already employ the technology for many of the fields of application discussed.
- Regarding the context, there are significant differences depending on whether an RFID system is employed within a company, thus closed-loop, or whether many companies are engaged in an open-loop system which makes the implementation more complicated.

On the one hand, the varied technology landscape neither makes it easy to select the components for an RFID system that is tailored to the specific needs of a company nor to implement this system. On the other hand, many sectors already deal with RFID technology which indicates that the technology and its applications must be giving important benefits.

For this reason, the next section examines the main factors that are driving and hampering the implementation of RFID. After the discussion of automatic identification and data capturing technologies, we will focus on benefits and barriers to the implementation of RFID.

4.3 Factors driving and hampering the implementation of RFID

In this section, we focus on the question why companies are interested in investing in RFID technology which is our second research objective. Instead of investing in RFID companies could, for example, rather focus on alternative, existing technologies that might be well established and less expensive, such as the barcode. For this reason, we will examine the technology landscape of automatic identification and capturing (AIDC) technologies in section 4.3.1 where we will compare alternative technologies to RFID. Based on this assessment, we will analyse different levels of benefits arising from RFID and oppose them to barriers to the adoption of RFID.

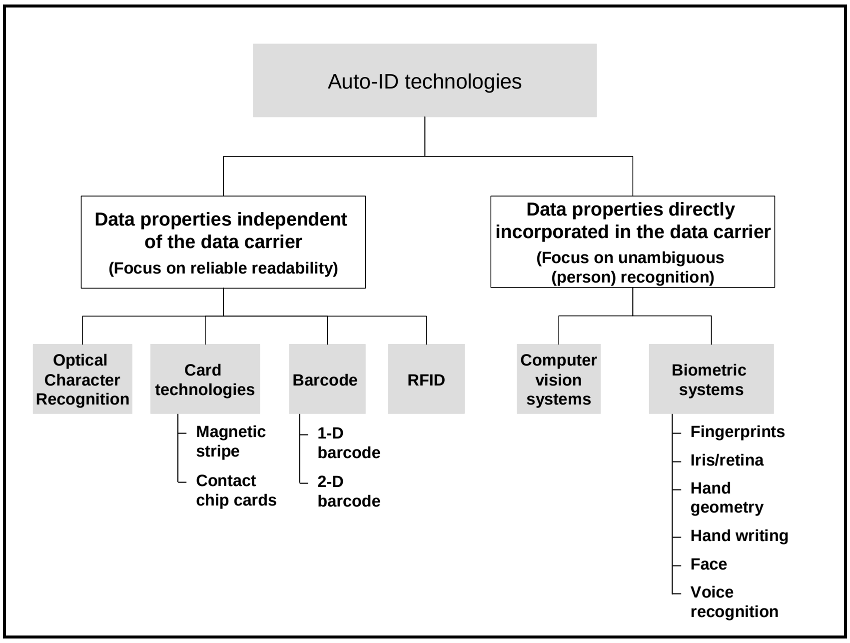
4.3.1 Technology landscape

RFID technology combines two important features: automatic identification (the "ID" part) on the one hand and data transmission via radio communication (the "RF" part) on the other hand. To date, no alternative technology really combines these two parts. In the following, we will thus focus on the "ID" part for two reasons: first, in our industry sector sample (section 4.4.), we will mainly deal with fields of application along the supply chain for which automatic identification (auto-ID) plays a crucial role (*e.g.* item flow control, inventory audit). Second, during the interviews experts primarily focused on the auto-ID part when reporting on alternative technologies.[17]

The main alternative auto-ID technologies can be grouped into two categories (see Figure 5): technologies where data properties can be stored independently of the data carrier and technologies where the data for identification purposes is directly incorporated in the data carrier itself. For example, in the first case, it is possible to store personal data "externally" on a data carrier such as a chip card whereas in the second case, a person directly carries unique personal data, comparable for example to the unique geometry of the individual hand.

[17] For an overview of alternative radio communication technologies which would be the "RF" part of RFID see Gaßner *et al*. (2006), pp. 26-32.

Figure 5: Overview of auto-ID technologies



Biometric systems and computer visions systems constitute the second category where data is directly incorporated in the data carrier. A **biometric system** is "essentially a pattern recognition system that recognizes a person by determining the authenticity of a specific physiological and/or behavioural characteristic possessed by that person" (Maltoni *et al*. 2003, p. 3). Main biometric identifiers include fingerprints, iris/retina, hand geometry and writing as well as face and voice recognition. Currently, biometric systems are an alternative to RFID in only one field of application, which is the authentication for the access control of persons. To date, this technological alternative to RFID is used for applications with high safety requirements, *e.g.* the access to research laboratories.[18]

Computer vision systems are computer based systems that 'identify items based on their visual appearance' (Hodges/McFarlane 2005, p. 6) through processes of feature extraction and computing-intensive algorithms. Thus, no additional identifier is required (Strassner 2005, p. 57) as the object itself is identified and not a tag. The major drawback is that computer vision systems are expensive with costs reflecting the quality of the system components such as the system's optics or processing hardware and software (AIM global 2006 e). However, increasingly powerful visions systems are expected to enter the market accompanied by cost reductions in the following years (AIM global 2006 e, Strassner 2005, p. 57). Typical applications of computer vision systems include quality control in logistics and computer-aided manufacturing. Newer systems are also used for "high-speed sorting in industries such as electronics, automotive, and mail and package delivery" (AIM global 2006 e).

The first category includes the following alternative technologies: optical character recognition, magnetic stripes, contact chip cards as well as the 1-D and 2-D barcode. These auto-ID technologies fulfil the requirements of different fields of application in different ways. To illustrate, it is crucial for auto-ID technologies used for payment systems such as chip cards to dispose of security techniques. In the fields of asset utilisation or item flow control along the supply chain, though, a fast and efficient data capture of

18 For a good introduction and further reading (especially on fingerprints) see Maltoni *et al*. (2003), chapter 1. See also DSTI/ICCP/REG(2003)2/FINAL (www.oecd.org/document/20/0,2340,en_2649_34255_35011988_1_1_1_1,00.html).

auto-ID technologies (*e.g.* barcodes) is of paramount importance. The relative advantages and disadvantages of these auto-ID technologies are summarised in Table 6.

Optical character recognition (OCR) uses optical scanners and computer software to translate stylised typewritten characters. Currently, OCR is further developed to allow the system to read a variety of common, not stylised fonts (Kern, p. 18). An advantage compared to RFID, is that the characters are readable by humans in case automatic identification fails (Strassner 2005, p. 65). However, robustness is very low as OCR is very susceptible to dirt and humidity. It is currently used in the financial sector, for example for high-volume payment or remittance processing, as well as for the processing of high document volumes in healthcare and insurance companies (AIM Global 2006 g). Overall, due to alternatives such as the barcode, traditional OCR systems become less important (Kern 2006, p. 18).

Another auto-ID technology is the **magnet stripe** technology. Information which is stored in iron-based particles on the magnetic strip of a card is read by a reader transforming the information into a number (Kern 2006, p. 19). The magnetic stripe is already well-established, it is a low-cost data carrier and a range of security features have been developed (AIM global 2006 f). These advantages compared to RFID are opposed to some detriments, mainly the fact that magnetic stripe cards can be demagnetised meaning low operational reliability. Magnetic stripe cards are mainly used in the field of payment systems for financial cards and transit cards (AIM global 2006 f) but also in the field of access control for employees and boarding passes.

As well as the magnet stripes, **contact chip cards** belong to the group of card technologies. They rely on galvanic connection for data transmission between the chip card and the reader (Kern 2006, p. 28). The overall advantage of contact chip cards consists in the fact that data can be protected against unauthorised access. However, in contrast to RFID technology, a direct contact is required to read the data. This makes the reading process more transparent, but contact chip cards cannot be used when contactless reading is important (Gaßner *et al* 2006, p. 26). Two types of contact chip cards can be distinguished: simple memory cards with a memory register and more sophisticated microprocessor cards with a one-chip processor (Finkenzeller 2006, pp. 4-7). Memory cards are optimised for very specific applications involving low flexibility and, accordingly, low costs. In consequence, these cards are used for high-volume applications such as health insurance cards (Kern 2006, p. 28). Compared to memory cards, microprocessor cards are very flexible. They are mainly used for applications with high security requirements such as electronic cash (EC) cards or chip cards for GSM mobile phones (Finkenzeller 2006, p. 6).

Table 6: Comparison of auto-ID technologies[19]

	OCR (optical character recognition)	Computer vision systems	Magnetic stripes	Contact chip cards	Barcode		RFID
					1D-Barcode	2D-Barcode	
Functional principle	Electronic identification and translation of typewritten or handwritten characters via an optical scanner and a computer software	Computer based systems identifying items based on their visual appearance	Information stored in iron-based magnet particles on a magnetic stripe of a card that is read by a reader transforming the information into a number	Contact chip cards rely on a galvanic connection for data transmission to the reader. Two main types: memory cards with only a memory register and microprocessor cards with a one-chip processor	Information is stored on a tag in spaces and widths of parallel lines and read by optical scanners which transform optical impulses into electrical impulses	Information is stored in a matrix code in a two-dimensional way and thus has a higher data capacity than the 1D-barcode. Information read by optical readers	Information is stored on an electronically programmed tag and communicated to the reader using radio waves
Data capacity	Low	Low	Low	High	Low	Medium	Medium/High
Data type	Read only	Read only	Rewriteable	Rewriteable	Read Only	Read Only	Rewriteable
Human visibility/ readability	Readable	n/a (no specific tag)	Stripe visible, no readability	Contacts visible, no readability	Visible, potentially readable	Visible, no readability	Hidden
Simultaneous identification	No	Possibly	No	No	No	No	Yes
Robustness	Low	n/a	Medium	Medium	Medium	Low	High
Operating distance	Low (< 1 cm)	High	Low (direct contact)	Low (direct contact)	Medium (0-50 cm)		High[20]
Problematic objects (*e.g.* metal)	No	Yes	Yes	Possibly	No	No	Yes
Reader cost	Medium	Very high	Low	Low	Low	Medium	High

19 Based on Finkenzeller 2006, pp. 2-8; Hodges/McFarlane 2005, p. 6; Kern 2006, pp. 13-30.

20 Read ranges of RFID systems vary, but high read ranges are possible.

The last alternative auto-ID technology discussed in this section and which has probably the highest impact is **barcode technology**. It is currently the most widespread auto-ID technology, it can be found on most products in our daily life (Gaßner *et al.* 2006, p. 25) and the experts during interviews referred to it as the main competitor to RFID at the moment. Especially for supply chain applications, this can be explained by the fact that both technologies rely on tags or labels attached to an item containing information that can be identified by any reader and computer system (Hodges/McFarlane 2005, p. 5).

Barcodes can be divided into one-dimensional (1-D) and newer two-dimensional (2-D) barcodes. 1-D bar codes are made up of parallel bars with varying widths and spaces. 2-D barcodes are a further development of 1-D barcodes resulting from the need for higher data density (Dittmann 2006, p. 36). In 2-D barcodes, information is either stored in stacked codes made up of stacked vertical bars or in matrix codes (Strassner 2005, p. 56). Compared to 1-D barcodes, 2-D barcodes require more sophisticated and thus more expensive readers (Strassner 2005, p. 56). For both codes, industry sectors rely on different symbologies. Prominent examples for 1-D barcode symbologies are the EAN (Electronic Article Number) standard in Europe and the UPC (Universal Product Code) standard in the United States used in the consumer goods – retail value chain. Prominent 2-D barcodes are the PDF-(portable-Data-File)-417-standard which is used in the automotive sector and the data matrix code employed, amongst others, by the electronic industry (Dittmann 2006, p. 36, Strassner 2005, pp. 56-57).

Table 7: Comparative advantages of barcode and RFID technology compared to each other

		Barcode	RFID
System costs	• Tags prices significantly cheaper	+	-
	• Reader costs normally less important	+	-
Technology	• Easy to use – no interferences	+	-
	• Better control of scanned data	+	-
	• Possible security issues	+	-
	• Possibly privacy issues	+	-
	• Contactless transmission, no line-of-sight	-	+
	→ Less manual intervention	-	+
	→ Higher read ranges	-	+
	• Data storage	-	+
	→ Higher storage capacity	-	+
	→ Modification of data possible	-	+
	• Bulk reading possible	-	+
	• Robustness	-	+
	• Integration of sensors possible	-	+

In comparison to RFID technology, the main advantages of the barcode include significantly cheaper tags and in the majority of cases less expensive readers (Gaßner *et al.* 2006, p. 25, Strassner 2005, p. 55). In addition to this, there are no interferences due to water or metal as it is the case for RFID. Another important point is the better control of scanned data. For example, when different barcode-labelled cases on a pallet are scanned and errors occur, it is usually obvious which cases have not been scanned correctly. However, if errors occur when RFID tagged cases are read in bulk, it is more complicated and time consuming to detect, for example, which cases have not been read at all.

However, there are also a number of significant disadvantages compared to RFID technology. At first, barcodes are not very robust compared to RFID tags. Poor weather conditions such as rain or extreme temperatures as well as dirt render barcode labels inoperable. In terms of data storage, storage capacity does not attain the same level as for RFID tags. Furthermore, once the particular barcode is generated, data cannot be changed or augmented. For example, it is therefore not possible to store additional data during the production process (Hodges/McFarlane 2005, p. 5). A major drawback is also the need for line-of-sight (Gaßner *et al*. 2006, p. 25) which implies that pallets or containers must be unpacked in order to read cases or items. In addition to this, it is not possible to obtain the same level of high read ranges as with RFID technology. Finally, integration of other technologies such as sensor technology is unrealisable. Table 7 summarises the advantages of both barcode and RFID technology. The disadvantages of barcodes on the technological level discussed above mirror the image of technological benefits of RFID technology. We will focus on these core benefits in the next section and see how they entail usage and business benefits.

To sum up, this section on the technological landscape has shown that, besides barcode technology, alternative technologies are used for very specific applications and that amongst these alternative technologies, no technology covers all the fields of application discussed in section 4.2.2. Barcode technology is currently the main competing technology for most fields of application such as inventory audit or asset utilisation. Costs for barcode systems are lower and for some applications barcodes will be sufficient as long as no important storage capacity or robustness of labels is needed and as long as the required line-of-sight does not raise problems. RFID will thus not replace the barcode for some applications. However, barcode technology lacks substantial technological advantages, highlighted in Table 7. These advantages are further discussed in the following section.

4.3.2 Benefits and barriers of RFID

In the previous section, we focused on an overview of alternative technologies, their advantages and drawbacks. Based on this examination, especially on the comparison between the barcode and RFID, the following section discusses benefits and barriers to the implementation of RFID to better understand why companies engage in RFID (research objective 2).

4.3.2.1 Benefits of RFID

To assess the benefits of RFID, our point of departure is the sum of technological properties of an RFID system which make this system more powerful than alternative systems. These technological core benefits determine the base functions discussed above. Furthermore, they entail usage benefits in operations and processes in and between companies. Finally, different usage benefits are combined to generate four fields of business benefits. The different levels of benefits as well as specific benefits of each level are illustrated in Figure 6 and Figure 7 respectively.

Figure 6: Benefit levels of an RFID system

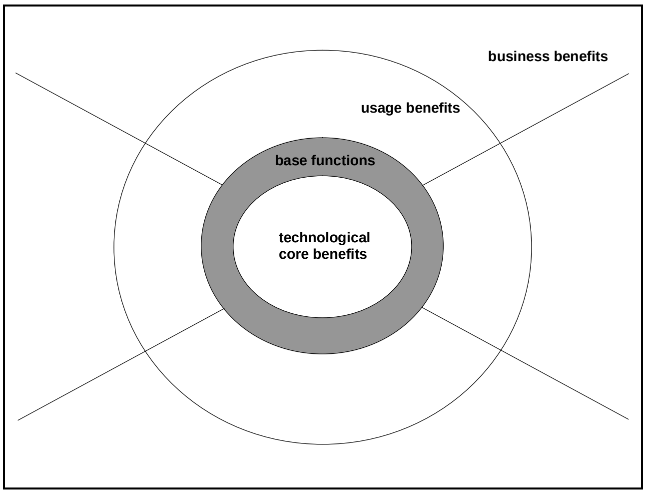
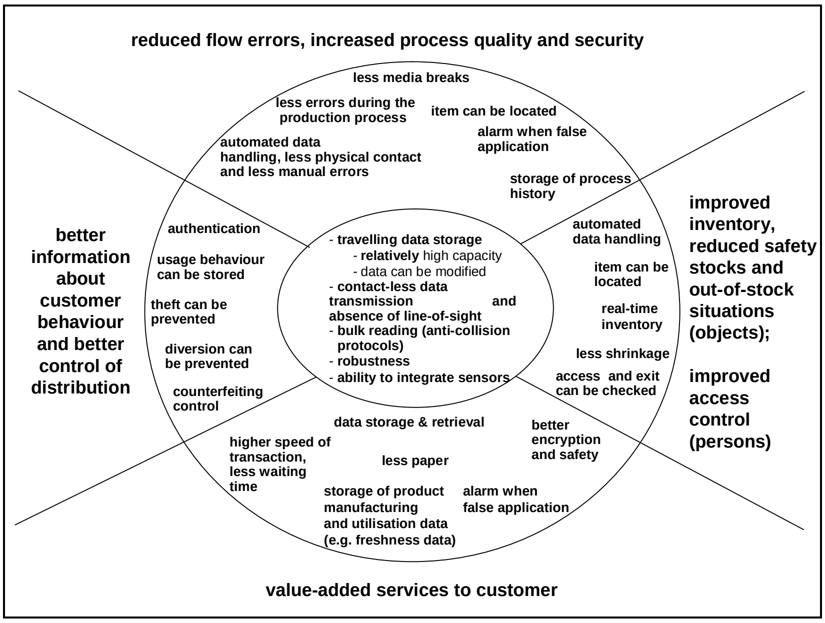


Figure 7: Detailed overview of RFID benefits



4.3.2.1.1 Technological core benefits

Five technological core benefits distinguish RFID technology from alternative technologies: travelling data storage, contactless data transmission and absence of line-of-sight, bulk reading, robustness and the ability to integrate sensor technology.

Compared to other **identification technologies (*e.g.* barcodes)**, RFID tags have a high **"travelling" data storage** capacity. This is especially important when a significant amount of data is directly stored on the tag and not on the network (data on tag approach; see also section 4.2.1.6) and when a tag is moved to places without network connections (Lahiri 2005, p. 54). Additionally, stored data can be modified which is very useful for asset monitoring and maintenance and for fields of application along the supply chain, in particular for the area of item flow control where information can be processed at each production stage.

Contactless data transmission induces that no physical contact is needed between the RFID tag and the reader. As a consequence, operations can be carried out more rapidly and a higher number of tags can be read in a short period of time which is very useful for item flow control on assembly lines (Lahiri 2005, p. 50). In contrast to barcode technology, **no line-of-sight** is required (see also section 4.3.1). For example, items in cases or boxes can be read out simultaneously without the need to unpack them. Both contactless data transmission and the absence of line-of-sight entail the possibility of **bulk reading**. However, as many tags are sending data at the same operating frequency and at the same time, signals overlay each other and collide. For this reason, anti-collision protocols have to be used when applying bulk reading to assure that RFID systems function properly.[21]

Another important technological core advantage is the **robustness** of RFID tags. They can be employed in poor weather conditions or in processes involving high temperatures. Finally, **sensor technology can be integrated** in RFID tags enabling new applications such as the permanent monitoring of cool storage and handling chains.

4.3.2.1.2 Usage benefits

Technological core benefits entail a variety of usage benefits illustrated in Figure 7. For example, the highly automated data handling and authentication results in less paper and media breaks. To illustrate, one of the interviewed experts said that media breaks, in the form of additional papers attached to objects in addition to information in the backend systems, used to disturb production processes before RFID technology was implemented. Furthermore, automated data handling requires less physical contact, reduces manual errors and allows for real-time inventory and, generally speaking, an overall higher speed of operations and transactions.

Thanks to travelling data storage, contactless data transmission and bulk reading, items can be tracked and their location can be precisely determined which prevents shrinkage and allows for theft and diversion prevention as well as anti-counterfeiting measures. Moreover, as a result of high data storage capacity and the possible modification of data, product manufacturing data and utilisation data as well as usage behaviour can be stored. However, the storage of information belonging to the latter two categories is still in its early stage and, at least for the latter case, raises the question of the consent of the individual.[22] An example of the storage of utilisation data is the storage of user manuals for electrical equipment. Finally, data storage capacity may also contribute to better encryption and higher safety of RFID systems.

4.3.2.1.3 Business benefits

Different combinations of the usage benefits discussed above constitute four fields of business benefits. The first field of business benefits relates to **improved processes**. As processes can be highly automated and made more transparent because of the storage of process history, less flow errors occur. Alarms can be triggered if applications are erroneous. Consequently, process quality and security increase, which is particularly important for sectors with high safety requirements. In the aviation sector, for example, it is crucial that the right wiring harnesses are installed at the right place or that parts of the air-conditioning systems are built in at the right places. For both types of parts, it is not visible to the eye and errors would have far-reaching consequences.

21 For an overview of two prominent anti-collision protocols see BSI 2004, pp. 34-39.

22 For this discussion see also DSTI/ICCP/REG(2007)9/FINAL (forthcoming).

The second field of business benefits is improved census of objects and persons. Regarding objects, RFID allows improved **inventory auditing** thanks to automated data handling and the possibility to locate items at any point in the supply chain. It is thus possible to conduct real-time inventory checks of stocked items. As a consequence of improved and more transparent stock taking, safety stocks can be reduced and shrinkage can be better controlled. Furthermore, shelves can be restocked more quickly, out-of-stock situations can be reduced and as a consequence costumer services can be increased at different points of an open supply chain. As for people, the use of RFID ensures an **efficient access and exit control** in a rapid manner as data can be transmitted without contact and as RFID allows for on-tag security mechanisms.

While the fields of benefits discussed above can be realised in open-loop and closed-loop RFID systems, fields three and four are related to open-loop applications only. Currently, as we will show in section 4.4, a relatively small number of open-loop systems are fully implemented. Accordingly, these benefits are realised for some particular applications but are future-oriented and will gain in importance in the future.

Value-added services to customers constitute the third field of business benefits. Due to contactless data transmission and bulk reading, transactions and processes can be accelerated and waiting time for customers reduced. For example, lending procedures in libraries can be organised in a more efficient way, reducing waiting time for users. Additionally, production and utilisation data can be directly stored on the item's tag. Less paper is needed and information such as freshness data for food, or user manuals and the period of guarantee for non-food products are directly attached to the product itself.

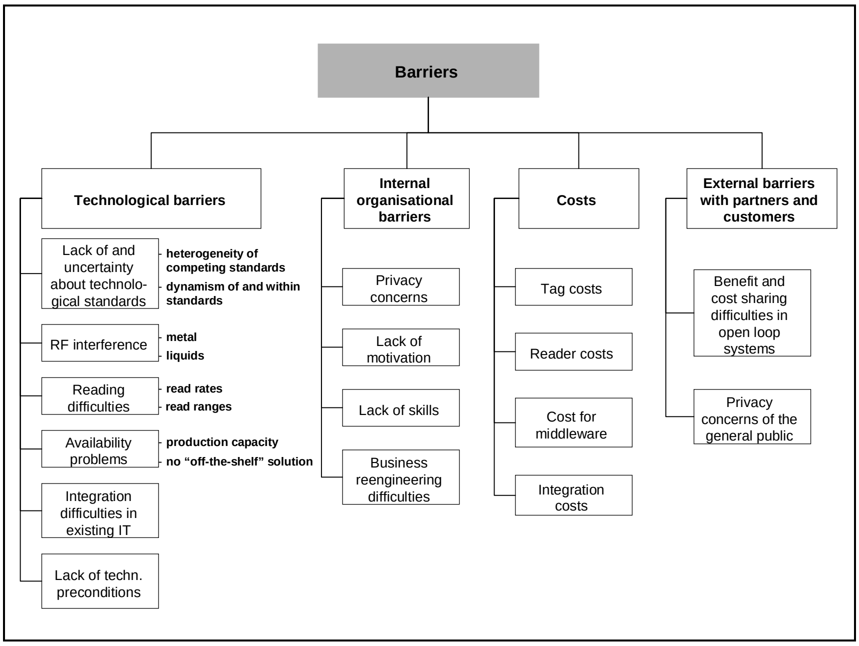
The last field of business benefits **consists of better information on the customer and better control of distribution.** As usage behaviour and preferences can be stored on tags and in databases (preferably with the consent of the individual), companies can gather more information and tailor services to customers' needs.[23] One example for future applications would be the storage of information on a customer's preferences regarding his or her car and customising services at the repair shop. However, it will depend on customers' acceptance whether this information can be gathered (see also section 4.3.2.2.4). Concerning distribution, due to the authentication of items and their location, diversion and theft can be prevented and counterfeited products can be detected more easily.

4.3.2.2 Barriers to the adoption of RFID

Barriers to the implementation of RFID have a variety of origins. Besides technological barriers, companies face internal and external barriers as well as cost barriers. Figure 8 gives an overview of these four main categories which will be further elaborate in the following subsections.

23 For this discussion see also DSTI/ICCP/REG(2007)9/FINAL (forthcoming).

Figure 8: Overview of barrier categories



4.3.2.2.1 Technological barriers

As the majority of RFID applications in companies are at an early stage of development, technological barriers play an important role as they occur most frequently. Most of the experts interviewed , however, agreed that they found solutions to the majority of these problems within 6 to 12 months. It is thus important for companies to be aware of the different sources of technological barriers discussed below and to be aware of the fact that it will take some time to overcome these problems. But in the majority of cases, technological barriers are not insurmountable.

Lacking technological standards and the **current uncertainty of technological standards** are seen by many interviewed experts as major barriers to RFID implementation. Although a number of standards have been developed (see section 4.2.1.6), experts complain that standards are still missing for some components of RFID systems and that in particular industry sector-specific standards are not developed yet. Furthermore, heterogeneity of existing standards due to different, sometimes competing standard organisations poses a problem, as does the pace with which new standards are developed and partly replace existing ones. The latter creates a climate of uncertainty because companies do not know at which point in time important investments in RFID systems should be made.

The next two technological barriers, radio frequency **interference problems** and **reading difficulties** concerning read ranges and read rates, are most inherent to RFID technology and have already been discussed in section 4.2.1. Interference problems are mainly relevant for industry sectors operating in metallic environments or where liquids play an important role. In addition, liquids play an important role in the hospital sector where patients are authenticated with RFID bracelets. Read ranges depend on the operating frequency and on a variety of different other factors as illustrated in section 4.2.1.5. When choosing RFID systems, it is thus important to bear in mind these factors and to test different systems. Insufficient read rates can also pose a problem as, as opposed to other auto-ID technologies, a read rate of nearly 100% cannot always be obtained. Reasons for insufficient read rates include unfavourable alignments of RFID tags and reader antenna, collisions in spite of anti-collision mechanisms, as well as the presence of background noises (Lampe/Flörkemeier/Haller 2005, pp. 79-81).

Availability problems arise from low production capacities of technology suppliers as well as from the lack of off-the-shelf solutions. In the first case, technology suppliers are not able to provide companies with high quantity orders because the pace of technological development of RFID technology is so important that the quantities of RFID systems being produced are too small to avoid stocks being filled up with outdated systems. In the latter case, companies deplore that an off-the-shelf solution of one single provider rarely exists. If a company decides to install RFID systems, it often has to perform an extensive search of which companies provide which components of an RFID system, leading to substantial search costs.

Another barrier to the implementation of RFID technology is the **integration of RFID systems in existing IT infrastructure**. First, companies question if they need a middleware between RFID systems and the existing infrastructure. Second, middleware systems available on the market are still not tailored to their needs. As a consequence, many companies had to develop an internal middleware system for early applications. Third, when companies decide to rely on a particular middleware, the process might be complex because RFID middleware might only "send granular RFID events to the existing systems, leaving them to deduce information and route the right event to the right process" (Bhargava 2006, p. 4).

Finally, the last technological barrier is the **lack of technological preconditions** which, however, is not relevant for all companies. Implementation of RFID systems is problematic when IT infrastructure in the form of backend systems has to be overhauled because it does not meet the prerequisites for the implementation of RFID systems. For companies along the consumer goods – retail value chain, for instance, it is crucial to dispose of electronic data information and to be able to deliver and accept dispatch advices.[24] Otherwise RFID will not help to optimise supply chains.

4.3.2.2.2 Intra-organisational barriers

After having discussed technological barriers, we raise the question of which additional barriers to RFID implementation can be found within a company. In contrast to technological barriers, intra-organisational barriers apply more generally to the introduction of a new technology. However, since they also decide on the success of the implementation of RFID systems, they are discussed in the following.

As processes become more transparent through the implementation of RFID systems, **privacy concerns** of employees are an important issue (see also DSTI/ICCP/REG(2007)9/FINAL, forthcoming). If employees, for example, carry RFID tagged tools and many RFID gates are installed in a production plant, they could be tracked. It is crucial to address these concerns carefully and transparently in co-operation with staff representatives to establish clear frameworks. All companies in our framework that were potentially confronted with this barrier could eliminate concerns in co-operation with staff representatives.

Another intra-organisational barrier is the employee's **lack of motivation** when introducing RFID systems. This is especially the case when employees do not realise the need for changing established processes that, in their eyes, function properly. Possible measures to deal with this barrier include a high level of communication between system integrators and employees to highlight why processes are changed and how overall operations improve.

Besides the lack of motivation, employees often **lack** required **skills** at different implementation levels. At the installation and first implementation level, the internal IT staff often lacks skills. This barrier can be tackled by relying on external providers. At the usage level, employees have to be trained how to use the new systems.

24 Dispatch advices are advance ship notices sent by the supplier to inform the customer about the contents of shipments which are ready to be sent or already have been sent.

Finally, **business reengineering difficulties** are a further internal organisational barrier. As benefits of RFID applications increase with the number of processes involved, as many processes as possible have to be analysed in order to define how RFID systems can best be implemented. This normally also leads to significant changes in processes. If, for instance, RFID systems are only conceived to replace barcode technology for existing processes without optimising some processes based on different RFID inherent benefits discussed in section 4.3.2.1, overall quantitative and qualitative benefits would be suboptimal.

4.3.2.2.3 Costs

Because the implementation and use of RFID technology is significantly more expensive than barcode technology, costs are often referred to as a significant barrier. They include tag costs, reader costs, costs for middle/edgeware as well as integration costs. The importance of different cost varies according to the RFID system in use. In open-loop systems, tag costs are often the main costs driver as tags cannot be reused. If closed-loop systems are deployed along a major part of the supply chain, a significant number of readers are needed for item flow control. There, reader costs are an important cost driver but also the integration into the software infrastructure. The importance of middleware costs depends on whether companies develop their own middleware or whether they can rely on middleware which is already on the market.

4.3.2.2.4 External barriers with partners and customers

In addition to the barriers reported above, there are two further barriers relating to open-loop RFID applications: cost benefit sharing difficulties and privacy concerns of the general public.

In open supply chains, the question arises who pays for and who benefits from RFID. To date, in most cases, suppliers have to bear the costs of RFID tags as well as the cost for their internal hard- and software infrastructure. As a consequence, suppliers pay the majority of the costs and purchasers often benefit the most. Alternative cost-sharing models could solve this issue but are currently not in use according to the interviewed experts.

Privacy concerns of the general public arise when people have the feeling that they can be tracked and their behaviour monitored (see also DSTI/ICCP/REG(2007)9/FINAL forthcoming)). Furthermore, there are concerns that due to a lack in transparency people are unaware of RFID tags in purchased items. These two concerns already have prompted some companies to stop their RFID trials. Without addressing these concerns, backlash by the general public is a “potential risk that could limit long-term benefits and development” (OECD 2005, p. 15). As currently there is a lot of misinformation and confusion about RFID technology, it is important to address privacy concerns as well as educate the general public about the capabilities of RFID technology and to render the use of RFID transparent at the point-of-sale.

Interestingly, when asked, interviewees did not perceive information security issues or health and safety issues as significant barriers to the implementation of RFID.

Overall, in section 4.3.2, we assessed the benefits and barriers related to RFID on an aggregated, industry sector-spanning level to examine what induces companies to invest in RFID (research objective 2) and which hindrances they face. In summary, the following main points can be highlighted at the aggregated level:

- RFID offers a multitude of benefits.

- These benefits originate from technological benefits which, in this composition, cannot be realised by alternative auto-identification technologies.

- As a result, quality, efficiency and transparency of processes can be increased, which - in particular in comparison to barcode technology - was not previously possible.

- These positive aspects are opposed to a number of different barriers – namely technological barriers, internal organisational barriers, costs as well as external barriers with partners and customers – illustrating that implementation of the technology is not always simple.

The occurrence and importance of single benefits, however, are highly dependent on the specific RFID application in use and differ very widely across sectors. The next section, which illustrates the current situation of RFID implementation in eight different industry sectors, addresses benefits and difficulties at the industry sector level.

4.4 Industry sector specific RFID situation and outlook

RFID tags can be found on pallets of consumer goods, car bodies, tree trunks, and even on patients' bracelets in hospitals. However, the specific RFID system in use, the scope and barriers linked to each case vary considerably: Pallets with consumer goods are tagged with low-cost tags with a read range of a couple of meters that aim at increasing efficiency and avoiding out-of stock situations. Expensive active tags on car bodies with a rather high data capacity ensure that the right parts are built-into the right car. Tree trunks are tagged with tags supporting harsh weather conditions and disposing of a short read range to provide paper-mills with freshness information about the trunks. Finally, patients are provided with RFID tags for the purpose of monitoring and controlling medication.

These examples illustrate that the way RFID is used varies significantly across industry sectors. For this reason, section 4.4 discusses the current situation of RFID implementation and use in eight different industry sectors (research objective 3). After an overview of the industry sectors, we examine each industry sector following one consistent structure that allows for cross-sector comparison. After having outlined relevant industry sector highlights, we give an overview of the use of RFID and fields of application and single out one application which we describe in more detail. Subsequently, we examine industry sector-specific barriers and give an outlook on industry sector-specific trends.

4.4.1 Overview of industry sectors

After the presentation of industry sectors covered in our study, we will compare the stage of RFID implementation in this section. Additionally, to give a general idea of RFID systems in use, we will map industry sectors according to frequency ranges and open vs. closed-loop projects.

4.4.1.1 Industry sectors and RFID applications covered in the sample

As described in section 3.2, our study focuses on sectors in which RFID pilot and implementation projects are already undertaken and where RFID technology applications seem very promising. Furthermore, for sectors dealing with open loop applications, we assess both the supplier and buyer side in an attempt to map the entire open-loop value chain. In total, we will deal with the following sectors in this section:

• Automotive • Automotive suppliers	Automotive value chain
• Retail • Consumer goods	Retail – consumer goods value chain

- Aviation[25]
- Airports

Aviation – airports value chain

- Forestry
- Hospitals

In terms of applications, payment systems and access control cards for people based on RFID have already been in use for many years. Currently, as our manager and expert interviews pointed out, the main new developments of RFID applications occur in processes along the supply chain. As a consequence, we will consider neither payment systems, nor access control cards for persons which are a well-established subfield of authentication.[26] Instead, we will rather focus on the fields of asset utilisation, asset monitoring and maintenance, item flow control, inventory audit, automatic release of information as well as theft control (see also section 4.2.2).

4.4.1.2 Stage of RFID implementation in the industry sectors

Table 8 represents the stage of RFID projects for different industry sectors. Overall, RFID projects at the pilot stage and very first roll-outs still prevail. Currently, numerous roll-out projects can primarily be found in the automotive sector, where all important companies in Germany dispose of RFID roll-out projects, and in the hospital sector. Consumer goods companies, automotive suppliers and airports are at a rather early stage of implementation.

25 In our sample, the aviation sector includes aircraft manufacturers as well as airlines.

26 We will deal with authentication for other applications than access control cards for people, such as the authentication of authorised spare parts in the aviation industry.

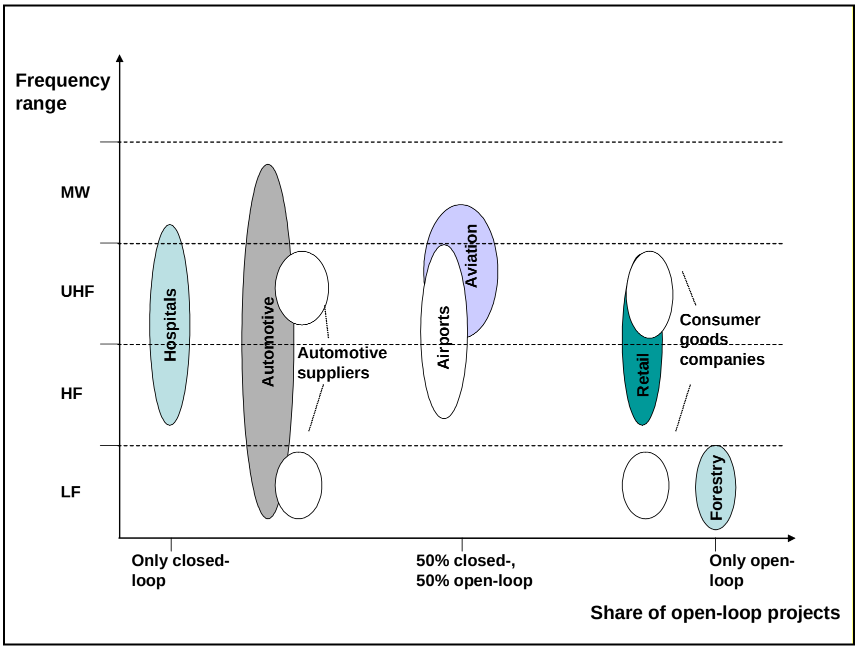
Table 8: Stage of RFID implementation in industry sectors (CL: closed loop, OL: open loop)

	Very first pilots	Pilots by a few companies	Very first roll-outs	Roll-outs by a few companies	Numerous roll-outs
Automotive	OL asset utilisation with suppliers			CL authentication	CL asset monitoring and maintenance, item flow control, inventory audit
Automotive suppliers	OL asset utilisation OL inventory audit	CL asset utilisation		CL inventory audits	
Retail	OL item flow control OL automatic release of information		OL inventory audit (item level)	OL inventory audit (case level) Theft control	OL inventory audit (pallet level)
Consumer goods companies			OL inventory audit	OL inventory audit (pallet level)	
Aviation		CL authentication	CL item flow control	CL inventory audit CL asset monitoring and maintenance CL asset utilisation	
Airports	Item flow control (baggage)		CL asset monitoring and maintenance		
Forestry			OL inventory audit		
Hospitals		CL item flow control (*e.g.* blood bottles)		CL asset utilisation CL authentication CL theft/security control	

4.4.1.3 Industry sector clusters

Figure 9 maps industry sectors covered in our sample according to two aspects of RFID technological systems: the operating frequency range and the context in which the RFID application is embedded. First, some industries, for example the automotive and the aviation sector, rely on a broad range of frequencies whereas other industry sectors, such as the retail and forestry sector, concentrate their applications on one operating frequency. Second, industry sector clusters can be identified whereby clusters correspond to the value chains presented above. This indicates that it is important to examine both suppliers and buyers within a value chain. Sections 4.4.2 to 4.4.7 illustrate to what extent suppliers and buyers have a similar approach to RFID implementation.

Figure 9: RFID industry sector clusters



In the following section we examine RFID implementation in eight industry sectors using the following structure: after summarising industry sector highlights, we give an overview of the use of RFID and current fields of application and describe one application in detail. Furthermore, we assess barriers related to the industry sector and close with an outlook on industry sector-specific trends.

4.4.2 RFID in the automotive sector

Industry sector highlights

- Most experienced sector in the use of RFID. Technology used for more than ten years
- Currently dominated by closed-loop applications
- Technological characteristics :
  - Important use of active technology
  - Use of **all** frequency ranges
- Broad diffusion of different fields of application
- High diffusion: all important German companies rely on RFID technology
- Trends:
  - First open-loop applications with suppliers
  - Tagging of security-relevant parts is a promising new field

The automotive sector is the most experienced sector in the use of RFID technology. Companies have been using RFID for over ten years. Overall, it relies on six different fields of application and is characterised by a broad use of RFID. Implementation projects are widely diffused and dominated by closed loop applications and active tags. The latter is due to the fact that, when RFID technology was implemented, only active tags had the necessary capabilities. Table 9 gives an overview of **fields of application** as well as examples for applications and technologies.

Table 9: Overview of RFID applications in the automotive sector

Field of application	Application example	Examples of technology in use	Closed- vs. open-loop	Project stage
Asset utilisation	Container management Loading equipment management Truck control at loading stations	Active UHF Passive UHF, HF Passive UHF Active UHF	Mainly closed-loop projects	Mainly implementation projects (Pilot projects for first open loop projects)
Asset monitoring and maintenance	Torque key control	Passive HF	Closed-loop projects	Mainly implementation projects
Item flow control	Tagging of car bodies in • body shell work • painting • assembly	Active UHF Passive UHF	Closed-loop projects	Implementation projects
Inventory audit	Tracking of finished cars	Active UHF Active MW	Closed-loop projects	Implementation projects
Authentication	Assembly documentation for security-relevant items (*e.g.* hood-liner)	Passive LF	Closed-loop projects	Mainly implementation projects
Theft control	Car keys	Passive LF	Isolated application	Implementation projects

Benefits: To illustrate some of the **benefits**, we focus on the field of asset utilisation. In the automotive sector, highly specialised, high-value containers are used during the production process. Before relying on RFID technology, these containers could not be tracked and production departments used to neglect returning containers.

As a consequence, not only a high number of containers had to be used but sometimes containers ran out during production. By using containers that are equipped with RFID tags, containers can be tracked along the production line. As a result of increased transparency, containers can be used more efficiently leading to a reduction of their total number. Additionally, incentives to return empty containers as well as new internal cost allocation possibilities can be created. An example would be internal leasing fees for containers. Overall, in terms of quantitative results, one manager commented that by relying on RFID technology instead of barcode technology, they could increase container capacity utilisation by 30%

Barriers: Besides these benefits, there are also a number of **sector specific barriers**. To date, there are three main barriers:

- As car manufacturers operate in a highly metallic environment, there are signal interference problems.
- Another major problem is the fast development of RFID technology. This creates availability problems as technology providers have difficulties in supplying RFID equipment.

- The discussion about one single standard in the automotive industry is splitting the sector into two camps. One camp would prefer to join the EPC global standard (see section 4.2.1.6) as organisational structures are already built up and as the probability of a wide acceptance of the standard would be higher. The other camp argues that the EPC standard is primarily driven by the retail sector and does not fit the needs of the automotive sector. Currently, no consensus has been reached but there are some indications that the automotive sector could join the EPC standard as some companies have signed up for informational membership.

Other barriers which are less important than those discussed above include costs in some particular cases as well as the lack of employee motivation. In the latter case, managers point out that, in some departments, employees do not feel the need to change existing processes.

A number of barriers discussed in section 4.3.2.2 are not relevant to the automotive sector. They include privacy concerns and lack of skills.

Trends: Trends can be grouped into technological trends and application trends:

- On the technological level, a shift from active to passive technology can be expected. This is due to the fact that passive systems have significantly increased in performance and that they are less expensive. In addition to this, further technological developments make interference problems less important.

- In terms of new applications, first open loop systems with suppliers are commencing, in particular in the fields of item flow control, where security-relevant parts are tagged, and asset utilisation. Managers estimate that “internal” open loop implementation projects between internal suppliers and production departments will be realised in 3 to 6 years and “external” open loop projects in about 5 to 10 years. In the longer term (from about 2016 on), the automotive sector is also thinking of additional services to the customer relying on data stored on RFID tags in cars.

- A broader implementation of open-loop projects will significantly depend on advances in standardisation.

Overall, the automotive sector is characterised by broad use and extensive experience with RFID technology in closed-loop systems.

4.4.3 RFID in the automotive supplier sector

Industry sector highlights

- Significantly fewer projects in the automotive supplier sector than in the automotive sector.
- Mainly pilot projects, assessment of business cases not yet completed.
- Rather low diffusion of different fields of application and low diffusion in the industry sector.
- Currently, mainly closed-loop projects but focus on future open-loop application.
- Technological characteristic:
  - Mainly passive technology in use due to recent introduction of projects.
- Important driver for implementing RFID: potential future mandates from the automotive sector.

Compared to the automotive sector, there are significantly fewer RFID projects in the automotive supplier sector. According to a research institute expert, this is because it initially implies higher costs for automotive suppliers as implementation will probably first take place at their expense. As a consequence, it will be some time before suppliers realise that the technology can also contribute to improved internal processes.

Projects that are already at the implementation stage and in use for several years can mainly be found in the field of inventory audit (see Table 10). For example, pallets are tagged to achieve improved warehouse management. However, these are often niche applications which are not integrated in company-wide IT systems. More recently, in the last two years, automotive suppliers conducted pilot projects in the fields of asset utilisation and item flow control for open-loop applications. One main reason is that suppliers want to be prepared for requests by the automotive industry.

As these newer projects are still at the pilot stage, some are currently being tested internally in closed-loop projects. Passive RFID tags dominate as they are less expensive. Overall, there is a rather low diffusion of RFID projects across a limited number of fields of application within the industry sector and the assessment of business cases is not yet completed.

Table 10: Overview of RFID applications in the automotive supplier sector

Field of application	Application example	Examples of technology in use	Closed- vs. open-loop	Project stage
Asset utilisation	Loading equipment management	Passive UHF	Closed/Open loop projects	Mainly pilot projects
Authentication	Identification of car gears	Passive UHF	Closed/Open loop projects	Mainly pilot projects
Inventory audit	Warehouse management – pallet tagging	Passive LH	Closed-loop projects	Implementation projects

Benefits: When highlighting some **benefits**, we will concentrate on the management of loading equipment in open-loop systems. For instance, loading equipment for gears is highly specialised and thus expensive. As one manager stated, without RFID technology, loading equipment had been managed rather poorly. By relying on RFID, automotive suppliers can locate the equipment and record when it is shipped to and returned by the automotive sector. As process transparency increases, administrative expenses become less important and, in the longer term, loading equipment in use can be reduced and purchases of new equipment avoided. Furthermore, as not many automotive supplier companies are dealing with RFID technology, suppliers that are already using RFID technology expect to improve their corporate image.

Barriers: As automotive suppliers belong to the same value chain as the automotive sector, they share the three main **barriers** including interference problems, standards, as well as availability problems relating to the supply of RFID equipment. Concerning the latter barrier, managers mainly complain about inappropriate middleware solutions and device management. For example, one complaint concerns middleware solutions that are often too EPC oriented. In terms of standards, a central issue is the lack of standards for open-loop projects with the automotive sector.

Besides these main barriers, suppliers also face less important barriers such as some integration difficulties in existing IT infrastructure and business re-engineering difficulties.

A number of barriers listed in section 4.3.2.2 do not apply to the automotive supplier sector. As for the automotive sector, privacy concerns as well as lack of skills are not relevant. Benefit and cost sharing difficulties in open-loop systems are currently not perceived as an obstacle, probably due to the fact that open-loop pilot projects are still at a very early stage.

Trends: Four main trends can be identified in the automotive supplier sector:

- In terms of technological barriers, interference problems will become less important as specialised tags are further developed.

- The number of closed-loop applications in the field of asset utilisation will increase as more solution packages are available on the market. Current closed-loop pilot projects are expected to evolve into implementation projects within the next two years.

- Open-loop projects at the pilot stage will be partly rolled out in the next two to three years. This is in particular the case for open-loop applications between one supplier and customer or where only a very limited number of suppliers and automotive manufacturers are involved. When standardisation issues are at least partly solved, industry experts estimate that the first open-loop projects will be started within the next five years for standardised assets such as small load containers. It takes this longer period as this open-loop involves a number of different suppliers and a huge number of containers as, according to an expert of a research institute, over 35 million small load containers are circulating. Not all containers can be tagged at the same time and there is a major concern that tagged containers will not return to the companies that invested in the technology.

- Finally, it is likely that automotive manufacturers will invite suppliers to deal with RFID technology and integrate it in future calls for tender, which could lead to strong mandates and thus the same development as for the consumer goods / retail value chain as discussed in the following two sections. This development may raise cost-benefit sharing difficulties in the automotive value chain.

Overall, the automotive supplier sector is at a rather early stage in terms of RFID implementation and is dealing with RFID technology due to presentiments that there will be future mandates by the automotive sector.

4.4.4 RFID in the retail sector

Industry sector highlights

- Sector with most press coverage, partly due to RFID being used as a marketing tool by early adopters.
- Dominated by open-loop applications.
- Tagging mainly on the pallet and case level; item-level tagging currently only for high-value goods.
- Important use of passive, EPC standardised UHF tags.
- Sector which triggered most standardisation activities via EPCglobal and continues to push further standardisation.
- In terms of diffusion within the sector, two major retail companies have implemented RFID technology in Germany.

- Slower adoption than expected as not all retail companies invest in the technology and only a few consumer goods companies currently implement RFID technology.
- In the long run, a variety of new services for customers can be offered.

In the last three to four years, it is mainly the retail sector[27] that has brought RFID into the news and that has received most press coverage. This is partly due to publicity and important image campaigns by a couple of important retail groups. These groups are intensively dealing with RFID technology for two reasons: First, they see the possibility to optimise the monitoring of the whole supply chain from consumer goods companies to the point-of-sale, involving a high quantity of different goods. Second, they underline their image as early adopters of new technologies. As retail companies have the upper hand in the consumer goods – retail value chain, they are in the position to demand RFID implementation from consumer goods companies.

In terms of RFID diffusion in the sector, however, the adoption of RFID technology is very fragmented. In the "bricks and mortar" retail sector, only two German retailers currently deal intensively with RFID pilot and implementation projects. In the mail order business, only one company uses RFID technology at present.

Table 11 gives an overview of fields of application in the retail sector. Overall, open-loop applications in the field of inventory audit largely prevail. In contrast to the automotive sector, the quantity of tags is very high as tags cannot be reused. Companies thus rely on inexpensive, EPC standardised, passive tags operating at UHF frequency. As standardisation is crucial both for price reductions and international sourcing, major retail companies have been triggering standardisation activities at EPCglobal and are pushing for further standards development. Because these tags are still too expensive for low-value consumer goods, the large majority of inventory audit applications focus on the pallet level and applications are beginning at the case level.

Table 11: Overview of RFID applications in the retail sector

Field of application	Application example	Examples of technology in use	Closed- vs. open-loop	Project stage
Asset utilisation	Carousel systems in warehouse management	Passive HF	Closed loop projects	Implementation projects
Item flow control	Item level tagging of garments	Passive HF Passive UHF	Open loop projects	Pilot projects / Implementation projects
Inventory audit	Sorting, checking and counting of inventory	Passive UHF	Open-loop projects	Pilot projects / Implementation projects
Theft control	Tracking of expensive goods along the supply chain	Passive HF	Open-loop projects	Mainly implementation projects
Automatic release of information	Information on products at the point of sale (*e.g.* wine bottles, hair care products)	Passive HF	Open-loop projects	Mainly pilot projects

27 In our survey, the category “retail” includes stationary retail as well as mail ordering.

The fields of item flow control, theft control and asset utilisation play a minor role. Some closed-loop projects are found in the field of asset utilisation where, for example, bins are tagged in carousel systems to increase warehouse automation.

In open-loop projects in the fields of item flow control and theft control, item-level tagging is tested and implemented for high-value goods. Contrary to inventory audit projects where suppliers have to tag pallets and cases, items for the purpose of flow and theft control are currently tagged by retailers. A manager of a mail order company overseeing an implementation project in the field of theft control explained that the company has tagged high-value electronic products such as mobile phones, camcorders or navigation systems. These products were selected based on price and susceptibility to theft.

Benefits: To discuss **benefits**, we assess inventory audit processes along the supply chain. To date, some consumer goods companies attach RFID tags to pallets and cases of their outgoing shipments. Via an automatic flow of information and dispatch advice, retail companies obtain the information on kinds and quantities shipped. At distribution warehouses, RFID gates automatically check incoming goods. This information is entered into a merchandise management system and compared to information included in the dispatch advice. Subsequently, inventory is sorted and shipments to the point-of-sale are checked relying on RFID. In an analogous way, inventory is automatically checked at the point-of-sale. As a consequence, according to a manager of a "bricks and mortar" retail company, processes can be optimised leading to an increase in quality and precision along the supply chain. Furthermore, in terms of visibility, there are multiple benefits such as a better traceability of goods.

Overall, due to a high degree of automated data handling and the fact that pallets and cases can be located along the whole supply chain, retail companies are able to perform real-time inventory management leading to an improved availability of goods. According to an expert from a research institute, this is in particular crucial at the point-of-sale in order to avoid out-of-stock situations and to increase customer satisfaction.

Barriers: Besides these benefits, there are also a number of different **barriers**. Main barriers on the technological level which apply for all projects in the retail sector include:

- Lack of off-the-shelf solutions for pilot and implementation projects.
- Interference problems with liquids and metallic products.
- High insecurity about when to invest in RFID systems. This is due to the fact that EPCglobal is developing standards and specifications at a fast pace (see also section 4.2.1.6).

In addition to these general barriers, there are specific barriers for item-level tagging as well as specific barriers for open-loop applications in the retail sector:

- Item level tagging is frequently done with RFID systems operating at high frequency (HF) with short read ranges. Furthermore, there are recent pilot projects which also test RFID systems operating at ultra high frequency. As a consequence, two competing frequency ranges are in use and standardisation activities for item level tagging are only beginning.

- Main barriers for open-loop applications are co-operation difficulties with consumer goods companies. On the one hand, retailers have to convince suppliers to implement RFID technology and share costs. On the other hand, the majority of suppliers still lack electronic data exchange (EDI) with retailers and integrated RFID applications cannot be used at all. Further barriers for open-loop applications are privacy concerns of the general public and costs for the infrastructure and tags if the latter are paid by the retailer.

Compared to other sectors, it is noteworthy that – according to firms - at the internal level employees have no privacy concerns nor do they lack motivation.[28]

Trends: Trends in the retail sector can be grouped into diffusion trends, trends on different tagging levels and application trends:

- In terms of diffusion, more consumer goods companies will be asked to equip their goods with RFID tags. However, this process will probably be slower than expected at the beginning as consumer goods companies face important barriers (see section 4.4.5). Experts from research institutes estimate that it will take a further five to ten years for open-loop implementation projects to be widely realised. Interviews with managers and experts showed that current projects focus simply on automation aspects when replacing barcode technology by RFID technology but in most cases not on a far-reaching assessment of how existing processes can be changed. This is probably because companies at this stage are familiarising with RFID technology. As a consequence, the few business cases that are currently available usually focus on very specific processes and not on larger parts of the value chain. In addition, as distribution centres of retailers are already highly automated in Europe due to high labour costs, benefits calculations are rather low. In the medium term, retailers will likely analyse how existing processes can be reengineered to achieve a great leap forward to increased benefits.
- On the tagging level, there are first projects at the case level in "bricks and mortar" retail and the number of projects will certainly increase in the years to come. On the item level, the main challenge consists in achieving one standard and to focus on one frequency range to allow for an increased production of tags and thus price declines. Once this issue is solved, an increase of item level tagging of high-value goods can be expected.
- In terms of new applications, there are many possible new applications at the point-of-sale. As already mentioned in this section, smart shelves but also smart in-store promotion stands can prevent out-of-stock situations and permit tracking the popularity of goods and the success of promotion activities. Experts of research institutes estimate that there will be a number of implementation projects in about three to five years. Furthermore, new customer services can be created at the point-of-sale which provide more and better information. They include, for instance, smart changing rooms providing additional information on available clothes, information points (*e.g.* for wine bottles) where customers obtain information on the product and fast check-out for specific products. According to managers and experts of our sample, the implementation of these services at the point-of-sale will take between six and ten years and depend on customers' acceptance. According to firms interviewed, customers will accept RFID technology if the perceived benefit outweighs the drawbacks.
- Besides these new applications at the point-of-sale, there are very promising new applications in the combination with sensor technology. Built-in sensors in RFID tags are particularly interesting for the monitoring of the fresh groceries supply chain and the traceability of groceries. We will further discuss the integration of sensor technology in section 4.6.2.

Overall, RFID implementation in the retail sector is very fragmented and at an early stage. A number of important retailers use RFID intensively and push further implementation and standardisation activities. Implementation will proceed more slowly than expected but steadily. In terms of trends, there are many interesting new applications.

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28 Note employees have not been surveyed directly by this study.

4.4.5 RFID in the consumer goods sector

Industry sector highlights

- RFID implementation is at an early stage (lack of technical/infrastructure preconditions such as integrated EDI systems in many companies).
- Apart from early adopters, many consumer goods companies only tag their goods because they have retailer mandates.
- Besides open-loop applications with the retail sector, there are also closed-loop niche applications.
- Many companies do not improve internal processes when implementing RFID.
- Tagging is mainly at pallet and case level.
- Important use of passive, EPC standardised UHF tags.
- Main barrier: cost-benefit sharing difficulties along the supply chain.

RFID implementation in the consumer goods sector is very customer-driven. Compared to the retail sector, the implementation is at an earlier stage. Overall, in terms of RFID diffusion within the sector, only a minority of consumer goods companies has pilots and implementation projects.

Consumer goods companies already dealing with the technology can be divided into two groups for open-loop applications with the retail sector:

- Companies that implement RFID technology which aims at optimising internal processes relying on RFID technology. Usually, these companies are either important consumer goods companies with a complex distribution structure or are companies which undertook important changes of internal processes and IT infrastructure when implementing RFID.
- Companies tagging pallets at the end of their internal supply chain because they have retailer mandates. Implementation is customer driven and often internal processes are not improved and pallets tagged only when delivering the goods to retailers. According to managers and experts in our sample, these companies represent the majority of those using RFID.

Table 12: Overview of RFID applications in the consumer goods sector

Field of application	Application example	Examples of technology in use	Closed- vs. open-loop	Project stage
Asset utilisation	Forklift tracking for warehouse management	Passive LF	Closed loop projects	Implementation projects (few projects)
Inventory audit	Sorting, checking and counting of inventory	Passive UHF	Open-loop projects	Pilot projects / Implementation projects

Besides these open-loop applications with retailers in the field of inventory audit, there are also some closed-loop asset utilisation applications (see Table 12).

Benefits: Since we already discussed inventory audit benefits for the retail sector belonging to the same value chain, we will focus on a closed-loop internal application of forklift tracking to illustrate some **benefits** in the consumer goods sector.

One consumer goods company in our sample monitors forklifts via about 2 500 RFID tags that are sunk in the ground at their distribution centre. The forklift can be tracked via a reader which allows for a better organisation of the warehouse and batch tracing to the customer. The exact monitoring of the forklifts is crucial as around 10 000 pallets have to be moved per day which is the equivalent of 250 to 500 trucks daily. The company was thus looking for a solution which relieved forklift drivers a maximum and did not require entering data manually or stopping forklifts to scan data on barcodes.

Besides these usage benefits, there are three main business benefits according to the operations manager: reduced flow errors, a significant increase in process speed and higher accuracy and process quality. Additionally, customers could be provided with new services such as batch tracing information.

Furthermore, the implementation of RFID guarantees an efficient implementation of the EU directive on the traceability of foodstuffs as movements of goods can be precisely and permanently controlled and documented.

Barriers: This closed-loop success story, however, does not mean that the consumer goods sector does not face serious **barriers** to RFID implementation. As stated above, most consumer goods companies are not yet dealing with RFID technology although they are aware of potential mandates from the retail sector. A major barrier is the lack of technical preconditions, particularly lacking electronic data interchange (EDI) with retailers. The retail sector only benefits from RFID if it simultaneously receives the dispatch advice, and only 5-10% of the companies can transmit this advice electronically.

If consumer goods companies already rely on EDI, the main sector specific barriers include:

- On the technological level: standardisation, availability and interference problems. Consumer goods companies face the problem of a fast pace of standards developments as in the retail sector. International companies additionally have difficulties concerning the non-liberalisation of frequency ranges in different European countries. Furthermore, as no off-the-shelf solutions are available, companies encounter availability problems. Radio-frequency interference problems entail the need for different tags for different products in one company.
- If suppliers use RFID technology in open-loop systems, the main barriers are benefit and cost sharing difficulties. As many suppliers meet retailer mandates via “slap & ship”, *i.e.* add RFID tags on logistic units and ship them without realising internal benefits, they face the considerable costs of the RFID tags. Even when using RFID for internal processes, most of the consumer goods companies currently have difficulties to present positive business cases according to experts, as costs are important. The limited number of retailers using RFID technology is a further barrier for consumer goods companies which want to deploy RFID.

In contrast to other sectors and according to firms interviewed, potential internal organisational barriers such as lack of employees’ motivation or employees’ privacy concerns do not occur (note employees have not been surveyed directly by this study).

Trends: In terms of trends, four main trends can be identified for the consumer goods sector:

- Generally, due to major retailer mandates there will be a further implementation of open-loop projects in companies already dealing with RFID as well as in those which so far have not.

- Currently, tagging mainly takes place at the pallet level. There are only a limited number of projects dealing with case-level tagging. The number of the latter will increase according to experts and managers in our sample.
- As consumer goods companies become more familiar with RFID technology, their focus will shift from the pure tagging of outgoing goods to the assessment and improvement of internal processes with RFID, with resultant positive business cases.
- Finally, in the longer-term (six to ten years) consumer goods companies can benefit from detailed point-of-sale information from retailers. However, this depends on the willingness of retailers to provide such information and the number of retailers that have implemented RFID systems.

Overall, implementation of RFID in the consumer goods sector is clearly customer-driven. As companies have to pay for the tags, most of them currently face benefit and cost sharing difficulties.

4.4.6 RFID in the aviation sector

Industry sector highlights

- Promising sector for RFID technology due to complex production processes, long life cycles of planes and tight safety regulations.
- RFID projects only started in the past few years.
- Use of multiple different fields of application.
- Major aircraft manufacturers and airlines are using the technology.
- Aircraft manufacturers co-operate intensively with each other as well as with airlines on detailed standards.
- To date, mainly closed-loop projects because of lack of established standards.

In comparison to the automotive sector, the aviation sector[29] has started to engage in RFID technology more recently, with the first initiatives launched in 2000. Due to three main characteristics, RFID implementation is very promising:

- Aircrafts have a long life cycle.
- Production and maintenance of planes are subject to strict safety regulations.
- Production processes are complex. For example during assembly it is not always possible to observe with the naked eye where which components have to be installed. Dampers for an air-conditioning system are equipped with different numbers of holes and these parts could be mixed-up during the production process.

As a consequence, sophisticated, high-quality tags are used and tag prices play a minor role. These are often characterised by high data storage capacity and robustness against high temperature and pressure.

In terms of scope, the aviation sector relies on a variety of different fields of application and is thus characterised by a multifaceted use of RFID (see Table 13). Applications in the field of asset management

29 In our sample, the aviation sector includes aircraft manufacturers as well as airlines.

are similar to applications that were already discussed in the automotive and supplier sector (see sections 4.4.2 and 4.4.3). Tools and tool boxes are tagged by aircraft manufacturers that subsequently lend them to smaller airlines in the field of asset monitoring and maintenance. To avoid errors, parts are tagged on the item level during the production process and for later maintenance. Finally, another important field of application is authentication to assure that no unapproved spare parts are used. Overall, as RFID implementation is recent, pilot projects still prevail. Consequently, many projects, including projects conceived for open-loop RFID systems, are currently closed-loop.

Table 13: Overview of RFID applications in the aviation sector

Field of application	Application example	Examples of technology in use	Closed- vs. open-loop	Project stage
Asset utilisation	Loading equipment management (*e.g.* for aircraft engines)	Active UHF + GPS Passive UHF	Mainly closed-loop	Pilot projects / Implementation projects
Asset monitoring and maintenance	Tagging of tools	Passive UHF	Closed and open-loop	Implementation projects
Item flow control	Tagging of parts and storage of life cycle data (*e.g.* for engines, wiring harnesses)	Passive UHF	Open-loop	Mainly pilot projects
Inventory audit	Counting of pallets (production process) Counting of life jackets	Passive UHF	Closed-loop	Pilot projects / Implementation projects
Authentication	Detecting of unapproved spare parts for anti-counterfeiting	--- (early pilot stage)	Open-loop	Pilot projects

Benefits: To highlight the main **benefits** in the aviation sector, we will concentrate on applications in the field of item flow control as there are many pilot projects. Structural parts of aircrafts are equipped with RFID tags. In contrast to the automotive sector, tags remain attached to the respective component for further maintenance, repair and documentation. To date, for instance, wiring harnesses or spare parts are tagged.

In terms of technological core benefits, the most important benefits for the aviation sector are the robustness of tags and travelling data storage. Often, barcodes cannot be used as they become dirty and cannot be read. Travelling data storage is crucial for the aviation sector for three main reasons:

- Data can be directly read out *in situ* as it is stored on the RFID tag which is attached to the item.
- Storage capacity is significantly higher than for barcodes.
- Data on tags can be modified.

As these benefits allow for storage of the history and of modifications on the item level, data quality can be significantly increased which in turn leads to increased process quality and security during the aircraft life cycle. When they are resold by the seller's airlines, maintenance information can be directly read out at the component level and no further access to databases is required. Another important benefit on the usage level, often cited by managers, is the significant reduction of manual interventions. To date, data collection is still partly manual and paper based. When these processes are automated, reaction time and process speed can be increased as capital costs can be reduced. Overall, process efficiency can thus be increased and technical costs per flight hour reduced. However, a thorough process reengineering is needed to fully benefit from the migration to RFID.

Barriers: To fully realise these benefits, a number of **barriers** have to be overcome. Currently, there are two main obstacles:

- The first important barrier is a lack of standardisation. To date, there are almost no standards in this industry sector. According to one manager, aircraft manufacturers have reached some early agreements on data standards but for many applications, there is no consensus on which frequency range to use. However, this is indispensable for further RFID projects as major airlines rely 70% on the same suppliers and share important customers. Aircraft manufacturers are co-operating intensively on the standardisation issue, which is rather uncommon for this particular industry sector.
- The second important barrier concerns data capacity on tags. Although the data capacity on RFID tags is much higher than for alternative technologies, aircraft manufacturers and airlines need tags with a higher data capacity than currently available to store maintenance documentation, for example. The industry is thus pushing suppliers to develop new tags with increased performance.

Further barriers include two technological barriers and two internal organisational barriers:

- In terms of technological barriers, there are some interference problems due to a metallic environment and metallic parts and some integration issues with existing IT systems. But managers estimate that it is only a question of time to overcome these barriers.
- On the internal level, privacy concerns of employees are important. If, for example, an employee carries RFID tagged tools and production facilities are equipped with a large number of readers, the employee could easily be tracked during work. Furthermore, as one manager highlighted, motivation problems may occur if employees are not adequately trained to deal with the technology or if there are technological problems. For example, a high number of unsuccessful attempts to read out data via RFID technology might result in a low level of acceptance of the technology.

It is worthwhile mentioning that several barriers discussed in section 4.3.2.2 are not relevant to the aviation sector. On the internal level, lack of skills does not play a role. This may be due to the fact that the sector intensively co-operates with research institutes. On the external level, there are neither privacy concerns of the general public nor current benefit and cost sharing difficulties. An explanation for the latter point may be that RFID implementation is at a very early stage and that, as mentioned above, the sector is not as price-sensitive as other sectors as far as tag costs are concerned.

Trends in the aviation sector are significantly influenced by the characteristic long-term contracts between companies along the value chain. As a result, trends can be grouped in terms of time frames:

- Within the next year, managers and experts estimate that aircraft manufacturers and airlines will focus on internal item flow control projects which are currently at a conceptual or pilot stage. Examples include tagging of wiring harnesses and spare parts in warehouses.
- In a time frame of about three years, RFID technology will be further implemented in warehouses for the purpose of improved inventory auditing. This includes first implementation projects with suppliers at the pallet level. Furthermore, in the field of item flow control, managers plan to test active technology for very high-quality parts and to dispose of RFID tagged parts in aircraft. As a consequence, maintenance and checks of completeness of parts would be highly automated.

- Over a longer time horizon of about six years, aircraft manufactures expect to close first contracts with suppliers which include RFID technology at the item level for selected structural parts. Furthermore, they expect the technology to be spread over the whole value chain from suppliers to airlines and plan to create an RFID integrated value chain for some applications.

Overall, the aviation sector is a very promising sector for RFID implementation due to long life cycles of aircrafts, complex processes and strict safety regulations resulting in a lower price sensitivity concerning RFID tags.

4.4.7 RFID in the airport sector

Industry sector highlights

- Use of RFID technology for asset monitoring and maintenance and for asset utilisation.
- RFID projects only recently.
- Closed-loop projects.
- Rather low diffusion within the sector.
- Currently not used for baggage handling due to lacking standards and technological preconditions.
- Currently no tracking of passengers.
- Airport dependant on airlines' plans concerning RFID implementation.

RFID projects at airports are at a relatively early stage and use in the industry is rather low with few RFID projects from German airports. All airport projects are currently closed-loop and concern management of fixed infrastructure facilities and moveable assets. Application examples include the maintenance of fire shutters and pilot projects with dollies (see Table 14). For the latter, dollies transporting pallets are tagged to permit cargo dispatchers to precisely allocate costs according to the quantity of pallets. Open-loop projects are currently not carried out because standards are lacking and airports highly depend on airlines in particular in passenger operations.

Table 14: Overview of RFID applications in the airport sector

Field of application	Application example	Examples of technology in use	Closed- vs. open-loop	Project stage
Asset utilisation	Tracking of dollies	Different frequencies tested (early stage) Passive HF Active UHF Active MW	Closed-loop	Pilot projects
Asset monitoring and maintenance	Maintenance of fire shutters	Passive HF	Closed-loop	Implementation projects

Benefits: Currently, an application example in the field of asset monitoring and maintenance is the maintenance of fire shutters. At Germany's largest airport, 22 000 fire shutters are installed in the air-conditioning system of the buildings for fire protection. In the case of fire, these shutters close. As safety regulations are very high, a thorough inspection of these shutters is performed at least annually by contractors. Since 2003, these fire shutters are equipped with passive RFID tags and technicians have to scan themselves, follow a predefined maintenance process and finish checking by scanning themselves again. One of the most important benefits is tamper-proof documentation that maintenance has been carried out.

Additionally, data handling is automated as no manual entry of data is required. Consequently, process speeds can be increased significantly; less paper is needed and, in particular, fewer errors occur as automation entails highly standardised processes. Furthermore, misunderstandings are avoided and thus an overall increased process quality can be attained. Finally, the airport has to perform less double-checks to control whether the work of the contractor is satisfactory.

Barriers: However, despite the benefits outweighing costs in this particular field of application, airports face significant **barriers** to further adoption:

- On the technological level, the most important barrier is lacking standardisation which is crucial to the sector as it is extremely tightly knit.
- This results in a high level of uncertainty and concern with adopting the appropriate standard.
- Another technological barrier consists of lacking technological preconditions for applications that are conceived as open-loop applications. Baggage tagging on the item level is complicated due to different preconditions in this complex open-loop system. For example, there are still some smaller airports which provide handwritten luggage tags.
- In terms of internal organisation difficulties, privacy concerns of employees may arise as they partly can be tracked. Is it therefore important to agree which and what kind of information is gathered.
- Regarding external difficulties, some projects are not planned due to potential privacy concerns of the general public and unclear legal bases of data security, for example airport passenger tracking.
- Finally, costs are a major issue. Airports assessed some projects and abandoned them due to long payback periods. As one manager stated, for example, a project involving tagged luggage carts would have had a payback period of more than eight years as active technology would have been necessary due to high ceilings at the airport.

Trends in the airport sector can be grouped into open-loop and closed-loop trends:

- Closed-loop applications in the fields of asset monitoring and maintenance as well as asset utilisation will be further developed. Current pilot projects, in particular in the field of asset utilisation, for instance, the tracking of dollies, will, in all likelihood be implemented. New RFID projects in these fields probably will be undertaken and proliferation within the industry will increase.
- The realisation of open-loop projects depends significantly on standardisation activities as standards are a *sine qua non* condition, for example, in the field of luggage tracking. If airlines agree on one standard, managers estimate that important airlines and airports may have pilot projects within the next two to three years.

Overall, the airport sector is characterised by some RFID projects in the fields of asset utilisation and maintenance which are successful and pay off, but by significant barriers as well as a certain dependence on airlines as far as open-loop projects are concerned.

4.4.8 RFID in the forestry sector

Industry sector highlights

- Only open-loop applications.
- Integration of the whole value chain from the forester to the saw- or paper mill.
- RFID used in the field of inventory audit where tree trunks are tagged.
- RFID technology only technology to cope with bad weather conditions.
- Creation of new services.

RFID has been used in German forestry for about two years. The sector in Germany is characterised by an important market share of the public sector in the field of forest cultivation. It is an interesting example of an advanced application in a new field. To date, there is only one private company providing forestry services. To improve the open supply chain, the company implemented RFID technology. The RFID system in use covers the whole open supply chain from the forester to the skidder, to the transport company and finally to the saw- or paper mill. It is thus the only sector where RFID is deployed along a complete value chain. Furthermore, in the forestry sector, RFID is regarded as the only current auto-ID technology which can be used to deal with challenging working conditions such as low temperatures, deep frost and no energy supply.

Table 15: Overview of RFID applications in the forestry sector

Field of application	Application example	Examples of technology in use	Closed- vs. open-loop	Project stage
Inventory audit	Checking and counting of inventory	Passive LF	Open-loop	Implementation projects
Automatic release of information	Information on the freshness of tree trunks	Passive LF	Open-loop projects	Pilot projects

Fields of application include inventory tracking and automatic release of information (see Table 15). For all applications, RFID tags are integrated in nails which, are inserted into the tree trunk after the tree has been felled. Tags are only used once; they are terminated in production facilities at the end of the supply chain.

Benefits: To discuss **benefits** along the value chain, we will focus on the field of inventory audit. In this field of application, high-value trunks amounting to at least EUR 40-50 are tagged. After the RFID tag has been hammered into the trunk, an identification number, which is the only information stored on the tag, is sent to a central database via a handheld computer together with additional data such as the species of the tree and the quality. The forester provides this information to subsequent companies in the value chain. A skidder pulls tree trunks out of the forest, piles them up and scans data to verify if all trees have been put out. Trees are subsequently loaded on a truck by another company in the value chain. Again, data is scanned and sent to the central database when the trunks have been loaded. Finally, a third data collection takes place at the final stage of the open-loop chain at the entrance of *e.g.* the saw mill.

On the technological level, the key benefit is the robustness of the technology. As stated above, no other current auto-ID technology can be used for this kind of application. On the usage and business level, there are three main benefits:

- All companies involved in the value chain benefit from an increased level and quality of information. At any time, information on felled trees and their location can be retrieved from the central database preventing the loss of wood. Without RFID technology, these losses normally amount to 5-10% as often felled trunks are simply forgotten in forests.
- Logistic processes along the value chain can be optimised due to an improved organisation of available resources. Routes can be better planned leading to improved inventory management and to faster processes. As a consequence, firm liquidity can be significantly improved.
- Multiple new services for companies are created along the value chain. Forest owners receive information on their tree population and what happens to sold trees. Skippers dispose of control mechanisms for their performance, for instance, they know exactly how many cubic meters they processed at the end of the day. Most important, however, is information on the freshness of trunks in order to minimise quality losses: too long periods of storage lead to a loss of moisture and colour. A certain degree of moisture is important for paper production. As the CEO of the forestry company explained, trunks which lie too long in woods no longer meet the requirements for paper production and thus face devaluation leading to a lower payment or no sale at all.

Barriers: Besides these benefits, there are also some sector-specific barriers. Main barriers are technological ones as well as costs. Regarding the first category, the lack of off-the-shelf solutions is an obstacle. Additionally, the sector faces the problem of very low read ranges of about 10 cm, as low frequency tags have to be used to deal with poor weather conditions. Finally, further development of software systems is required. In terms of costs, tag prices of about EUR 1 are currently too expensive for tagging all felled trees.

Besides the above-mentioned barriers, other barriers discussed in section 4.3.2.2 are not relevant to the industry sector. It is worthwhile mentioning that, currently, there are no benefit-cost sharing difficulties along the value chain. This is due to the fact that the forestry company pays for the whole RFID infrastructure and sells services packages. Prices for the service are offer prices but are expected to rise.

Trends in the sector consist of integration of further companies. For instance, different saw-mills announced co-operation for further development of the RFID system and software. Furthermore, other technologies are integrated in the system such as voice entry of data by workers in order to avoid entering the data manually into a handheld. Finally, the number of tagged trees is expected to increase significantly when tags become less expensive.

4.4.9 RFID in the hospital sector

Industry sector highlights

- Already a significant number of implementation projects.
- Use in many fields of application.
- Only closed-loop applications.
- Already positive business cases.
- Although persons are tagged, no privacy concerns so far.
- RFID projects are highly dependent on and driven by budget considerations.

The hospital sector is characterised by a significant number of RFID projects which are already at the implementation stage. It is a promising sector for RFID implementation due to two main aspects:

- Patient safety is high priority.
- Cost pressure is important.

Table 16: Overview of RFID applications in the hospital sector

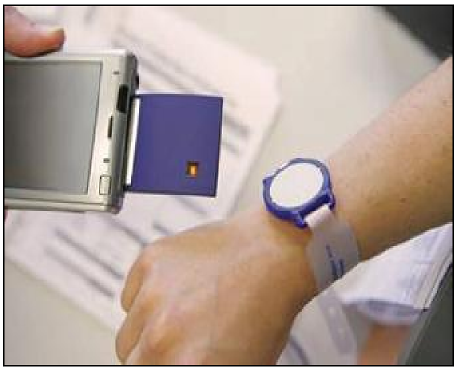
Field of application	Application example	Examples of technology in use	Closed- vs. open-loop	Project stage
Asset utilisation	Tracking of beds Container management	Active UHF Passive HF Passive HF	Closed-loop	Implementation projects
Item flow control	Blood bags tracking and usage	Passive HF	Closed-loop	Mainly pilot projects
Authentication	Patient authentication for medication control	Passive HF	Closed-loop	Implementation projects
“Theft control”	Baby tracking	Semi-active HF	Closed-loop	Mainly implementation projects

Current RFID projects aim at improving both patient safety and reducing costs. All applications are closed-loop and can be grouped into two categories: applications for the tracking of objects including assets and items such as blood bags and transfusions and applications for patients (see Table 16).

On the object level, for example, beds are equipped with RFID tags to allow for a more efficient use. Blood bags, for instance, are equipped with RFID tags operating at high frequency to monitor the supply chain of the bags and the proper use.

Applications for patients are currently deployed for three different groups of patients according to tagging purposes: patients are equipped with RFID bracelets for medication control (see Figure 10), babies can be tracked through RFID bracelets and there are RFID applications for dementia patients to increase their security, triggering an alarm when patients leave a predefined area.

Figure 10: RFID system for the authentication of patients



Source: Siemens Business Services (2006).

Benefits: As the **benefits** of asset utilisation are very similar to other industry sectors, we will concentrate on equipping patients with RFID tags to illustrate important benefits. For the purpose of medication control, passive HF RFID tags contain at least an identification number of the patients which is linked to medical records via a secured access. In some hospitals, they also contain additional information such as the blood type and other laboratory test data. Main benefits include more secure processes and thus an increase in patient safety due to a reduction of prescribing errors. According to a study by Dean *et al*. (2002) which assessed prescribing errors in a 550-bed hospital in London, a potential serious error occurred in 0.4% of all orders, which amounted in total to 34 potential serious errors per week. By relying on RFID technology, patient information can be electronically compared to medication and proper dosage ensured. As a consequence, process security can be highly increased and costs reduced as serious errors normally lead to a longer stay of patients in hospitals and are thus avoided. Other benefits include increased process speed and easier and more precise data entry and processing in patient information systems.

Babies are equipped with semi-active RFID tags to avoid abduction and mix-ups. Tags become active triggering an alarm when leaving areas without authorisation. As hospitals face increasing competitive pressures, RFID baby-tagging is seen as one way of improving customer satisfaction.

Barriers: In comparison to other sectors, the hospital sector faces relatively few **barriers**. The most important current barrier is budget constraints which result in longer project preparation and in some cases in postponements of investments. On the internal level, there is the potential barrier of privacy concerns of employees, for instance, at maternity wards where nurses are identified when taking care of babies. It is thus important to clearly define which processes and parts of the work are tracked. In the majority of cases, when this aspect was taken into account, there were no serious problems.

It is worth mentioning that some barriers which are important for other industry sectors are not relevant to hospitals. As many projects are already at the implementation stage, main technological barriers such as some difficulties with interference are in large parts already overcome for current RFID projects. In addition, our results interestingly indicate that privacy concerns are not perceived as a barrier. Patients can opt out, but they rarely made use of this option. According to one manager, this is due to the fact that patients usually want to be discharged from hospitals as soon as possible and will do as much as possible to achieve this aim.

Trends in the hospital sector can be grouped into the further diffusion process and new fields of application:

- In terms of diffusion, the number of hospitals relying on RFID technology will increase, as there are already many implementation projects and increasingly standardised packages. According to managers in our sample, the main focus will be put on patient identification and medication safety as benefits are highest for this field of application and further improvement of patient safety is needed.
- Besides existing applications, there are various promising future applications. These applications include tags with integrated sensor technology and tagging of assets such as specific surgery instruments. For both fields, the very first pilots exist. In the first case, for instance, blood bags are tagged with RFID tags containing sensors for temperature monitoring. Currently, the centrifugation poses significant problems for the tags. In the second field, technology providers develop first applications for instruments which are not too small to tag. The main problem is that, in the longer term, this would be a first quasi open-loop application requiring a certain level of standardisation.

Overall, the hospital sector is a very promising sector for RFID applications as the technology enables increased patient safety and reduced costs and thus addresses two crucial challenges for the sector.

4.4.10 Summary of commonalities across industry sectors

In sections 4.4.2 to 4.4.9, we have assessed the implementation and use of RFID in industry sectors in an isolated way. This assessment has revealed that industry sectors rely on a variety of different RFID systems and applications. However, some commonalities can be identified.

This section will deal with the search for commonalities. It will follow the structure of the isolated analysis of industry sectors and thus addresses commonalities according to:

- The stage of RFID development.
- RFID technology.
- Benefits and barriers.

Our cross-sector assessment of the use of RFID has shown that industry sectors differ widely in the **stage of RFID development**. For example, whereas the automotive sector has more than ten years of experience with RFID projects, other sectors such as the forestry sector and a large part of the consumer goods sector are only beginning implementation projects. Furthermore, diffusion of RFID technology within industry sectors varies significantly. Multiple automotive companies and hospitals rely on RFID systems in contrast to the airport or the forestry sector, for instance.

On the **technological level**, various RFID systems are in use depending on specific applications. The main difference lies in the choice between passive, low cost tags and sophisticated, high performance tags, for instance with a high data capacity or high read ranges. Accordingly, two different approaches exist. The first is data on a network where only a small amount of information is stored on the tag and most data is stored on the network. The opposite would be data on a tag where information is available *in situ* without the need for a network connection (see also section 4.2.1.6).

In terms of **benefits** and **barriers**, our assessment highlighted that the occurrence of specific benefits and barriers was sector-specific. We could observe, however, some similarities on a cross-sector level.

Currently, most companies focus on the business **benefits** of process optimisation in the form of increased process quality and security and improved inventory management (see also section 4.3.2.1). As implementation projects are overall at a rather early stage many companies have not changed existing processes yet but are planning to do so. Furthermore, apart from the retail, consumer goods and forestry sectors, most companies try to realise these benefits in a first step on the internal level.

In terms of **barriers**, a common problem is standardisation in certain industry sectors where standards play a particular important role. In this context a lack of standards is an important obstacle as is high uncertainty in some industry sectors regarding the optimal timing for an investment in RFID when considering the fast pace of standards' evolution and change. There are some further frequent technological barriers such as interference and availability problems. Most of the companies, however, agreed that these problems could be overcome to a satisfactory degree. Availability problems will decrease when standardisation issues are solved and the number of companies adopting RFID increases.

Based on our assessment of the use of RFID technology in different industry sectors, we will focus on the further development of RFID in the following two sections. Section 4.5 will provide a roadmap for future **applications** in the field of RFID. Subsequently, section 4.6 will focus on the further development of RFID **technology**.

4.5 General prospects for RFID applications

In sections 4.2 to 4.9, we have provided trends for each industry. Based on these trends, we develop an expected roadmap of future applications in the industry sectors discussed. Furthermore, we illustrate trends regarding the proliferation of RFID technology. To outline this expected roadmap for future RFID applications, Table 17 summarises the **trends** discussed for each industry sector. It is based on estimates of interviewed managers and experts of research institutes. Dates indicated are approximate values aiming at giving a general idea on further RFID development in industry sectors in Germany.

The table indicates four main aspects:

- In terms of fields of application, applications in the area of asset utilisation and maintenance will increase in the next two to three years. Furthermore, applications in the area of authentication focusing on the prevention of counterfeiting are expected to increase. In the longer term, there is a clear trend towards applications in the field of item flow control. In addition, completely new applications will arise, for instance, the combination of RFID technology with other technologies (see also section 4.6.2).
- On the usage level of particular RFID systems, a slight shift from active towards passive technology can be observed. This is due to the fact that performance of passive technology increased significantly during the last years.
- There is a trend towards open-loop systems for most industry sectors which can be explained by the fact that overall benefits for open-loop systems are higher. As illustrated in Figure 7 of section 4.3.2.1, better information about customer behaviour and better control of distribution as well as better customer services, can only be realised in open-loop systems.
- Regarding these open-loop benefits, we noticed that companies are already thinking of how to realise them as a tendency towards more customer oriented services can be observed in the longer term.

Overall, based on the trends in table 17, we observed a future diffusion process as depicted in figure 11 along the following three categories:

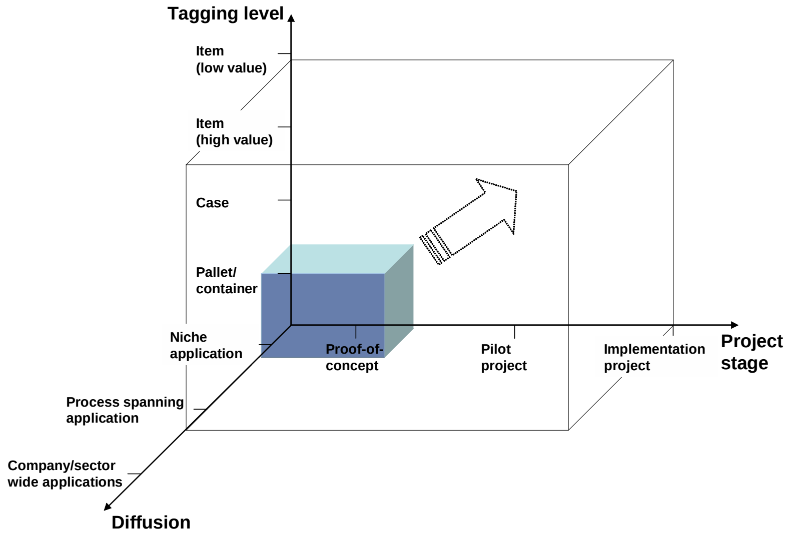
- Project stage.
- Tagging level.
- Diffusion.

Table 17: Overview of future RFID applications in different industry sectors (IMPL: implementation, PIL: pilot, CL: closed loop, OP: open loop)

	2006	'07	'08	'09	'10	'11	'12	'16	'17
Auto-motive	IMPL projects -asset utilisation (CL)	PIL projects - tagging of security-relevant parts (CL/OL)		First "internal" OL projects for item flow control and asset utilisation			First "external" OL projects for item flow control and asset utilisation	Additional services to the customer (*e.g.* for automated release of information)	
Auto-motive supplier		IMPL projects - asset utilisation rather (CL)	IMPL authentication of parts (CL/OL)	First OL projects (rather bilateral projects)			First OL projects for item flow control and asset utilisation		
Retail	Increase of IMPL and PIL projects with cons. goods sector			A number of IMPL projects at the item level			Additional services for customers at the point-of-sale		
Con-sumer goods	Slow increase of OL projects with retailers								
Aviation		Further PIL/IMPL projects item flow control		First IMPL projects inventory audit with suppliers (OL)	Test of active technology for high value components	Pilot projects for RFID tags with integrated sensors	First IMPL projects item flow control with suppliers Integrated RFID value chain		
Airports		IMPL projects asset utilisation	Increase of asset mainten-ance and utilisation projects (CL)	Potential PIL projects in the field of baggage handling					
Forestry		Integration of further companies along the value chain							
Health		Further IMPL projects – increased number of hospitals	PIL projects for new applications for asset utilisation	PIL/IMPL projects-RFID tags with integrated sensor technology					

At the project stage, with practically no off-the-shelf solutions existing, projects sometimes pass a proof-of-concept phase, where the technological feasibility is tested, and always undergo a pilot phase before final implementation. Currently, most projects are at the pilot stage or, in case of newer applications, at the proof-of-concept stage.

Figure 11: Schematic illustration of the diffusion process



On the tagging level, a general trend from the pallet and container level to the item level can be observed. For applications where items are directly tagged, for example, like in the aviation or forestry sector, the diffusion process starts with the tagging of high-value goods or components to pass into the tagging of low-value goods. However, this development depends on a further decline in price for tags which in turn depends on an increase in supply.

Finally, in terms of diffusion, we observed that many companies have started with RFID projects that had often been niche applications and either expanded these projects or deployed additional, process spanning RFID systems. As illustrated for the aviation sector in section 4.4.7 and in table 17, companies aim at creating integrated RFID applications at the company level and, in a longer perspective, even on the level of a whole sector value chain.

Overall, these trends and further diffusion of RFID also depend on the technological development. In the following section, we will thus briefly outline the prospects for new developments in RFID technology as well as for the combination of the technology with other technologies.

4.6 General prospects for RFID technology

General prospects for RFID technology can be divided into two main questions:

- What are further developments of RFID technology?
- How will the technology be used in combination with other technologies in a broader context?

4.6.1 Further development of RFID technology

Technological development of RFID continues at a very fast pace. The main technological developments include:

- **Improvement of specialised tags**

  Currently, tags for difficult environments, such as metallic environments, and conditions, such high temperature and rough weather conditions, are available. According to managers and experts in our sample, these specialised tags are further developed and improved. Overall, the variety of tags is supposed to increase so that there will be multiple highly specialised tags for specific environments and conditions.

- **Improved battery supply**

  An important obstacle for the use of active technology is the limited life-span of an active tag due to factors such as short-lived batteries, the design of wake-up protocols and whether tags are read continuously or at pre-set intervals. In the next few years, further improvements are very likely.

- **Improved read-ranges**

  Further improvements are also expected in the field of current read ranges for particular frequency ranges. Whereas most managers and experts agree that read ranges of RFID systems operating at UHF are at a satisfactory level, improvement of read ranges for RFID systems operating at 13.56 MHz would be welcome. However, due to physical constraints, improvements of read ranges for systems operating at HF will probably be limited.

- **Increased storage capacity**

  Especially for process-spanning applications, for example in the field of item flow control, companies rely on the data-on-tag approach for particular applications and want to store as much data as possible on an RFID tag. As a consequence, they need a relatively high data storage capacity which currently cannot always be provided by technology suppliers as shown in section 4.4.6 for the aviation sector. Therefore, managers and experts are confident that storage capacity will increase over the next few years.

- **Use of new materials for RFID tags**

  In order to further significantly decrease costs of RFID tags, new materials are being tested. It is hoped that RFID tags with silicon-based chips currently in use will be replaced by polymer-based chips. By using polymer-based chips, costs could be significantly reduced and tags could serve as a low-cost means for a broad use of RFID at the item level. Prototypes are already developed and different polymers are being tested. However, when comparing those to an RFID tag using a silicon-based chip, one expert commented that, at the beginning, there will be a significantly lower read range as well as a significantly lower read rate. Overall, the development of polymer-based chips is still in the prototype phase. Many managers and experts expect a lot from these new materials, but are aware that significant technological barriers will have to be overcome in order to enable broad use.

The progress presented above leads the way for increased real-time information of different processes in companies. In particular, advances in storage capacity of tags allow for systems and machines to be controlled based on the information stored on tags resulting in the internet of things according to one expert from a research institute.

Significant research and development is also ongoing in the field of improving security and privacy of RFID.

4.6.2 Combination with other technologies

In the previous section, we discussed technological developments of RFID systems. Many of them will progress significantly and will be achieved in a short time frame. This section provides a longer term perspective. There are certainly already some prototypes and some applications in the fields illustrated below, but, according to experts from research institutes in our sample, broader developments have to be considered over a time horizon of at least ten years.

A reason for this longer time frame is that this section deals with the combination of RFID technology with other technologies. As we showed in section 4.3.2.1, RFID technology already provides an important number of benefits on a stand-alone basis. These benefits can be further increased when the technology is combined with other promising technologies or when other technologies are directly integrated in RFID systems. Two technologies which are in particular relevant in this context and which were often mentioned during our interviews are communication technologies and sensor technology.

Communication technologies play a crucial role in receiving and transmitting data from RFID tags to networks and backend systems and in interlinking data of different tags.

Currently, communication devices are developed with integrated RFID readers to be able to directly read out tags. They include, for instance, personal digital assistants (PDAs) and mobile phones. Both for business and consumer applications, these devices, when being widely used, will entail significant benefits. In the field of business applications, PDAs can be used to monitor production processes and levels of stock. In the field of consumer applications, there is a particularly high potential for these devices in the field of automatic release of information. For instance, customers could receive information on tagged products, such as the availability of clothes, via their mobile phones. Other application examples include information on artworks in museums, or bus schedules.

In terms of communication standards, according to Mattern (2005, p. 48), wireless communication such as W-LAN or Universal Mobile Telecommunications System (UMTS) is crucial in order to realise the “internet of things”. One relatively new wireless standard is the Near-Field Communication (NFC) standard which was jointly developed by Sony and Philips. It is a short-range wireless connectivity standard which relies on inductive coupling at 13.56 MHz but requires significantly less energy (Phelps 2005, Mattern 2005, p. 49). It allows nearby devices to detect each other and thus to “exchange information and initiate applications automatically when they are brought in close proximity, or touched together” (Phelps 2005). Thereby, NFC can either be used as a means of data transmission or simply to establish a first contact where devices recognise each other, if they additionally dispose of other wireless communication interfaces with a higher data transmission rate (Mattern 2005, p. 49). This near field communication technology standard is of high value for RFID applications as RFID tags can be read out by NFC-enabled devices. For example, mobile phones with an active NFC device can act as readers and either directly display data or retrieve additional information from the mobile network or the internet (Mattern 2005, p. 50).

Another technology which is of great interest for the further development and potential of RFID technology is **sensor technology**. Thanks to technological innovation, sensors have been miniaturised and can now be implemented in RIFD tags. They allow for measuring environment conditions as well as conditions of tagged items. For example, they are able to measure:

- Temperature.
- Pressure.
- Vibration.
- Humidity.
- Gases etc.[30]

Currently, tags with integrated sensor technology are mainly used in pilot projects and are relatively expensive. However, managers and experts from our sample estimate that these tags have a high future potential, especially for items with high industrial requirements and where human security is involved.

RFID tags with integrated sensors are particularly relevant to the aviation sector and the automotive sector. Examples include tags with integrated vibration sensors which could indicate when security-relevant parts have to be replaced. Where the security of humans is involved, tags with integrated sensors are very interesting for the health sector as well as the consumer goods - retail value chain. As mentioned in section 4.4.9, there are already first pilot projects with blood bags in hospitals. Furthermore, there are pilot projects in the consumer goods and retail value chain where temperature in the whole cool chain is monitored.

Overall, the crucial advantage of RFID tags with integrated sensors is that sensor-enabled RFID tags can function based on the information gathered by the sensors and directly take action. These developments, together with wireless communication technologies, could lead to the communication of RFID tags among each other.

In conclusion, a progressive combination of RFID technology, sensor technology and communication technologies allows for continuously determining the status of objects and the communication to users and thus to bridge the gap between the virtual world and the world of physical objects.

30 For a more detailed list and information on the ability to integrate those sensors in different kind of RFID tags see Finkenzeller (2006, p. 349).

5. GOVERNMENT POLICY

One part of the questionnaire was dedicated to the role of governments and international organisations. Participants were asked what role governments should play and which initiatives governments or international organisations should undertake. Overall, the result was very diverse. Table 18 gives an overview of the most cited possible roles and initiatives of the public sector. Most participants agree that governments should raise awareness and better inform citizens and companies of the capability and the limits of RFID technology, as many articles were misleading and do not deal with the technology in an objective way. Studies on the technology are also thought to be very helpful. Participants also agree on the importance of the standardisation and liberalisation of frequency ranges.

Table 18: Possible roles of the public sector

Roles of the public sector
Information on RFID • What can be done with RFID and what are the limits of the technology? • What is RFID used for? • What are the fields of application? • What risks does the technology entail?
Studies on RFID technology
Frequency band allocation • Standardisation (*e.g.* Europe-wide standardisation of UHF) • Liberalisation of frequency ranges
Securing personally identifiable information • Checking the data protection act • Communicate what is intended to be done
Financial support for RFID projects
Convincing industry to invest in RFID technology
Bringing together all RFID stakeholders

Concerning securing personally identifiable information, answers are very diverse. All interviewed agreed that this data has to be secured but for some participants existing regulations are sufficient, for others not. There is no consensus on the question whether governments and international organisations should fund R&D projects and convince the industry to invest in RFID technology. Finally, most participants agree on the importance of bringing different stakeholders together. Overall, most participants agree that governments and international organisations have some role to play. Only a few participants think that neither governments nor international organisations should intervene.

ANNEX

A-1 RFID applications by sector

(sectors in italics were covered in the empirical study)

	Asset Utilisation	Asset monitoring and maintenance	Item flow control	Inventory Audit	Authenti-cation	Theft Control	Payment systems	Automatic release of information
Automotive	• Container management • Loading equipment management • Truck control	• Machine maintenance	• Tagging of body parts on the assembly production line • Tagging of built-in parts	• Finished vehicles real-time location system	• Car keys combining automobile immobiliser system and access control			
Automotive suppliers	• Container management • Loading equipment management			• Finished products identification • Automation of warehouse management				
Trade and Retail			• Goods movement control from store warehouses to the sales area • Control of goods freshness	• Goods receipt checking and entry into a database in the distribution warehouse • Automated sorting and counting of inventory • Checking shipments of outgoing goods		• Checking deliveries (in trucks) for theft prevention • Anti-theft systems at the point of sale	• Contact-less payment cards	• Customer services at the point-of-sale (*e.g.* starting of video-clips, information release on screens)

	Asset Utilisation	Asset monitoring and maintenance	Item flow control	Inventory Audit	Authenti-cation	Theft Control	Payment systems	Automatic release of information
Consumer Goods			• (Goods tracking along the supply chain) • control of goods freshness	• Checking of outgoing shipments				
Aviation	• Container manageme nt	• Tool box maintenanc e • Aircraft main-tenance	• Tagging of built-in parts to avoid errors (wiring harnesses)		Proof of authenticity (*e.g.* for spare parts)			
Airports	• Manageme nt of dollies	• Maintenanc e of fire shutters	• Baggage handling	• Equipment check				
Pharma-ceutical Industry			• Tracing of drugs		• Proof of authenticit y of drugs			
Agriculture and *Forestry*			• Tracing of goods (*e.g.* for freshness monitoring)	• Inventory audit in forestry and animal-ID				
Logistics	• Container manageme nt			• Checking of shipments				
Tourism and Leisure			• Recording of time during a course (*e.g.* tags in shoes)		• Ski passes check • Event ticketing			
Financial sector							• Contact-less payment cards	

	Asset Utilisation	**Asset monitoring and maintenance**	**Item flow control**	**Inventory Audit**	**Authenti-cation**	**Theft Control**	**Payment systems**	**Automatic release of information**
Luxury Goods			• Tracking of finished products for diversion control		• Proof of authenticity of distri-buted goods	• Anti-theft systems at the point of sale • Tracking of products from the distribution centre to the retail shop to minimise theft		• Customer services at the point-of-sale
Public Sector Educational institutions Science *Public Health* Payment systems	• Location of medical equipment and patient transporta-tion equipment		• Tracking of medication from the pharmacy to the patient • Tracing of blood bottles	• Lending systems in libraries • Expositions in museums • Tagging animals and plants for research purposes	• Patient authentica-tion for monitoring of medica-tion in hospitals • E-passport			
Waste				• Waste management	• E-passport		• Tolling systems • Payment cards for public transport	

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