Pervasiveness of RFID technology: A survey based on case studies analysis

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Abstract. RFID technology is no longer an experimental technology but is now widely applied in business processes aiming to increase performance both in public and private sectors. Together with traditional sectors (e.g. logistics, retail), the large potentiality of this technology is supporting its adoption in completely new emerging sectors (e.g. entertainment, payments). Thus, several challenges are still open: one critical point is the application cost; furthermore, as several research studies have pointed out operational as well as strategic benefits, this is yet an open research topic. The aim of the proposed study is to “measure” the adoption level of RFID technology by critically analyzing field study applications: a survey has been performed on case studies published by RFID Journal – a well-known media company – in two years (from January 2010 to January 2012). A specific taxonomy – based on main critical points characterizing RFID application – has been proposed in order to support potential RFID adopters in designing their own application. Results have showed as RFID technology is really pervasive in several sectors and geographical areas, even if the level of diffusion is quite different from one area to another.

Keywords: RFID, field application, industry, benefits analysis

1. Introduction

Radio Frequency Identification (RFID) is progressively becoming more common, and hence a part of individuals’ lives in a variety of domains from logistics and retail to healthcare and public services (Ilie-Zudor et al., 2011). RFID technology is now one relevant pillar of the Internet of Things (A佐佐等，2010) approach, a novel paradigm based on the shift from a network of interconnected computers (the so called “old Internet”) to a network of interconnected objects (e.g. books, cars, electrical appliances, food).

Although this technology is more than 50 years old, there is a renewed interest in research field as confirmed by the widespread of academic studies: two relevant literary reviews have been recently proposed by Chao et al. (2007) and Ngai et al. (2008). Although it has only been a few years since those two literary reviews, now RFID are effectively “... more ubiquitously diffused and assimilated into our daily
lives” as predicted by Chao et al. (2007): several market analysis data confirm this trend. According to IDTechEx media release (Idtechex, 2013), at the start of 2012, the cumulative number of RFID tags sold over the last 65 years was 15.1 billion. The value of the entire RFID market has been $6.51 billion in 2013 including (passive and active) tags, readers and software/services for RFID cards, labels, fobs and all other form factors. In total, 2.93 billion tags have been sold in 2011. The report estimates that the value of the entire RFID market will be $7.67 billion in 2012 and 3.98 billion tags will be sold; this study also outlines 1 billion for apparel tagging. 500 million in the form of tickets used for transit and about 300 million for tagging of animals. Furthermore, one of the most promising areas for RFID application is contactless cards used for person identification, transportation and ticketing management, and payments. A recent report by ABI research (ABI, 2013) forecasts about 1.4 billion contactless cards will be shipped around the world in 2013.

It has to be outlined that the spread of RFID is often pushed also by public policies through several actions such as:

- Governments could force the adoption of RFID-based systems. This is the case of the Visa Waiver Program – established by US Government – that requires an e-passport to travel to the United States without a Visa. The e-passport – whose technical specifications have been defined by International Civil Aviation Organization – is now widely adopted by various countries;
- Governments could prescribe the traceability of products and animals. Although these regulations are technology-neutral, RFID technology is the one mostly applied for animal tracking. Currently, several countries – US, Europe, Canada, Australia – have adopted the ISO 11784, 11785 and 14223-1 standards to support RFID application for animal tracking;
- Several public interventions are now supporting consolidated RFID markets by public procurements, such as public utilities (e.g. non-stop road tolling, library tagging) and person identification (e.g. national ID cards, passports, etc.).

These brief considerations highlight large diffusion of RFID technology in traditional as well as in innovative market sectors. The aim of the proposed study is to critically analyze the diffusion and the effectiveness of this technology starting from results obtained from real field applications worldwide: the data source is the well-known commercial media tool “RFID Journal”.

The aim of this study is twofold: the first one is outlining current state of RFID adoption in several public and private sectors; the latter is critically analyzing the actual effectiveness of its adoption by discussing declared field results. After a brief introduction about main challenges to RFID adoption (Section 2), results of the survey are described in detail in Section 3. A specific taxonomy has been defined in order to analyze each case study according to a multifactorial prospective. A brief discussion is then proposed in order to outline main issues derived by the proposed survey analysis (Section 4).
Table 1
Overview of used frequencies and typical RFID features

<table>
<thead>
<tr>
<th>Technology</th>
<th>Typical characteristics</th>
<th>Standards</th>
</tr>
</thead>
<tbody>
<tr>
<td>100–134 kHz Low Frequency (LF)</td>
<td>Short to medium reading range; inexpensive; low reading rate</td>
<td>ISO 11784, ISO/IEC 18000-2A, ISO/IEC 18000-2B</td>
</tr>
<tr>
<td>13.56 MHz High Frequency (HF)</td>
<td>Short to medium reading range; inexpensive; medium reading rate</td>
<td>ISO/IEC 14443, ISO/IEC 15693, ISO 18000-3</td>
</tr>
<tr>
<td>433 MHz Ultra-High Frequency (UHF)</td>
<td>Long reading range; high reading speed; expensive</td>
<td>ISO 18000-7</td>
</tr>
<tr>
<td>860–960 MHz Ultra-High Frequency (UHF)</td>
<td>Long reading range; high reading speed; expensive</td>
<td>ISO 18000-6A, ISO 18000-6B, ISO 18000-6C</td>
</tr>
<tr>
<td>2.45 GHz Ultra-High Frequency (UHF)</td>
<td>Long reading range; high reading speed; expensive</td>
<td>ISO 18000-4, ISO/IEC 24730-2</td>
</tr>
<tr>
<td>5.8 GHz Super-High Frequency (SHF)</td>
<td>Long reading range; high reading speed; expensive</td>
<td>No standards</td>
</tr>
<tr>
<td>&gt;5.8 GHz</td>
<td>Long reading range; high reading speed; expensive</td>
<td>No standards</td>
</tr>
</tbody>
</table>

2. Challenges to global RFID adoption: A brief state of the art analysis

Before introducing the survey, a preliminary discussion about open challenges in promoting the widest dissemination of RFID technology is briefly proposed. The purpose is to outline more critical issues which will be analyzed following in the survey discussion section. As RFID deployments are scaling-up from pilot projects and proof-of-concept trials towards fully-fledged enterprise applications, RFID challenges will escalate. Therefore, many of the challenges of the past (Wu et al., 2006) have been addressed and resolved, while new challenges have emerged and are being addressed. Following, a brief analysis about technological, organizational and business challenges that are still open is proposed.

2.1. Technology challenges

RFID is an Automatic Identification and Data Capture technology, enabling an electronic device (reader) to use safe, low power radio frequency to identify a tagged item. Table 1 shows used frequency bands and typical characteristics for each band. One critical technological factor is the tag characteristics which heavily influences the application field. As an example, specific types of tags don’t work properly on metal objects or on containers filled with liquid as, depending on their operative frequency, radio waves can be absorbed by water and biological tissues and can be shielded by metals; furthermore, a limited range of tags could be applied in harsh environments due to extreme temperatures or a mechanical stress. Many of these challenges have been addressed in recent years, thus increasing the pervasiveness of this technology.
By analyzing metal interference issue, the “on-metal tags” have been applied on metal objects by placing an antenna on a spacer: they are usually characterized by 0.5 and 3 cm thick, depending on the tag type. New technological solutions are facing towards producing thinner tags tuned to work specifically on metal. Furthermore, new tags – defined as “in-metal tags” – embedded into a metallic surface have been also introduced in the marketplace. This new approach – i.e. embedding RFID tags at the point of manufacture – is now enabling manufacturers to differentiate their product portfolio by offering “RFID ready” or fully “RFID enabled” items. In addition, several tags have been specifically designed for harsh environments: applications could be outlined for liquid-filled containers or inside oil pipelines, as well as for low and high temperature environments (e.g. below $-40\,\text{degrees Celsius}$ and above $+100\,\text{degrees Celsius}$).

Even if several technological issues have been overcome, new emerging topics are still open. One example is the hazardous content of each tag: as the diffusion of these systems increase, an environmental problem could be outlined as RFID tag added to materials may lead to additional pollution of those materials (Kanth et al., 2012). Thus, innovative projects are now focusing on realizing biodegradable (or organic) tags (Myny et al., 2009) aiming to reduce their intrinsic environmental impact.

2.2. Standards challenges

The definition of global standards represent a critical point which could enable a very massive diffusion of RFID as happened for others innovative technologies (Angerer et al., 2012): they mainly guarantee an effective interoperability across countries as well as different applications (e.g. from payment systems to tracking goods or reusable containers in open supply chains).

The RFID application in supply chains requires the definition of both technological and functional standards.

By focusing on technological standardization, a huge work has been done over the past decade to develop standards for both different RFID frequencies and applications. These standards have been mainly issued by the International Organization for Standardization (ISO) and by the International Electrotechnical Commission (IEC): a synthesis has been reported also in the last column of Table 1. A great effort has been done – although it is not yet complete – for the UHF technology which is usually applied for tracking assets and goods: approved operative frequencies vary according to different geographic areas. GS1 – an international not-for-profit association – outlines (GS1, 2013) that regulations for using RFID in the UHF spectrum at March 2013 are in place in 72 countries representing circa 95% of the world’s Gross Domestic Product (GDP); regulations are being defined in 5 countries (representing circa 2% of the world’s GDP) and finally, information are not available for countries representing circa 3% of the world’s GDP. Operative frequencies for UHF are centered on 866 MHz, 915 MHz and 955 MHz in Europe, in the United States and in Japan respectively. Consequently, aiming to accommodate variations in worldwide
regulations, RFID hardware manufacturers are forced to offer either three separate RFID tag models – each designed specifically for one of the three different bands – or a tag designed to operate across all three bands (i.e. 865.6 to 957.4 MHz, a frequency range of nearly 100 MHz). Fortunately, Japan has shifted in July 2012 its RFID band in the range 915–928 MHz, which closely matches that of North America, allowing the country to benefit from a greater global alignment. Therefore, slowly, RFID market is moving towards a single and global market, also for UHF technology.

By focusing on functional standardization, the Electronic Product Code (EPC) represents the main reference when applying UHF technology in supply chains. The EPC is a unique number used to identify a specific item in the whole supply chain. Thus, as the EPC is stored on a UHF tag, it can be associated with data — e.g. the place or the date an item has been produced — held in a secured database every time it is retrieved from the tag. References and specifications for EPC implementation are defined by the EPCglobal, a neutral, not-for-profit standards organization consisting of manufacturers, technology solution providers, and retailers.

2.3. Cost challenges

At first, it has to be noted that the actual cost of a tag is heavily influenced by several factors, such as the number of purchased tags, the amount of memory, the tag packaging (e.g. whether it is encased in plastic or embedded in a label), and the tag type (e.g. active or passive). Therefore, most companies selling RFID tags usually do not quote unitary prices. Nevertheless, one issue is certainly confirmed: unitary costs have fallen steadily over the past years and they will further decrease as its adoption ramps up. Currently, a passive 96-bit EPC inlay (i.e. chip and antenna mounted on a substrate) costs from 7 to 15 U.S. cents. As defined previously, the tag packaging could influence its cost: if the tag is embedded in a thermal transfer label allowing companies printing a barcode, the price could rise to 20 cents and up. Low- and High-frequency tags usually are characterized by a slightly higher cost. A recent contribution to price reduction of RFID devices has been supplied by the application of printed semiconductor technology (Yang et al., 2007). Integrating printed semiconductors in RFID tags will allow to overcome challenges of traditional silicon integrated circuits, where this activity is quite complex and expensive mainly due to interconnecting antenna to the tag. As a result, producing a fully printed tag (including both antenna and circuit) at a cost of less than half the silicon-based tag would enable a rapid expansion of new services/applications not yet been fully realized due to the relatively high costs of silicon-based tags and their integration. However, it has be noted that, although printed semiconductors are expected to play a major role in the future RFID market, traditional silicon integrated circuits are not expected to be entirely substituted: applications requiring long reading distances, high memory, data security will yet represent the main domain of application of integrated circuit-based tags. Other technologies are also emerging aiming to reduce tag manufacturing costs. One example are processes which replace current metal and
semiconductor solutions with organic materials, which allow cheap mass-production processing, such as printing on a carrier surface. An interesting pilot initiative is the MadriX project, carried out by a Consortium of major European companies, focusing on plastic (polythiophene) semiconductor technology to produce a tag with a manufacturing unitary cost of 2.5 cents (MadriX Consortium, 2008).

Therefore, the “Five-Cent tag” – defined as the threshold value for the massive adoption of this technology – target could be reached in few years.

2.4. Benefits and ROI challenges

Another open question that affects the spread of RFID, is the evaluation of its potential benefits, and, consequently, the return on investment (ROI) from its adoption. This is mainly due to the type of potential benefits supplied by this technology: three main categories could be outlined: direct, indirect and strategic ones. Direct benefits are easily measurable, but indirect ones are still complex to assess. According to Zhu et al. (2012), the correct way to look at RFID adoption is to analyze the “added value” the RFID brings to companies instead of the “added cost”. According to this approach, a “Two-cent tag” will not be attractive if it not allow any added value; thus, RFID adoption could not be fully justified based only on the low cost of devices as the main purpose of its adoption is to add intelligence and capabilities to organizations by its identification, tracking and tracing nature. Recent academic researchers have proposed several models to evaluate in a more effective way the global value of RFID investments (Doerr et al., 2006; Becker et al., 2010; Lee and Lee, 2010; de Souza et al., 2011; Curtin et al., 2013; De Marco et al., 2012; Vlachos, 2013): thus, several direct benefits deriving from RFID adoption have now been recognized in the literature. For instance, by comparing RFID versus barcode technology, one main direct benefit is the reduction of required labor force in handling activities (Curtin et al., 2007; Lee and Ozer, 2007; Bottani and Rizzi, 2008; Roh et al., 2009; Garfinkel and Holtzman, 2005). A brief review about recent research studies outlining measurable benefits supplied by RFID adoption is reported in Table 2.

Furthermore, indirect and more strategic benefits could also be outlined: an improved overall operational efficiency of the organization mainly due to an increase in overall information visibility (Elia et al., 2010; Sarac et al., 2010; Bundach et al., 2011; Bertolini et al., 2012; Ngai et al., 2012). These benefits mainly result from the ability of RFID to find misplaced items, to reduce shrinkage from theft, and to reduce transaction errors especially in traditional industrial sectors, such as supply chain management, logistics, and transportation (Ustundag and Tanyas, 2009). This is also confirmed by Tajima (2007); authors outlined that RFID improves the firm’s competitive advantage through: (a) increased supply chain efficiencies; (b) increased
Table 2: Quantitative benefits of RFID adoption evaluated by several authors

<table>
<thead>
<tr>
<th>Authors</th>
<th>Application</th>
<th>Quantitative benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Doerr et al. (2006)</td>
<td>Inventory management</td>
<td>The expected ROI for this RFID application (ordnance inventory by US DoD) is 154.8%. A sensitivity analysis has been also carried out</td>
</tr>
<tr>
<td>Wang et al. (2007)</td>
<td>Inventory management</td>
<td>The results indicated that the RFID-enabled pull-based supply chain could effectively achieve a 19% decrease in the total inventory cost and a 7.60% increase in the inventory turnover rate (simulation to evaluate the impact of an RFID system on inventory replenishment of the TFT-LCD supply chain in Taiwan)</td>
</tr>
<tr>
<td>Bottani and Rizzi (2008)</td>
<td>Supply chain management</td>
<td>They evaluated a ROI varying between 24% (for the retailer) and 62% (for the manufacturer)</td>
</tr>
<tr>
<td>Gnoni and Rollo (2010)</td>
<td>Asset tracking</td>
<td>Authors estimated a ROI value of 62.4% and a Pay Back period of 2.5 years by adopting RFID for tracking reverse logistics of wooden pallets (economic feasibility study for adopting RFID in asset tracking of returning pallets)</td>
</tr>
<tr>
<td>de Souza (2011)</td>
<td>Operations management</td>
<td>Authors estimated that the total production time in the flow line – from product assembly to test and final packaging – can be reduced by 21.6% using RFID technology compared to the barcode enabled process (feasibility study for adopting RFID in a high-tech company located in Italy)</td>
</tr>
<tr>
<td>Bertolini et al. (2012)</td>
<td>Operations management</td>
<td>Benefits obtained by comparing “as is” with “to be” scenarios outlined a decrease (i.e. 92–95%) in the time for checking for the shipping process, allowing an increase in manpower efficiency as well as a slight (i.e. 1%) increase in sales by optimizing item turnover (RFID adoption in the apparel and fashion industry, involving manufacturers as well as retailers)</td>
</tr>
<tr>
<td>Gu-Escribano et al. (2012)</td>
<td>Asset tracking</td>
<td>The experimental application (real-time monitoring of special loads) confirmed there is a reduction from the previous 20–40% of error (on the first read attempt) using traditional barcodes, to less than 5% for the new system for product localization in the storage area</td>
</tr>
<tr>
<td>De Marco et al. (2012)</td>
<td>Inventory management</td>
<td>Data showed that a fully adoption of RFID could support a larger staff available for customer care, a 2.5% as a result of reduced time spent by store personnel on backroom operations; furthermore, the analysis outlines also an increasing in seasonal sales, about 2.5% (system dynamics simulation model to assess RFID benefits in apparel retailer stores)</td>
</tr>
<tr>
<td>Bertolini et al. (2013)</td>
<td>Supply chain management</td>
<td>Quantitative data showed a reduction (i.e. 0.28%) of out-of-stock level at the retail store, a more efficient (i.e. 0.03%) shelf inventory management and, finally, a shrinkage reduction (1.14%)</td>
</tr>
<tr>
<td>Vlachos (2013)</td>
<td>Supply chain management</td>
<td>RFID adoption in a Greek fruit supply chain. Declared benefits across the supply chain are:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• A reduction from about 10% of delayed deliveries to 1-2% within 12 and 6 months respectively</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• A reduction in order fulfillment lead time (from 30 to 8 days)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• A reduction in the numbers of inventory holding (from 20 days to 9 days)</td>
</tr>
</tbody>
</table>
innovation capability; (c) "learning to adjust"; (d) "learning to transform". Roh et al. (2009) identify the "new process creation in business operations" as the added value of RFID adoption. Tzeng et al. (2008) proposed to measure the added value of RFID in terms of refinement of business processes and the expansion of the business model. These strategic benefits have also been confirmed for new emerging sectors of RFID applications – i.e. the service sector: Oztaysi et al. (2009) analyzed potential positive contributions of RFID diffusion in the tourism sector, by supporting in a more effective way customer loyalty and satisfaction.

The survey results presented in the next section also contain useful information about the benefits obtainable from the adoption of RFID, even if only on a qualitative level. The value of these results arises from the large number of the case studies used.

3. The proposed survey

The objective of the review analysis is to analyze the state of the real-world applications of RFID technology both in industry and government agencies to provide insights for RFID practitioners and researchers. The review has been conducted by analyzing end-users case studies proposed by the "RFID Journal", an independent media company devoted to communicate and promote RFID technology and its business applications. The analysis has been carried out on electronic issues of RFID Journal, considering all case studies published from January 2010 to January 2012: the total number of analyzed papers is 306.

3.1. Geographical distribution of case studies

First of all, an analysis based on geographical basis has been carried out: the observed distribution is reported in Table 3. The final distribution is reported in Fig. 1: results show wide distribution of analyzed field applications in most regions of the world, even if a heavy concentration (i.e. more than 80%) in North America and Europe could also be outlined. In detail, US is the leading country with exactly 50% (i.e. 153 field applications) of the total sample; in the European area, Germany and France are the two leading countries with respectively 19% and 14% of this sample. Regarding results obtained for the Far East area, it has to be noted that its actual weight seems to be underestimated as it does not include case studies from Japan. Instead, Japan and the entire Asian region are quite active in the development and application of RFID (Wang et al., 2010; Wu et al., 2010). For instance, Japan has invested in RFID technology and contactless payments and ticketing over the past 10 years, mainly thanks to the initiative of its Ministry of Economy, Trade and Industry (METI) (Loebbecke and Huyskens, 2007).

3.2. Sector-based distribution of case studies

Next, a four level taxonomy has been proposed in order to analyze case studies: the first level regards the industry sector; the second the functional area of business where
RFID has been applied, the third and the fourth regard the type of technological devices and declared benefits supplied by the technology adoption respectively. Following, categories defined for the first level are detailed:

- **Manufacturing**: it includes applications both in manufacturing plants (e.g. automotive, fashion, etc.) and process industries (e.g. oil and gas). Firms under pharmaceutical and aerospace sectors have been considered separately due to their specific characteristics;
- **Pharmaceutical**: this category includes companies focused on producing drugs on full or in pilot scale application (e.g. in a research laboratory);
- **Aerospace**: it refers to private or public companies involved in the design, development, manufacture and in-service support for aeronautical, space products and also technologies;
- **Retail**: this category refers to companies focusing on selling goods directly to the end user. Main examples are firms in the apparel and the fast moving consumers good distribution sectors;

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**Table 3**

<table>
<thead>
<tr>
<th>Region</th>
<th>Countries</th>
</tr>
</thead>
<tbody>
<tr>
<td>North America</td>
<td>Canada, US</td>
</tr>
<tr>
<td>Europe</td>
<td>Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Kyrgyzstan, Lithuania, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, UK</td>
</tr>
<tr>
<td>South America</td>
<td>Argentina, Brazil, Colombia, Costa Rica, Haiti, Mexico</td>
</tr>
<tr>
<td>Far East</td>
<td>China, Hong Kong, India, Malaysia, Singapore, South Korea, Taiwan, Thailand</td>
</tr>
<tr>
<td>Australia and New Zealand</td>
<td>Australia, New Zealand</td>
</tr>
<tr>
<td>Middle East and Africa</td>
<td>Bahrain, Israel, Nigeria, Saudi Arabia, Tanzania</td>
</tr>
</tbody>
</table>

Fig. 1. Geographical distribution of end-users case studies (total applications: 306).
Logistics: it involves all service activities (from transportation to handling and warehousing) in the freight distribution sector developed in national and international scale;

Healthcare: it refers to activities focused on providing services to patients; it includes both private and public organizations;

Public utilities: it refers to public asset management services which could be carried out directly by a public organization (e.g., police management) as well as by a private partner (e.g., parking management, water and gas service management);

Defense: this category includes field applications dedicated only to military services and its logistical activities;

Public administration: this category includes public organization management and services (e.g., municipal offices and schools);

Entertainment: it mainly refers to manage services for leisure, e.g., theme parks, sporting and social events;

Tourism: it refers specifically to hospitality management (e.g., hotel, residences, etc.);

Other: this last category includes different sectors like building and construction, private associations and foundations, and financial services.

Results obtained are in Fig. 2: “manufacturing” has revealed as the largest industry of application for RFID, followed by “healthcare management” and “retail”. Thus, data confirm the larger adoption of RFID traditional sectors – such as manufacturing and retail - but data outline several healthcare management as new emerging sector. This result could be mainly due to the increasing diffusion of Real Time Location Services (RTLS) applied for indoor localization (Boulos and Berry, 2012) especially in the Northern America areas. An important result has been obtained by the “public
administration” sector: this confirms that public organizations could play an important role in supporting RFID adoption. Finally, completely new adoption sectors are now emerging such as “entertainment”, “tourism” and “financial services” (included under “other” section). The main reason is due to the spread of so-called contactless smart cards supporting business services such as payments, ticketing, and access control. Typically, contactless smart cards come in the form of plastic cards using the MIFARE technology – a registered Trademark of NXP (formerly Philips) – based on the standard ISO/IEC 14443 Type A. A new impetus for these services is coming from the spread of the Near Field Communication (NFC) technology embedded in mobile phones (Coskun et al., 2012). Thanks to NFC, you can use the mobile phone instead of the plastic smart card for payments, ticketing and access control.

3.3. Functional distribution of case studies

Another classification proposed is based on the business functional area where RFID technology has been mainly applied. Categories are defined as follows:

- **Marketing**: the technology has been applied to communicate information about products and to support new services based on real-time interaction with customers (e.g. by social networks, etc.);
- **Operations management**: RFID has been applied for supporting production planning and control activities in manufacturing and/or service activities;
- **Inventory management**: the RFID adoption is focused on warehouse management activities, starting from order replenishment to internal material handling activities;
- **Supply chain management**: as previous category focuses on one single tier of a supply chain, this category includes field applications aiming to integrate and coordinate information and physical flows among all actors involved in a business network, e.g. from producers to retailers;
- **Asset tracking**: RFID is applied to locate and trace the movement of physical assets usually outlined as critical resources for a company (e.g. working tools, equipment, pallets);
- **Monitoring**: RFID is applied to control and monitor such a condition or a physical parameter – e.g. pressure, humidity and temperature – within an area;
- **Access control**: the technology supports people identification and authentication; it could also support emergency communication;
- **Counterfeit and Electronic Article Surveillance (EAS)**: it represents one of the first field of RFID application; this category refers to the adoption of RFID to identify original versus false items and for preventing shoplifting from stores/public offices;
- **Payment**: RFID has been applied to support contactless payments.

Figure 3 shows the data distribution: a first outline is that, together with traditional fields of applications, innovative fields are now emerging, such as “marketing” and
“payments”. The most clear example is that the largest category is “asset tracking” which has exceeded pioneer fields of application such as “inventory management”, “access control” and “counterfeit”. The low result obtained by this last category is mainly due to its well-established adoption since several years; thus, few innovative applications have been reported in the RFID journal.

“Payments” are emerging and rapidly growing markets for RFID (Wen, 2010): a contribution to this trend has been offered by major payment networks (e.g. Visa, Mastercard and American Express) which already offer solutions with contactless cards. This availability could also support to enlarge services supplied by traditional cards, by adding ticketing and loyalty management.

Furthermore, another positive feedback will be suggested by the relative high result obtained for the “marketing” category (the fifth category in absolute): it is a signal that companies are now starting to analyze strategic benefits of RFID adoption, such as a larger availability of information to customers and the creation of new services (Bardaki et al., 2010).

On the other hand, “supply chain management” applications are quite limited. As reported in the previous section, although several research articles have highlighted different types of benefits in supply chain management, companies are cautious to invest in this field. Main barriers to a wide adoption rather than technological issues are due to organizational or inter-organizational ones (Chang et al., 2010; Hinkka, 2012). The lower value observed for “monitoring” is essentially due to current high investments costs.

Next, a crossing analysis has been carried out aiming to outline distributions across sectors as well as functional area of RFID adoption: data are reported in Fig. 4. The RFID impacts could be observed in multiple functional areas in most of sectors, although with different intensity. By analyzing distribution according to the field of
RFID application, results confirm traditional field of RFID adoption, such as “operations management” and “inventory management”, on the other hand, “asset tracking” is outlined as an inter-sectorial field of application with a focus in healthcare management, public administration and logistics, where it usually represents a critical activity (Chen et al., 2007; Holmström et al., 2009). RFID applied for “access control” in “healthcare” is also an emerging topic.

By analyzing data according to the sector, the “retail” is outlined as the sector where RFID technology impacts on the largest number of functional areas; furthermore, the data distribution highlights new emerging field of applications, such as “marketing” and “supply chain management” – together with traditional ones. RFID adoption in new emerging sectors (e.g. entertainments, tourism) seems to be currently focused on specific application fields.

3.4. Technology-based distribution of case studies

Another taxonomy refers to the type of RFID technology applied in case studies. Results, reported in Table 4, show as the most wide-spread technology is based on UHF tags, followed by active tags. This is an expected result as UHF is the most flexible and adaptable technology; furthermore, this result is also in line with the previous discussion: as the larger outlined functional areas are mainly “asset tracking”,

Table 4

<table>
<thead>
<tr>
<th>Technology type</th>
<th>Passive (LF)</th>
<th>Passive (HF)</th>
<th>Passive (UHF)</th>
<th>Active tags</th>
<th>Semi-passive</th>
<th>Combined</th>
</tr>
</thead>
<tbody>
<tr>
<td>N° of applications</td>
<td>15</td>
<td>31</td>
<td>138</td>
<td>89</td>
<td>2</td>
<td>9</td>
</tr>
</tbody>
</table>

Fig. 4. Two-dimensional distribution according to sector and functional area of application (values in each box are the number of applications).
“operation management” and “inventory management”, they usually require a large reading distance. On the other hand, HF technology is the reference technology of contactless smart cards and NFC. Data about the application of active technology show an increasing trend of adoption: active tags in addition to battery, have RF transmission capability, allowing a greater reading distance (i.e. more than 10 meters). This feature, more than the potential higher memory, is supporting the diffusion of this technology.

Finally, semi-passive technology has been applied in very few applications: in detail, one application was in cold chain tracking by using semi-passive UHF tags, and the latter was in railways control by using a 2.45 GHz semi-passive tags.

3.5. Distribution based on declared benefits

Finally, a taxonomy based on declared benefits obtained by RFID adopters has been introduced. Six main categories have been identified:

- **Enhancing service level**: the main contribute of RFID refers to improve external (e.g. to the customer) service level. An example is adding new service (e.g. based on social network interaction) to traditional ones supplied by the company;
- **Increasing overall productivity**: it refers to an increase of such a performance for a specific process activity (e.g. optimizing labor force, reducing queues);
- **Speed up process**: it focuses on reducing the total cycle time of a service and/or an activity (e.g. manufacturing or handling rates);
- **Faster location**: it specifically refers to reduce time and efforts applied to trace and, consequently, locate critical items and/or resources;
- **Increasing process reliability**: it focuses on improving the reliability of a process and/or a service;
- **Increasing visibility**: it focuses on enhancing specifically information sharing between different tiers of a supply chain.

According to the classification proposed previously (see Section 2.4), “increasing overall productivity” and “increasing process reliability” could be classified as direct benefits; “speed up process”, “faster location” and “increasing visibility” belong to indirect benefits, and finally, “enhancing service level” could be outlined as strategic one. Thus, for each observed field application, the main benefit declared by the authors has been analyzed: thus, two separate two-dimensional distributions (based on observed percentage) are reported in Figs. 5 and 6 respectively.

By analyzing data in Fig. 5, the most wide spread declared benefit due to RFID adoption is “increasing visibility” as it is present in all analyzed sectors by crossing with data about field applications (see Fig. 6), this benefit is the most outlined for “supply chain management” and “counterfeit and EAS” applications. Higher results obtained for the tourism and the aerospace sectors are mainly due to concentration of RFID adoption in few specific field of application (e.g. “inventory management” and “asset tracking” respectively). Other data confirm such a consolidated trend: for
instance, “faster location” is the larger category in the “defense” as well as “logistics” sector which represent first field of RFID application. The adoption of RFID technology in new emerging sectors (such as “entertainment” and “tourism”) is more focused on strategic benefits (i.e. “enhancing service level”) rather than in direct ones. Direct benefits (i.e. “increasing overall productivity” and “increasing process reliability”) could be outlined in complex environments, e.g. as “healthcare” and “public utilities”.

By analyzing data according to benefits in each application field main issues that could be outlined are:
Applying RFID in marketing activities will essentially support to enhance service level; a common issue could be outlined for payment where RFID is applied to speed-up process; RFID could mainly support an optimization of performance by direct benefits (in terms of both “increasing overall productivity” and “process reliability”) in operations management; A wide range of declared benefits are outlined for “inventory management” and “access control”; Applying RFID for monitoring such a condition mainly focuses on “increasing the process accuracy”.

4. Discussion

The survey carried out on 306 field applications have provided some interesting insights into the current state of RFID adoption across different industries and functional areas. The main elements emerging from the analysis could be:

• Currently, RFID technology is really pervasive, being applied worldwide in many industrial sectors as well as public activities, even if the level of diffusion is quite different from one area to another. The analysis of this huge number of field applications has outlined a significant result (often neglected in academic articles): together with first pioneer sectors – mostly “retail” and “logistics” – other sectors are now starting to adopt RFID, such as “entertainment”, “tourism”, and “financial services”. This growing trend is driven also by the potentiality of an easy integration with other new communication services (e.g. social networks) characterizing RFID (Fried et al., 2012). Together with these completely new markets, RFID has being widespread in other complex sectors – e.g. public utilities and public administration (Wei et al., 2011; Gnoni et al., 2012) – which are now fully approaching the challenges of its application.
• By analyzing the field of application, RFID has revealed as an effective tool for supporting a large number of core business processes, from operations management to asset tracking. Furthermore, applying RFID for improving service level to the customer (Kowatsch and Maass, 2010; Boeck et al., 2011; Luvisi et al., 2011) has been demonstrated by its wider adoption in marketing activities in most of the analyzed sectors. Together with these cross applications, the survey has also outlined few specific applications, such “counterfeit and EAS” and “payment”. Furthermore, survey results show a strong correlation between industries and types of applications in such a case. For instance, the use of RFID in the retail sector focuses mainly on “inventory management”, as well as “asset tracking” and “access control” have revealed the most common applications in healthcare management. Thus, the use of RFID could be outlined as a “de facto” standard in these sectors in order to achieve a competitive advantage.
• About technological issues, the UHF technology has confirmed as the most applied due to its intrinsic adaptability for different application fields, from “asset tracking” to “inventory management”. On the contrary, the survey has outlined an increasing trend in applying also active tags as suggested by recent pilot projects (Martínez-Sala et al., 2009; Lo et al., 2011; Rizzo et al., 2011; Cully et al., 2012); due to their high cost and the lack of a common standard (Ogirala et al., 2012), data have showed a current wide adoption especially in complex environments and applications (e.g. healthcare management and monitoring activities).

• RFID benefits, as already mentioned, are still a controversial topic. Although in our survey quantitative benefits are not listed, a number of declared benefits are outlined. These benefits (perceived or measured) are evident in traditional as well as in newer fields of adoption. Thus, most of the analyzed applications outline direct measurable benefits in terms of “improved productivity” and “process efficiency”, but in several many cases indirect and also strategic benefits have been outlined by adopters, mainly focusing on “improved service level”. The value of this survey is that it refers to a large number of field applications, therefore, can be considered a starting point for determining the conditions in which the RFID is a profitable technology. According to this survey, the question is no longer whether the RFID produce benefits, but how it is possible to construct general models from best practices.

5. Conclusions

RFID represents currently one of the main emerging technology being applied in different industrial sectors as well as social activities. In the last 10 years, researchers and practitioners have analyzed pitfalls and benefits of this technology in first mover sectors (logistics, retail and manufacturing); recent studies, and our own survey, highlight the spread of RFID in different sectors (entertainment, tourism, financial services, etc.) and new applications (payments, marketing, etc.). In our survey, end-users case studies have been analyzed by evaluating different topics, from geographical distribution to organizational and technological issues. Even if the sample has not been specifically selected for statistical significance, the analysis has provided several qualitative results, that can be the starting point for further explorations. In detail:

• A still open question is about the benefits of RFID adoption. A gap exists between the ideal vision and the current perception regarding the value of RFID. In recent years, academic researchers have recognized the importance of closing this gap between the reality and the potential of RFID, as evidenced by the increase in the number of publications dealing with this subject (Section 2.4). An effective analysis model could be useful to close the gap and to reconcile the different awareness about RFID for researchers as well as practitioners;

• Results of our survey show that many new sectors now adopt RFID technology, benefit analysis should be applied also to these sectors beyond the early adopters.
For instance, the increasing diffusion of contactless applications based on smart-cards – outlined both from market analyses as well as our survey results – are forcing new scenarios, which have to be analyzed for assessing potential benefits of their adoption, compared to traditional applications such as asset tracking and inventory management;

- Some of analyzed field applications in the survey are based on NFC technology, which represents a very promising technology as it supports an effective convergence between RFID and “mobile” technologies. In spite of the still scarce literature on this topic, analysts highlight a great interest worldwide on its adoption in several sectors. The spread of this technology depends on the construction of “digital ecosystems” and the sharing among multiple players of the benefits arising from the adoption of the technology itself. Thus, further developments could be focused on analyzing the potentiality of this technology by assessing effective approaches to analyze its impact on both the operational and the strategic levels.

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