İSTANBUL TECHNICAL UNIVERSITY ★ INSTITUTE OF SCIENCE AND TECHNOLOGY

DATA STORAGE ON RADIO FREQUENCY IDENTIFICATION TAGS IN CONSTRUCTION INDUSTRY

M.Sc. Thesis by
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Programme : Construction Managemet

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İNŞAAT SEKTÖRÜ'NDE RADYO FREKANSLI TANIMLAMA ETİKETLERİ ÜZERİNDE VERİ DEPOLANMASI

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FOREWORD

I first would like to thank and express my appreciation to my thesis advisor, Asst. Prof. Dr. Esin ERGEN, for her continuous support and patience.

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January 2010 Gürşans GÜVEN

Civil Engineer

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ABBREVIATIONS

AIDC	: Automatic Identification and Data Capture
AOA	: Angel of Arrival
ATA	: Air Transport Association
BIM	: Building Information Model
BP	: British Petroleum
CAD	: Computer Aided Design
CIDD	: Container Intrusion Detection Device
CMB	: Contact Memory Button
DB	: Database
DC	: Distribution Center
DEPMEDS	: Deployable Medical System
DS	: Discovery Service
EAS	: Electronic Article Surveillance
EPC	: Electronic Product Code
EPCIS	: EPC Information Services
ERP	: Enterprise Resource Planning
ETO	: Engineered-To-Order
FAA	: Federal Aviation Administration
FDA	: Food and Drug Administration
GHz	: Gigahertz
GIS	: Geographic Information System
GPS	: Global Positioning System
GPRS	: General Packet Radio Service
HF	: High Frequency
HKIA	: Hong Kong International Airport
HVAC	: Heating, Ventilation and Air Conditioning
ID	: Identification
IFC	: Industry Foundation Classes
iGPS	: Intelligent Global Pooling System
IP	: Internet Protocol
IR	: Infrared
ISO	: International Organization for Standardization
ITV	: In-Transit Visibility
Kbps	: Kilobits per second
kHz	: Kilohertz
LAN	: Local Area Network
LF	: Low Frequency
MHz	: Megahertz
MIT	: Massachusetts Institute of Technology
Mbps	: Megabits per second
NATO	: North Atlantic Treaty Organization
NEMO	: Networked Embedded Models and Memories of Physical Work Activity

OCR	: Optical Character Recognition
ONS	: Object Naming Service
PC	: Personal Computer
PDA	: Personal Digital Assistant
RF	: Radio Frequency
RFID	: Radio Frequency Identification
RFID-IR	: Radio Frequency Identification-Infrared
RR	: Radar Responsive
RTLS	: Real Time Location System
SARS	: Severe Acute Respiratory Syndrome
SIAD	: Sierra Army Depot United States Army
TDOA	: Time Distance on Arrival
UHF	: Ultra High Frequency
URL	: Uniform Resource Locator
USA	: United States of America
U.S. DoD	: United States Department of Defense
UWB	: Ultra Wideband
VIN	: Vehicle Identification Number
VMC	: Vehicle Management System
VRML	: Virtual Reality Modeling Language
Wi-Fi	: Wireless Fidelity
WMS	: Warehouse Management System
WORM	: Write Once Read Many

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DATA STORAGE ON RADIO FREQUENCY IDENTIFICATION TAGS IN CONSTRUCTION INDUSTRY

SUMMARY

Radio Frequency Identification (RFID) technology automatically identifies tags that are attached to objects through the use of radio waves and enables local storage of object-related data on objects themselves. RFID technology has been used in various applications for many years, and has been utilized in several research studies and real-life applications for identification and tracking of components and related information in construction industry.

When RFID applications are examined, it is observed that there is an ongoing debate as to whether the necessary data should be stored on RFID tags or on a network. In some studies, despite the on-board data storage capacity, RFID was only used to replace the barcode technology by storing a unique identification code on the tag. In such cases related data were kept in a remote database and the unique ID on the tag was used to associate this object with the data. On the other hand, it is possible to store object-related data directly on the tag that is attached to the object itself and data can be accessed from the object. In this data storage approach, the object-related information is accessible without the need for a connection to the database. Both approaches have their advantages and disadvantages and require different types of RFID technologies. In some cases, network accessibility, might not be always provided throughout the lifecycle of a component within the construction phases.

The main purpose of this research work is to determine under which conditions storing data on the tag is more appropriate for the construction industry, and to identify what types of data are being stored in different RFID cases. It is also aimed to make a comparison of the construction industry with other industries that utilize RFID technology, in terms of the data storage approaches followed in several RFID applications. This comparison is aimed to identify the different characteristics and data storage needs of each industry, as well as to evaluate how these differences/similarities shape the RFID implementations within those industries. Both the research studies and real-life industry applications were investigated within the construction industry and other five large industries. The characteristics of each case in each investigated industry and their data storage needs were identified. Moreover, the types of information groups that were both stored in databases and on tags were identified for each industry. The results show that there is a need for tags/storage mediums that are specially designed for construction industry with large memories to store information related to components and equipments on the job site, as well as to store the records of their operation and maintenance histories.

İNŞAAT SEKTÖRÜ'NDE RADYO FREKANSLI TANIMLAMA ETİKETLERİ ÜZERİNDE VERİ DEPOLANMASI

ÖZET

Radyo Frekanslı Tanımlama (RFID) teknolojisi nesnelerin radyo dalgaları yoluyla otomatik olarak belirlenmelerini sağlayan ve aynı zamanda nesneler üzerinde lokal olarak bilgi saklanmasına olanak veren bir teknolojidir. RFID teknolojisi uzun yıllardır çok çeşitli uygulamalarda kullanılmış olup, İnşaat Sektörü'nde de gerek akademik alanda gerekse gerçek yaşam uygulamalarında malzemelerin tanımlanması ve ilgili bilgilerin takibi çalışmalarında kullanılmıştır.

RFID uygulamaları incelendiğinde, gerekli bilginin RFID etiketleri üzerine mi yoksa bir ağ üzerinde mi saklanacağı konusu üzerinde görüş ayrılıkları olduğu tespit edilmiştir. RFID teknolojisinin bazı kullanımlarında RFID etiketlerinin kendi üzerlerinde bilgi depolama özellikleri olmasına rağmen, barkod çözümlerinde olduğu gibi sadece bir tanımlama kodunun etiketlerin belleklerinde saklandığı biçimde kullanıldığı görülmektedir. Bu tür uygulamalarda gerekli bilgiler ise bir ağ üzerinde saklanmakta, etiketler üzerindeki tanımlama kodları da ağ üzerindeki bu bilgilere ulaşılabilmek için kullanılmaktadır. Ancak, nesne ile ilgili bilgileri direkt olarak nesnenin üzerine sabitlenen RFID etiketlerinin belleklerinde saklamak da mümkündür. Bu şekilde nesne ile ilgili gerekli bilgiye ulaşılabilmesi için bir ağa bağlanmaya gerek kalmamaktadır.

Her iki yaklaşımın da avantaj ve dezavantajları vardır ve farklı RFID çözümleri uygulanmasını gerektirmektedirler. Ancak özellikle inşaat sektörü gibi değişken koşullar altında çalışılan bir sektörde, her zaman bir ağ bağlantısının kurulabilmesi mümkün olmayabilmektedir.

Bu çalışmanın ana amacı hangi koşullar altında RFID etiketleri üzerinde lokal olarak bilgi saklanmasının İnşaat Sektörü uygulamaları için daha uygun olacağının ve mevcut uygulamalarda etiketler üzerinde ne tür bilgilerin saklandığının belirlenmesidir. Ayrıca RFID teknolojisini yaygın olarak kullanan bazı büyük sektörlerdeki uygulamalar incelenerek, İnşaat Sektörü ile aralarında bir karşılaştırma yapmak amaçlanmıştır. Bu karşılaştırma ile her bir sektörün kendine has özelliklerinin ve veri saklama gereksinimlerinin RFID uygulamalarını nasıl şekillendirdiğinin belirlenmesi hedeflenmiştir. Bu nedenle İnşaat Sektörü'ndeki RFID uygulamalarına ek olarak RFID teknolojisinin yoğun olarak kullanıldığı diğer beş büyük sektörden yüzün üzerinde uygulama incelenerek değerlendirilmiştir. Sonuçlar İnşaat Sektörü'nün koşul ve beklentileri doğrultusunda özel olarak geliştirilmiş, yüksek bellek kapasiteli RFID etiketleri ve/veya veri depolama ortamlarına ihtiyaç duyulduğunu göstermektedir. Bu sayede şantiyelerdeki malzemeler ya da ekipmanlar ile ilgili bilgilerin direkt olarak üzerlerinde saklanması mümkün olabilecek, nesneler kendileri ile ilgili bilgiyi herhangi bir ağ bağlantısı kurmaya gerek kalmadan sağlayabileceklerdir.

1. INTRODUCTION

Construction sites are known as challenging environments due to their dynamic and complex natures. Location of things are never stable on a job site, which makes it generally a daunting and time-consuming task to keep track of necessary materials, as well as to locate them. There are typically great amount of different pieces on a construction site, as a result, things can easily get lost. Workers spend considerable amount of time looking for a particular item (e.g., a tool), sometimes more than the time they spend on their work. Another reason for things to get lost is that theft and pilferage are commonly observed on construction sites. There are always multiple parties involved in construction works, which leads to difficulties in organizing the job. Usually, construction professionals use cell phones to manage the ongoing work on the site, as well as to learn the locations of workers, materials, components, equipments, etc. In addition to these, construction sites are generally chaotic environments due to the fact that majority of the construction workers are uneducated.

Sites are in need for being able to identify and track objects accurately, and locate the necessary materials and components quickly. Not only during the construction phase, but also after the construction is completed, facility managers would need to know information related to building components (e.g., quality control records, specifications). Radio Frequency Identification (RFID) technology possesses benefits and advantages against these complexities of the construction industry in areas such as jobsite logistics, asset tracking, location tracking, facility management, concrete curing, theft prevention, access control, etc.

Radio Frequency Identification (RFID) technology automatically identifies tags that are attached to objects through the use of radio waves and enables local storage of object-related data on objects themselves. RFID technology has been used in various applications for over decades, such as the retail product tracking applications, electronic toll payment applications, logistics applications, and animal tracking and identification applications.

Additionally, there are already several research studies and real-life applications of RFID technology for identification and tracking of components and related information in the construction industry. But in construction, RFID technology is as not widely adopted as in aforementioned industries.

According to some authorities and initiatives such as the EPCglobal, RFID technology will replace the barcode technology, and the "Internet of things", in which the pyhsical objects are connected to computer networks, will be created in the future (Schuster et al., 2007). But RFID technology is well beyond the capabilities of the barcode technology, and is more than just a means of an identifier. Moreover, construction sites are usually not suitable environments to deploy a network and to ensure that it works efficiently. Thus, construction industry needs further functionalities that cannot be served by barcodes, such as large data storage capabilities to store data directly on the object to access that data without connecting to a database. Furthermore, construction sites require the technologies to be durable against harsh conditions. Communication without the line-of-sight requirement is another need in construction, where large pieces and large number of components are usually utilized. Due to these features over barcode technology, RFID is more suitable to be used in construction industry.

When RFID applications are examined, three different utilization of RFID tags can be seen: (1) as a replacement to barcodes, where only an identification (ID) number is stored on tags, (2) as local data storage units where all object-related information is stored on tags, and (3) the combination of the approaches (1) and (2). This is an ongoing debate among the RFID technology implementers, as to whether the necessary data should be stored on RFID tags or on a network.

In some studies in construction, despite the on-board data storage capacity, RFID was only used to replace the barcode technology by storing a unique identification code on the tag (Ko, 2008; Grau and Caldas, 2009).

If there were additional data needed to be stored in relation to the object, this data were kept in a remote database and the unique identification (ID) code on the tag was used to associate this object with the data. On the other hand, in some of the studies in construction, object-related information was stored directly on the tag that is attached to the object itself and related information was accessed from the object (Goodrum et al., 2006, Ergen et al., 2007a).

In this data storage approach, the object-related information is accessible without the need for a connection to the database. Both approaches have advantages and disadvantages, and require different types of RFID technologies. In some cases, network accessibility, might not be always provided throughout the lifecycle of a component within the construction phases. For instance, wireless internet signal integrity lacks in basements (Ko, 2008). In addition, an existent network may not work efficiently due to the dynamic environment of construction sites, or due to a failure or disaster such as an earthquake that would make the data on network inaccessible inside a building (Yabuki et al., 2002). On the other hand, storing all object-related data on tags can be disadvantageous in terms of cost, since it requires relatively expensive active RFID systems attached on each object, due to their higher memory capacities. But recently, there are emerging efforts in increasing the memory capacity of passive RFID systems (Bacheldor, 2009; Burnell, 2009), which is known to be cheaper in than the active ones. These studies that are being carried out by the RFID technology suppliers can be the enabler for implementations of more affordable "data-on-tag" applications in construction industry in the near future.

Construction sites need to accurately locate objects, identify and keep track of components, materials and equipment more efficiently. Construction companies need to reduce both the cost caused by lost items (i.e., material, component, equipment) and the time spent for locating and finding those items. Information related to an object needs to be easily accessible, and retrieval of this information should not be affected by the failure in a network. Additionally, facility managers need to know information related to a building component's lifecycle, as well as the historical records related to operation and maintenance activities and quality inspections.

1.1 Goal and Methodology of the Thesis

The main goal of this research work is:

- to identify what types of data are being stored in RFID cases that are applied in construction industry and other industries, and
- to determine under which conditions storing data on the tag is more appropriate for the construction industry.

To reach the goal of the thesis, the specific conditions that require different data storage approaches needs to be identified, and thus the contexts of specific cases need to be known. Therefore, an extensive literature review related to RFID technology usage both in construction industry and other large industries was conducted to identify under which specific conditions each data storage approach was selected. The industries that were included are the major industries that are known to adopt RFID technology in a widespread manner and for long years. These industries are aerospace, defense, retail, manufacturing and healthcare industries.

Both the research studies and real-life industrial applications were investigated and analyzed in the construction industry and other large industries. While academic research studies were retrieved from academic journal papers and/or conference papers, real-world applications were obtained through RFID-related web-sites (e.g., RFID journal), technology suppliers' web sites (e.g., Savi Technology) and from the web sites of the companies who implemented the technology (e.g., Airbus). As a result, the characteristics of each case (e.g., type of tags utilized, type of data stored) in each investigated industry and their data storage needs were identified.

Moreover, the types of information groups that were both stored in databases and on tags were identified particularly for construction industry, as well as for other industries.

1.2 Organization of the Thesis

Background information on RFID technology and other local data storage technologies that have on-board memory capacities is given in the following section, Section 2. This section also explains the data storage concepts that are used in RFID systems. In the third section, RFID case studies both in construction industry and other aforementioned industries are given in detail. RFID cases are grouped according to their types of application areas and their purposes, and analyzed. The fourth section includes the identification of the information groups, which are the information items stored within the scope of the investigated cases. These information items are identified and categorized, and each industry is analyzed in terms of the data it stored on tags within its own applications. The fifth section comprises of the findings of the thesis and recommendations according to the analysis of the six industries.

A future work vision is also given in this section, where it is envisioned that RFID tags can be used as a means of communication between construction components to prevent errors in their connections. Finally, summary of the work performed during the thesis, the findings and concluding remarks are given in the seventh and the last section.

2. BACKGROUND ON RADIO FREQUENCY IDENTIFICATION TECHNOLOGY

Information on the components and characteristics of the Radio Frequency Identification (RFID) technology is given in this section. Furthermore, data management approaches in RFID systems, as well as their characteristics and requirements are explained.

2.1 Radio Frequency Identification Technology

As represented in Figure 2.1, Radio Frequency Identification (RFID) systems have two main components, a reader and a tag. The tag, which consists of an electronic microchip and an antenna, is used for being attached to an object, and store data about that object.

The reader, on the other hand, is a handheld or fixed unit that is equipped with an antenna, used to interrogate nearby RFID tags, and read data from and write data to a tag via radio frequency (Ergen et al., 2007b; Ward and Kranenburg, 2006).

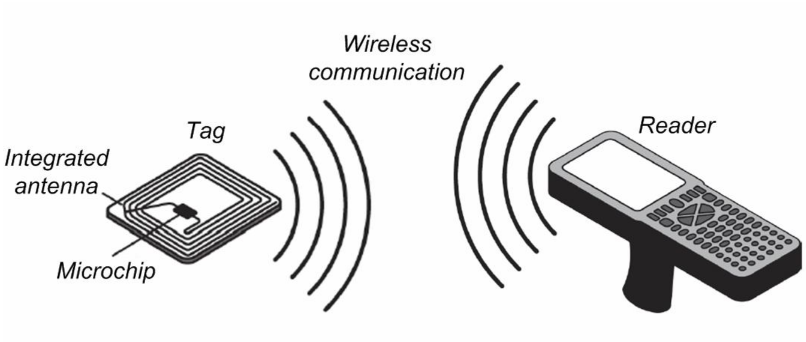

Figure 2.1 : Components of an RFID system (adapted from Karygiannis et al., 2007).

RFID tags are basically classified into two groups based on their method of powering: (1) active and (2) passive (Jaselskis and Misalami, 2003). Passive tags are powered by the electro magnetic field of the reader, that is the radio frequency (RF) energy transferred from the reader to power the tag (Url-1).

Therefore, passive tags can only operate in the presence of a reader. Active tags, on the other hand, have their own internal batteries to continuously power themselves and their RF communication circuitry, The communication range is limited for passive RFID, because of (1) the need for very strong signals to be received by the tag to power the tag, limiting the reader-to-tag range, and (2) the small amount of power available for a tag to respond to the reader, limiting the tag-to-reader range (Url-1). Passive tags have a much longer lifecycle and are much cheaper to produce, which makes them suitable for tagging individual product items (Ward and Kranenburg, 2006).

Active tags, on the other hand, allows very low-level signals to be received by the tag since the reader does not need to power the tag, and the tag can generate high-level signals back to the reader using its internal power source (Url-1). Thus, they can be read or written to from approximately 5 to 100 feet (i.e., about 1,5 to 30 meters) (Url-1; Jaselskis and Misalami, 2003). Active tags have a limited life (e.g., three to ten years), while some active tags that use the incoming radio signal to recharge their internal battery to extend their life beyond ten years are being produced (Jaselskis and Misalami, 2003). Passive tags, in contrast with active tags have an unlimited lifetime due to being powered by the magnetic field from the reader (Jaselskis and Misalami, 2003).

Another type of RFID tag is the battery-assisted tag, also known as "semi-passive" tag, where it includes on-board batteries, but still communicates using the same technique as passive tags (Url-2). These tags use their battery to run the circuitry on their microchip and the onboard sensor, if there is any. They have a longer read range than a regular passive tag since all of the energy gathered from the reader can be reflected back to the reader (Url-2).

Additionally, RFID tags can also be divided into two categories depending on their data storage capabilities: (1) read-only and (2) read/write tags (Jaselskis and Misalami, 2003; Domdouzis et al., 2007). Read-only tags can be programmed either during manufacture or by the user only once in their lifetime and the information cannot be altered at a later time.

Thus, read-only tags are generally used for simple identification purposes and only have a unique ID prewritten to them, which points to a database that provides information about the object that the tag is attached to (Domdouzis et al., 2007).

On the contrary, read-write tags allow the user to alter the information stored within the tag. There are also write once read many (WORM) formatted tags which are fundamentally read-only and can be programmed by the user one time after manufacture (Jaselskis and Misalami, 2003).

Both the active and passive types of RFID tags can dynamically store data, however, because of power limitations, passive RFID typically provides only a small amount of read/write data storage (e.g., 128 bytes or less). Active RFID, on the contrary, has the flexibility to remain powered for access and search of larger data spaces (e.g., 128 Kbytes), as well as the ability to transmit longer data packets (Url-1). Technical features and capabilities of active and passive RFID systems are summarized in Table 2.1.

Table 2.1 : Technical features and capabilities of active and passive RFID systems (adapted from Domdouzis et al. (2007)).

	Passive RFID systems	**Active RFID systems**
Tag power source	Energy transferred from the reader	Internal battery
Availability of tag power	Only when within the field of the reader	Continuous
Required signal strenght from reader to tag	High	Low
Communication range	Short range (i.e., around 3 meters)	Long range (i.e., 100 meters or more)
Lifetime range	Unlimited	Limited (e.g., 3 to 10 years)
Data storage	Small (i.e., typically 128 bytes)	Large (i.e., max available memory 128 Kbytes)
Sensor capability	Can monitor sensor input only when being powered by the reader	Can continuously monitor sensor input

RFID systems can also be classified in terms of the frequencies they use, where frequency is the size of the radio waves used to communicate between the RFID system components. Higher frequencies allow faster data transfer rate and longer read ranges, however are more sensitive to environmental factors (e.g., liquid and metal). Frequency bands used by the RFID systems are (1) Low Frequency (LF), (2) High Frequency (HF), (3) Ultrahigh Frequency (UHF) and (4) Microwave.

Characteristics of the frequencies in which the RFID systems communicate, are summarized in Table 2.2.

Table 2.2 : RFID operating frequencies (adapted from Ward and Kranenburg, 2006; Domdouzis et al., 2007; Ayoade and Symonds, 2009).

Band	**Low Frequency (LF)**	**High Frequency (HF)**	**Ultre High Frequency (UHF)**		**Microwave**
Frequency	30-300 kHz	3-30 MHz	300 MHz–3GHz		2–30 GHz
Typical RFID Frequencies	125–134 kHz	13.56 MHz	433 MHz	865-956 MHz	2.45 GHz
Active or passive tags	Passive	Passive	Active	Active and passive	Active and passive
Read range	< 0,5 m	Up to 1,5 m	3 to 100 m	0,5 to 5 m	1 to 10 m
Typical data transfer rate	< 1 kbit/s	25 kbit/s	30 kbit/s	100 kbit/s	Up to 100 kbit/s
Characteristics	- short range, - low data transfer rate, - penetrates water but not metal	- higher ranges, - reasonable data rate, - penetrates water but not metal	- long ranges, - high data transfer rate, - concurrent read of <100 items, - cannot penetrate water or metals		- long range, - high data transfer rate, - cannot penetrate water or metal
Common usage areas	Animal identificationc ar immobilizer	Applications related to access and security	Asset tracking, logistics	Logistic, pallet tracking, baggage handling	Highway toll collection

Additionally, the existing protocols such as Wi-Fi (802.11x), ZigBee (802.15.4), and Ultra-Wideband are all platforms for RFID technology (Banks et al., 2007). Details about these platfroms are given in the following paragraphs (Banks et al., 2007, Url-2):

Wi-Fi: Active tags that communicate over the 802.11x protocol, the wireless technology used to link computers and other devices to each other and to the Internet, are called Wi-Fi tags. They have their own IP addresses that uniquely identify the tags across the network. Thus, using a Wi-Fi type active tag allows leveraging existing wireless infrastructure to quickly become RFID enabled, where each wireless access point on the network functions as a reader. Wi-Fi tags are expensive, large in size, and have a relatively short battery life.

ZigBee: Within this platform, RFID tags communicate over the 802.15.4 protocol, where data communication rates (i.e., maximum 250 kbps) are as not high as the 802.11 Wi-Fi protocol (i.e., 54 Mbps). Therefore, it is an ideal choice for certain types of applications where data throughput is not an issue. The ZigBee infrastructure require ZigBee access points to be installed like conventional active tag infrastructures. ZigBee tags offer a longer battery life than Wi-Fi tags, and smaller than Wi-Fi tags and generally cost less. ZigBee can operate at various frequencies (e.g., 303 MHz, 433 MHz, or 2.4 GHz).

Ultra Wideband: Classically, any protocol that has a bandwidth greater than 500 MHz or that is 20% of its center frequency is classified as Ultra Wideband (UWB). UWB bandwidth begins at 3.1 GHz and ends at 10.6 GHz. Different than the traditional RF communications where the bandwidth is narrow and the information is encoded onto an RF carrier wave, UWB communicates by sending very short and low power signals throughout its wide spectrum at specific points in time. UWB can transmit over 100 megabits per second, where the highest data rates are achievable within the 10 meter range. UWB transmissions are not powerful enough to interfere with classic RF transmissions, actually, its transmissions are weaker than the signals that are emitted by most consumer electronic devices. Due to the low power requirements for UWB transmissions, UWB RFID tags have a battery life of up to one year. UWB can pinpoint an object in a room to within 30 centimeters using triangulation and location algorithms (e.g., time distance on arrival (TDOA) and angle of arrival (AOA)), therefore it is sutiable to be used in localization applications.

In addition to the RFID technology, there are also several other Automatic Identification and Data Capture (AIDC) technologies that are used as a means of identification. Among these AIDC technologies (e.g., barcodes, RFID, biometrics, magnetic stripes, optical character recognition (OCR), smart cards, etc.) some technologies can be used as local data storage units like RFID tags, as well. But they possess several disadvantages (e.g., line of sight requirement, small data storage capacity, non-durable against harsh conditions, etc.) when compared to RFID.

One of these solutions is the Contact Memory Button (CMB), a compact device that cost six hundred times more than barcodes but can store up to 64 Kbytes of information, and survives most types of environmental damage (Gardner, 2004). CMBs are being utilized by the United States (U.S.) Department of Defense (DoD) in applications where space is limited and access to current data are critical (Gardner, 2004) as well as by aircraft manufacturers to store data related to parts (Roberti, 2009). Unlike RFID, CMBs requires physical contact to a reader for data transmission. This is the main drawback of this technology when compared to RFID, where contactless data transmission can be performed and no line-of-sight required for data transmission.

In general, RFID technology is different from other identification and data storage technologies due to its capabilities such as long reading ranges, ability to integrate with sensors, and communication without line-of-sight requirement.

2.2 Data Storage Approaches in RFID Systems

Several types of RFID systems are available for different data storage needs. In the following section, three main data storage approaches and the types of RFID systems that were used in those approaches are described.

2.2.1 Storing data on a remote database

In this approach, RFID tags basically replace barcode labels and only a unique object ID is stored on the tag. Object ID is used to associate the object with the related data that is kept on a remote database.

In this approach, ID that is stored in the tag is permanent and therefore, updating is not needed. Consequently, usually read-only tags are used and a unique ID is prewritten on them. Since only a small memory is needed to store an ID, passive tags, which have limited memory, are usually selected in this approach unless longer read distances are needed. Passive tags do not have batteries and are smaller and less costly compared to active tags.

However, this approach requires a strong middleware that is able to manage the tag data efficiently. The tag can be read multiple times by the same or different readers at different points in the supply chain, where each such read generates tag data on the reader side and thus on the network (Lahiri, 2005). As a result of reading the tags, a tremendous amount of data are generated on the network.

If this data were stored and transported as is, most storage systems and networks would collapse. Thus, to handle this data efficiently, it requires to be sorted, filtered, and processed by a middleware, so that it can be managed in real time (Lahiri, 2005).

EPCglobal Network is a commonly used example of this approach in retail sector (Diekmann et al., 2007). The EPCglobal, formerly the MIT Auto-ID Center, is a non-profit organization that achieved standardization of Electronic Product Code (EPC) technology. EPC is a serial number created by the Auto-ID Center, which has digits to identify the manufacturer, product category and the individual item (Figure 2.2).

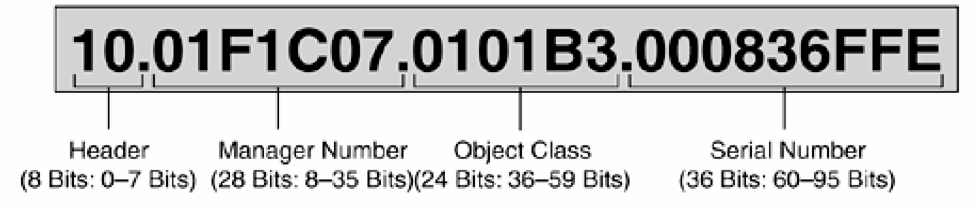

Figure 2.2 : Electronic Product Code (EPC) Architecture (Lahiri, 2005).

Figure 2.3 : An EPC tag (Url-3).

Within the EPCGlobal Network, each RFID tag is equipped with a unique EPC. The EPC functions as a pointer and it references object-related data that is kept in the network within the supply chain.

After each instance of product in the supply chain is assigned with an EPC and the RFID tags that are attached to objects are encoded with EPC numbers, the EPCglobal works as described in the following paragraphs (Lahiri, 2005; Brown, 2007):

1. As the object moves through the supply chain, it is detected by RFID readers at different locations.

2. The information is passed to the RFID middleware where the middleware aggregates information, removes duplicates, applies filters, and passes filtered information to enterprise systems.

3. The EPC is sent to the Object Naming Service (ONS), and it returns a pointer to the item's Discovery Service (DS). The Discovery Service (DS) provides the location information of the EPCIS (EPC Information Services) instance to the middleware.

4. The middleware adds location and event information to the processed data and moves it to the appropriate EPCIS instance for storage and action.

5. Finally, proper systems are updated with the received information. This process is represented in Figure 2.4 :

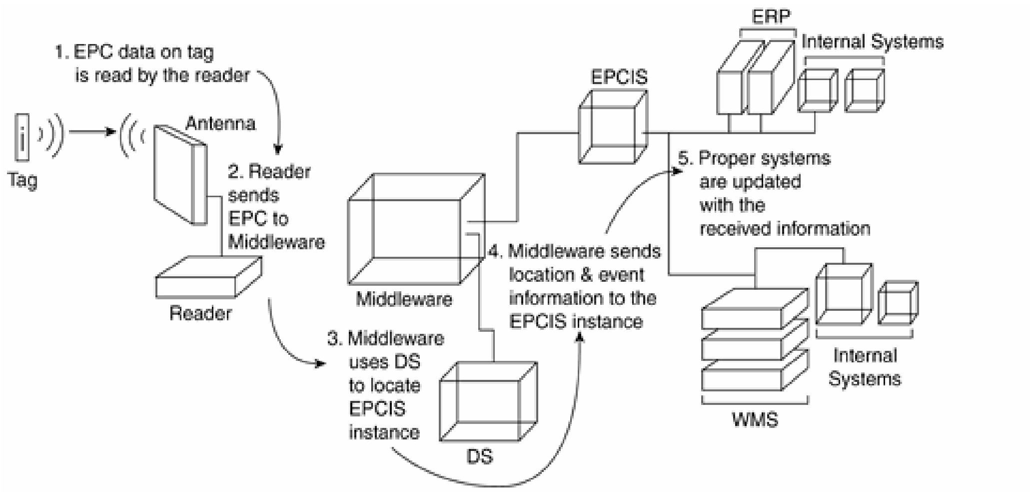

Figure 2.4 : EPCGlobal Network Architecture, (Lahiri, 2005).

Discovery Services (DS) are the suite of services that mediates and provides the access to EPC data, where Object Naming Service (ONS) is a component of these services (Lahiri, 2005).

Object Naming Service (ONS) is a public service that can be used to find related EPCIS (EPC Information Services) servers from where data about a product can be extracted. An EPCIS associates EPC data with business events and information where it act as an interface to a collection of business back-end systems (e.g., warehouse management systems (WMS), enterprise resource planning (ERP), and homegrown systems) (Lahiri, 2005).

Finally, the middleware aggregates and filters data, as well as it removes duplicates. Additionally, it is responsible for movement of relevant information through the network to EPCIS or other business back-end systems of an enterprise.

EPCglobal has defined four classes of RFID tags, namely (1) EPC Class-0/Class-1, identity tags, (2) EPC Class-2, higher functionality tags (3) EPC Class-3, battery-assisted passive tags, and (4) EPC Class 4, active tags (Lahiri, 2005; Ward and Kranenburg, 2006, Url-4):

EPC Class 0/Class 1, identity tags: These tags are purely passive, identification tags and can store either 64 bits or 96 bits of EPC data. A Class 0 tag, defined for UHF, has the data consists of a unique serial number that has already been written by the manufacturer before this tag is shipped to a customer. Class 1 are write once read many (WORM) tags that allow data to be written by a customer at the point of use. Class 1 is defined for both UHF and HF. A UHF Generation 2 tag (i.e., EPC Gen 2 or Gen 2 tag), is a new generation of EPC WORM tags aimed to replace the Class 0 and Class 1 tags. It is based on the UHF Generation 2 Protocol, the specification of which was ratified as an EPC standard by EPCglobal on 2004. A Gen 2 tag is defined for UHF and consists of a 128-bit read/write tag 96 bits and 32 bits of which is reserved for EPC data and for error correction and a kill command (i.e., for permanently disabling the tag), respectively.

EPC Class 2, higher functionality tags: Passive read/write tag that can store an EPC together with user data. The minimum user data capacity of such a tag is 224 bits.

EPC Class 3, battery assisted passive tags: Read/write tags that have an ddition of on-board memory power and have a large user data capacity. Battery-assisted tags communicate as the passive tags, but they can use their on-board batteries to run the circuitry on their microchip and the onboard sensor, if there is any.

EPC Class 4, active tags: Read/write active tag with a large user data capacity. The minimum read range is 300 feet (i.e. about 91 meters).

2.2.2 Storing data on a tag

The “data-on-tag” approach is based on the idea of integration of the object with related data. In this approach data are decentralized and made available with the object itself.

Figure 2.5 : is an active tag that is integrated with a temperature sensor. This tag have 128 Kbytes of on-board user memory capacity and a 32 Kbytes of sensor logging memory (Url-5).

Figure 2.5 : Active sensor integrated RFID tag with 128 KB user memory, 32 KB sensor logging memory (Url-5).

The storage of additional data on the tag serves four main functions: (1) information function, (2) documentational function, (3) temporary storage function and (4) decentralized control function (Melski et al., 2007). Each function is explained in the following paragraphs:

Informational function: Data are stored in the tag to deliver additional information about the object such as dimensions, materials that were used, handling instructions. This approach guarantees immediate access to object-related information at all times and at all locations, even if there is no access to a network. Since informational data usually describes the characteristics of the object, it is typically static, thus it does not need to be modified or extended once it is stored. Therefore, read-only or tags can be preferred for this type of functionality.

Documentational function: Additional data are stored on the tag to document history of the object, including object-related activities (e.g. quality measures and inspections). If the tag is used to record historical information, the data in the tag becomes dynamic since it needs to be updated or extended as the object goes through different phases (e.g. production, storage, delivery). To store dynamic information, the tag needs to be re-writable. Moreover, the storage capacity must be sufficient enough to document all the activities during the lifetime of the object. As active tags have larger memories compared to passive tags, usually active tags are preferred for having documentational function.

Temporary storage function: In this function, information stored in the tag: (1) is captured at the point of action, and (2) is temporarily stored, because of unavailability of a network to transfer data (e.g. during transportation). For example, sensors integrated to an RFID tag measure environmental parameters as the tag moves with the object throughout its supply chain and this data are temporarily stored in RFID tags until the next possible fixed reading point is reached. This function also requires active re-writable tags since data are updated.

Decentralized control function: RFID tags can be equipped with microprocessors and thus given the ability to make their own calculations (Collins, 2006). As a result, objects themselves are authorized to make decisions and control systems are relieved since they can (1) pre-process data, and (2) carry out actions (e.g. activating alarms). They can even make independent decisions on the basis of their data (e.g. routing information). This function requires an active tag since it would perform some actions without receiving any power from a reader. Moreover, this kind of utilization of RFID tags is one step further from its traditional usage. It enables the sensor integrated tag to become a sensor node that belongs to a sensor network, where tags can communicate with each other and can make local processing. A visionary example to this kind of utilization of RFID tags in construction is given in the discussions and recommendations section within the context of future work.

2.2.3 Integrated approach

In some RFID cases only an integrated approach can guarantee the availability of the relevant information at all times. For example, an RFID tag memory may not be sufficient to store all the object-related data within an application. Thus, some of the data needs to be stored in a remote database. In another case, a seamless connection to a remote database may not be available in all phases that an object goes through. Therefore, all the object-related data that is needed when the object is outside the range of the network can be stored on the tag and the rest of the data can be kept in a remote database. This integrated approach enables data availability under different conditions. Another example for the integrated approach is a case where the tag data (e.g. temperature) needs to be transferred to a computer system to perform some necessary calculations (e.g. concrete maturity calculations) or to trigger some alerts.

There are some cases where the data that is stored on tags may also be transferred and stored on remote databases to create data redundancy. These kinds of applications are considered as data-on-tag cases within this thesis, since the goal in these applications is to make data available on the tags.

A comparison of explaned data storage approaches is given in Table 2.3. This table gives an overview of the differences and the similarities of the three data storage approaches in terms of various factors. The factors that are mentioned in the table are the need for data access in each approach, type of data stored on tags and type of tags that are typically used in each approach, as well as the data storage capacities and capabilities, and costs of these tags. The table also gives insights about how the data security is provided in each approach (Table 2.3).

Table 2.3 : Comparison of data storage concepts (adapted from Diekmann et. al., 2007).

	Data-on- remote DB	**Data-on-tag**	**Integrated approach**
Needs for data access	Necessary infrastructure (I)	Presence of object (II)	Both (I) and (II)
Storage of object data	Centralized (database) (III)	Decentralized (object) (IV)	Both (III) and (IV)
Content of data on tag	ID number (e.g. EPC)	All object-related data (e.g. history information)	Some part of the object-related data (e.g. environment conditions)
Nature of data on tag	Static (mostly)	Dynamic (mostly)	Dynamic (mostly)
Storage capacity on tag and type of tags	Low (mostly passive tags)	High (mostly active tags)	Low or high- depends on application characteristics
Storage capabilities of tags	Mostly Read-Only tags	Mostly Read-Write tags	Mostly Read-Write tags
Cost of tags	Low	High	Depends
Data security	Access mechanism in DBs (V)	Coding on the tag (VI)	Both (V) and (VI)

However, to understand the specific conditions that require different data storage approaches, the contexts of specific cases need to be known. Therefore, in this thesis, cases which leveraged RFID technology that are applied in different industries were investigated to identify under which specific conditions each data storage approach was selected. Furthermore, the types of data that is being stored in RFID applications are identified.

Both research studies and industry applications were investigated for the construction industry and other large industries. As a result, the characteristics of each case in each investigated industry and the types of information groups that were both stored in databases and on tags were identified. The industries that are compared with the construction industry are aerospace, retail, manufacturing, defense and healthcare industries. Investigation of RFID case studies within these six industries are given in the following sections.

3. RFID CASE STUDIES

The case studies that were examined in terms of their characteristics and their data storage needs, were both conducted by academia and industry. These case studies utilized RFID within several business processes throughout construction industry and aerospace, defense, retail, manufacturing, and healthcare industries. Table 3.1 illustrates the distribution of the cases and their numbers in each industry.

Table 3.1 : Number of academic studies and industrial applications in each industry.

Name of the industry	Number of applications conducted by		Total
	Academia	Industry	
Construction	24	10	34
Aerospace	1	16	17
Defense	-	16	16
Retail	1	15	16
Manufacturing	-	17	17
Healthcare	-	13	13
Total	**26**	**87**	**113**

As the Table 3.1 reports, 77% of the investigated one hundred thirteen cases (i.e., eighty seven) are real-life applications conducted by relevant industries. Academic reseach studies, on the other hand, are the 23% of the entire cases (i.e., twenty six cases) all of which were retrieved from academic journal papers and/or conference papers. They are mostly observed in construction industry (i.e. twenty four out of twenty six), while the aerospace and the retail industry also include one academic study. Defense, manufacturing and healthcare industry applications are all real-world implementations of RFID technology, which were obtained through RFID-related web sites (e.g., RFID journal), technology suppliers' web sites (e.g., Savi Technology), and from the web sites of the companies who implemented the technology (e.g., Airbus).

The investigated cases were classified under appropriate categories according to the application areas and purpose of utilization of the technology. When a case fell under more than one category (e.g., object tracking and object localization), the primary purpose in using RFID was considered and the case was included in that category.

3.1 RFID Cases in Construction Industry

Thirty four case studies were investigated in the construction industry in total. While the twenty four of these cases are academic research studies, the rest of the ten cases are industrial applications. The investigated cases were classified under five categories in accordance with the application fields and RFID technology utilization purposes (Table 3.2).

Table 3.2 : Categorization of the investigated cases in the construction industry.

<table>
<tr><th>Category</th><th>Number of cases</th><th>Purpose</th></tr>
<tr><td>Material tracking</td><td>8</td><td rowspan="3">Identifying and tracking components (e.g. pipe spools, steel members), tools (e.g. hammer drill, band saw), workers, etc. at the jobsite.</td></tr>
<tr><td>Equip./tools tracking</td><td>3</td></tr>
<tr><td>People tracking</td><td>1</td></tr>
<tr><td>Lifecycle information tracking</td><td>4</td><td>Tracking data that is related to the components throughout their lifecycles (e.g. manufacturer name, installation instructions, maintenance records, etc.).</td></tr>
<tr><td>Mobile object localization</td><td>2</td><td rowspan="2">Determining the exact location of mobile objects (e.g. workers) and stationary objects (e.g. materials, buried cables) at the jobsite.</td></tr>
<tr><td>Stationary object localization</td><td>5</td></tr>
<tr><td>Construction/ progress management</td><td>6</td><td>Gathering status information of components (e.g. manufactured, delivered, installed, etc.) at different phases during construction.</td></tr>
<tr><td>Quality management/ control</td><td>5</td><td>Tracking quality control test results and inspection results (e.g. concrete tests).</td></tr>
</table>

The largest group of cases belongs to the category of tracking objects at the jobsite. It includes applications that identify materials (e.g. pipe spools, steel members), tools and workers only when they pass by specific locations at job site (e.g. gates) or when read by a handheld reader. This category is followed by the localization category which includes cases where RFID is used to pinpoint the exact location of objects, such as materials at the jobsite and buried assets (e.g., cables). In six cases, status information of components (e.g. manufactured, delivered) were tracked by scanning RFID tags when specific tasks were completed.

In a group of four cases, RFID was used for tracking life cycle/historical information of various components. In quality management and control category, RFID is utilized for keeping a record of quality control tests and inspections (Table 3.2).

In each category, data storage approaches were investigated for each case. The goal was to determine under which conditions storing data on the tag is more appropriate for the construction industry by identifying the characteristics and data storage needs of the available cases.

3.1.1 Object tracking applications

Three types of objects were tracked at construction site: (1) materials (e.g. pipe spools, steel members, timber components) (2) people (3) equipment or tools (e.g. hammer drill, band saw). Object tracking cases mostly focused on material tracking (i.e. eight out of twelve cases).

All types of data storage approaches that were identified in Section 2.2 were used for material tracking cases. Data-on-tag approach was more frequently used within this context (i.e. four out of eight). For example, when automating current tracking process of pipe spools, Song et al. (2006a) stored relevant data (i.e, piece marked number, spool number, sketch number and purchase order number), on active tags that are attached to pipe spools (Figure 3.1).

Figure 3.1 : (a) Pipe spools attached with RFID tags and (b) loaded on truck for shipment to job site (Song et al. 2006a).

After the tagged pipe spools are loaded on a truck and made ready for shipment, the trcuk arrives at the job site, where it passes through an RFID-enabled portal for an automated delivery and receipt (Figure 3.2).

Jaselskis and Misalami (2003) also followed a data-on-tag approach and stored pipe supports' and hangers' procurement data (e.g. purchase order number, client number, job number, item number) on passive tags (Figure 3.3). Passive RFID tag that is placed on the pipe support is preprogrammed with above mentioned data at the supplier's fabrication plant.

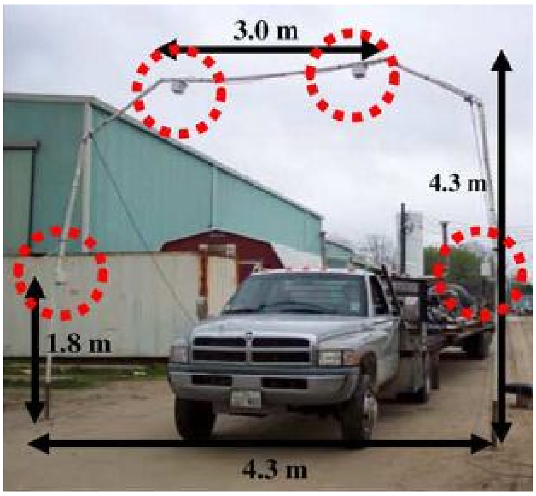

Figure 3.2 : RFID-enabled portal where truck full of tagged pipe spools pass through for an automated delivery and receipt (Song et al. 2006a).

Figure 3.3 : Passive RFID tag attached to pipe support (Jaselskis and Misalami, 2003).

At the job site, workers use a reader to read/write information to the tag instead of manually recording information on the packing list, the procedure with the current manual approach (Figure 3.4). Additionally, the location of pipe supports in the lay down area and existence of any damage is also written to tags to make a permanent record for others to access at a later time (Jaselskis and Misalami, 2003).

These applications benefited from the informational function and the documentational function brought by the additional data that is stored on RFID tags.

Figure 3.4 : Worker receiving pipe support using RFID approach (Jaselskis and Misalami, 2003).

Three material tracking cases followed an integrated approach for data storage. For instance, Yin et al. (2009) proposed a system where the data about inventory and delivery processes of precast concrete components (e.g., beams, columns) are stored in passive RFID tags. More detailed information is sent to the main office or to a site worker via Personal Digital Assistant (PDA) and wireless Internet. This detailed information includes data related to inventory and transportation management of precast components, their date and time of delivery, quality inspection results, as well as the information related to production and quantity. Cheng et al. (2008) also used an integrated approach and the tags stored information about how to restore timber components. This information was modified and updated according to the needs of a specific restoration phase. In addition to the data stored on tags, other information such as restoration sequence, restoration contractors, supervisors, evaluated strength capacity data and drawings was available via a GIS application which was accessible online through a handheld PDA reader-writer used onsite (Cheng et al., 2008). Similarly, Ren et al. (2007) developed an RFID facilitated construction material management system to obtain up-to-date production and installation information about the pipes in a water supply project. PDAs were used to collect data from RFID tagged fittings and this data were transferred to a remote database everyday. Production and installation data related to the pipes such as their ID, manufacturer, drawing number, scheduled installation date, site to be installed, person in charge, etc. were stored in tags on the fittings. According to the data collected on site via RFID, comparison with the actual situation and the baseline schedule and analysis was made based on usage of fittings and changes on site (Ren et al. 2007). To have a cost-effective solution, both active and passive tags were utilized in this project where active tags are used for the fittings which suffer from the highest risk of shortage or being misused.

Two material tracking cases followed data-on-remote database approach (Furlani and Pfeffer, 2000; Swedberg, 2009b). For example, in one of these cases the tag ID is used for querying the graphical representation of steel components that are kept in databases (Furlani and Pfeffer, 2000). It can be seen that, storing additional object-related data on tags is more preferable within material tracking applications.

There are three cases related to tracking of equipment (e.g., tools, crane parts). Data-on-remote database approach was used more often. Only Goodrum et al. (2006) followed a data-on-tag approach and tested a tool tracking system on a number of construction jobsites. In this case, active RFID was used to keep an inventory of small tools and to store pertinent operation and maintenance data on the tools (e.g., hammer drills) (Figure 3.5). This application benefited from the documentational function of additional data storage on RFID tags.

Figure 3.5 : Tools that are installed with active RFID tags (Goodrum et al., 2006).

The two remaining cases stored equipment-related data of power tools (e.g., last person who used the tool, time and place of last check out) (Swedberg 2005) and tower cranes and their large individual components (e.g., their location in a jobsite) on remote databases (Swedberg 2007a). Table 3.3 summarizes object tracking applications in terms of the data storage concepts they applied, the type and frequency of tags they utilized and finally the type of data they stored on tags and/or on remote databases.

Table 3.3 : Summary of the cases in object tracking applications in construction industry.

	Data storage	Type of tag	Frequency	Type of data stored
Material tracking (8)	Data-on-tag (3)	Passive	HF (125 kHz)	Procurement data (i.e., purchase order number, client number, job number, item number), location information, damage information of pipe supports
		Active	UHF (433.92 MHz)	Information related to delivery and receipt process of pipe spools (e.g., piece marked number, spool number, sketch number and purchase order number)
		Passive	HF (13.56 MHz)	Material information (i.e., description, weight, installation location, lifting schedule)
	Data-on-remote DB (2)	Passive	HF (13.56 MHz)	Name of manufacturer, date of manufacture, history of usage of safety nets.
		Passive	N/A	Graphical representation of steel components (i.e. CAD information, VRML models).
	Integrated data storage (3)	Passive	HF (13.56 MHz)	**Data on tag:** Information related to inventory and delivery of precast components (e.g., project category, component code, serial number), location in the storage area, **Data on remote DB:** Inventory and transportation management data of precast components, dates and times of delivery, quality inspection results, information related to production and quantity of precast components.
		Active + Passive	N/A	**Data on tag:** Scheduled installation date, site to be installed, designed location, person in charge of each fitting, manufacturer and drawing number of pipes. **Data on remote DB:** Comparison with the actual situation and the baseline schedule
		N/A	N/A	**Data on tag:** Restoration data of timber components **Data on remote DB:** GIS-based graphic and non-graphic information about components, their restoration records.
Equipment/ Tools (3)	Data-on-DB (2)	Passive	UHF (915 MHz)	Last person who used the tool, where and when it was checked out and the tool's replacement cost
		Active	UHF (433.92 MHz)	Location of large individual tower crane components
	Data-on-tag (1)	Active	UHF (915 MHz)	Operation and maintenance data of tools
People (1)	Integrated data storage (1)	Active	N/A	**Data on tag:** Amount and time of exposure to vibration **Data on remote DB:** Each worker's records

The only case where people were tracked, preferred an integrated data storage approach. The NEMO (Networked Embedded Models and Memories of Physical Work Activity) project utilized RFID technology to gauge the safety of construction employees at risk for hand/arm vibration syndrome, which is caused as a result of overexposure to heavily vibrating equipment (Swedberg 2008c). Active RFID tags with built-in accelerometer sensors, were attached to tools to measure the level of vibration, as well as duration of operation for a particular tool. The tag transmits accelerometer's data to an RF reader in the employee's badge. The badge contains a chip, battery and display, and computes and stores the time and level of vibration that the worker is exposed to. A Wi-Fi access point installed in a project truck downloads the badge's data when the worker approaches the truck and transmits that information to a back-end server via a GPRS signal (Swedberg 2008c). Tags utilized in this application served the temporary storage function.

3.1.2 Applications for lifecycle information tracking

In this category, the main goal is to track component-related data through different phases within component's lifecycle. In the existing studies, it is mostly preferred to store additional object-related data on the RFID tags (i.e. three out of four). These cases benefited the advantages served by the additional data stored on RFID tags, namely the informational and the documentational function.

Ergen et al. (2007a, 2007b) and Motamedi and Hammad (2009) preferred storing all object-related data on tags. For example, in a study data such as the ID number, manufacturer and owner information, handling, storage and installation instructions and maintenance information of engineered-to-order components were stored on active RFID tags (Ergen et al. 2007b).

Similarly, in another study, active RFID tags were used to store maintenance data (e.g. date, inspector name, inspection results) of fire valves in the facility maintenance phase (Ergen et al. 2007a). Motamedi and Hammad (2009) stored information on both active and passive tags that are attached to fire safety equipments (e.g. extinguishers and valves). The goal was to provide information about the history and the conditions of these components for inspectors and maintenance/repair personnel without accessing any central database.

On the contrary, Ko (2008), developed a web-based building maintenance system and examined its performance in a material test center in Taiwan. This center has valuable experimental equipments (e.g. electron microscope, e-beam, etc.) and laboratory facilities (e.g. rain and wind laboratories, wind tunnel laboratory, etc.) that require periodic maintenance. In the developed system, maintenance information of specific maintenance objects (e.g., equipment or facility) is kept in a database which is accessed over the Internet.

Table 3.4 summarizes the data storage methods applied, type and frequency of tags utilized and the type of data stored on tags and/or on remote databases in applications related to lifecycle information tracking.

Table 3.4 : Summary of the cases in lifecycle information tracking applications in construction industry.

	Data storage	Type of tag	Frequency	Type of data stored
Total number of cases: 4	Data-on-tag (3)	Active	UHF	Maintenance records (e.g., date, inspector name, inspection results) of fire valves
		Active	UHF	Information of engineered-to-order (ETO) components (i.e., manufacturer and owner information, handling, storage and installation instructions)
		Active + Passive	N/A	Type, model, serial number, manufacturing date, history (e.g., last inspection date), location (e.g., building, floor, room) of fire safety equipments
	Data-on-DB (1)	Passive	UHF	Information related to an equipment or facility (i.e., name, supplier, holder, purchasing date and cost, safety degree, durability, warranty period, frequency of use, maintenance and repair records, location)

3.1.3 Localization applications

Localization applications focused on determining the location of mobile and stationary objects at the construction site. In this category, both data-on-tag and data-on-remote database approaches are applied.

Workers are the mobile objects that were localized within two cases where active tags were used (Url-6, Friedlos 2008a). Ekahau's emergency tracking system was used in the construction of an underground tunnel in Spain and Wi-Fi enabled active RFID tags were used for tracking workers. The movement and location of each tagged worker was tracked by the software that calculates each tagged workers' position from the signal strength measurements that were sent from worker's tags. The collected tracking data were stored in a database and shown on a visual map on a computer screen (Url-6). Similarly, a company in Australia was using a data-on-remote database approach to know the location of its 1,700 employees and its construction vehicles in one of the country's biggest road projects (Friedlos 2008a). Active tags, which were attached to workers and vehicles, transmitted signals to the readers deployed on every 250 meters inside a tunnel. Location data of workers and vehicles were stored in a remote database. One reason for using active tags in these two cases is the long reading range that is provided by active tags. Moreover, applications related to determining and tracking the location of objects (e.g., workers, vehicles, etc.) necessitate a centralized management point-of-view and thus, data-on-tag method is not suitable in such cases. RFID was also used to determine the locations of stationary buried assets (Swedberg, 2006; Dziadak et al., 2008) and steel components that were relocated at construction site (Grau and Caldas, 2009). In two of these three cases data are stored in passive tags (Swedberg, 2006; Dziadak et al., 2008). In Atlanta Airport case RFID markers were used to track cables and pipes buried around 5 feet (i.e., 1,5 meters). The marker's serial number, the type of cable and its location, its owner and its material (e.g. copper, fiber, etc.) was stored on passive tags (Swedberg, 2006). Dziadak et al. (2008) also tried to locate the position of non-metallic buried assets using passive RFID with other technologies such as Global Positioning System (GPS). The proposed concept is still in its development stage but RFID gave promising results in determining the depth of buried assets during initial tests. It was suggested that additional data such as the type of the buried pipe (i.e., metallic/non-metallic), its dimension, material in the pipe (e.g., gas, water, sewer, etc.) can be stored directly on the tags. This kind of utilization of RFID tags serve both the informational and the documentational functions. The type and frequency of tags utilized, the type of data stored on tags and/or on remote databases and the data storage concepts followed in localization applications are given in summary in Table 3.5.

Table 3.5 : Summary of the cases in localization applications in construction industry.

	Data storage	Type of tag	Frequency	Type of data stored
Mobile (2)	Data-on-remote DB (2)	Active	Microwave (2.41-2.484 GHz)	Movement and location of workers on a visual map.
		Active	UHF (433 MHz)	Location of employees inside a tunnel.
Stationary (5)	Data-on-tag (2)	Passive	N/A	Type of buried cable, its location, its owner and its material (e.g., copper, fiber).
		Passive	N/A	The type of the buried pipe (i.e., metallic/non-metallic), its dimensions, material in the pipe (e.g., gas, water, sewer, etc.)
	Data-on-remote DB (1)	Active	UHF (915 MHz)	GPS data of steel components, their estimated locations, errors and additional computing parameters.
	No data (2)	Passive	N/A	RFID tags are used in determining the location of tagged materials, no data are stored either on tags or on remote databases.
		N/A	N/A	

3.1.4 Construction/progress management applications

Applications within this category mostly stored data on remote databases (i.e., five out of six) and used RFID tags to identify tagged components at different phases. As a result, the status information, as well as the progress information related to construction phases, can be tracked. Since the progress data needs to be collected at site but needs to be managed at centralized offices, a centralized data management approach is more suitable. After the status data are collected at site, it can be integrated into a schedule or a Building Information Model (BIM), to be able to understand the general situation of the construction. Typically, in four cases within this category, passive tags were attached to components (e.g., steel components, HVAC components). These tags were scanned at certain phases and the related status information (e.g., manufactured, received, installed, etc.) was collected by a reader (Hammad and Motamedi 2007, Wang et al. 2007, Chin et al. 2008, Wenfa 2008). This information was then transferred to a remote database. Additionally, a comparison between the baseline and actual conditions of components was made on the scheduling software (Hammad and Motamedi 2007, Chin et al. 2008, Wenfa 2008). Different then the other three cases, Wenfa (2008) followed an integrated approach and stored additional data about the steel beams and columns on tags for additional verification during receiving process (Figure 3.6).

Figure 3.6 : RFID tags attached to structural steel beams and columns (Wenfa, 2008).

The data written on passive RFID tags is the procurement information of the steel components (e.g., order number, release number, requisition number, mark number, client number, job number, item number, and quantity ordered). It is used for verifying the components by checking their information against the packing list of the steel items arrived at the jobsite. In another study a construction management approach was introduced where tagged component parts were read as they pass through gates. Data-on-remote database approach is followed where the product

URL, a unique address, stored on the chip of each part was used to determine the type of part, its place and its state within the information network (Yagi et al. 2005).

Table 3.6 summarizes the type and frequency of tags utilized, the type of data stored on tags and/or on remote databases and the data storage concepts followed in construction/progress management applications.

Table 3.6 : Summary of the cases in construction/progress monitoring applications in construction industry.

	Data storage	Type of tag	Frequency	Type of data stored
Total number of cases: 6	Data-on-remote DB (5)	Passive	HF (125 kHz)	Status information (e.g., ordered, manufactured, shipped, received, installed) of steel components
		Passive	HF	Status information (e.g., production, test, storage, delivery, on-site, inventory, installation, inspection statuses) of precast components
		Passive	UHF	IFC number, type, dates (e.g., ordering date, manufacturing date, shipping date, receiving date, stockyarding date, piling-up date, lifting-up date, assembling date, installation date, quality control date, task start-finish dates, last and next inspection date) related to HVAC components
		N/A	N/A	Status information (e.g., ordered, manufactured, shipped, received, installed) of precast components.
		N/A	N/A	Product ID, producer information, of construction parts, their current states and nstallation sequences.
	Integrated data storage (1)	Passive	HF (125 kHz)	**Data on tag:** Information related to procurement (e.g., order number, release number, requisition number, mark number, client number) of components (e.g., steel beams, columns, panels, etc.) **Data on remote database:** Schedules and building models, actual construction status of the building

3.1.5 Quality management/control applications

The cases classified within this category, most commonly applied the integrated data storage method (i.e. three out of five). Yabuki et al. (2002) suggested a "hybrid method" by distributing data on tags, on PDAs and on Internet to make sure that quality inspection data are continuously accessible at necessary level. For example, if basic data about a facility or a member is needed at the field, data on RFID tags (ID, main feature or specification, inspection procedures, latest measured data, latest inspection notes, etc.) would be sufficient. When more detailed data are needed on that item, PDAs that is preloaded with related information such as measured data, digital photographs, digital sounds, information about inspection routes, etc. can be used. Finally, all the inspected data, document and drawing files were made available on a local server (Yabuki et al. 2002).

Two cases make use of the tag data for doing relevant computations on remote computers (Peyret and Tasky 2004, O'connor, 2006b). For example, a company used

RFID to detect the concrete's temperature and estimate its strength without having to wait for the results of conventional testing methods. Therefore, active RFID tags integrated with temperature sensors were embedded in the test cylinders. Data such as the tag number, location, and its depth within the concrete was written on tags and temperature was stored periodically on tags. The software that runs on handheld computers used tag data to calculate the maturity of concrete (O'connor, 2006b).

On the other hand, rest of the two cases preferred storing data on a remote database (Wang, 2008; Url-7). One of them was a case of a Hong Kong Company where they placed RFID tags onto the top surface of the concrete test blocks, while the blocks were still wet. Tags were programmed with data pertinent to the origin of the concrete before the samples were sent for testing (Url-7). These data were also uploaded to a server. Since each sample was uniquely identified by its serial number, creating reports and doing statistical analysis were more accurate than the conventional way (Url-7). Table 3.7 summarizes the data storage approaches followed in quality management/control applications, as well as the type and frequency of tags they utilized, and the type of data they stored on tags and/or on remote databases.

Table 3.7 : Summary of the cases in quality management/control applications.

	Data storage	**Type of tag**	**Frequency**	**Type of data stored**
Total number of cases: 5	Data-on-remote DB (2)	Passive	N/A	Results of the tests conducted with concrete samples during inspection (e.g., compression test status, inspection status, curing status).
		N/A	N/A	Reports and statistical analysis about concrete samples.
	Integrated data storage (3)	Active	UHF (915 MHz)	**Data on tag:** Tag's location and depth within the sample during concrete curing, periodic temperature measurements of concrete. **Data on remote database:** Maturity calculation results of concrete samples.
		Active	UHF (868 MHz)	**Data on tag:** Batch number, ID number of tag and truck, quality parameters (i.e., proportion of each component, asphalt fabrication rate of the plant, bitumen temperature, asphalt temperature, bitumen weight for each batch) and quantity parameters (i.e.,weight of the material batch for each truck, weight of the empty truck), and type of mix design. **Data on remote database:** Computed parameters of asphalt quality.
		N/A	N/A	**Data on tag:** Data related to main features of each facility or member, advices and warnings from senior inspectors, recent inspection data. **Data on remote database:** Digital photographs, digital sounds, information about inspection routes, all inspected and measured data, document and drawing files.

3.1.6 Analysis of the Cases in Construction Industry

The results show that out of thirty four cases, the data-on-tag approach was followed and/or suggested in nine cases within the construction industry. These cases mainly include lifecycle information tracking and material tracking applications. They typically benefited from the informational and the documentational function of the additional data stored on tags. In life cycle information tracking applications, mostly historical data (e.g., maintenance and inspection records) was stored on tags. Additionally, information related to components (e.g., engineered-to-order components, fire valves) that include the manufacturer and owner information, as well as the handling, storage and installation instructions are stored on tags within this context. In material tracking applications, data stored on tags was mostly related to the identification and receiving process of the materials (e.g., purchase order number, release number, requisition number, client number, quantity ordered) during the delivery and receipt processes of pipe supports, pipe spools, steel components, etc. These information items were stored directly on the component because this information is needed in the field at multiple places (e.g. production plant, storage yard, construction site) by multiple parties (e.g. manufacturer, contractor, inspector) throughout the lifetime of the component. Network accessibility cannot always be provided in all stages of a construction component throughout its lifetime. Thus, it is necessary to store related data on the component itself to make sure that the data (e.g., maintenance history, handling and installation instructions, delivery and receipt information) is available at multiple places and accessible by multiple parties.

In eight cases, integrated data storage approach was followed, and information items were both stored on the tags and in central databases. In four of these cases, data that is stored on the tags was transferred to a central database because this data would be used in making further interpretations or computations about the objects on remote computers (Peyret and Tasky, 2004; O'connor, 2006b; Ren et al., 2007; Swedberg 2008c). Another method in following the integrated approach was making the most necessary information immediately available on the tag and keeping the rest of the information on a PDA or on a remote computer, server, etc. Seventeen cases in total preferred additional data storage on RFID tags within the construction industry.

On the other hand, storing related data on remote databases (e.g. company databases, portal) was preferred in fifteen cases, most of which are related to construction/progress management applications, localization of objects and equipment tracking. These cases utilized RFID tags for identification of objects and stored object-related data (e.g., status of the object, GPS data of objects, graphical representations of objects, their locations) on remote databases. These information items are already present on the object itself when one is next to the object in the field. Thus, it is not additionally needed to store this data on the tag. Instead, this data should be made available to the ones who are not on the jobsite and not next to the object. Also, in some cases, the current status of the components was updated in the 3D model. These information items were stored in a central database since they need to be made available to multiple parties working at different locations at the same time. PDA integration was also observed in the applications that stored data on remote databases, since PDAs enable uploading up-to-date data immediately to the network to improve the decision-making processes (Wang et al., 2007; Chin et al., 2008). In two cases RFID was only used for positioning/locating the tagged components, thus no additional data were stored either on tags or on remote databases (J. Song et al., 2006b; J. H. Song et al., 2007).

In applications that stored additional data on tags, active tags are used in seven applications while passive tags are used in six applications. Active tags, due to their larger data storage capacities, are more suitable for applications where additional data needs to be stored on tags. However, passive tags also have user memory and read/write capabilities, which allow the implementers to store data that does not hold a large place (e.g., data related to material written in text format). Thus, passive tags were preferred when only a small amount of data, such as the identifier data (e.g. description of components, type of material) was needed to be stored on tags. Another reason in using the passive tags is their short reading ranges that requires a person to be close to the tag, thus to the object, to perform read/write processes. In this way, passive tags ensure that a person who is in charge of an activity which requires him/her to be in close proximity of an object (e.g., quality control inspection) performed that activity.

Table 3.8 reports the characteristics of the cases investigated within the construction industry, in terms of the type of tags used and the information items stored on tags and/or on remote databases in each case.

Table 3.8 : Characteristics of the cases in construction industry and the type of data stored on tags and/or remote databases.

		Tag types	Type of data stored
Data-on-tag	**9 cases**	4 Active (UHF); 2 Passive (HF), 2 Passive (N/A); 1 Active+Passive (N/A)	- Procurement data (i.e., purchase order number, client number, job number, item number), location information, damage information of pipe supports. - Information related to delivery and receipt process of pipe spools (e.g., piece marked number, spool number, sketch number and purchase order number). - Material information (i.e., description, weight, installation location, lifting schedule). - Operation and maintenance data of tools. - Maintenance records (e.g., date, inspector name, inspection results) of fire valves. - Manufacturer and owner info, handling, storage and installation instructions of ETO components. - Type, model, serial number, manufacturing date, history (e.g., last inspection date), location (e.g., building, floor, room) of fire safety equipments - Type of buried cable, its location, its owner and its material (e.g., copper, fiber). - Type of buried pipe, its dimensions, material inside pipe (e.g., gas, water, sewer, etc.).
Data-on remote DB	**15 cases**	3 Active (UHF), 1 Active (Microwave); 3 Passive (HF), 3 Passive (UHF), 2 Passive (N/A); 3 N/A	- Name of manufacturer, date of manufacture, history of usage of safety nets. - Graphical representation of steel components (i.e. CAD information, VRML models). - Last person who used the tool, where and when it was checked out and the tool's replacement cost. - Location of large individual tower crane components - Information related to an equipment or facility (i.e., name, supplier, holder, purchasing date and cost, safety degree, durability, warranty period, frequency of use, maintenance and repair records, location) - GPS data of steel components, their estimated locations, errors and additional computing parameters. - Status information (e.g., ordered, manufactured, shipped, received, installed) of steel components, precast components -IFC number, type, dates (e.g., ordering date, manufacturing date, shipping date, receiving date, stockyarding date, piling-up date, lifting-up date, assembling date, installation date, quality control date, task start-finish dates, last and next inspection date) related to HVAC components - Product ID, producer information of construction parts, their current states and installation sequences - Concrete sample test results during inspection (e.g., compression test status, inspection status, curing status), reports and statistical analysis.
Integrated approach	**8 cases**	2 Active (UHF), 1 Active (N/A); 2 Passive (HF); 1 Active+Passive (N/A); 2 N/A	**- Data on tag:** Information related to inventory and delivery of precast components (e.g., project category, component code, serial number), location in the storage area. **Data on remote DB:** Inventory and transportation management data of precast components, dates and times of delivery, quality inspection results, information related to production and quantity of precast components. **- Data on tag:** Scheduled installation date, site to be installed, designed location, person in charge of each fitting, manufacturer and drawing number of pipes. **Data on remote DB:** Comparison with the actual situation and the baseline schedule. **- Data on tag:** Restoration data of timber components. **Data on remote DB:** GIS-based graphic and non-graphic information about components, their restoration records. **- Data on tag:** Amount and time of workers' exposure to vibration. **Data on remote DB:** Each worker's records (time and amount of exposure to vibration). **- Data on tag:** Information related to procurement (e.g., order number, release number, requisition number, mark number, client number) of components (e.g., steel beams, columns, panels, etc.). **Data on remote DB:** Schedules and building models, actual construction status of the building. **- Data on tag:** Tag's location and depth within the sample during concrete curing, periodic temperature measurements of concrete. **Data on remote DB:** Maturity calculation results of concrete samples. **- Data on tag:** Batch number, ID number of tag and truck, quality parameters (i.e., proportion of each component, asphalt fabrication rate of the plant, bitumen temperature, asphalt temperature, bitumen weight for each batch) and quantity parameters (i.e.,weight of the material batch for each truck, weight of the empty truck), and type of mix design. **Data on remote DB:** Computed parameters of asphalt quality. **- Data on tag:** Data related to main features of each facility or member, advices and warnings from senior inspectors, recent inspection data. **Data on remote DB:** Digital photographs, digital sounds, information about inspection routes, all inspected and measured data, document and drawing files.
No data	**2 cases**	1 Passive (N/A); 1 N/A	RFID tags are used in determining the location of tagged materials, no data are stored either on tags or on remote databases.

HF: High Frequency, UHF: Ultra High Frequency, N/A: tag type/frequency not available.

In two cases both passive and active tags are used in different parts of applications at the same time. For the remaining two cases, the type of tag that was used was not provided.

Passive tags are more frequently used in data-on-remote database cases (i.e. eight out of fifteen) than active tags (i.e. four out of fifteen), since only a little data storage capacity is needed for data-on-remote database approach. Another reason for using the passive RFID systems was to have a more affordable application, since it is less expensive than active tags (Wang et al., 2007; Wang, 2008; Chin et al., 2008). Consequently, if cost is an important issue, passive tags are used and additional data on tags is usually not stored due to low data storage capacity of passive tags. For the remaining three cases that stored data on remote databases, information on the tag type was not available. If no other information is stored on active tags, the reasons for using active tags were the need for longer reading ranges or self-signaling tags that can only work on their own batteries, particularly in localization applications.

3.2 RFID Cases in Other Industries

One of the main objectives of this research was to compare the construction industry with other industries that utilize RFID technology, in terms of the data storage approaches applied in RFID technology implementations. Based on this comparison it is aimed to identify the different characteristics and data storage needs of each industry, as well as to evaluate the way these differences and similarities formalize the implementation of RFID technology within each industry.

The industries that are compared with the construction industry are the major industries that are known to adopt RFID technology in a widespread manner and for long years. These industries are namely aerospace, retail, manufacturing, defense and healthcare industries. Investigation of the RFID case studies within these industries and related discussions are given in the following sections.

3.2.1 Aerospace industry

Seventeen real-life cases are investigated within the aerospace industry that utilized RFID technology in airports and in aircraft manufacturing facilities. The investigated cases were classified under three categories in accordance with the application fields and RFID technology utilization purposes (Table 3.9).

Table 3.9 : Categorization of the investigated cases in the aerospace industry.

Category	Number of cases	Purpose
Baggage handling (airline-wide)	4	RFID tagging the luggage of flight passengers at the time of check-in to be able to identify and track the luggage on its way to the plane.
Baggage handling (airport-wide)	6	
Lifecycle information tracking of aircraft parts and tools	4	Keeping an electronic record of maintenance history of parts (e.g. life-limited, time-controlled, replaceable parts) on RFID tags and tracking the aircraft tools.
Other applications	3	Several RFID-enabled applications (e.g., boarding pass, passport, airport maintenance).

RFID technology implementation within the aerospace industry is mostly observed in the baggage handling applications both in airline-based and airport-wide manner (i.e., ten out of seventeen). These applications typically tag the luggage of flight passengers with RFID tags at the time of check-in, and identify and track the luggage on the rest of its way to the plane. The existing barcode system for luggage identification lacks in terms of reading rates due to the random orientation of the labels to the optical scanner as they move through the airport luggage handling equipment. For instance, at McCarran International Airport in Las Vegas, USA, this leads to 15% to 30% of the bags to be misread and necessitates the airport workers to divert all piece of luggage whose barcode is not successfully scanned and read them manually (O'Connor, 2005b). Because of this manual intervention required to obtain the information and locate the luggage, the process slows down and results in misplaced or lost bags. Several airports have been testing and implementing RFID technology to identify and track passenger bags as a solution to those problems encountered with the barcode based system, since the RFID tags do not require line-of-sight with the reader and can be read more easily.

Other applications of RFID within this industry include aircraft parts and tool tracking (i.e. four out of seventeen) within the body of leading aircraft manufacturer companies Boeing and Airbus. These applications utilize RFID technology as a means of keeping an electronic record of maintenance history of parts (i.e. time-controlled, life-limited and replaceable parts as well as spare aircraft parts) on tags and tracking the aircraft tools.

There are several other types of RFID usage in this industry, which are grouped under the other applications category. Within these applications boarding passes and passports are tagged with RFID tags. Additionally, RFID is leveraged in the maintenance and service processes of fire shutters in an airport.

Each case is investigated in terms of their characteristics and data storage needs.

3.2.1.1 Baggage handling and baggage/luggage tracking applications

It is observed that the examined baggage handling applications all use passive RFID systems, mostly in a data-on-remote database concept. For example, South Korean Asiana Airline is the first airline that made a commitment to use RFID technology to tag and track passengers' baggage, after completing the trials they carried out at six South Korean airports (Collins, 2005b). The airline has its own gate and baggage handling conveyors that are assigned to Asiana at each of the six airports and as a result was able to deploy readers that are placed on the baggage conveyors at each of the six airports. The trial involved around fifty thousand passive Class 0+ EPC UHF tags that are attached to each baggage and resulted in an improvement of the efficiency of the airline's baggage tracking and monitoring systems by 20%, over the barcode based system (Collins, 2005b). RFID tags are solely used for identification and tracking of luggage pieces, and thus this is a data-on-remote database application.

United Airline is also started a trial with a purpose of reducing check-in times, and provided one thousand of its frequent flyers plastic RFID-enabled baggage tags as a part of this six-weeks test (Swedberg, 2009a). Within this trial, where a data-on-remote database approach is followed, baggage tags are embedded with EPC Gen 2 UHF inlay which are encoded with a unique ID number, as well as the United Airline's frequent flyer program number, named "Mileage Plus" number, of the customer to which that tag has been issued. This Mileage Plus number is linked to the passenger's information and reservation data in the airline's back-end system. As the passengers arrive and drop off their luggage at the United Airlines terminal, handheld RFID readers are used to read the RFID tags attached to the bags. The RFID inlay's ID number and Mileage Plus number encoded to each baggage tag are downloaded into the back-end system, and the bags are automatically checked in for the destination airport in the United Airline system (Swedberg, 2009a).

Delta Airline carried out two RFID-based baggage handling system pilots at Florida Jacksonville Airport in 2003 and 2004 (Collins, 2004b). During the trials data-on-remote database approach is followed and UHF RFID inlays were added to the company's existing baggage labels and those labels were fixed to checked-in luggage on the airline's Jacksonville to Atlanta route. RFID antennas and readers were placed throughout baggage conveyor system, to read tags as bags were loaded and unloaded from the containers that are loaded onto the plane (Collins, 2004b). Despite concluding the trial results were satisfactory, the airline has not yet started any deployment due to financial circumstances (Brown, 2007).

On the other hand, an integrated data storage approach is followed in Emirates Airline's baggage handling application. Emirates used RFID tags for tracking luggage during a six month trial to test the use of RFID to improve the luggage tracking processes and reduce lost bags (O'Connor, 2008a). By RFID-enabling all its check-in counters in London Heathrow Airport, UK, and placing baggage tags with embedded UHF EPC Gen 2 inlays onto each checked bag, Emirates track the bags on flights to and from airports in Dubai and Hong Kong. An integrated data storage approach is followed where Heathrow staff at Emirates check-in desks encodes the passenger's name and route along with the unique ID on RFID tags and fixed RFID readers read the tags to identify and track them (Sullivan, 2008). Past trials show the percentage of successful read rates ranges from the low 90s up to 99, whereas the typical successful read rate of baggage bar codes is roughly 85% (O'Connor, 2008a).

In addition to the airlines that utilize RFID in their own baggage handling systems, RFID usage in baggage handling can be observed in airport-wide applications as well. McCarran International Airport in Las Vegas, USA, is the first airport in the world to commit to deploying an airport-wide RFID system for tracking passenger baggage, with an approximately $25 million contract (Url-8). A data-on-remote database approach was followed where the RFID inlays were embedded in the label, which was printed with a bar code and wrapped around the luggage handle and encoded with a unique ID. A common database is used by all airlines in which each bag's unique ID is associated with the passenger's data and the McCarran airport ID. After being tagged, each bag is read and identified before they are checked for explosives by the RFID readers deployed on conveyors that bring the luggage through an explosive-detection system. Each piece of luggage is then routed to the appropriate plane or, to another security-screening station if the explosives detector finds suspect contents. By the second quarter of 2005, the system was expanded to all thirty airlines that use McCarran. The airport reported that baggage accuracy has increased to 99.5% (Url-8; O'Connor, 2005b; Brown, 2007).

Hong Kong International Airport (HKIA) began an RFID program to tag luggage in 2004, in which all of the airport's seventy airlines are participating now, and printing and scanning tags for luggage being checked in at their own terminals (Url-9). A data-on-remote database approach is followed during this process. When a baggage is checked in its RFID tag is encoded with a "Julian date", a number indicating the date and time, in addition to a unique ID number. Then in both text and barcode format, the flight number and the three-letter code representing the destination airport and the tag's ID number are printed on the front of the tag. The RFID number links to data in HKIA's back-end baggage handling system, where information related to the passengers are kept, such as the name of the passenger who owns the bag, the flight number and the destination airport. As the self-adhesive baggage tag is encoded and printed, it is folded around the bag's handle, in the same manner in which other airports worldwide attach bar-code-based baggage ID tags (Url-9) (Figure 3.7 and 3.8). The read rate accuracy of the airport's baggage handling system has increased from an average of 80% for bar-code-only tags to 97 for the integrated RFID tags after their introduction (Url-9).

Figure 3.7 : RFID-enabled baggage handling system at the HKIA (Url-9).

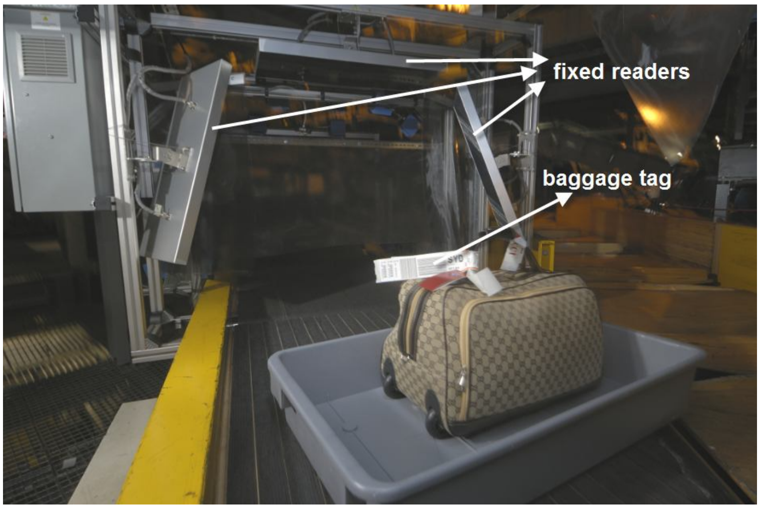

Figure 3.8 : RFID-enabled baggage handling system at the HKIA (Url-9).

Lisbon Airport opened a new transfer baggage terminal with RFID enabled baggage handling system. As the luggage is taken off airplanes and moved to the transfer terminal it needs to be tagged. An integrated data storage approach is followed within this baggage handling procedure. If a bag arrives that already carries an RFID tag, the bag is forwarded into the handling system directly. Otherwise a worker reads the flight information and serial number from the bag's bar-coded luggage tag, and then writes it onto an RFID tag using a handheld RFID reader. If a worker cannot read the existing barcode label, he or she manually enters the data into the RFID system, and the luggage is routed to the correct flight (Wessel, 2009a). As the luggage travels along belts that move it through the terminal, the tags are read at six baggage junctions within that terminal. Bags that are of interest are flagged in a database and officials are alerted once a flagged bag is collected (Garrun, 2009).

Brussels' Zaventem Airport and at Stockholm's Arland Airport currently use RFID embedded in reusable trays that carry the luggage (Url-10). This RFID-based luggage storage and sorting systems are built by deploying one hundred RFID readers and attaching tags to about four thousand totes in Brussels and ten readers and around eight hundred totes in Stockholm. Each tote carries one item of passenger luggage. Readers are deployed at key points along a system of conveyor belts at both sites and the totes can be routed automatically as they travel along the belts. The tags and readers operate at 13.56 MHz, since the longer reading range of a UHF system operating at 868 MHz found unnecessary and 125 kHz readers were unable to cope with the tote speed as they passed on the conveyor belt during the tests. An integrated data storage approach is followed where the tote tag holds information such as origination and destination for the specific piece of luggage it carries (Url-10).

Table 3.10 is created to summarize the data storage concepts and type of tags used in baggage handling applications, as well as the information items stored on tags and/or on remote databases.

Table 3.10 : Summary of the cases in baggage handling applications in aerospace industry.

<table>
<tr><th></th><th>Data storage</th><th>Type of tag</th><th>Frequency</th><th>Type of data stored</th></tr>
<tr><td rowspan="7">Airport-wide (6)</td><td rowspan="2">Data-on-remote DB (2)</td><td>Passive</td><td>UHF</td><td>Passenger information (i.e., name, flight number, destination airport, etc.), tracking the relevant luggage after they are checked in.</td></tr>
<tr><td>Passive</td><td>UHF</td><td>Passenger information (i.e., name, flight number, destination airport, etc.). Tracking the luggage through the explosive-detection system and on its way to the plane.</td></tr>
<tr><td rowspan="4">Integrated data storage (4)</td><td>Passive</td><td>UHF</td><td>Data on tag: Flight information and serial number.
Data on remote DB: Baggage handling, tracking the location of baggage, tracking the security conditions of baggage (i.e., flagged baggage).</td></tr>
<tr><td>Passive</td><td rowspan="2">HF (13.56 MHz)</td><td rowspan="2">Data on tag: Origination and destination of a specific piece of luggage
Data on remote DB: Routing the luggage on its way to the proper flight, tracking its location and status.</td></tr>
<tr><td>Passive</td></tr>
<tr><td>Passive</td><td>UHF</td><td>Data on tag: Carrier ID, destination, date, time, passenger name, mobile number.
Data on remote DB: Information related to the owner of the baggage, real-time tracking the baggage, its location and status.</td></tr>
<tr style="display:none"></tr>
<tr><td rowspan="4">Airline-wide (4)</td><td rowspan="3">Data-on-remote DB (3)</td><td>Passive</td><td>UHF</td><td>Passenger information (i.e., personal information, flight information, reservation information), location and status (e.g., checked-in, loaded on the plane, etc.) of passenger luggage.</td></tr>
<tr><td>Passive</td><td>UHF</td><td>Passenger information, baggage handling processes (i.e., tracking the location and status of passengers' luggage).</td></tr>
<tr><td>Passive</td><td>UHF</td><td>Passenger information needed to track the location and status of their luggage as they pass through RFID readers on conveyor belts, check-in counters, etc., and routing the baggage to the relevant flight.</td></tr>
<tr><td>Integrated data storage (1)</td><td>Passive</td><td>N/A</td><td>Data on tag: Passenger's name and route information, unique ID number
Data on remote DB: Location and status (e.g., checked-in, loaded on the plane, on the conveyor belt, etc.) of luggage.</td></tr>
</table>

Zhang et al., (2008) designed a RFID-based distributed aviation baggage traceable application to support baggage handling and baggage tracking and tested at the Beijing Capital International Airport. It is suggested that with the help of RFID technology, baggage in the airport can be assembled and checked more precisely and also can be traced within global world. An integrated data storage approach is followed and EPC Class 1 Gen 2 UHF RFID tags included the license plate number, the carrier ID, destination, date, time, passenger name, passenger mobile are written in their memory during the tests. Tags are then sealed in the printed baggage label and read by the RFID readers that are fixed on the baggage handling system in the Terminal 2 of the airport. Accurate recognition rates are measured during the tests and baggage's real-time situation is monitored on the screen. Results show that RFID-based average read rate nearly achieved 97% while the barcode read rates were between 75%-85% (Zhang et al., 2008).

3.2.1.2 Lifecycle information tracking of aircraft parts and tools

In the aerospace industry, the aircraft manufacturer Airbus pioneered the use of the RFID technology in aircraft tool management in 1999 (Url-11) and this was followed by Boeing, in 2001 (Url-12). They are following a data-on-tag approach and storing data about the history of the tool as well as shipping, routing and customs information of tools and tool boxes, on RFID tags.

After four years of the first introduction of RFID technology to its aircraft tools supply chain, Airbus reported that RFID is to be used in supply of its spare parts (Url-11). This allowed the RFID tag chip to be used for the first time on civil aircraft spare parts and aimed to simplify inventory and repair management of the equipped repairable and rotable spare parts. The repair and flight history of the component was made available electronically on the microchip, which assures the availability and accuracy of vital information and documentation, as well as allows a comprehensive tracking system. As a result, time is saved on trouble shooting, parts inspection, repairs administration and on the whole logistics cycle of the spare parts (Url-11).

And after five years, in 2006, Boeing launched a program to tag time-controlled, life-limited parts and replaceable units of its 787 Dreamliner aircraft (Url-13). The supplier of silicon RFID chip, Intelleflex, provided the largest memory available in the industry with a 64 kilobits memory UHF silicon chip for use on the 787 aircraft. Thanks to the extended memory feature, the data-on-tag approach can be used and part's maintenance information can be encoded directly on the tag. As a result, critical information about the history of marked parts such as current part number, date of manufacture, manufacturer code, serial number and country of origin, is made instantly available wherever and whenever needed. These information items are linked to an updateable database that aviation industry supply chain partners can access (O'Connor, 2006c).

Before Boeing started using RFID tags, ground crew members had to inspect parts and check serial numbers visually and personnel had to look up written records to find out when a certain part was last inspected. Under the RFID program, inspection crews are given with handheld readers, which have a range of 10 feet (i.e., about 3 meters), to read the data contained in the microchip and to input data. As a result, the service history is contained in the tag as the part goes through its lifecycle (Url-12; Url-13).

Following figures (Figure 3.9, 3.10, 3.11) are the examples of utilization of RFID tags on aircraft parts and units inside an aircraft (Porad, 2006).

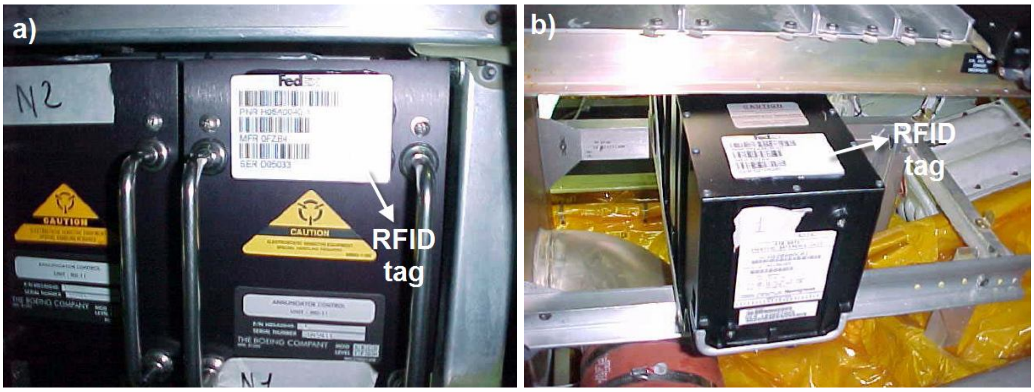

Figure 3.9 : RFID tag on (a) an annunciator control unit, (b) air data inertial reference unit (Porad, 2006).

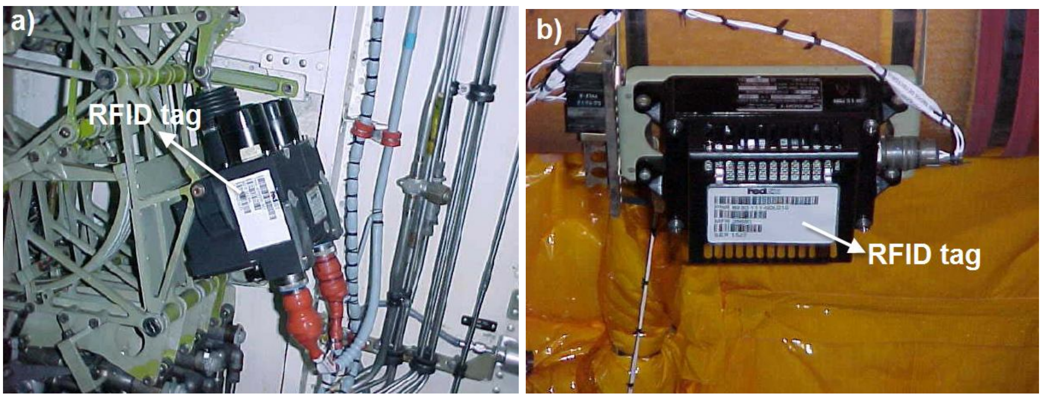

Figure 3.10 : RFID tag on (a) flap limit duplex actuator unit, (b) smoke detector (Porad, 2006).

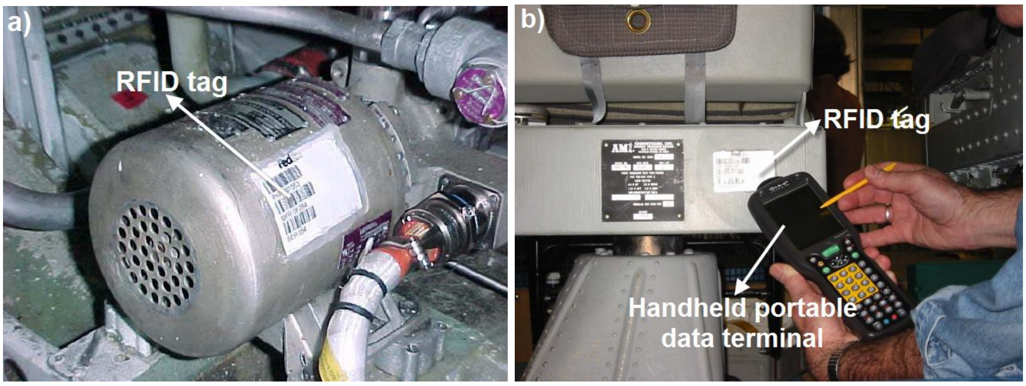

Figure 3.11 : RFID tag on (a) auxiliary hydrolic pump, (b) handheld RFID reader (Porad, 2006).

Table 3.11 summarizes the information items stored on tags in the lifecycle information tracking applications in aerospace industry, as well as the type of tags utilized.

Table 3.11 : Summary of the cases in lifecycle information tracking of aircraft parts and tools applications in aerospace industry.

Data storage	Type of tag	Frequency	Type of data stored
Data-on-tag (4)	Passive	N/A	History, shipping information, routing and customs information related to tools and tool boxes.
	Passive	N/A	
	Passive	N/A	Repair and flight history of components (e.g., repairable and rotable spare parts).
	Passive	UHF	Maintenance and inspection information, current part number, date of manufacture, serial number, country of origin of time-controlled, life-limited parts and replacable units.

3.2.1.3 Other applications

In addition to the baggage handling and parts and tool tracking applications, RFID technology is being used in variety of other ways within the aerospace industry, as well. For example, Air New Zealand started an RFID-enabled check-in process for its one hundred thousand frequent passengers with Gold and Silver membership status, which enables them to check in without paper documentation and reduces bag-check queues and customer waiting times (Url-14; Friedlos, 2008b). The airline provided RFID-enabled permanent and reusable boarding pass, named ePass. It is a small bar-code sticker like tag, which the passengers have been encouraged to attach to their mobile phones. The 13.56 MHz HF passive tags have been designed specifically for use on mobile phones. This is a data-on-remote database approach since the tag does not contain any additional or personal data but only a unique number sequence and tag identifier. Upon arrival at the airport, the passengers check in by scanning their ePass tag at the automated kiosks where flight and baggage details are matched and a paper boarding pass is printed (Figure 3.4), in case it is needed for security purposes, with standard boarding pass data and a barcode. They can also load their bags onto a conveyor belt at the kiosk, skipping the lines at a manual baggage check desk (Url-14; Friedlos, 2008b).

Figure 3.12 : Air New Zealand's RFID-enabled kiosks where passengers use their ePass to check in themselves (Friedlos, 2008b).

RFID tags usage can also be seen in facility maintenance applications, for instance, in Frankfurt Airport, where maintenance and inspection of technical components (i.e., fire shutters) are carried out in accordance with legal regulations by the help of the technology (Lenger and Thiesse, 2006). An integrated data storage approach is followed where the system architecture consists of twenty-two thousand RFID tags attached on all of the fire shutters, mobile devices equipped with an RFID reader and a mobile application, and middleware connecting a back-end asset management system. Custom designed passive tags have a 2 KB read-write memory and able to store both static and dynamic data. While the static data includes a transponder ID, an equipment ID from back-end system and the object's technical ID code, dynamic data consists of the date, time and duration of the last maintenance and enables local data storage of the last maintenance activity.

In another RFID implementation, three hundred United Airlines employees, pilots and crew, are given new passports equipped with RFID chips that can be read at border crossings by special readers installed in scope of the trial (Singel, 2005). The 64 KB chips, which are digitally signed to prevent counterfeiting or alterations, store a copy of the information from a passport's data page (i.e., name, date of birth and a digitized version of the passport photo) (Singel, 2005). Data-on-tag approach is followed in this implementation.

Table 3.12 summarizes the data storage approaches followed by these applications, as well as the type of tags they utilized and the information they stored on tags and/or on remote databases.

Table 3.12 : Summary of the other cases in aerospace industry.

Data storage	Type of tag	Frequency	Type of data stored
Data-on-tag (1)	Passive	HF (13.56 MHz)	Data of a passport (i.e., name, date of birth and a digitized version of the passport photo).
Data-on-rempote DB (1)	Passive	HF (13.56 MHz)	Information of frequent passengers with Gold and Silver membership status (e.g., name, contact information), information related to their flight, automated check-in.
Integrated data storage (1)	Passive	UHF	**Data on tag:** Tag ID, equipment ID, object's technical ID code, the date, time and duration of the last maintenance, maintenance and inspection records of fire shutters. **Data on remote DB:** Maintenance activity plans, work assignments ans task lists for service technicians, maintenance and inspection records of fire shutters.

3.2.1.4 Analysis of the cases in aerospace industry

There are seventeen cases investigated within the aerospace industry, among which all three data storage concepts are applied. The only tag type utilized within these applications is passive, since active tag usage on aircrafts has not yet been approved by the authorities in the industry, such as the U.S. Federal Aviation Administration (FAA). Another reason for the passive tag usage is to have a more affordable implementation, since both airlines and airports need to employ a great number of tags within baggage handling applications. On the other hand, Boeing in partnership with FedEx has conducted several series of tests with active RFID tags, some of which were integrated with sensors (O'Connor, 2006c). The results obtained from these tests show that active tags do not create any electromagnetic interference with the plane's navigation or communications systems. Similar extensive tests are conducted by the U.S. Air Force and the results determined that they did not interfere with onboard avionics, such as radios, navigation or flight instruments (Url-15). But existing real-life applications are carried out by using passive RFID tags, as summarized in Table 3.13.

The concept of storing additional data on tags is applied within eleven implementations of the RFID technology, five of which followed the data-on-tag approach while the remaining six cases applied the integrated data storage method. Four of these five cases that applied data-on-tag approach are in the area of aircraft parts and tool tracking within Airbus and Boeing's maintenance processes.

Table 3.13 : Characteristics of the cases in aerospace industry and the type of data stored on tags and/or remote databases.

		Tag types	Type of data stored
Data-on-tag	**5 cases**	1 Passive (HF); 1 Passive (UHF); 3 Passive (N/A)	- History, shipping information, routing and customs information related to tools and tool boxes. - Repair and flight history of components (e.g., repairable and rotable spare parts). - Maintenance and inspection information, current part number, date of manufacture, serial number, country of origin of time-controlled, life-limited parts and replacable units. - Data of a passport (i.e., name, date of birth and a digitized version of the passport photo).
Data-on remote DB	**6 cases**	1 Passive (HF); 5 Passive (UHF)	- Passenger information (i.e., name, flight number, destination airport, etc.), tracking the relevant luggage after they are checked in. - Passenger information (i.e., name, flight number, destination airport, etc.). Tracking the luggage through the explosive-detection system and on its way to the plane. - Passenger information (i.e., personal information, flight information, reservation information), location and status (e.g., checked-in, loaded on the plane, etc.) of passenger luggage. - Passenger information, baggage handling processes (i.e., tracking the location and status of passengers' luggage). - Passenger information needed to track the location and status of their luggage as they pass through RFID readers on conveyor belts, check-in counters, etc., and routing the baggage to the relevant flight. - Information of frequent passengers with Gold and Silver membership status (e.g., name, contact information), information related to their flight, automated check-in.
Integrated data storage	**6 cases**	2 Passive (HF); 3 Passive (UHF); 1 Passive (N/A)	**- Data on tag:** Passenger's name and route information, unique ID number **Data on remote DB:** Location and status (e.g., checked-in, loaded on the plane, on the conveyor belt, etc.) of luggage. - **Data on tag:** Flight information and serial number. **Data on remote DB:** Baggage handling, tracking the location of baggage, tracking the security conditions of baggage (i.e., flagged baggage). - **Data on tag:** Origination and destination of a specific piece of luggage **Data on remote DB:** Routing the luggage on its way to the proper flight, tracking its location and status. - **Data on tag:** Carrier ID, destination, date, time, passenger name, mobile number. **Data on remote DB:** Information related to the owner of the baggage, real-time tracking the baggage, its location and status. - **Data on tag:** Tag ID, equipment ID, object's technical ID code, the date, time and duration of the last maintenance, maintenance and inspection records of fire shutters. **Data on remote DB:** Maintenance activity plans, work assignments ans task lists for service technicians, maintenance and inspection records of fire shutters.

HF: High Frequency, UHF: Ultra High Frequency, N/A: tag type/frequency not available.

Aircraft parts have complex structures and need constant control and maintenance to ensure the safety of airline crews and passengers. There are several parties (i.e. aircraft manufacturers, airlines, maintenance providers and suppliers of aircraft components) involved during the servicing of aircrafts throughout their lifecycles, which makes it even more complex to handle the maintenance processes. All parties involved would require object related maintenance data and the maintenance history to be able to perform a correct service. In such case, centralized data storage is not advisable due to numerous actors taking part within the maintenance process (Diekmann et al., 2007).

Additionally, to enable the airline mechanics not spending a significant time for accessing a part's maintenance history and locating spare parts, they are given handheld computers to read the tag on a part that is brought in for service. This ensures immediate access to the part's repair history, without the need to look up the information in a maintenance log or an Internet-based parts database (O'Connor, 2006c). This is crucial since there are times when the mechanic does not have access to the Internet, or sometimes they want to loan, borrow or exchange parts, and need to know immediately if that part is interchangeable on their airplane (O'Connor, 2006c). Additional data storage on RFID tags within parts tracking applications is a need due to these reasons and that is why the U.S. airline trade association, the Air Transport Association (ATA), has approved a data structure regarding what information should be stored on tags used on parts (Roberti, 2009). According to Roberti (2009), high-memory tags which hold 64 kilobytes of data, will store the information on each part's birth record (i.e. code indicating the company that made it), date of manufacture, country of origin, part number and serial number. In addition to these, current data about the items (e.g. a part might has been refurbished, or had new software added), will also be stored on high-memory tags. Finally, there will be an open area within the tag's memory for users to add information (e.g., notes by a mechanic servicing the part). Moreover, low-memory tags are to be encoded with the birth record and current information but in a limited manner due to memory limits (Roberti, 2009).

To meet these additional on-board data storage requirements of the aerospace industry, technology providers are developing passive tags with large memory storage capabilities that have never been seen before. For instance, the RFID technology provider, Tego, developed 32 KB passive tags compliant with the EPC Gen 2 standard, and Airbus has already purchased some (Bacheldor, 2009). There are similar emerging efforts by other technology vendors, such as by Fujitsu, the company that is announced to be producing 64 KB passive tags (Burnell, 2009). These high-memory tags could be utilized by the aerospace industry to record the lifecycle and history of a specific part on an airplane, from its point of manufacture, through all inspections and repairs, including its entire maintenance history (Bacheldor, 2009). The data can be accessed by any party (i.e., maker of the parts, the manufacturer of the aircraft on which that component is installed and an airline that purchases that particular aircraft) (Bacheldor, 2009).

The remaining one case that applied the data-on-tag approach is the implementation of RFID-enabled passports within a trial that included United Airline crews where their information from a passport's data page (i.e., name, date of birth and a digitized version of the passport photo) are stored on passive 64 KB RFID tags (Singel, 2005). Cases that stored additional data on RFID tags in aerospace industry took advantage of both the informational and the documentational function.

Five cases, among the six cases that applied the integrated data storage approach, were in the baggage handling applications where the airports, or airlines themselves, applied RFID tags on luggage of flight passengers and enter passenger information such as the name and route of the passenger, ID number of the carrier Airline, date, time, and even passenger's mobile number in some cases.

The other case that applied the integrated data storage approach utilized passive RFID tags within the maintenance processes of twenty-two thousand fire shutters in an airport. Tags included both the static data (i.e. tag ID, equipment ID from back-end system and the object's technical ID code), as well as the dynamic data (i.e. date, time and duration of the last maintenance) (Lenger and Thiesse, 2006). It is aimed to give the technicians at least some basic information on the facility beyond its ID number, since a network connectivity is often unavailable, for instance in the field or in metallic environments (Lenger and Thiesse, 2006).

Remaining six cases are in the baggage handling and RFID-enabled boarding pass applications, in which low-memory passive tags are utilized to have a more affordable solution where numerous tags are needed to be utilized in such applications.

3.2.2 Defense industry

Defense industry is one of the early adopters of the RFID technology. The United States (U.S.) Department of Defense (DoD) has been using active RFID in its complex supply chain provided by Savi Technology since the early 1990's and has provided commanders in-transit visibility during major operations such as Operation Enduring Freedom and Operation Iraqi Freedom (Banks et al., 2007; Myerson, 2007; Url-16). Occurrence of several serious problems in tracking and obtaining necessary supplies during Operation Desert Storm in 1991, such as thousands of containers of materiel not reaching their destination, motivated the first application of active RFID in U.S. DoD (Banks et al., 2007). As a result, the U.S. military has spent millions of dollars over the past decade in implementing the RFID technology as a way of reducing the loss or misplacement of supplies and the shortages of ammunition, fuel, and water (Myerson, 2007) and installed a worldwide RFID infrastructure called the In-Transit Visibility Network (ITV) to track its RFID tagged supplies throughout the globe.

In addition to the U.S. DoD, other government agencies and international defense forces such as the United Kingdom, Australia, Canada, Sweden, Denmark, Spain, Poland are leveraging similar RFID-based solutions, as well (Url-17). North Atlantic Treaty Organization (NATO) built an RFID-based network solution from Central Europe through to Afghanistan where a reader network is placed at key transportation nodes along the logistic routes. When combined with NATO's own network, each nation's own network enables NATO's capacity the largest multi-national logistics network capability in the world (Grackin, 2008). These RFID-based networks can not only function independently but also can interoperate with each other during multi-national deployments. They are based on ISO 18000-7 standards operating at 433.92 MHz frequency, which is proven to be the most effective active RFID frequency in environments where large metal containers are tracked and stored (Url-18).

After its long time active RFID usage, in 2003, the U.S. DoD began to implement passive RFID program and mandated its suppliers to start attaching passive tags when shipping cases and pallets of merchandise, such as packaged petroleum, lubricants, oils, preservatives, chemicals, additives, construction and barrier materials, or medical materials (Url-19). Liquids, metals, and bulk commodities that interfere with transmission of radio signals are not subjected to the mandate (Myerson, 2007).

By 2005, DoD's RFID Policy, which aims the institutionalization of the deployment of the RFID network throughout all armed forces and their suppliers, is issued. According to the RFID Policy, Electronic Product Code (EPC) passive RFID tags must be affixed to cases and pallets, and every container, unit load, rolling stock and high-value piece of equipment to be shipped outside of the continental U.S. must be tracked using active RFID (Url-16). DoD aims to have a better inventory control at the soldier level, to make sure that soldiers receive the supplies continuously replenished to move about in battlefields (Myerson, 2007). Typically each day, the In-Transit Visibility Network (ITV) server has location information on more than 450,000 shipments and receives more than 35,000 unique tag reports in near real-time of shipments moving through the DoD's global supply chain (Url-20). RFID, along with satellite and cellular technologies, is playing a critical role in the war efforts in Iraq and Afghanistan, by enabling the DoD to track the movements of cargo to and from these regions (Swedberg, 2009c). Most of the supply chain into and out of the Middle East is managed through fixed RFID portals, but in some cases when portals are not available, or if closer management of a supply chain is necessary the DoD employs satellite technology, which is more expensive.

Currently, RFID technology is widely utilized in the supply chain management, asset tracking and localization, and security applications within the defense industry (Url-21). As a result, the cases investigated within the defense industry are categorized in four application areas namely the supply chain applications within RFID-based global networks, object tracking applications, applications related to localization of objects and security (Table 3.14). Among the four categories, the largest group is the object tracking category with eight applications in total. These applications utilized RFID for identifying and tracking assets/equipment (e.g., electronic assets), materiel (e.g., military supplies), people (e.g., wounded soldier on battlefield). There are three cases both in the categories of object localization and security applications. Latest category consists of the RFID-based global supply chain network applications of U.S. DoD, and NATO. These networks are for tracking the military cargos as they are being transported from origin (e.g., army depots) to destination (e.g., battlefield).

Table 3.14 : Categorization of the investigated cases in defense industry.

Category	Number of cases	Purpose
RFID-based supply chain/logistics networks	2	Tracking the military cargo within a RFID-based global supply chain network, while they are being transported from origin (e.g., army depots) to destination (e.g., battlefield).
Asset/equipment tracking	5	Identifying and tracking assets/equipment (e.g., electronic assets), materiel (e.g., military supplies), people (e.g., wounded soldier on battlefield).
Materiel tracking	2	
People tracking	1	
Object localization	3	Determining the exact location of stationary objects (e.g., medical devices and equipment) within an area.
Security applications	3	Preventing theft and pilferage of cargo containers and unauthorized access to military sites.

Characteristics of the investigated cases are identified and data storage methods, as well as data storage needs, are examined for each case in each category.

3.2.2.1 Global RFID-based networks for supply chain/logistics management

Among the defense organizations throughout the world, the U.S. Department of Defense is the pioneer in utilizing RFID, and has been using RFID technology in an increasing manner for long years (Robertson, 2004). They installed a worldwide RFID infrastructure called the In-Transit Visibility Network (ITV), which is now the world's largest active RFID network. All of DoD's cargo containers and pallets are tagged with active RFID tags and a complete and accurate electronic manifest of each container is tracked from the time a container leaves its origin, through the ports around the globe, till the time it arrives at its final destination. The network is installed in more than 50 countries across 4,000 locations with read-and-write stations where the U.S. DoD and allied international defense forces in Europe and Pacific Asia track more than 35,000 shipments tagged with RFID devices by air, rail, ship and truck across these locations daily (Url-15). These stations track and locate the flow of a wide variety of military supplies and equipment (e.g., boots, food, bullets and missiles) through the supply chain from point of origin to destination. The locations include, but are not limited to, the United States, Great Britain, Republic of Germany, Iraq, Kuwait, Egypt, Luxemburg, Belgium, Norway, Netherlands, Qatar, Bahrain, Djibouti, Spain, Korea, Japan, Hungary, Kyrgyzstan, Greece, Macedonia, United Arab Emirates, Turkey, and Italy (Url-16; Url-22). Active RFID tags on the containers could be automatically read remotely by fixed stations along the shipping route and by mobile and handheld readers in the field. The data-rich active RFID tags used within these applications can store data up to 128 kbytes, which is equal to 80 pages of text or the entire manifest of a container or pallet. The tags can also be linked to environmental sensors to track temperature, humidity and shock conditions during transit. While the sensors can be attached inside the containers, the tag itself can include sensors, as well. The environmental data can be used to provide an alert if the container environment reaches or passes predefined limits (Robertson, 2004).

Integrated data storage approach is followed where the manifest data are written into the tag over a computer link at the originating shipping point and the tag is read by a fixed reader when the container shipment leaves the originating depot. The information is relayed back to military supply-chain-management computers within the In-Transit Visibility (ITV) network. Similarly, as the container tags are read at various fixed sites during transit, data are relayed back to ITV servers to keep track of the shipment. The fixed locators can also write any desired additional data to the tag. At debarkation ports, container tags are read as they leave the ship and again as they are loaded on land carriers for transportation to the final destination. Similar tag readings are conducted as pallets move through military airlift ground facilities. The military also tracks the return of empty containers and container identification continues even after all contents have been emptied (Robertson, 2004).

Similarly, NATO and allied defense forces have nearly real-time visibility on their supplies and consignments with the help of RFID-based networks, where an integrated data storage approach is followed and consignment and shipment details are written on active tags. They can also monitor graphical maps to search for and find consignments and reach historical data about the journey of a consignment, as well. Sensor-based data, which allows monitoring environmental conditions inside containers that may affect the quality of supplies and materiel, is also being obtained through these networks (Url-23).

Table 3.15 summarizes the type of data stored both on tags and on remote computers within the global RFID-based networks for supply chain/logistics management applications in defense industry.

Table 3.15 : Summary of the global RFID-based networks for supply chain/logistics management applications in defense industry.

Data storage	Type of tag	Frequency	Type of data stored
Integrated data storage (2)	Active	UHF	**Data on tag:** Environmental conditions data monitored by sensors (e.g., temperature, humidity, etc.), content of cargo containers, consignment and shipment details of containers. Additional data storage at reading points during shipment. **Data on remote DB:** Graphical maps that track the journey of a consignment that is used for searching and finding consignments, historical data about the journey of a consignment, point and time of readings of tags to track their shipment, environmental conditions data temporarily stored on tags.

3.2.2.2 Object tracking applications

Objects that are tagged with RFID tags and identified and tracked within different applications are, (1) asset/equipment (e.g., electronic assets, medical equipment, vehicles, etc.), (2) materiel (e.g., military supplies, life jackets, life rafts, clothing, etc.) and (3) people. Asset/equipment is the most frequently tracked object in this category (i.e. five out of eight cases). The integrated data storage approach is slightly more generally followed within the asset/equipment tracking applications (i.e., three out of five cases) while the remaining two cases preferred the data-on-remote database approach (i.e., two out of five cases).

In one of these applications, electronic assets (e.g., desktop and laptop computers, projectors and other electronics), are tagged and tracked within the headquarters of the U.S. Army National Guard in Washington (Swedberg, 2008b). Every three months, the building's IT department takes an automated inventory of the electronic equipment with the help of passive RFID technology. A data-on-remote database approach is followed where an item's serial number and description, along with the location where it is expected to reside (i.e., the division's ID number and the person to whom the asset is assigned) are stored in a laptop computer (instead of integrating the inventory application into the Army National Guard's back-end computer system, a laptop is assigned to store that data. This is because it is thought that such software integration would have required a time-consuming certification process which would have delayed the use of the system). The 915 MHz EPC Gen 2 RFID tag is then encoded with a unique ID number which links to the item's serial number stored on the laptop. Before the staff takes inventory, a handheld reader is connected to the laptop to download the latest data about each asset, and the name and division of the person to whom that asset was assigned, as well. During the inventory taking, the staff carries that handheld reader through the office, and captures ID numbers from tags attached to assets up to 5 feet away (i.e., about 1,5 meters). The reader then displays alerts specific to missing or misplaced items. Once finished, the staff takes the readers back to the laptop to upload the reader data to the computer (Swedberg, 2008b).

In the late 1990's, to create a system for tracking devices of the military which is able to penetrate obstacles such as buildings and thick undergrowth, that often interfere with GPS tracking, the DoD was involved in a development partnership with two technology suppliers (Swedberg, 2007b). The developed technology, namely "Super RFID", uses long-range radar responsive (RR) tags and 3,500-watt readers. It was intended as a long-range radio frequency device for identifying and locating people and objects, and is still used today by the military to avoid friendly fire (Swedberg, 2007b). Originally, the active 430 MHz tags were designed using technology derived from a radar device requiring line-of-sight for reading. Since then, the technology is modified to its current form, which employs RFID to transmit ID numbers instead of radar. RR tags affixed to U.S. and allied tanks are read by RR readers in aircraft from great distances. The reader captures the unique IDs, and the coordinates provided by the built-in GPS receiver, to pinpoint the location. Thus, the military can precisely identify whether the tanks are friendly. RR tags can be read from a distance of up to 12 miles (i.e. about 19 kilometers), using highly sensitive readers which range from 5 watts (i.e., for small applications, such as within a building) to 100 watts (i.e., for broad-range search and rescue purposes) (Swedberg, 2007b).

The U.S. Army Sierra Army Depot (SIAD), California, is a 59-square-mile complex which encompasses one thousand two hundred buildings and serves as an Expeditionary Logistics Center for the storage, maintenance, assembly and containerization of operational stocks and other items (Url-24). SIAD implemented several RFID-based solutions, one of which is a wireless, active RFID-based industrial Vehicle Management System (VMS) (Url-25). The implementation aimed at reducing industrial vehicle maintenance costs, improving worker safety, increasing material-handling productivity and the speed of distribution of critical supplies out to the battlefield. The system includes active RFID tags and GPS units while the readers and antennas are affixed to buildings. Integrated data storage approach is followed where the GPS locations are communicated via a 900 MHz signal to the readers and tags can hold maintenance data as well as the speed, mileage and impact information of the vehicles that are tracked by sensors. The system enables to automatically track the vehicle usage and maintain its maintenance schedule more accurately (Url-25).

Another RFID solution implemented at SIAD is the automated asset and inventory tracking system which enables personnel to reduce hours spent searching for containers, major supplies and asset inventory as they move on, through, and off the facilities (Savi Technologies, 2009a). The solution is designed to improve the visibility and management of assets such as containers, trailers, generators and water purification units. In addition, the active RFID-based solution utilizes sensors that monitor the environmental conditions of DEPMEDS (Deployable Medical System), which are "hospitals in a container" and include necessary medical supplies and equipment required for rapid deployment into the field of operations. The solution follows an integrated data storage approach where an asset management software manages the real-time information related to supplies affixed with active RFID tags (Url-24).

In another tracking application, the U.S. Army tested an RFID-based sensor system to record and store how often the cannons on M1 Abrams tanks are fired, to support maintenance operations and to ensure the Army determines the right time when the barrels should go under service or be replaced (Burnell, 2008). It is important to track how often tank cannons and other artillery pieces are fired because the barrels have limits in withstanding the shock and recoil, and they must be refurbished or retired in time. During the tests, the Army used a sensor-based system that records readings on battery-assisted UHF tags combined with sensors into a single housing. Each time an M1 Abrams tank fired its cannon, a sensor mounted on the tank captured the recoil and recorded the event on the tag. The data were temporarily stored on the tag and retrieved with a handheld reader when the tank returned to the depot. Integrated data storage approach is followed where the tags have 60 kilobits of user memory, which is sufficient to store firing data for 500 rounds (Burnell, 2008).

There are two applications that tracked military materiel. One of them is being implemented by the French army and follows an integrated data storage approach where the French army utilizes RFID technology to identify and track emergency survival equipment (e.g., life rafts and life jackets) (Url-26). For this application, the French army is using 13.56 MHz tags that are unaffected by water, dirt, mud, or other environmental conditions and designed to withstand exposure to chemicals, high temperatures and other harsh industrial processes. The tags offer 2,000 bits of data storage and can be updated with information such as date of manufacture, service or maintenance records, or other specifications. The ultra-thin tags are embedded in the French army's assets, from clothing to emergency equipment, creating an efficient system to identify and track these items using relevant software (Url-26).

The other materiel tracking application followed a data-on-remote database approach where the U.S. Navy deployed an RFID system to track supplies and equipment as they pass through RFID portals deployed in two naval base warehouses on the Hawaiian island of Oahu (Swedberg, 2008d). The system aimed to improve the asset visibility as materiel is transported both onto and off of the island. The bases receive and ship materiel destined for troops or other bases, or broken equipment that need to be shipped to the mainland for repair. A data-on-remote database is followed in the process. When an item arrives at the warehouse, it is tagged with an EPC Gen 2 passive UHF RFID tag, then scanned and linked to information about that item. As the item enters or exits a dock door at the facility, an RFID portal consisting of fixed readers reads its tag. Data from each tag is captured by the readers is transmitted to the back-end system. When a driver picks up a tagged item, he employs a handheld computer with a built-in RFID reader to scan the tag once more, indicating the item has been picked up by the driver. Upon delivering the item to another base, the driver again scans the RFID tag. The Navy now has a visibility into when an item is shipped, what time it is expected to arrive at its next location or its whereabouts if it is delayed (Swedberg, 2008d).

The only people tracking application was conducted during the war in Iraq, where the U.S. Navy piloted Tactical Medical Coordination System which uses RFID to track injured soldiers as they move from the battlefield to hospitals (Yoshida, 2003). In order to make sure that relevant data are moving with the soldier himself, a data-on-tag approach is followed and tags with 2 Kb memory capacity that allow to store both a unique identification number, and the injury record as well as the treatment, are used. Figure 3.13 shows a soldier wearing an RFID wristband, and the process of reading information from the wristband via a handheld RFID reader. The military also deployed wireless LANs in Iraq to transfer patient information collected from the RFID tags to an electronic patient-management system, which eliminates the need to manually reenter data in a central computer.

Table 3.16 : Summary of the object tracking applications in defense industry.

	Data storage	Type of tag	Frequency	Type of data stored
Asset (5)	Data-on-remote DB (2)	Passive	UHF (915 MHz)	Information related to inventory of electronic assets (e.g., laptops) (e.g., description, serial number, the person to whom the asset is assigned, location where the asset is expected to reside, division's number).
Asset (5)	Data-on-remote DB (2)	Active	UHF (430 MHz)	Identifying whether the tanks are friendly by using the tag ID number and determining their location by the use of GPS.
Asset (5)	Integrated data storage (3)	Active	UHF (900 MHz)	**Data on tag:** Maintenance data of vehicles, sensor data (i.e., speed, mileage, impact information). **Data on remote DB:** Records of vehicle usage and maintenance schedule of vehicles.
Asset (5)	Integrated data storage (3)	Active	N/A	**Data on tag:** Environmental conditions of deployable medical systems (DEPMEDS) **Data on remote DB:** Visibility and management of real-time information of assets such as containers, trailers, generators, water purification units.
Asset (5)	Integrated data storage (3)	Battery-assisted	UHF	**Data on tag:** Number of firing number of tanks. **Data on remote DB:** Records of tanks that are being tracked to identify their needs for service and replacement.
Materiel (2)	Data-on-remote DB (1)	Passive	UHF	Information related to shipment and receipt of an item (i.e., supplies, materiel, broken equipment to be shipped to mainland), time of shipment and arrival, whereabouts of a shipment.
Materiel (2)	Integrated data storage (1)	Passive	HF (13.56 MHz)	**Data on tag:** Date of manufacture, service or maintenance records, specifications related to emergency survival equipment (e.g., life rafts, life jackets) **Data on remote DB:** Identification and tracking of emergency survival equipment.
People (1)	Data-on-tag (1)	Passive	HF (13.56 MHz)	Identifier information about the wounded person, injury records, treatment records.

Table 3.16 gives a summary of the object tracking applications within the defense industry, in terms of the tag types used and the information stored both on tags and/or on remote databases.

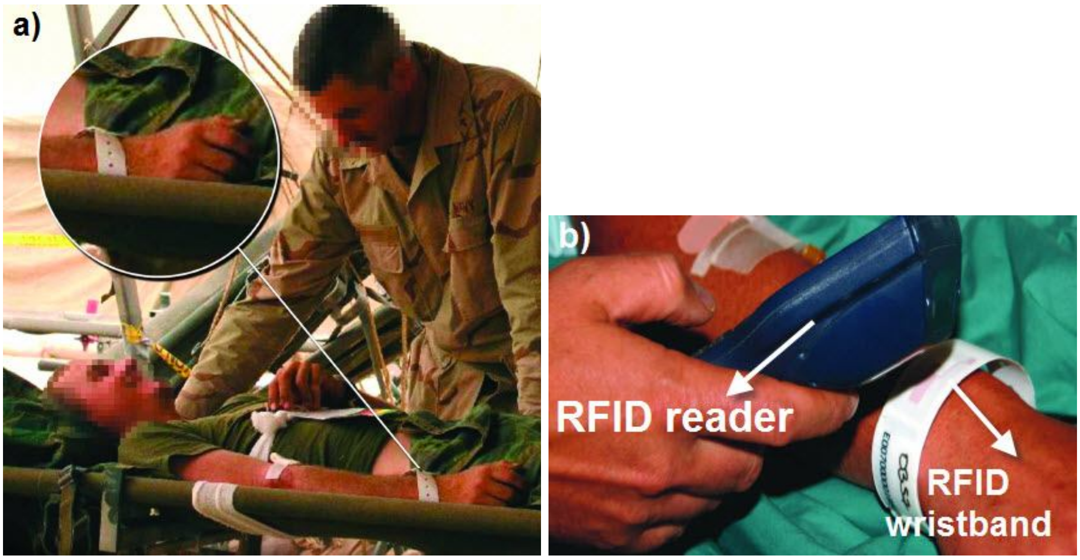

Figure 3.13 : (a) Soldier wearing RFID wristband, (b) RFID wristband is being read with a handheld reader (Url-47).

3.2.2.3 Localization applications

This category comprises of localization applications that utilized RFID technology to determine the location of stationary objects (e.g., medical devices and equipment) in facilities (e.g., medical center, army depot). In this category, both data-on-remote database and integrated data storage approaches are used. For example, Walter Reed Army Medical Center, one of the largest medical treatment facilities within the U.S. DoD, is using a real-time location system (RTLS) for tracking 4,000 pieces of equipments and assets throughout the 1.1-million-square-foot (i.e., around 102,000-square-meter) facility (O'Connor, 2007). Active RFID tags operating at 2.48 GHz are employed and data-on-remote database approach is followed where the tags transmit their unique IDs over the ZigBee communications protocol, to small receivers, namely access points. These tags and receivers also function as transceivers, communicating with each other through the mesh networking protocol where one tag can pass data to a main access point (called a bridge) by first sending it to another tag. In the network, a tag can send data to a bridge through up to five other tags and receivers. The receivers forwards the first tag's ID number and signal strength, along with the time it was read and the ID of the transceiver that picked up its signal, to a bridge. There are generally two bridges installed on each floor of a facility all of which links to a central server via an Ethernet cable. The server calculates the location of all tagged assets and display this information is on a map of the facility. Additionally, any computer linked to the system's local area network (LAN) can access the map and search for a specified type of asset. The software can provide the asset's location to an accuracy level of 1 to 3 meters where a proprietary algorithm to determine asset locations, based on the tags' RF signal strength is used by the technology provider (O'Connor, 2007).

At another medical center in Ohio, the Wright Patterson Medical Center, a passive RFID system is tested, which is designed to help the hospital track medical equipment critical for patient care (Url-27). EPC Class 1 Gen 2 UHF tags are affixed to medical devices and equipment, such as emergency aspirators, electrocardiogram monitors, defibrillators, infusion pumps, monitors, wheelchairs, beds. Readers are positioned at proper points at different floors and zones to accurately find tagged equipment in both storage areas and passage zones (i.e., surgical unit to intensive care unit, surgical unit to medical equipment maintenance center) within the hospital. When tagged equipment passes through any of the choke points, the fixed readers read each tag's unique ID number and send that information to back-end software. There the ID is associated with the information about the medical device and its location can be monitored (Url-27).

On the other hand, the U.S. Army conducted an RFID pilot at the Tobyhanna Army Depot followed an integrated data storage approach (O'Connor, 2005a). This depot is a full-service repair, overhaul and fabrication facility servicing surveillance and radar systems, where it utilized an RFID-based real-time location system (RTLS) to streamline the process of overhauling U.S. Army radar antenna systems. The antenna systems are sent to the Tobyhanna facility for refurbishment about every five years, where each system is disassembled, repaired and tested before being returned to use, which can take up to 15 months. The RFID system aims to automate the tracking of individual parts and assemblies of radar systems as they are refurbished in order to prevent them from being lost and have a better asset visibility. Active 2.4 GHz RFID tags were attached either directly to large antenna components (e.g., a radar dish), or to containers used to transport assemblies or subassemblies of small items that are deconstructed for refurbishment. The tags transmitted a 32-bit unique ID number, as well as 12 bytes of supplementary data determined by Tobyhanna personnel, and were associated in a database with the assets to which they were attached. RFID readers placed throughout the facility and surrounding grounds for the Army personnel to locate items more easily. RFID readers scanned the tags, recorded the read times and sent that information to the server, which processes the RFID data and calculates the distance of the tag. Personnel also used the software to access a graphical map illustrating the locations of the tags within the facility (O'Connor, 2005a).

Table 3.17 : Summary of the localization applications in defense industry.

Data storage	Type of tag	Frequency	Type of data stored
Data-on-remote DB (2)	Active	Microwave (2.48 GHz)	Tracking the real-time location of medical equipment and devices.
	Passive	UHF	Tracking the location of medical devices and equipment as they pass by the readers, information related to them.
Integrated data storage (1)	Active	Microwave (2.4 GHz)	**Data on tag:** ID and additional information related to individual parts and assemblies of radar systems. **Data on remote DB:** Information about both the container that carry the parts and the parts inside the container; map of the facility, locations of the containers on the facility map.

In Table 3.17, applications that are related to localization in defense industry are summarized in terms of the data storage concepts they applied, the tag types they utilized, and the information items they stored on tags and/or on remote databases.

3.2.2.4 Applications related to security

There are three cases related to security. One of them is being implemented to prevent theft and pilferage along the southern transport route between Pakistani ports and U.S. troops in Afghanistan (Url-21). The U.S. military containers are equipped with active RFID tags, that work as container intrusion detection devices (CIDD). These tags, as shown in Figure 3.14, are written with content data and then secured in the container door and the intrusion sensors are activated using a handheld reader. Once the alarms and parameters are set, any breach will be visibly displayed on the In-Transit Visibility portal throughout the journey of the container.

Figure 3.14 : Sensor integrated active RFID tags used at container doors for intrusion detection (Url-28).

The CIDD detects any unauthorized intrusion into the container and provide an alert at the next RFID reader that reads the tag (Url-21).

Rest of the two security applications utilize passive RFID tags and follow data-on-remote database approach. One of these cases aimed access control at Fort McPherson, a U.S. Army base in Atlanta, where an RFID system tracks the vehicles pass through the main gate (Southerland, 2003). The system works similar to highway tollbooths, where the drivers attach tags to their windshields which allow them to speed through the gates without stopping to drop in money, since the readers at the tollbooths recognize the tag and deduct the appropriate amount from the driver's account. Within the Army's application, initially five thousand vehicles and drivers, most of whom are military personnel and civilian base workers, are registered as part of the test phase and basic information about each person, (e.g., the basic facts found on a driver's license, vehicle type, color, photos of vehicle and the driver, and level of access granted) is entered to a secure, private database. Data-on-remote database approach is followed and an RFID tag is mounted in the upper portion of the driver's side windshield, while fixed readers are mounted in the entrance lanes at the main gate. When a vehicle enters the readers' 15 ft (i.e. about 5 meters) range, the tag's unique 16-character code is read, which is associated with records stored in the database. Based on the information, the system then either grants or denies access of the vehicle into the Army base (Southerland, 2003).

Other security related application is at a U.S. Army ammunition depot in Utah, Tooele Army Depot, where a passive RFID verification system was installed to authorize the use of keys in order to gain entry to stored munitions (Robertson, 2004). Each key is fitted with a passive RFID tag key chain with its identification.

Thus, the data-on-remote database approach was followed where the readers, which are connected with a computer database, read the tags and identify the authorized users and their privileges (Robertson, 2004).

In Table 3.18, applications that are related to localization in defense industry are summarized in terms of the data storage concepts they applied, the tag types they utilized, and the information items they stored on tags and/or on remote databases.

Table 3.18 : Summary of security related applications in defense industry.

Data storage	Type of tag	Frequency	Type of data stored
Data-on-remote DB (2)	Passive	N/A	Basic information from a driver's license, vehicle type, color, photos of vehicle and the driver, and level of access granted to the driver.
	Passive	N/A	Information about the authorized users and their privileges.
Integrated data storage (1)	Active	UHF	**Data on tag:** Content of the container, sensor data (i.e., intrusion). **Data on remote DB:** Information related to the journey of the containers (e.g., any breach is visible on the ITV network)

3.2.2.5 Analyis of the cases in defense industry

Sixteen RFID cases, which are divided into four main categories, are investigated within the defense industry. Half of the cases (i.e., eight out of sixteen cases) followed the integrated data storage approach which is observed to be the mostly preferred data storage method in this industry. Furthermore, in one application, case-related data are solely stored on tags. As a result, there are nine cases that stored additional data on RFID tags, in total. Remaining seven cases utilized RFID only as a means of identification and thus, followed a data-on-remote database approach.

Active RFID tags are more frequently (i.e., nine out of sixteen cases) utilized than the passive RFID tags (i.e., seven out of sixteen cases) within the defense industry applications. These results are in accordance with the memory capacity requirements of the integrated data storage method, which is the mostly preferred approach in this industry. Since, this approach requires the RFID tags to be able to store additional data in their memories, active tags, thanks to their large memory capacities, are more likely to be utilized in this kind of applications (Table 3.19). Out of nine cases that utilized active RFID tags, seven of them were used in applications which followed the integrated data storage approach.

Table 3.19 : Characteristics of the cases in defense industry and the type of data stored on tags and/or remote databases.

		Tag types	Type of data stored
Data-on-tag	**1 case**	1 Passive (HF)	Identifier information about the wounded person, injury records, treatment records.
Data-on remote DB	**7 cases**	1 Active (UHF), 1 Active (Microwave); 3 Passive (UHF), 2 Passive (N/A)	- Basic information from a driver's license, vehicle type, color, photos of vehicle and the driver, and level of access granted to the driver. - Information about the authorized users and their privileges. - Tracking the real-time location of medical equipment and devices. - Tracking the location of medical devices and equipment as they pass by the readers, information related to them. - Information related to shipment and receipt of an item (i.e., supplies, materiel, broken equipment to be shipped to mainland), time of shipment and arrival, whereabouts of a shipment. - Identifying whether the tanks are friendly by using the tag ID number and determining their location by the use of GPS. - Information related to inventory of electronic assets (e.g., laptops) (e.g., description, serial number, the person to whom the asset is assigned, location where the asset is expected to reside, division's number).
Integrated data storage	**8 cases**	4 Active (UHF), 1 Active (Microwave); 1 Active (N/A); 1 Battery-assisted (UHF); 1 Passive (HF)	**- Data on tag:** Environmental conditions data monitored by sensors (e.g., temperature, humidity, etc.), content of cargo containers, consignment and shipment details of containers. Additional data storage at reading points during shipment. **Data on remote DB:** Graphical maps that track the journey of a consignment that is used for searching and finding consignments, historical data about the journey of a consignment, point and time of readings of tags to track their shipment, environmental conditions data temporarily stored on tags. - **Data on tag:** Content of the container, sensor data (i.e., intrusion). **Data on remote DB:** Information related to the journey of the containers (e.g., any breach is visible on the ITV network). - **Data on tag:** ID and additional information related to individual parts and assemblies of radar systems. **Data on remote DB:** Information about both the container that carry the parts and the parts inside the container; map of the facility, locations of the containers on the facility map. - **Data on tag:** Date of manufacture, service or maintenance records, specifications related to emergency survival equipment (e.g., life rafts, life jackets) **Data on remote DB:** Identification and tracking of emergency survival equipment. - **Data on tag:** Number of firing number of tanks. **Data on remote DB:** Records of tanks that are being tracked to identify their needs for service and replacement. - **Data on tag:** Environmental conditions of deployable medical systems (DEPMEDS) **Data on remote DB:** Visibility and management of real-time information of assets such as containers, trailers, generators, water purification units. - **Data on tag:** Maintenance data of vehicles, sensor data (i.e., speed, mileage, impact information). **Data on remote DB:** Records of vehicle usage and maintenance schedule of vehicles.

HF: High Frequency, UHF: Ultra High Frequency, N/A: tag type/frequency not available.

Moreover, the majority of these seven cases (i.e., six out of seven) benefited from the advantage of using active tags integrated with various sensors (e.g., humidity, temperature, and shock sensors). Active tags that are utilized by the U.S. DoD have the largest memory capacity available today, which is 128 KB. These tags, also known as data-rich tags, are able to store the whole manifest about a container that is being shipped through the global supply chain network of the U.S. Military, namely the In-Transit Visibility Network. Furthermore, these tags are integrated with sensors and providing a way of monitoring the environmental conditions of the military containers that are being transported from army distribution centers to the soldiers in the battlefield (Robertson, 2004). Active RFID tags on the containers could be automatically read by fixed stations along the shipping route of the container as well as by handheld readers in the field. This ensures the availability of the data without the need to connect to a network, thus shortens the time required to access data. Similar approach is utilized within the supply chain network applications of NATO and allied defense forces, as well. Active tags are used to store consignment and shipment details and combined with sensors to monitor conditions of shipments. Within one case additional data storage is fulfilled by utilizing passive tags with memory of 2000 bits (Url-26). These tags are used to store the date of manufacture, service and maintenance records and other specifications of the clothing and emergency survival equipment of the French Army.

The only application of storing all the data on the tag was a pilot project which is carried out during the war in Iraq where the injured soldiers are identified and tracked (Yoshida, 2003). It is aimed to make the relevant data available with the soldier himself wherever he goes, and thus passive RFID tags in the form of wristbands with memory of 2 Kb are used. All the patient information such as the injury record and the treatment information are directly stored on the tags.

There are two applications where active tags are used but no additional data are stored in the memory of tags. Both of the applications are performed in large areas where they need to identify (Swedberg, 2007b) and locate (O'Connor, 2007) the tags and thus required self signaling tags and long reading ranges. Other five cases that followed the data-on-remote database approach utilized passive RFID tags where various asset/equipment (e.g., medical devices, electronic assets) and military materiel are tagged. Three of these applications aimed to keep track of these objects within facilities such as depots, medical centers where tagged objects pass through RFID-enabled portals or zones, or taken inventory by hand-held readers. Remaining two cases utilized passive tags for access control with security purposes.

3.2.3 Retail industry

Major retailers throughout the world, such as Wal-Mart in the U.S., Metro in Germany, Tesco in the U.K., and Carrefour in France, are driving the adoption of RFID technology within the retail business, in which the technology is anticipated to be adopted widely worldwide by 2015 (Banks et al. 2007) and even small companies will be able to place RFID tags on their outbound shipments in time (Url-29). This RFID initiative in retail industry is started by Wal-Mart in 2003, when it announced that its top 100 suppliers would be required to put RFID tags carrying EPC on pallets and cases, by January 2005 (Banks et al. 2007, Url-30). This is followed by several other large vendors throughout the world, such as Home Depot, Best Buy, Alberston's and Target in the U.S., and Metro Stores and Tesco in Europe (Banks et al. 2007; Myerson, 2007). Lots of supplier and manufacturer companies worldwide affected by this trend due to the size of these organizations. It is still expensive to fully apply the technology within the item level, since for some products the cost of the RFID tags are more than the cost of the product itself. However, RFID is proven to have opportunities in improving the operations in terms of efficiency and effectiveness, and decreasing the operating costs significantly and holds great promise for the retail industry (Banks et al. 2007; Myerson, 2007).

Sixteen real-life cases that leveraged RFID technology within the retail business are investigated within this research (Table 3.20).

Table 3.20 : Categorization of the investigated cases in the retail industry.

<table>
<tr><th colspan="2">Category</th><th>Number of cases</th><th>Purpose</th></tr>
<tr><td rowspan="4">Product tracking</td><td>Item-level tracking</td><td>5</td><td rowspan="3">Tracking the retail products (e.g., apparel items, food, meat, etc.) through the shipment, delivery and receiving processes for inventory management.</td></tr>
<tr><td>Pallet-level tracking</td><td>6</td></tr>
<tr><td>Container-level tracking</td><td>2</td></tr>
<tr><td>Tracking environmental conditions</td><td>3</td><td>Tracking the environmental conditions of foods (e.g., ice cream) during transportation and/or at the store.</td></tr>
</table>

Majority of the sixteen cases are related to identification and tracking of the retail products in different levels of interest, namely item-level, pallet-level, container-level (i.e., thirteen out of sixteen cases). RFID tags are applied to cases and pallets of goods, or to the goods themselves, to be able to track them through their shipping, delivery and receiving steps, and to better manage their inventory. Furthermore, there are other cases where the environmental conditions of perishable foods (e.g., ice cream) are tracked with the help of RFID technology (i.e., three out of sixteen cases).

Data storage approaches were investigated for each case in each category with the purpose of understanding the conditions that lead to different data storage methods. The characteristics and data storage needs of the applications are identified and examined.

3.2.3.1 Item-level tracking applications

There are five cases in implementing the RFID technology for tracking the retail goods in item-level, all of which follows data-on-remote database approach and utilizes passive RFID tags. For example, a Turkish apparel retailer, LC Waikiki, is using an RFID system to manage inventory and replenish stock in two of its stores in Istanbul and plans to extend the implementation to 50 of its stores through the country (Bacheldor, 2008d). Additionally, they combined the RFID technology with acousto-magnetic Electronic Article Surveillance (EAS) technology to prevent theft. The company attaches EAS-RFID tags to its garments before putting them out on the sales floor, where the tags include an EPC Gen 2 RFID inlay and a 58 kHz acousto-magnetic EAS that are embedded in a thick plastic case (Figure 3.15). The deployment follows a data-on-remote database approach and includes handheld and fixed RFID readers, EAS portals and software integrated with the retailer's inventory-management and point-of-sale systems.

Figure 3.15 : Hard plastic EAS-RFID tags are attached to garments prior to being put out on the sales floor (Bacheldor, 2008d).

Clothing is attached with the combination EAS-RFID tags as they are received from the distribution center. Tags are then encoded and the clothes are placed in RFID-enabled cabinets in the stock room. When apparel needs to be moved from the stock room onto the sales floor, they are placed in an RFID-enabled bin used to transport the clothes, and the inventory is updated in real time. An employee then moves the bin to the sales floor, where the clothes are put on display shelves and racks. When an item is purchased, an RFID reader at the sales counter reads the tag, and updates the inventory once more. The tag is then removed for later reuse on another garment. An EAS portal at the front door would detect the tag's EAS component and sound an alarm if a person were to attempt to take an item out of the shop with the tag still attached to it. Simultaneously, an RFID reader deployed at the door would identify the items being stolen (Bacheldor, 2008d).

Another apparel retailer, American Apparel, one of the largest apparel retailers in the world, is tagging individual garments with RFID tags, to achieve item-level visibility within several of its stores in the United States (O'Connor, 2008b). The company attaches hangtags that are integrated with EPC Gen 2 inlays to all of its items bound for RFID-enabled retail locations. The stores, where RFID pilots are being conducted, are installed with RFID readers, and the tags are read to track inventory within the store and to identify the purchased items. Readers read each garment's RFID tag at the point of sale and transmit this data to the software, which triggers an alert on a computer monitor in the stock room as soon as the item is sold. A worker then pulls a number of that garment from the stock room and brings them to the sales floor. As items are being brought to the sales floor, a reader mounted around the doorway between the stock room and sales floor, reads their tags and sends this information to the software which updates the inventory of the store (O'Connor, 2008b).

A research conducted by the RFID Research Center at the University of Arkansas in the apparel retailer Bloomingdale's stores, where RFID tags are put on individual apparel items (Hardgrave et al., 2009). The study shows that inventory accuracy decreases or diminishes over time with conventional systems that rely on barcodes and/or human counting to track inventory. The investigation included two Bloomingdale's stores one of which was a test store with an automated RFID-enabled system and the other was a control store with Bloomingdale's inventory-management system. During the 13-week project EPC Gen 2 passive UHF RFID tags were placed on men's and women's denim jeans at the test store. The tags were attached to the items as they arrived at the test store, and sales staff was instructed to remove the tags at the point of purchase. Staff was supplied with handheld RFID readers for inventory tracking and RFID readers were mounted at all employee and customer exits and entrances in the test store, to monitor the tagged item was leaving or entering the store (Hardgrave et al., 2009).

Another large apparel retailer, Marks and Spencer (M&S) is using RFID in item-level within its 42 stores, which is the world's biggest item-level use of RFID (Url-31), and plans to extend the usage of the technology to 120 stores (McCue, 2006). The RFID tags are contained in throwaway paper labels attached to a variety of men's and women's clothing items in stores. To scan garment tags, M&S uses mobile scanners on the shop floor. Differently, portals are used at the distribution centers and the loading bays of stores which enables the staff to push through and read rails of hanging garments.

Table 3.21 reports the type of tags utilized within the item-level tracking applications as well as the information stored on remote databases.

Table 3.21 : Summary of the item-level tracking applications in retail industry.

Data storage	Type of tag	Frequency	Type of data stored
Data-on-remote DB (5)	Passive	UHF	Real-time tracking of the inventory and status of apparel (e.g., in stock room, on sales floor), trigger alarms in case of theft.
	Passive	UHF	Information related to the inventory of garments within the store, identification of purchased items to determine stock levels, triggering alerts in case of out-of-stock situations.
	Passive	UHF	Inventory management of garments (i.e., denim jeans) at the store.
	Passive	HF (13.56 MHz)	Tracking the garments (e.g., men's suits, trousers, jackets, women's casual trousers, skirts and suits) at distribution centers, loading bays and at the shopfloor level.
	Passive	N/A	Information related to food packages (i.e., food's ingredients, place of origin, manufacturer's message, cooking suggestions).

Different then the other three item-level tracking applications where the products that are being tracked are apparel items, a supermarket food retailer in Japan, Maruetsu Inc., tested the use of RFID tags on food packages (Lee et al., 2008). During the tests, RFID tags were put on about 90 items. When a customer holds the tag up to one of the four scanners in the store, he/she was able to obtain detailed information about food's ingredients, place of origin, the manufacturer's message and cooking suggestions. According to the company, sales of the items with tags increased significantly during the test period (Lee et al., 2008).

3.2.3.2 Pallet-level tracking applications

All of the six cases that track retail products in pallet-level follow the data-on-remote database approach and utilize passive RFID tags. For example, Norway's largest food supplier, Nortura, is employing RFID to track meat from its processing plant to the store (Url-32). Right after they are born, animals get an individual ear tag which follows the animal throughout its entire life. In the processing plant, animals are divided into portions of meat and placed in plastic transport containers which are called totes. Totes are tagged with unique EPC numbers that are associated with the animal's farm of origin, age and health records. Each time the product moves through subsequent stages (e.g., slicing the meat into smaller pieces or grinding it into sausage and hamburger), adjacent RFID readers record the time, date and location of each procedure and send it to a server. Data-on-remote database approach is followed and the same scan-and-record process occurs when the meat is packaged and delivered from the plant, received at the distribution center, sent to the stores and finally received at the back of the supermarket. In this way, the product's movements and history all the way back to its origins can be tracked (Url-32).

The German retailer, Metro, is using the RFID technology to track pallets loaded with food products at all of its food markets in Germany and at least eighty nine in France (Swedberg, 2009e). After the vendors ship pallets loaded with cases of food and other goods to nine Metro Group distribution centers (DCs) in Germany, the products are stored until they are packed on new pallets and shipped to Metro stores. When one of Metro's DCs receives an order from a store, employees pick the requested cases of goods and place them on mixed pallets to be shipped to the site, tag those mixed pallets with one RFID tag and encode them with a unique ID number. As the pallets are loaded onto trucks, RFID readers capture the ID numbers of pallet tags, and send it to software running on Metro Group's server along with a date and time stamp. The software includes a database of pallet RFID tag ID numbers linked to the bar-code numbers of the products loaded on those pallets. This enables the software to interpret the RFID data and track when a pallet was shipped. RFID readers are also installed at the receiving docks of the retail locations to capture the ID number on each pallet's tag and to update the system when the pallets are delivered to the specific retailer (Swedberg, 2009e).

Similarly, another German retailer, Rewe started receiving tagged pallets from its suppliers after conducting a pilot to test the use of RFID tagged pallets and saw the benefits (Wessel, 2007). For the pilot, Rewe constructed six RFID receiving portals, fitted two forklifts with RFID readers and tested several handheld readers on 1,500 pallets all of which are attached with EPC Class 1 Gen 2 passive UHF tags.

Companies such as manufacturers, distributors and retailers can also rent pallets from pallet pools for use in their product shipping processes and then return them to the pool for reuse. Intelligent Global Pooling System (iGPS) is one of these pallet pools but offers a different solution where each plastic pallet have passive UHF EPC Gen 2 RFID tags that are embedded in the corners of the pallet during manufacturing (Figure 3.16).

A unique ID number is written on each of the four passive EPC Gen 2 RFID tags, which enable shippers and receivers to track and trace shipments in real time (Url-33).

Figure 3.16 : Plastic pallet equipped with RFID tags on the corners (igps.net).

For instance, Imperial Sugar Company, one of the largest processors and marketers of refined sugar in the United States, is using these tagged plastic pallets to track its shipments from the refinery to the stores (Swedberg, 2007c). As the sugar is refined and packaged at Imperial Sugar's plants, it is moved down a conveyer, stacked on a pallet and stretch-wrapped. At that time, workers input product data (i.e., the type of sugar, when it was refined and its destination), and fixed RFID readers capture the pallet's EPC number. Data-on-remote database approach is followed and the product data and pallet ID number are transmitted to a server on the plant floor, which directs the data to the company's warehouse management system via a cabled connection. There, the software directs the data to the database of iGPS, which stores the data regarding where the pallets are located, time a pallet spends with a customer and specific information about the return dates. All iGPS customers can also access that data. Once arrived at the retailer and unloaded, the pallets are sent to pooling areas located near major retail stores. At these sites, pallet's tag is read again, and the company is alerted that the pallet has been emptied and is ready for reuse (Swedberg, 2007c).

Type of tags utilized in pallet-level tracking applications, as well as the information they stored on remote databases, are reported in Table 3.22.

Table 3.22 : Summary of the pallet-level tracking applications in retail industry.

Data storage	Type of tag	Frequency	Type of data stored
Data-on-remote DB (6)	Passive	UHF	Details related to the meat product (i.e., type of meat (e.g., pork, lamb, beef), farm of origin, animal's age and health records), tracking the meat's movements through production processes and its history all the way back to its origins.
	Passive	UHF	Pallet RFID tag ID numbers linked with the barcode numbers of the products loaded on the pallets to interpret the RFID data and track shipment of pallets. Tracking of the delivery and receipt processes of pallets.
	Passive	UHF	Product records (e.g., product descriptions, number of boxes on each pallet, receiving orders) linked with each pallet's tag, tracking the delivery and receipt of shipments.
	Passive	UHF	Unique ID numbers of pallet tags, and the data associated with each number, history of the pallets (i.e., where the pallets have been used in the past, what was loaded on the pallets, etc.), location and status of the pallets, information about the product loaded on the pallets (e.g., type of sugar, time of refinement, destination, etc.), shipment, delivery and billing information.
	Passive	UHF	Times and dates of movement of pallets, their locations, information related to the product on the pallets, historical reports of pallets, shipment, delivery and billing information.
	Passive	UHF	

Several fresh food providers are also using the plastic RFID-enabled pallets made by Intelligent Global Pooling Systems (iGPS) such as Martori Farms, a produce grower in Scottsdale Arizona and HEB Grocery Co., in San Antonio, Texas, rather than the wooden ones without RFID tags (Swedberg, 2007d). The broccoli and melons Martori Farms grows is first shipped to distribution centers nationwide, and then transferred to local retailers. When Martori ships its products, the loaded pallets are carried through an RFID portal at its dock doors. The reader sends data to a server at the warehouse and linked to its LAN, using the iGPS software. This makes the data available at the iGPS database via the Internet where Martori and iGPS can access that data to confirm the shipment or receipt of the pallets at a specific location. Similarly, the Texan retailer HEB is using the same system at its San Antonio warehouse (Swedberg, 2007d).

3.2.3.3 Container-level tracking applications

There are two cases related to product tracking in container level, where one of them preferred an integrated data approach while the other is following a data-on-remote database approach.

The Metro Group, one of the world's largest retailers and a world leader in RFID deployments, started a project in which it employs the Savi Technology's SaviTrak Network to monitor the location and security of its inventory shipped from Asia to Europe, in real-time (Url-34). SaviTrak is a web-based real-time information service that is built upon a network of multiple automatic identification and data collection (AIDC) devices, such as bar-codes, EPC compliant passive and active RFID tags and Global Positioning Systems (GPS), that are deployed at global supply chain checkpoints (e.g., transportation terminals). RFID readers and other infrastructure has been installed at ocean transportation terminals throughout the world, thus shipments are monitored automatically as they move through each location (Url-35). Integrated data storage is followed within this application and the active tags on containers store information such as the container's identification, its contents and interior environmental conditions. Metro used active RFID tags on containers to automatically transmit information into the SaviTrak information service while they are transported from a consolidation center in Hong Kong, to the Port of Hong Kong, to the Port of Rotterdam, to the inland Port of Duisburg in Germany and finally to a Metro Group distribution center in Unna, Germany. In Table 3.23, summary of the data storage concepts applied in container-level tracking applications, as well as the type of tags used and the type of data stored.

Table 3.23 : Summary of the container-level tracking applications in retail industry.

Data storage	Type of tag	Frequency	Type of data stored
Data-on-remote DB (1)	Active	UHF	Supply chain management of cargo containers and tracking their shipment process, recording their locations on their way to the stores, distribution centers, etc.
Integrated data storage (1)	Active	UHF (915 MHz)	**Data on tag:** Container's identification information, its contents and interior environmental conditions monitored by sensors. **Data on remote DB:** Tracking the transportation process and the location of the shipments and containers of retail products throughout the global network, supply chain and inventory management.

A supermarket chain in Alaska, Safeway, is using a system of active RFID tags and readers to track its cargo containers transported by the shipping company Horizon Lines, which has installed an RFID infrastructure at terminals, distribution centers, and highway locations for its Alaska trade lane (Burnell, 2007). Data-on-remote database approach is being followed where active RFID tags on the containers transmit signals every few seconds and the readers along the lane capture the container's unique ID number while they are being transported. Via cellular connection, readers send the ID number and the time of reading to Horizon's portal where the data are made available to its clients. All the data about the container's contents is stored in the Horizon’s back-end system.

3.2.3.4 Tracking environmental conditions

RFID technology is utilized for tracking the environmental conditions of perishable goods (e.g., ice cream, fish, etc.) to ensure their quality and to avoid any spoilage. Typically active RFID tags that are integrated with temperature sensors are utilized within these applications and thus an integrated data storage approach is followed (3 out of 3). For example, during the deliveries of its frozen goods, the Swiss retailer Migros, utilizes active RFID technology integrated with temperature sensors that are mounted inside the trucks (Lampe et al., 2006). Each RFID tag stores a unique ID that is linked to a specific truck. The readers are mounted at the entry and exit of the warehouse and at the loading platforms. The readers are connected to the fleet management system of Migros and integrated data storage approach is followed. When a truck enters or exits the warehouse, the reader at the gate reads the truck ID and transmit it to the fleet management system along with the direction (i.e., entry or exit), and time information. If a truck is entering the warehouse, it is directed to a loading platform where a reader acquires the truck ID and the temperature information that is stored on the RFID tag during transport. The data are transferred to the fleet management system and an alert is given if the temperature has exceeded the permitted limits during transport. Otherwise the system provides the truck driver with a new tour. Similarly during the loading of a truck with frozen goods, a reader at the platform checks the temperature data from the RFID tag inside the truck. If the temperature is too high, the system alerts the driver to check the cooling unit (Lampe et al., 2006).

Similarly, the Italian arm of Swiss food company Nestlé is employing active RFID tags to track ice cream to ensure it stays frozen at prescribed temperatures while being moved through a massive cold-chain network from the production factories to distribution centers and to retail stores (Wessel, 2008b). During a pilot conducted in April 2007, temperature-sensing RFID tags and readers were placed at the production plants, distribution centers, cold storage areas and the trucks that are involved in the pilot. When a large truck carrying a sensor reached the production plant, the reader picked up the signal from the active tag inside the cold storage area at the production plant. Readers at the distribution center collected time and temperature readings recorded by the tag within the truck while goods were moving between sites. The final reading occurred when small trucks, also equipped with readers, approached shops and collected data from tags mounted within the shops' freezers. When the truck returned to the depot, all data saved on the truck's reader was collected by another reader, which then transferred that data to a database. Integrated data storage approach was followed where each sensor tag carries a unique ID number, which is associated in a database with the freezer, dock, storage area or truck information. Additionally the tag logs the temperature data and time the temperature was taken (Wessel, 2008b).

Cases in this category benefited from the temporary storage function served by the additional environmental conditions data that is stored on sensor integrated tags.

Table 3.24 gives the details on the data storage concepts followed in environmental conditions tracking applications, the type of tags they utilized and the data that they stored on tags and/or on remote databases.

Table 3.24 : Summary of the environmental conditions tracking applications in retail industry.

Data storage	Type of tag	Frequency	Type of data stored
Integrated data storage (3)	Active	UHF	**Data on tag:** Temperature conditions recorded during transport. **Data on remote DB:** Real-time information on arriving and departing trucks and their records of temperature conditions during transport, triggering alerts if the temperature has deviated outside the permitted ranges.
	Active	UHF (868 MHz)	**Data on tag:** Temperature data and time records of ice-cream produts on their way from production factories to distribution centers, and to retail stores. **Data on remote DB:** Sensor-integrated tag ID number, linked with freezer, dock, storage area and truck information, records of temperature readings with time information.
	Active	UHF	**Data on tag:** Temperature conditions of freezers and refrigerators at stores **Data on remote DB:** Monitoring the temperature measurements of the freezers and refrigerators at stores, their locations, alerting if the temperature exceeds the predefined temperature limits.

Different than the other two environmental conditions tracking applications, Switzerland's largest retail chain, Manor, is using active tags with built-in sensors to track the temperatures of freezers and refrigerators at about 30 of the company's supermarkets across the country rather than during their transportation (Wessel, 2008a). The system measures and logs the temperatures of 1,800 freezers and refrigerators every 10 minutes and a team monitors the temperatures during operating hours. Integrated data storage approach is followed where each tag contains a temperature sensor and a 16-kilobyte memory module able to hold 8,000 temperature readings. Specially designed RFID readers are mounted in a store's ceiling. Every 15 minutes, the gateways forward the tag data they have collected to a server. The system is designed to alert the operators in predefined situations such as a refrigerator containing fish becoming warmer than 2 degrees Celsius or colder than -1 Celsius. Store managers can monitor the temperatures on a Web site which also includes maps of stores indicating the tags' locations. Also on the web site, managers can inform system monitors about their cleaning plans for freezers and refrigerators, to ensure that unnecessary alarms are not generated (Wessel, 2008a).

3.2.3.5 Analysis of the cases in retail industry

Among the sixteen RFID cases investigated within the retail industry, none of them preferred the data-on-tag approach. Most of the cases (i.e., twelve out of sixteen) followed the data-on-remote database approach and stored the information on computers (e.g., servers). Those computers are used for running the software that manages specific processes (e.g., warehouse management software for managing inventory) or containing the databases where information related to products (e.g., inventory conditions: out-of-stock, sold, received, delivered, etc.) is stored. These applications typically used passive RFID tags, since no information other than an identification number is stored on tags. Only one case utilized active RFID tags but preferred to store data on a remote database rather than on the tags (Burnell, 2007). Active tags are needed for their self-signaling and long reading range features within this application.

Remaining four cases followed an integrated data storage approach and utilized active RFID tags that are integrated with sensors (e.g., temperature). These applications aimed to track the environmental conditions of the retailers' products both during their shipments between product plants to distribution centers and finally to stores and only at the time they spent at stores. RFID technology integrated with temperature sensors enables the retailers to determine if the limits that the foods supposed to stay in between, are exceeded. This ensures that the food (e.g., fish, ice cream) is sold without being spoiled and in good quality. Active tags can also be used to store the contents of a container during transport such as in the case where the Metro Group's containers are tracked (Url-34).

Table 3.25 summarizes the types of tags utilized and the data storage concepts applied in retail industry, as well as the information items stored on tags and/or remote databases. It is observed that the retail industry typically prefers using RFID tags as a means of identification and tracking the inventory of products within the retail processes such as shipment, delivery and receipt. Thus, data-on-remote database approach is usually followed and RFID tags are used to store only an ID number (e.g., EPC) that references the product-related data being stored on computers. Consequently, passive tags are leveraged more frequently with regard to their low data storage capacities.

Table 3.25 : Characteristics of the cases in retail industry and the type of data stored on tags and/or remote databases.

		Tag types	Type of data stored
Data-on remote DB	**12 cases**	1 Active (UHF); 1 Passive (HF), 9 Passive (UHF); 1 Passive (N/A)	- Supply chain management of cargo containers and tracking their shipment process, recording their locations on their way to the stores, distribution centers, etc. - Times and dates of movement of pallets, their locations, information related to the product on the pallets, historical reports of pallets, shipment, delivery and billing information. - Unique ID numbers of pallet tags, and the data associated with each number, history of the pallets (i.e., where the pallets have been used in the past, what was loaded on the pallets, etc.), location and status of the pallets, information about the product loaded on the pallets (e.g., type of sugar, time of refinement, destination, etc.), shipment, delivery and billing information. - Product records (e.g., product descriptions, number of boxes on each pallet, receiving orders) linked with each pallet's tag, tracking the delivery and receipt of shipments. - Pallet RFID tag ID numbers linked with the barcode numbers of the products loaded on the pallets to interpret the RFID data and track shipment of pallets. Tracking of the delivery and receipt processes of pallets. - Details related to the meat product (i.e., type of meat (e.g., pork, lamb, beef), farm of origin, animal's age and health records), tracking the meat's movements through production processes and its history all the way back to its origins. - Information related to food packages (i.e., food's ingredients, place of origin, manufacturer's message, cooking suggestions). - Tracking the garments (e.g., men's suits, trousers, jackets, women's casual trousers, skirts and suits) at distribution centers, loading bays and at the shopfloor level. - Inventory management of garments (i.e., denim jeans) at the store. - Information related to the inventory of garments within the store, identification of purchased items to determine stock levels, triggering alerts in case of out-of-stock situations. - Real-time tracking of the inventory and status of apparel (e.g., in stock room, on sales floor), trigger alarms in case of theft.
Integrated data storage	**4 cases**	4 Active (UHF)	- **Data on tag:** Container's identification information, its contents and interior environmental conditions monitored by sensors. **Data on remote DB:** Tracking the transportation process and the location of the shipments and containers of retail products throughout the global network, supply chain and inventory management. - **Data on tag:** Temperature conditions recorded during transport. **Data on remote DB:** Real-time information on arriving and departing trucks and their records of temperature conditions during transport, triggering alerts if the temperature has deviated outside the permitted ranges. - **Data on tag:** Temperature data and time records of ice-cream produts on their way from production factories to distribution centers, and to retail stores. **Data on remote DB:** Sensor-integrated tag ID number, linked with freezer, dock, storage area and truck information, records of temperature readings with time information. - **Data on tag:** Temperature conditions of freezers and refrigerators at stores **Data on remote DB:** Monitoring the temperature measurements of the freezers and refrigerators at stores, their locations, alerting if the temperature exceeds the predefined temperature limits.

HF: High Frequency, UHF: Ultra High Frequency, N/A: tag type/frequency not available.

3.2.4 Manufacturing industry

RFID mandates that are consequently issued both by major retailers, such as Wal-Mart and Metro Group, and the U.S. DoD, affected lots of supplier and manufacturer companies worldwide. As a result, most RFID projects are being implemented in warehouses and distribution centers by suppliers, generally with the purpose of complying with tagging mandates of their customers, such as Wal-Mart (O'Connor, 2008b).

Generally, a manufacturing business can be summarized as a three-step operation that includes (1) the inflow of raw materials into a factory, (2) production of goods, and (3) delivery of goods to the wholesalers. Manufacturers can benefit the use of RFID technology in various manufacturing areas such as work-in-progress tracking, quality assurance, parts identification, inventory control, production planning, and replenishment, as well as for tracking the returned products, returned pallets and containers and returned materials for disposal or recycling (Banks et al., 2007). Tracking the assembly and manufacturing processes with the help of RFID technology can increases the visibility and accuracy of the inventory control and management of parts and accessories that are utilized in production.

There are seventeen cases investigated within this industry, which are categorized into four groups: (1) Identification and tracking of the production processes, (2) object localization, (3) inventory and warehouse management applications, and (4) lifecycle information tracking applications. Largest group of cases is the inventory and warehouse management category with seven applications. In these applications, RFID is used to automatically update the inventory levels of both raw materials and finished products as they pass through RFID-enabled portals or read by handheld readers at certain points.

Another category consists of the five cases that utilized RFID for production process tracking of the goods as they are being manufactured. Four cases comprise the third group where RFID is leveraged to determine the exact location of products within a production plant, for example in the storage yard. Finally, there is one case where RFID tags are utilized in the manufacturing phase of a product and aimed to stay attached to the product throughout its lifetime. Detailed analyses in terms of data storage needs and characteristics of each case in each category are given in the following sections (Table 3.26).

Table 3.26 : Categorization of the investigated cases in the manufacturing industry.

Category	Number of cases	Purpose
Identifying and tracking the production processes	5	Identification and tracking of products while they are being manufactured.
Object localization	4	Determining the exact location of products (e.g., cars) within the production plant.
Inventory and warehouse management applications	7	Automated inventory and warehouse management (e.g., automatic update of inventory levels).
Lifecycle information tracking	1	Tracking data related to products (e.g. tires) throughout their lifecycles (e.g. time and place of manufacture, specifications).

3.2.4.1 Identification and tracking during production

There are five cases that leveraged RFID within the manufacturing processes to identify and track materials and parts as they become finished products. Both the data-on-remote database and the integrated data storage approaches are applied within these cases.

One of the two cases that applied the data-on-remote database approach, is an international company in Austria, which provides assembly and warehousing services for its customers who are mostly automobile manufacturers and tire wholesalers. The company uses RFID to track the assembly and shipment of wheels for its automotive customers (Wessel, 2009c). The company produces about 150,000 wheels annually and needs a way of identification for being able to distinguish between different customers' products and avoid any confusion. Thus, they utilize RFID tags on the tires and follow a data-on-remote database approach. After the foremen checks the production quality of the wheels and ensure the wheels are assembled correctly, an employee applies an adhesive RFID label onto each tire and loads them on pallets as stacks of ten, and then the pallets are read by RFID readers. The warehouse management system assigns a place for the pallet to be stored, and the pallet of wheels are moved to that storage area until a customer places an order.

With the customer’s order, employees pick the requested wheels and pack them on pallets and make them ready to be shipped out. The pallet is moved to a stretch-wrap machine, where another RFID reader reads the wheels' RFID labels and the system confirms that the wheels were picked correctly (Figure 3.17). If the picked products do not match the customer's order, the packing machine shuts down (Wessel, 2009c).

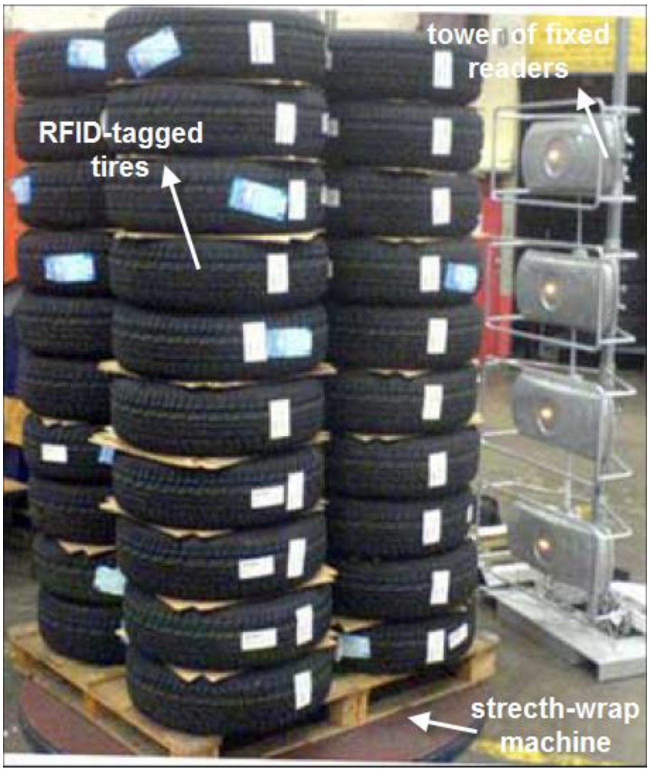

Figure 3.17 : RFID-tagged tire stacks on a stretch-wrap machine prepared for a customer order (Wessel, 2009c).

Similarly, the Dow Corning Corp., which is a global leader in silicon-based technology, utilizes RFID in tagging its 55-gallon drums that hold various silicone-based liquid products within its chemical processing area (Url-36). The tracking process starts with the tagging of 55-gallon drums in the manufacturing area and they are read by fixed readers at the dock door when exiting the area. RFID tags are enclosed in a protective plastic sleeve that is affixed to the drum and each drum is tagged individually, and then the 4-drum pallet is tagged, as well. After tagging, each pallet is transported to a repack area, where the products are transferred into smaller containers to fulfill customer orders, and tags are read once again at entry by a handheld reader. Information related to the products are stored in a database and a chain of custody or an electronic document for authentication, namely “ePedigree”, is created to enable the product’s track and trace process. As the liquids are transferred, tags are removed from the 55-gallon drums and sent to a decommissioning station where they are disassociated from the previous data and prepared for reuse (Url-36).

An integrated data storage approach is being followed where Honda Italia is employing a combination of active and passive RFID to track motorcycle production, ensuring that the proper components are installed on the motorcycles it produces (Wessel, 2009b). UWB RFID readers are installed along the 80-meter-long production line and an active tag is temporarily attached to each motorbike's chassis which stores the bike's vehicle identification number (VIN) written by a handheld reader. Thus, the location of the frame on the production line can be tracked during the entire production process. Additionally, to make sure that parts are not mixed up, and proper components are installed on the appropriate frames, containers of components are fitted with both passive tags with 1,024 bits of memory, and active UWB tags. The active tags allow operators to locate a particular container within the production zone, while the passive tags are used to hold critical information about the parts (e.g., the supplier code, part number, lot number and date of production). The passive tags are not read in the production zone since they are used to store additional information and link that data to the active tags via the database. Active tags, on the other hand, are constantly read during the production to continually confirm that the correct components are being assembled on the proper vehicle. Thus, RFID helps the company use proper parts on the right motorcycle frames (e.g., bikes to be shipped to UK, where vehicles are driven on the left side of the road in contrast to the U.S. or continental Europe, must have the correct headlight design). After the production is finished, the active tags are removed from the bikes (Wessel, 2009b).

Another manufacturer that followed an integrated data storage application is the Seagate Technology, which is recognized as the largest global producer of disc drives, magnetic discs, read-write heads and tape drivers (Banks et al., 2007). It is using a conveyor system which incorporates RFID technology and thus enables tracking the hard disks in real time as they go through manufacturing process to ensure their quality. Each disk is tagged with a passive RFID tag to be able to tracked and identified as it moves on the conveyor, and the processing information for the disk is stored on the tag. At each decision point along the assembly line, the data that is stored in the tags is read and sent to the host computer. Based on the specific routing information written on the tag, the host computer determines the direction of the disk within the manufacturing process. The computer tracks the information collected for each disk during manufacturing, to confirm successful completion of all preceding processes before entering the following process (Banks et al., 2007). Similarly, car manufacturer Ford at its Essex Engine Plant in Windsor, Ontario, is applying a data-on-tag approach where engine parts are equipped with active RFID tags that have a 32 KB memory capacity (Diekmann et al., 2007). In the beginning of the production process, the customization details, including the motor configuration, are loaded onto the tag. At each of the approximately two thousand work stations, the necessary production steps and quality controls are read out and acknowledged on the tag. In order to create a history of the assembly of each engine, the time and date of each stage is also stored and, each production step and quality control is made easily verifiable. If the engine fails to pass the quality check at any of these stages, it is directed to the repair station. At the end of the production, the data that has been collected on the tag is transferred to the central system to document the production and quality control processes (Table 3.27).

Table 3.27 : Summary of the applications related to identification and tracking during the production process in manufacturing industry.

	Type of tag	Frequency	Type of data stored
Data-on-remote DB (2)	Passive	UHF	Tracking the assembly and shipment of wheels, taking customer orders, assigning a location for wheels in the storage area.
	Passive	UHF	Information related to products (i.e., silicon-based liquid products), their chain of custody.
Integrated data storage (3)	Active	N/A	**Data on tag:** Customization details (e.g., motor configuration) of engines, record of production steps and quality control results. **Data on remote DB:** History of assembly of each engine (i.e., time and date of each production stage), records of production and quality control processes.
	Passive	HF (13.56 MHz)	**Data on tag:** Processing information of the disk drives. **Data on remote DB:** Routing the disk drives and determining their direction on the assembly line, based on the routing information read from the tags. Information related to disks collected while being manufactured.
	Active + Passive	Active UWB + Passive HF (13.56 MHz)	**Data on tag:** Critical information about motorcycle parts (e.g., supplier code, part number, lot number and date of production) on passive tags. Vehicle Identification Number (VIN) on active tags attached to motorcycle's chassis. **Data on remote DB:** Location of containers that carry the motorcycle components and parts, location of the motorcycle's chassis on the production line, tracking the production to ensure proper parts are used on the right motorcycle frames.

These applications that stored additional data on RFID tags and followed an integrated data storage approach took advantage of the informational and the documentational function served by the additional data stored on tags. The data storage concepts followed in applications where production process is tracked, and the type of tags they utilized in addition with the information they stored both on tags and/or on remote databases are given in summary in Table 3.27.

3.2.4.2 Localization applications

There are four applications where RFID technology is utilized to determine the location of products (e.g., cars) in a production plant. All cases investigated under this category followed a data-on-remote database approach. For example, the prestigious sports car manufacturer Aston Martin is using RFID as a means of real-time location system (RTLS) through its daily production operations at the company's headquarters in Gaydon, Warwickshire (Url-37). Ultra Wideband (UWB) active RFID tags are attached inside the windscreen of the cars as they begin their off-line finishing process in which they go through several tests and data-on-remote database approach is followed. Readers that are installed within the facility read the tags and transmit their ID numbers to the back-end Web-based server, where the software calculates the tag's location within about 6 inches (i.e., about 15 cm) and also links each tag's ID number with data about each car (i.e., its VIN and description) (Swedberg, 2009). Each time the car passes from one place to another, its new location is tracked through the facility, where the readers can receive signals from tags as far away as 150 meters outdoors, and 60 to 80 meters indoors. The tags are then removed when the car is dispatched to sales (Url-37). A similar approach is utilized by the vehicle manufacturer, Land Rover, where it tracks the finished cars in the shipping yard at its plant in Solihull, England (Swedberg, 2008a). When a vehicle completes its assembly, an active tag is hung from the rearview mirror or attached to the vehicle's interior door handle, the unique ID number of which is linked to the vehicle's VIN in Land Rover's back-end system. The active tag beacons every four minutes as the vehicle leaves the assembly line and passes through several portals on its way to testing, then to repair or to the 308 acre (i.e., about 1.25 square kilometer) yard. Data-on-remote database approach is followed and the vehicle's real time location can be tracked and viewed on a graphical map on the computer (Swedberg, 2008a).

Another automobile manufacturer BMW equipped a number of its factories with a real-time location system where the finished vehicles are tagged as they leave the production line and used by the BMW workers to instantly locate cars before they are shipped to dealers (Collins, 2005a). Data-on-remote database approach is followed and an active tag is placed on the front passenger seat of each completed vehicle as it is prepared to leave the production line. A worker scans the car's unique VIN that is printed on a bar-coded label attached to the vehicle, and also the unique ID encoded on the RFID tag. The two numbers are then linked in the RTLS database. The tag emits its unique tag ID number every four minutes and a network of RFID readers, linked together over a wireless LAN, detects the tag for all the time the vehicle remains at the plant. When it is time to do additional work or ship the car, the BMW staff can track the vehicle in real time on the company's intranet via a Web browser, also an application that graphically displays the car's location. When the vehicle leaves the plant, a worker removes the tag and returns it to the production line for reuse (Collins, 2005a).

Another manufacturer, Navistar Defense, which produces armored vehicles specially designed to withstand roadside bombs and other threats, is also employing a similar RFID-enabled real-time location system (RTLS) to track the assembly process of the vehicles, and makes sure they are delivered on time to U.S. troops in Afghanistan and Iraq (Bacheldor, 2008c). A 2.4 GHz active RFID tag is affixed to a vehicle's chassis, and every four minutes, it emits the unique ID number encoded to it. The location sensors capture that ID number and transmit it wirelessly to the access points. By tracking the vehicles' location in real time, Navistar Defense can determine where a vehicle is located within a particular process at any given time (e.g., initial painting, mounting the body and roof, installing the turret, finishing the inside trimming and adding the interior equipment, inspecting the vehicle, or testing the vehicle) (Bacheldor, 2008c).

The data storage concepts followed in localization applications along with the type of tags utilized and the information stored on remote databases are given in summary in Table 3.28. Cases in this category all utilized active tags to benefit from their long reading ranges and their self-signaling features. Localization applications necessitates a centralized management point-of-view, and thus cases in this category followed the data-on-remote database approach (Table 3.28).

Table 3.28 : Summary of the object localization applications in manufacturing industry.

	Type of tag	Frequency	Type of data stored
Data-on-remote DB (4)	Active	UWB (6-8 GHz)	Tracking the cars during their finishing process where they go through several tests according to their locations, along with the information related to the cars (i.e., Vehicle Identification Number (VIN) and description).
	Active	Microwave (2.4 GHz)	Tracking the location of cars on a graphical map, as they pass through several portals on their way to testing, then to repair area or to storage yard.
	Active	Microwave (2.4 GHz)	Tracking the location of cars on a graphical map during their time in the production plant.
	Active	Microwave (2.4 GHz)	Tracking the assembly process and the locations of cars in real-time as they go through several stages (e.g., initial painting, mounting the body and roof, installing the turret, finishing the inside trimming and adding the interior equipment, inspecting, testing).

3.2.4.3 Inventory and warehouse management applications

There are seven implementations of RFID technology within the inventory and warehouse management applications, all of which followed the data-on-remote database approach. For instance, an Australian telecommunications company Telstra carried out a three-month RFID trial during which the company tagged the packaging of 12,800 mobile phones and tracked them from its Sydney distribution center to six retail outlets around the nation, with a purpose of reducing the loss of mobile phones in the supply chain, and shrinkage at the retail stores (Friedlos, 2009). Data-on-remote database approach is followed where passive UHF EPC Class 1 Gen 2 tags were attached to the packaging of 12,800 mobile phones (Figure 3.18).

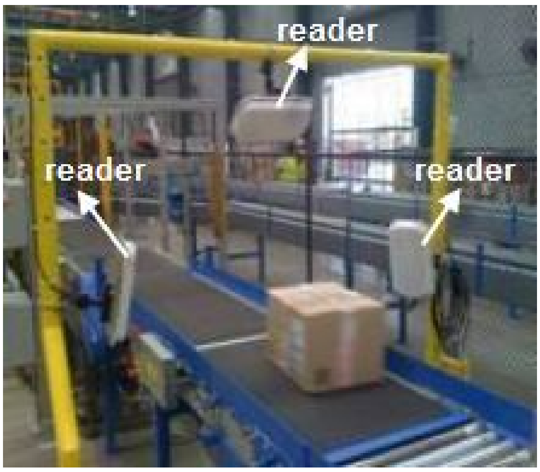

Figure 3.18 : RFID tagged packages of mobile phones moving on RFID-enabled packaging line (Friedlos, 2009).

The company installed RFID readers at the stock-room door and on the ceiling at the entrance in the distribution center and six retail outlets, where all readers are connected to a central server, and information is sent over Telstra's own LAN. Information is made available to the staff via a web-based portal thus providing the company with immediate access to data such as the inventory levels, goods lost in transit and transit time, which could trigger alarms for certain events, such as delayed delivery or out-of-stocks (Friedlos, 2009).

Philips Semiconductors performed a trial RFID project for its supply chain management that covered the tracking and tracing of wafer cases and carton packages for flows of goods between its manufacturing facility in Kaohsiung, Taiwan and its Asia Pacific distribution center in Hong Kong (Url-38). Every year, the company ships and tracks several million wafer cases and carton packages between this facility and this distribution center. At the manufacturing facility in Taiwan, microchips are typically packed into boxes or in plastic tubes that are then placed in cartons. Within the trial, data-on-remote database approach is followed and boxes are tagged with RFID tags. Workers then stacked the boxes on a pallet and used a handheld reader to read the tags on the boxes before they left the facility for Hong Kong distribution center and the inventory was updated. When the pallet arrived at the distribution center in Hong Kong, the RFID tags on the cases were read with a handheld reader and again, the inventory was updated automatically (Url-38).

Thermo King, an Irish manufacturer of heating, ventilation and air-conditioning equipment for vehicles such as buses, trains and trucks, is utilizing a Wi-Fi active RFID technology for inventory management of the parts used within the production processes (Url-39). The solution leverages Thermo King’s existing Wireless Network, which the staff also uses for data communications with laptops and handheld mobile computers, thus data-on-remote database approach is followed. Wi-Fi active RFID tags are mounted next to parts containers throughout the facility. The workers use the system at the production line by pressing call buttons located on tags when additional parts are needed. Additionally, when the parts quantity in a container reaches a pre-determined level, workers press the call button to request more parts. Battery-powered active tags transmit the request over the facility’s standard network to the software where these requests are processed, and appropriate materials replenishment steps are initiated (Url-39). A similar approach is utilized at a plant of the vehicle manufacturer Land Rover, in Solihull, England (Swedberg, 2008a). During assembly, if an operator notices the quantity of a specific part is decreasing, he or she presses a button on an active RFID tag on the assembly line for the tag to transmit its ID number, which is correlated to the specific part that requires replenishment. The receiver installed on the facility ceiling captures that ID number and sends it to a computer where the software running on the computer alerts warehouse staff regarding which particular part needs to be replenished, and where (Swedberg, 2008a).

A brick manufacturer company, Lee Brick and Tile Co., is using RFID to automate its inventory management and order fulfillment processes (Url-40). With this system, the company affixes RFID tags to each strapped cube of new bricks and tracks the inventory with a data-on-remote database approach. The system informs the forklift operator's computer where to place the cubes in the yard, based on the type of product being unloaded when the cubes are delivered to the brickyard. Once the bricks are placed in the proper bin, the inventory system is automatically updated. Likewise, once they are removed from the yard for shipping, they are automatically removed from the inventory count (Url-40).

Marigold Industrial, manufacturer of gloves that protect workers from sharp knives, harsh chemicals or frozen packages, uses RFID in its manufacturing facility in Poiares, Portugal, to track the materials used to construct the gloves, and the finished products (O'Connor, 2009). When pallets loaded with boxes of materials and components, such as various grades of rubber and cloth, arrive at the factory, each box is labeled with an RFID tag that is encoded with a unique ID number. Data-on-remote database approach is followed where the ID numbers are associated with the order information in the back-end software. When the factory receives a glove order from its customers, the software directs workers to pull the boxes of materials and components necessary to fill that order. The software tracks the movement of the boxes as they pass through a portal reader located between the warehouse and production area (Figure 3.19).

Once the materials are made into gloves, the finished products are tracked again using RFID, in a manner similar to the tracking of the raw materials. RFID tags are printed for each case of finished goods and a unique ID number that is encoded in the tag is associated with the customer's order.

Figure 3.19 : RFID-tagged cases of material is being brought through a portal reader at Marigold Industrial Plant (O'Connor, 2009).

The tagged cases are then brought directly to the shipping dock, where they are placed on pallets for shipment. Here, the cases are read again by an RFID reader to ensure that all of the products required to fulfill the order are present, and in the correct quantities (O'Connor, 2009).

A sour cream and cottage cheese maker company, Daisy Brand, has been using an RFID system for inventory tracking since the beginning of 2005 (Url-41). The RFID solution follows a data-on-remote database approach and includes RFID tagged pallets and forklifts outfitted with RFID readers and tablet computers used in conjunction with an RFID middleware platform. The forklift readers and fixed readers capture the EPC numbers of passive Gen 2 tags used on pallets and the data about the product on a tagged pallet (i.e., its type (e.g., no-fat or regular sour cream) and sell-by date) is stored in the company's ERP system.

When a truck arrives to pick up the pallets, the system ensures the driver is picking up the proper pallet (e.g., products with imminent sell-by dates should be shipped to a near retail destination) and can also alert the driver if wrong pallet is loaded on the truck (Url-41).

The type of tags utilized in this category, as well as the information they stored on remote databases are given in summary in Table 3.29.

Table 3.29 : Summary of the inventory and warehouse management applications in manufacturing industry.

	Type of tag	Frequency	Type of data stored
Data-on-remote DB (7)	Active	Microwave (2.4 GHz)	Receiving the parts replenishment request coming from the active tags located along the production line, processing the request, initiating the material replenishment steps.
	Active	Microwave (2.4 GHz)	Which particular parts needs to be replenished and their location inside the plant, controlling the material replenishment process.
	Passive	UHF (920-926 MHz)	Inventory management of telephones, tracking their supply chain as they travel from the distribution centers to stores, triggering alarms if needed (e.g., delayed delivery, out-of-stock situation), delivery time, goods lost in transit, inventory levels.
	Passive	HF (13.56 MHz)	Tracking the inventory conditions of products from the manufacturing plant to the distribution centers, automated inventory management.
	Passive	UHF	Arranging the locations to place the brick products in the storage yard, according to their information (e.g., type), automatically updating the inventory.
	Passive	UHF	Location of materials and products as they pass through portals between the production area and the warehouse, material and finished product information linked to customers' orders, managing the customers' orders.
	Passive	UHF	Data related to the products that are loaded on the pallets (e.g., types), managing the shipment of products (i.e., ensuring the right pallets of products are being loaded on trucks).

3.2.4.4 Lifecycle information tracking applications

Michelin, the tire manufacturer company, is providing product lifetime identification for automobile tires with the help of RFID technology (Wing, 2006). A data-on-tag concept is being applied where the company utilizes a read/write passive RFID system. Table 3.30 summarizes the characteristics of this lifecycle information tracking case.

Table 3.30 : Summary of the lifecycle information tracking applications in manufacturing industry.

	Type of tag	Frequency	Type of data stored
Data-on-tag	Passive	UHF (868-915 MHz)	The time and date of manufacture, tire dimension and pressure specifications, modified data related to the tire during its lifetime.

Within Michelin's application, RFID tags are embedded into tires which are used to identify the manufacturer's name and plant, as well as to store vital identification information such as the time and date of manufacture, tire dimension and pressure specifications. When the tire is mounted on a new vehicle, the tire identification number and the vehicle's VIN are linked in a computer database. Data on the tags can also be modified during its lifetime (Wing, 2006). The only data-on-tag application in manufacturing industry benefited from the informational and the documentational function by storing data related to the tires (dimensions, specifications), and related to their lifetime.

3.2.4.5 Analysis of the cases in manufacturing industry

There are seventeen cases investigated in the manufacturing industry, which are separated in four categories. When these cases are examined in terms of their data storage methods, it is observed that the data-on-remote database approach is applied more usually (i.e., thirteen out of seventeen). The rest of the cases (i.e., thirteen out of seventeen) followed the integrated data storage method, whereas only one case applied the data-on-tag approach, as summarized in Table 3.31, along with other characteristics of the cases in manufacturing industry.

Passive tag usage (i.e., seven out of thirteen) is only one case more than the active tag usage (i.e., six out of thirteen) within the applications that followed the data-on-remote database approach. Among these cases, four of them utilized active RFID tags in the real-time location system applications (Collins, 2005a; Swedberg, 2008a; Bacheldor, 2008; Url-37), which require self-signaling tags with long reading ranges. This is because these cases are implemented in large manufacturing facilities, where it is a daunting task to locate products (i.e., cars) both during the wide variety of production processes (e.g., manufacturing, inspection, painting, testing, etc.) and during their time in large storage areas.

Other two cases that leveraged active RFID tags but did not take the advantage of their large memory capacities, also benefit their self-signaling feature (Swedberg, 2008a; Aeroscout, 2009). These two applications use the active tags as a means of requesting additional parts when needed during the production. These tags, when their buttons are pressed on demand, transmit the parts/components request over the network to initiate the materials replenishment steps. Such implementation can only be realized with an active RFID system, since the passive RFID tags do not have their internal batteries, and thus not able to transmit signals on their own. Table 3.31 gives the details about the characteristics of the cases in the manufacturing industry.

Table 3.31 : Characteristics of the cases in manufacturing industry and the type of data stored on tags and/or remote databases.

		Tag types	Type of data stored
Data-on remote DB	**13 cases**	1 Active (UWB); 5 Active (Microwave); 1 Passive (HF), 6 Passive (UHF)	- Receiving the parts replenishment request coming from the active tags located along the production line, processing the request, initiating the material replenishment steps. - Which particular parts needs to be replenished and their location inside the plant, controlling the material replenishment process. - Inventory management of telephones, tracking their supply chain as they travel from the distribution centers to stores, triggering alarms if needed (e.g., delayed delivery, out-of-stock situation), delivery time, goods lost in transit, inventory levels. - Tracking the inventory conditions of products from the manufacturing plant to the distribution centers, automated inventory management. - Arranging the locations to place the brick products in the storage yard, according to their information (e.g., type), automatically updating the inventory. - Location of materials and products as they pass through portals between the production area and the warehouse, material and finished product information linked to customers' orders, managing the customers' orders. - Data related to the products that are loaded on the pallets (e.g., types), managing the shipment of products (i.e., ensuring the right pallets of products are being loaded on trucks). - Tracking the cars during their finishing process where they go through several tests according to their locations, along with the information related to the cars (i.e., Vehicle Identification Number (VIN) and description). - Tracking the location of cars on a graphical map, as they pass through several portals on their way to testing, then to repair area or to storage yard. - Tracking the location of cars on a graphical map during their time in the production plant. - Tracking the assembly process and the locations of cars in real-time as they go through several stages (e.g., initial painting, mounting the body and roof, installing the turret, finishing the inside trimming and adding the interior equipment, inspecting, testing). - Tracking the assembly and shipment of wheels, taking customer orders, assigning a location for wheels in the storage area. - Information related to products (i.e., silicon-based liquid products), their chain of custody.
Integrated data storage	**3 cases**	1 Active (N/A); 1 Passive (UHF); 1 Active (UWB) + Passive (HF)	- **Data on tag:** Customization details (e.g., motor configuration) of engines, record of production steps and quality control results. **Data on remote DB:** History of assembly of each engine (i.e., time and date of each production stage), records of production and quality control processes. - **Data on tag:** Processing information of the disk drives. **Data on remote DB:** Routing the disk drives and determining their direction on the assembly line, based on the routing information read from the tags. Information related to disks collected while being manufactured. - **Data on tag:** Critical information about motorcycle parts (e.g., supplier code, part number, lot number and date of production) on passive tags. Vehicle Identification Number (VIN) on active tags attached to motorcycle's chassis. **Data on remote DB:** Location of containers that carry the motorcycle components and parts, location of the motorcycle's chassis on the production line, tracking the production to ensure proper parts are used on the right motorcycle frames.
Data-on-tag		1 Passive (UHF)	The time and date of manufacture, tire dimension and pressure specifications, modified data related to the tire during its lifetime.

HF: High Frequency, UHF: Ultra High Frequency, UWB: UltraWideband, N/A: tag type/frequency not available.

Other seven cases that followed the data-on-remote database approach utilized passive tags and keep the object-related data on networks. Within these applications, as the materials and/or products passed through RFID-enabled portals, or carried by forklifts, or read by handheld readers at certain points, related information is stored in a database. This helps the manufacturers to have a chain of custody and use the RFID as a means of track and trace their manufacturing processes. Since the data-on-remote database approach is more widely adopted among manufacturing industry cases, it can be deduced that manufacturing plants are suitable places to deploy a network that can work efficiently.

There are three cases that followed the integrated data storage approach, all of which utilized different types of RFID systems. One of them utilized passive tags (Banks et al., 2007), another utilized active tags (Diekmann et al., 2007), where the third case utilized both type of tags (Wessel, 2009b). These cases show that RFID can be used to track the production process and to ensure it is taking the correct steps to finish a product. This can be achieved by entering the routing information on the tags and by reading that information at every decision point on a production line to ensure processes are being carried out in a correct sequence. Other than this, RFID tags can be attached to containers of parts that are used on a production line and read continually during production to make sure the correct parts are being assembled on the proper product.

The only application in which data-on-tag approach is applied, embedded passive tags in car tires during the time of manufacture to stay together with the tire throughout its lifecycle (Wing, 2006). RFID tags embedded in tires store information the time and place of manufacturing, tire sizes and some specifications related to pressure. Information on tags can also be modified with a handheld reader, which leads to gathering and reporting industry information efficiently and in an up-to-date manner. This kind of utilization of RFID tags bring the informational and the documentational functions.

3.2.5 Healthcare industry

RFID technology has several opportunities for the healthcare industry which has already been using RFID to track patients, staff, medical device and assets within healthcare facilities. RFID can help the industry fighting with counterfeit drug and detecting whether a drug is tampered, adulterated, substituted or it is expired (Url-42). Although the U.S. Food and Drug Administration (FDA) has not yet mandated

RFID adoption, for several years FDA has defended the usage of RFID to track and trace pharmaceuticals as a means of fighting counterfeit drugs (Url-42).

RFID cases that are investigated within the scope of this research are divided into three categories, namely (1) object identification and tracking applications, (2) object localization applications, and (3) pharmaceutical tagging applications (Table 3.32)

Table 3.32 : Categorization of the investigated cases in healthcare.

Category	Number of cases	Purpose
People tracking	5	Identification and tracking of people (e.g. patients and hospital staff) and equipment (e.g. electronic devices, implantable devices) within a facility.
Equipment tracking	3	
Mobile object localization	1	Determining the exact location of people (e.g. patients and hospital staff) and equipment (e.g. electronic devices, implantable devices) within a facility.
Stationary object localization	1	
Tagging pharmaceuticals	3	Tagging boxes of medicine to create an authorization for preventing drug counterfeit.

3.2.5.1 Object identification and tracking applications

There are eight applications within this category, five of which are related to identification and tracking of patients and employees in a medical facility, while the rest of three cases are about the identification and tracking of medical equipment and devices. Both the integrated data storage and the data-on-remote database approaches are applied within this category.

One of the patient tracking application is being implemented at Chang-Gung Memorial Hospital, in Taiwan, implemented an RFID-based patient management system in its operating room, to enhance patient safety and streamline hospital procedures (Url-43). Integrated data storage approach is followed where the passive 13.56 MHz read/writable RFID chip-enabled wristbands are used to store patient information including the patient's name, medical record number, gender, age, and doctor's name (Figure 3.20).

Figure 3.20 : RFID wristband application at Chang-Gung Memorial Hospital, Taiwan (Url-43).

The tag's ID number is then associated with patient records stored in the hospital's back-end information system. To have an increased patient and data security, the information stored on the wristband is password protected and only selected doctors and nurses have access to that data (Url-43).

Another hospital in U.K., Birmingham Heartlands Hospital, is implementing RFID-enabled wristbands to track surgical patients and procedures in two of its thoracic (i.e., chest) and ear, nose and throat surgical departments (Bacheldor, 2007). Plastic wristbands embedded with passive RFID inlays are being issued to surgical patients when they are admitted to the hospital and an integrated data storage approach is applied. The RFID inlay embedded in each wristband is encoded with a patient's ID number, name, date of birth and gender information. This information is then associated with patient records held within back-end hospital systems: the patient administration and surgical booking systems. A digital photograph is also taken of each patient, which is uploaded into the hospital's systems to further verify that person's identity. Surgeons, anesthesiologists and pre-operative nurses are given wireless personal digital assistants (PDAs) allowing them to view related operating schedules and patient records. The PDA is equipped with an RFID reader and can scan the wristband within about 10 inches (i.e., about 25 centimeters). Once it is read, the system can pull up the patient's record and access the patient's photo. As the patient goes through various checks, staff can utilize the PDA to update the individual's record, which can also be accessed by hospital staff from PCs (Bacheldor, 2007).

To reduce blood-handling errors, an RFID-based solution is piloted at blood transfusion center of San Raffaele Hospital, Milan, Italy, that dealt with autologous transfusions, in which, blood is returned to the same donor (Url-44). 13.56 MHz passive RFID tags are attached to patient's wristband and are applied to the blood bag as an RFID card tag. The hospital's entire blood transfusion center is deployed with a wireless network and the developed software runs on stationary PCs, laptop PCs, and personal digital assistants (PDAs). At the beginning of the donation, information such as patient identification number, name, date of birth, an administrative fiscal code, a photo, blood group and type, a donation transition ID and a patient file ID and a hospital code are recorded in the computer system, and an RFID-enabled wristband with 16 KB of memory is assigned to the patient at the clinic room. The patient then enters the blood donation area, where a staff member reads the patient's wristband with a portable RFID reader and copies the information onto the blood bag. Blood bag and the wristband are then checked once more to ensure that they are identical. Finally for third verification, staff members scan their badges which contain their personal data, into the system and the donation begins. As the donation ends, staff member again compares the full blood bag and wristband with PDA and send the blood bag to the blood bank. At a later time for transfusion, the blood bag is brought to the patient's bedside and verified as matching the patient's wristband via a PDA reader. If all the information on the blood bag matches the information on the wristband, the transfusion proceeds and the information is sent from the bedside to the blood transfusion center using a wireless antenna within the area (Url-44).

Different than the above mentioned cases, data-on-remote database approach is followed at two hospitals in Singapore during the Severe Acute Respiratory Syndrome (SARS) outbreak (Url-45). Hospitals tested an RFID system that tracks the movement of their staff, visitors and patients to be able to trace all of the people with whom a suspected SARS patient had contact. All patients, visitors and staff who enter areas of trial within the two hospitals provided their names and contact information at the registration counter, to be contacted later if necessary. They are given a card with an embedded active RFID tag that has a small battery. Hospital employees are also given ID cards with RFID tags in them. Tags continually transmitted RFID signals at 433 MHz to readers placed around the facilities. Data-on-remote database approach is followed where the back-end software is used by the staff to query the database for information. Hospital staff can access the application through a web-based portal on the hospital's Intranet. If a patient is suspected of having SARS, staff can run an immediate check to find out who had contact with the patient, where and at what time. The system was set up to store information on visitors for 21 days, to make sure that information about a SARS patient's contacts within the hospital remains available well after the 10-day incubation period ends. The confidential information was deleted from the system after 21 days (Url-45).

Another data-on-remote database application is being carried out at Apollo Hospitals Dhaka, in Bangladesh, where employee attendance is tracked with a passive RFID system (Bacheldor, 2008a). RFID-enabled employee badges are given to hospital employee, such as doctors, nurses and other staff. RFID readers cull unique ID numbers from employees as they enter and exit the hospital grounds. Next step of the implementation is planned as the integration of the attendance tracking system to the hospital's payroll application. The hospital also plans to use RFID to track, employees' and assets' location within the facility in real time (Bacheldor, 2008a).

Remaining cases are related to tracking of medical equipment and devices within a healthcare facility. For example, the El Paso County 911 facility in Texas, USA, is using active tags integrated with temperature-tracking sensors to prevent the facility's electronic equipment (i.e. telecommunications equipment, an uninterruptible power supply (UPS) system, and servers that operate the 911 district's e-mail, BlackBerry and administrative networks) from being damaged due to excessive heat (Swedberg, 2009g). Two readers and ten sensor tags, that measure temperature, are deployed in the equipment room, where an integrated data storage approach is followed. Tags transmit the measured temperature data every 60 seconds along with their ID numbers to the readers. Then the readers send this sensor data to a back-end server located in the equipment room via a cabled connection for it to interpret the tag and sensor data and to notify the appropriate staff members via e-mail if the temperature level at any particular location exceeds the acceptable threshold. Also, authorized users can log onto the facility's web site and view the current temperatures at all locations, and the environmental history of any specific sensor as well (Swedberg, 2009g).

Similarly, another healthcare facility, Terrebonne General Medical Center, installed active Wi-Fi RFID tags to track temperatures within all of its refrigerators, freezers, medical fluid heaters and blanket warmers by using the hospital's existing Wi-Fi system (Swedberg, 2009j). Integrated data storage approach is followed where the staff inputs the refrigerator tag's ID number into the software on the server and configures temperature rules and other identifying data related to that cooler or heater. Then the tags beacon every 15 seconds at 2.4 GHz to existing access points which were previously installed by the hospital to provide network access to laptop computers within the building. The access points transmit the tags' data to the location manager, which routes that information into the software on the server. Software determines the asset's identity, along with the temperature reading. If the temperature passes a specific machine's high or low threshold, the software sends an alert to the hospital operator (Swedberg, 2009j).

Differently, a data-on-remote database approach is followed by the Memorial Hospital in Chattanooga, Tennessee, USA (Swedberg, 2009f). The hospital is employing an RFID-based system to solve the problem of unused and unbilled products that costs thousands of dollars to the hospital each year. As the hospital's workers receive new products (i.e. implantable devices, guide catheters, coronary wires and other high-value products), a passive RFID tag is read and attached to the product. The tag's ID number is linked with the bar-coded serial number of the product and other information regarding the product, such as its type, size, expiration date and cost to a patient. Those products are stored in ten cabinets located in various labs which are attached with multiple RFID readers to capture the tags' unique ID numbers. Readers forward the data approximately every twenty minutes to the software running on the Internet-based server, via an Ethernet cable, along with a time and date stamp. When an item is removed, the cabinet reader transmits its ID number to the back-end system and thus the software determines that the product has been removed, and changes its status to "missing". As the item is taken to a surgical room where employees use a handheld RFID/bar-code reader to scan the bar-coded number on a patient's ID bracelet, then interrogate the item's RFID tag and link the patient with that product. A bill to that patient for that particular item is then generated. If a predetermined span of time passes without the product being scanned with a patient's ID number, software generates an alert indicating the item is missing and not linked to a patient (Swedberg, 2009f).

The type of tags utilized in inventory and warehouse management applications, as well as the information they stored on remote databases are given in summary in Table 3.33.

Table 3.33 : Summary of the object tracking applications in healthcare industry.

		Type of tag	Frequency	Type of data stored
People tracking (5)	Data-on-remote-DB (2)	Passive	UHF (902-928 MHz)	Tracking and identifying the employee (i.e., nurses, doctors, staff) of the hospital as they enter to and exit from the building.
		Active	UHF (433 MHz)	Names and contact numbers of all patients and visitors, time and places the visitors and the patients have been, contacts of a patient.
	Integrated data storage (3)	Passive	HF (13.56 MHz)	**Data on tag:** Patient's ID number, name, date of birth and gender information on RFID wristband. **Data on remote DB:** Patient records held within the patient administration and surgical booking systems, a digital photograph of the patient, records of various checks that a patient goes through.
		Passive	HF (13.56 MHz)	**Data on tag:** Patient information (i.e., patient's name, medical record number, gender, age, and doctor's name). **Data on remote DB:** Patient's records linked with patient's wristband and the information stored on the wristband.
		Passive	HF (13.56 MHz)	**Data on tag:** Patient ID number, name, date of birth, a photo, blood group and type, administrative fiscal code, a donation transition ID, patient file ID and hospital code on blood bags. **Data on remote DB:** Same information on blood bags, information about the staff member that manages the donation.
Equipment tracking (3)	Data-on-remote-DB	Passive	N/A	Information related to the products (e.g., implantable devices, guide cathaters, coronary wires, other high-value products), their types, size, expiration date, cost. Tracking the items according to periodic readings, if item not scanned for a predefined span of time, an alert is generated for the missing item.
	Integrated data storage (2)	Active	UHF (433 MHz)	**Data on tag:** Temperature measurements of electronic equipment. **Data on remote DB:** Environmental history of the electronic equipment, their locations, records of temperature measurements provided by sensors.
		Active	Microwave (2.4 GHz)	**Data on tag:** Temperature measurements of refrigerators, freezers, medical fluid heaters and blanket warmers. **Data on remote DB:** Temperature rules and other identifying data related to the equipment, their locations, monitoring system that triggers alerts if temperature tresholds are exceeded.

3.2.5.2 Localization applications

There are two cases under this category, where both of them applied a data-on-remote database approach. For instance, the Virginia Mason Medical Center's clinic in Kirkland, Washington, USA, is using a hybrid RFID-Infrared (RFID-IR) system that enables the clinic's staff to track the locations of patients and workers in real time (Swedberg, 2009i). Data-on-remote database approach during this process.

After registering at the desk, a patient is assigned a room and given a card to which a battery-powered hybrid RF-IR tag is clipped. Every three seconds, the tag simultaneously transmits a 433 MHz RF signal and infrared light signal imperceptible to the human eye, both encoded with the same unique ID number. The tag's ID number is input with the patient's data into the software running on a back-end server. The staff can then access the software to track that individual's location throughout the facility. Similar procedure is applied for the employees (i.e. physicians, clinical assistants and other staff members) with permanently assigned ID badges that contain battery-powered hybrid RF-IR tags that transmit the ID number, as well. The clinic has one hundred fifty three readers, seven of which are RFID, while one hundred forty six are infrared, installed in its ceilings throughout the facility. The IR function helps the clinic pinpoint the room in which the tags, therefore patients and/or clinic staff, are located (Swedberg, 2009i).

The Brigham and Women's Hospital, Boston, USA, installed an RFID-based real-time location system throughout its 17 floors, enabling it to track about 8000 medical devices (i.e. infusion pumps, machines for removing waste products from blood, and machines that measure the oxygen saturation of a patient's blood) (Bacheldor, 2008b). Data-on-remote database approach is followed where active RFID tags communicate their IDs with the receivers mounted on walls within several zones of the hospital (e.g. emergency department, surgery units, cardiac care, and common areas). Then the collected RFID data are relayed to a server over the hospital's wireless local area network. The receivers can interrogate a tag from up to 50 or 60 feet (i.e., 15 to 18 meters) away, and can pinpoint its location within an accuracy of up to 3 feet (i.e., about 90 centimeters). The software determines a tag's location based on signal strength when three or more receivers pick up a tag's ID number (Bacheldor, 2008b). Table 3.34 summarizes the characteristics of localization cases.

Table 3.34 : Summary of the localization applications in healthcare industry.

		Type of tag	Frequency	Type of data stored
Mobile	Data-on-remote DB	Active	UHF (433 MHz)	Real-time locations of patients and workers throughout the facility.
Stationary		Active	UHF (433 MHz)	Real-time locations of medical devices (e.g., infusion pumps) within several zones inside the facility (e.g., emergency department, surgery units, cardiac care, common areas) by calculating the signal strenght of a tag.

3.2.5.3 Tagging pharmaceuticals

In 2004, the U.S. Food and Drug Administration (FDA) recommended the use of RFID for product authentication as a means of eliminating counterfeit drugs, which pose health risks to anyone taking them. To help protect against counterfeit and theft Purdue Pharmaceuticals adds RFID labels to bottles of its popular pain reliever OxyContin it ships to Wal-Mart Stores Inc. and H.D. Smith Wholesale Drug Co., which is highly abused, often stolen and counterfeited because of its addictive nature (Brown, 2007). As a part of the final manufacturing/packaging process, passive tags are placed on bottles and 48 bottles are then placed into a shipping carton and only boxes that produce 48 accurate reads leave the company's shipping docks. Once the bottles are labeled, the readers collect the EPC data at multiple points along the packaging line, passing it on to the software that ensures that each EPC collected is unique and valid for a bottle of OxyContin. As the bottles are aggregated into groups of 48 for casing, the software collects the EPCs once more to ensure that each bottle in the group is being cased for the first and only time. The EPC data read from RFID tags is then integrated into Purdue's enterprise-resource-planning system where a data-on-remote database approach is followed. Purdue donated 100 handheld RFID readers to federal law-enforcement cargo-theft units, FDA Office of Criminal Investigations field offices, and state and local task forces targeting prescription drug thefts. The readers can be used to identify bottles of OxyContin confiscated during robbery and burglary investigations (Malykhina, 2004).

Pfizer is also using RFID in its fights against fake drugs and started to tag each bottle of one of its most highly counterfeited drug, for the shipments in the United States pharmacists and wholesalers to use for ensuring the product is genuine (Sullivan, 2006). Data-on-remote database approach is followed where a label with an integrated tag is applied to each bottle of drugs as it moves down the packaging line. An RFID reader encodes an EPC to each label, and a second reader verifies the tag has been successfully encoded and can be read. The reader also reads the unique ID number of the chip, enabling Pfizer to record both the chip ID and the item's EPC in a database. After receiving the product, a pharmacist or wholesaler uses an RFID reader to retrieve the EPC with a reader to verify authenticity by running a query over a secure Internet connection to which pharmacists and wholesalers must subscribe (O'Connor, 2006; Sullivan, 2006).

Same procedure is used within another company, GlaxoSmithKline which is utilizing RFID to verify its HIV medication Trizivir drug, for preventing counterfeit and diversion (Url-46). The tags are placed on all bottles of Trizivir distributed in the United States. When scanned at close range, the tags help verify that the medicine bottle contains authentic Trizivir.

Table 3.35 summarizes the type of tags used in applications where pharmaceuticals are tagged and the type of information stored in these applications.

Table 3.35 : Summary of the pharmaceutical tagging applications in healthcare industry.

	Type of tag	Frequency	Type of data stored
Data-on-remote DB (3)	Passive	UHF (915 MHz)	Readings at several points on the production line, information related to the production of the medicine that ensures it is authorized and genuine.
	Passive	HF (13.56 MHz)	
	Passive	N/A	

3.2.5.4 Analysis of the cases in healthcare industry

There are thirteen cases investigated within the healthcare industry and two data storage approaches are preferred, namely the data-on-remote database and the integrated data storage approaches. As summarized in Table 3.36, data-on-remote database method is preferred more usually (i.e. eight out of thirteen) then the integrated data storage method (i.e. five out of thirteen) within these applications.

Passive tags are more frequently utilized within data-on-remote database cases (i.e. five out of eight), since this kind of an application does not require large data storage capacities. Three of these cases are related to pharmaceutical tagging, where RFID is attached to boxes of drugs at the packaging line, to prevent the drug counterfeit (Malykhina, 2004; Sullivan, 2006; Url-46). Three cases utilized active tags but did not leverage their large memory capacities and applied data-on-remote database approach. These three applications (Bacheldor, 2008b; Swedberg, 2009i; Url-45) took advantage of the self-signaling feature of active tags, as well as their long reading ranges. Two of these cases are real-time positioning applications where exact locations of medical devices (Bacheldor, 2008b) and hospital staff and patients (Swedberg, 2009i) are determined with the help of RFID. Third application used RFID to track the patients and hospital employees within the hospital during the

SARS outbreak, and determined the contacts of a SARS patient as well as with time and place of the contact (Url-45).

Table 3.36 : Characteristics of the cases in healthcare industry and the type of data stored on tags and/or remote databases.

		Tag types	Type of data stored
Data-on remote DB	**8 cases**	3 Active (UHF); 1 Passive (HF); 2 Passive (UHF); 2 Passive (N/A)	- Real-time locations of patients and workers throughout the facility. - Real-time locations of medical devices (e.g., infusion pumps) within several zones inside the facility (e.g., emergency department, surgery units, cardiac care, common areas) by calculating the signal strenght of a tag. - Information related to the products (e.g., implantable devices, guide cathaters, coronary wires, other high-value products), their types, size, expiration date, cost. Tracking the items according to periodic readings, if item not scanned for a predefined span of time, an alert is generated for the missing item. - Tracking and identifying the employee (i.e., nurses, doctors, staff) of the hospital as they enter to and exit from the building. - Names and contact numbers of all patients and visitors, time and places the visitors and the patients have been, contacts of a patient. - Readings at several points on the production line, information related to the production of the medicine that ensures it is authorized and genuine.
Integrated data storage	**5 cases**	1 Active (UHF); 1 Active (Microwave); 3 Passive (HF)	- **Data on tag:** Patient's ID number, name, date of birth and gender information on RFID wristband. **Data on remote DB:** Patient records held within the patient administration and surgical booking systems, a digital photograph of the patient, records of various checks that a patient goes through. - **Data on tag:** Patient information (i.e., patient's name, medical record number, gender, age, and doctor's name). **Data on remote DB:** Patient's records linked with patient's wristband and the information stored on the wristband. - **Data on tag:** Patient ID number, name, date of birth, a photo, blood group and type, administrative fiscal code, a donation transition ID, patient file ID and hospital code on blood bags. **Data on remote DB:** Same information on blood bags, information about the staff member that manages the donation. - **Data on tag:** Temperature measurements of electronic equipment. **Data on remote DB:** Environmental history of the electronic equipment, their locations, records of temperature measurements provided by sensors. - **Data on tag:** Temperature measurements of refrigerators, freezers, medical fluid heaters and blanket warmers. **Data on remote DB:** Temperature rules and other identifying data related to the equipment, their locations, monitoring system that triggers alerts if temperature tresholds are exceeded.

HF: High Frequency, UHF: Ultra High Frequency, N/A: tag type/frequency not available.

Integrated data storage approach is followed within five cases, among which three cases leveraged passive tags (Bacheldor, 2007; Url-43; Url-44) while the rest of the two cases utilized active tags (Swedberg, 2009j; Swedberg, 2009g). The ones that utilized passive tags used those tags to store information such as the patient information (e.g. patient's name, medical record or ID number, date of birth, gender age, doctor's name, blood type, patient's picture) on RFID-enabled wristbands (Bacheldor, 2007; Url-43; Url-44). RFID enables the important information related to the patient to travel with the patient wherever he/she goes and ensures the he/she is treated properly (i.e. given the right medicine and the correct blood type, etc.).

The ones that utilized active tags, on the other hand, tracked the temperature of electronic and medical equipment, thus temperature data are stored on the tags and then sent to the computers of the facilities for enabling the staff to track them.

4. IDENTIFICATION OF THE INFORMATION GROUPS

Within the scope of the literature review, given in the previous chapter, one hundred thirteen RFID cases from the construction industry, as well as from other five large industries were investigated in terms of their data storage needs and characteristics. Additionally, the types of information items that are stored both in tags and/or in central databases are identified. These information items could be classified into seven groups according to their characteristics:

1. Identifier information: The unique and mostly static data about an object (e.g., unique ID number, serial number, production number, manufacturer information, dimensions, etc.) or about a person (e.g., name, age, date of birth, flight information, etc.).

2. Technical features information: Data related to technical features of components or products (e.g., handling instructions, maximum load, warranty information, graphical representation etc.), as well as their procurement, delivery and receipt information (e.g., purchase order number, client number, job number, item number, etc.).

3. Historical information: Information about the processes that objects go through (e.g., records of production process, operation and maintenance data, etc.), the problems that were encountered (e.g., any damage to a component), documentation of history of a product (e.g., chain of custody), information related to a person (e.g., health information, records of treatment).

4. Location information: Spatial information about where the object (i.e., devices, people, equipment, vehicles, etc.) is (e.g., building, floor, room information).

5. Status information: Current status information (e.g. manufactured, installed, delivered, out-of-stock, sold, missing, etc.) about an item (e.g., products, objects, etc.).

6. Task-related information: Information about the object related tasks that are going to be performed by the people in charge (e.g., installation details and lifting schedule

of components in construction, daily maintenance work orders for maintenance activities, etc.).

7. Sensor data: Environmental data collected by tags integrated with relevant sensors (e.g., temperature, humidity, etc), as well as the data related to the usage of objects (e.g., containers, vehicles, etc.) (e.g., data collected by intrusion sensors, impact sensors, movement sensors, etc.).

All these types of information items are stored both in tags and in databases in different levels of detail, except the data about the environmental conditions. Sensor data can only be stored on sensor integrated tags and within data-on-tag and/or integrated data storage applications.

Melski et al., (2007) observed that four functions are served when additional data are stored on RFID tags within RFID implementations, namely the informational, documentational, temporary storage and decentralized control functions. Detailed discussions on the information items stored in each case in each industry, as well as the evaluation of each industry in terms of benefited functions which are described in Section 2.2.2, are given in the following sections.

4.1 Construction Industry

The information items that were stored on tags within the construction industry applications are investigated for all the five categories, in terms of the functions described in Section 2.2.2. It is observed that all of the seventeen cases stored additional data on RFID tags, which is the 50% of the entire thirty-four cases. All of these seventeen cases benefited from the informational function that is brought by the additional data stored on RFID tags (Table 4.1). This function ensures delivering characteristic information on the object at all times and it mostly remains unchanged. Both the identifier and technical features data are stored on tags within this context. Storing the object-related data with the object is also preferred when history of the component needs to be permanently available even after the construction phase. These kinds of applications are for keeping records of object-related activities, thus they take the advantage of the "documentational function" of the data-on-tag concept. Eight of the cases among the lifecycle information tracking, object tracking and quality management applications that stored additional data on tags benefited from this function.

Table 4.1 : Number of cases in terms of benefited functions in construction industry.

	Informational function	Documentational Function	Temporary Storage Function
Object tracking	8	3	1
Lifecycle information tracking	3	3	-
Object localization	2	-	-
Construction progress /management	1	-	-
Quality management/control	3	2	1
Total	17	8	2

RFID tags are used to permanently store historical data such as operation (Goodrum et al., 2006) and maintenance information (Ergen et al. 2007a; 2007b; Motemadi and Hammad, 2009), date of last inspection (Motemadi and Hammad, 2009) and recent quality control inspection data (Yin et al., 2009; Yabuki et al., 2002).

Data storage on a tag is also preferred when data about the environment is needed to be captured. For instance, sensors (e.g., temperature) can monitor and record environmental conditions data and store it into an RFID tag memory. In this case, RFID tags serve the "temporary storage function" and data captured by other devices/methods are temporarily stored on tags. Two cases used sensor integrated RFID tags as temporary storage units. One of them stored temperature data of concrete samples within quality control category (O'connor, 2006b) and the other stored the amount of vibration in people tracking application (Swedberg 2008c).

On the other hand, none of the cases that preferred the data-on-tag approach took advantage of the RFID tags for "decentralized control" function. While it seems as a future work for the construction industry, in other industries there are some examples where companies (e.g., BP) are already benefiting from this function in their applications (Collins, 2006). An example for this kind of utilization of RFID tags to serve the decentralized control function is given under discussions and recommendations.

Data stored in construction industry cases are classified according to the seven groups that are identified as the type of information stored both on tags and/or on remote databases within the investigated one hundred thirteen cases (Table 4.2).

Table 4.2 : Results of data analysis on the type of data stored on tags and on remote databases in construction industry.

		Data stored on tags	Data stored on remote database
Lifecycle information tracking (4)		Identifier data: Type, model, serial of fire safety equipments (Motemadi & Hammad 2009), manufacturer and owner info of engineered-to-order (ETO) components (Ergen et al. 2007c). Technical data: Handling, storage and installation instructions of ETO components (Ergen et al. 2007c), manufacturing date of fire safety equipments (Motemadi & Hammad 2009). Historical data: Maintenance records (e.g., date, inspector name, inspection results) of fire valves (Ergen et al. 2007a), history (last inspection date) of fire safety equipments (Motemadi & Hammad 2009). Location data: Building, floor, room information of fire safety equipments (Motemadi & Hammad 2009). Status data: Status (e.g. in service, installed, assambled), of fire safety equipments (Motemadi & Hammad 2009).	Identifier data: Category (equipment or facility), name, supplier, holder of equipment and facility (Ko 2009). Technical data: Safety degree, durability, purchasing cost, purchasing date, warranty period of equipment and facility (Ko 2009). Historical data: Frequency of use, maintenance and repair records of equipment and facility (Ko 2009). Location data: Location of equipment and facility (Ko 2009).
Object tracking (12)	Material	Identifier data: Description of materials (e.g., bars) (Lee et al. 2006). Technical data: Purchase order number, release number, requisition number, mark number, client number, item number of pipe supports and hangers (Jaselskis & Misalami 2003), piece marked number, spool number, sketch number, purchase order number of pipe spools (Song et al. 2006a), restoration data of timber assembly components (Cheng et al. 2008)*, manufacturer information, drawing number of pipes (Ren et al., 2007)*, Inventory and transportation information, delivery information of precast components (Yin et al. 2009)*, weight of materials (Lee et al. 2006). Task-related data: Lifting schedule of materials (Lee et al. 2006), person in charge of fittings (Ren et al., 2007)* Historical data: Quality control inspection records of precast components (Yin et al. 2009)*, damage on component (Jaselskis & Misalami 2003), Location data: Installation location of materials (Lee et al. 2006), location of pipe supports and hangers in the lay down area (Jaselskis & Misalami 2003).	Identifier data: Graphical representation of steel components (i.e. CAD information, virtual reality modeling language (VRML) models) (Furlani & Pfeffer 2000), GIS-based graphic and non-graphic information about components (Cheng et al. 2008)*, components information (Yin et al. 2009)*, manufacturer, date of manufacture and seven-digit serial number of safety nets (Swedberg 2009b). Task-related data: Restoration schedules and reports of components (Cheng et al. 2008)*, Technical data: Inventory and transportation management data of precast components, dates and times of delivery, information related to production and quantity of precast components (Yin et al. 2009)*, comparison with the actual situation and the baseline schedule (Ren et al., 2007)*. Historical data: Restoration records (Cheng et al. 2008)*, history of usage of safety nets (Swedberg 2009b), quality inspection results (Yin et al. 2009)*.
	People (1)	Historical data: The amount and time of vibration exposure (Swedberg 2008c)*.	Historical data: Records of each workers tool usage, interpretations based on the amount and time spent with vibrating tools.
	Equipment (3)	Historical data: Operation and maintenance data of tools (e.g. hammer drills) (Goodrum et al. 2006).	Historical data: Last person who used the tool, where and when it was checked out and the tool's replacement cost (Swedberg 2005). Location data: Locations of large individual tower crane parts (Swedberg 2007a).
Localization of objects	Stationary	Identifier data: Type of buried asset (Swedberg 2006, Dziadak et al. 2008), owner and material of buried cable (Swedberg 2006), material in the pipe (Dziadak et al., 2008). Location data: Location of buried cable (Swedberg 2006).	Identifier data: Individual details of employees (Friedlos 2008a). Location data: GPS data of steel components, their estimated locations, errors and additional computing parameters (Grau & Caldas 2009).
	Mobile		Location data: Movement and location of workers on a visual map (Ekahau Inc. 2006), location of workers inside a tunnel (Friedlos, 2008a).

Table 4.2 : Results of data analysis on the type of data stored on tags and on remote databases in construction industry (contd.).

	Data stored on tags	Data stored on remote database
Construction/Progress management (6)	Technical data: Information related to procurement of key components (e.g., steel beams, columns, panels, etc.) (e.g., order number, release number, requisition number, mark number, client number), job number, item number of components, and their quantity ordered (Wenfa 2008)*.	Identifier data: IFC number, type of HVAC components (Hammad & Motemadi, 2007), product ID, producer of construction parts (Yagi et al. 2005). Task-related data: Handling manuals, drawings, installation sequences of parts (Yagi et al. 2005), schedules and building models (Wenfa 2008)*. Historical data: Ordering date, manufacturing date, shipping date, receiving date, stock yarding date, piling-up date, lifting-up date, assembling date, installation date, qc control date, task start, task finish, last inspection date and next inspection date of HVAC components (Hammad & Motemadi 2007), Status data: Status information (ordered, manufactured, shipped, received, installed) of steel components (Chin et al. 2008), of precast components (Url-48), actual construction status of building (Wenfa2008)*, current state of parts (Yagi et al. 2005), status information of precast components (production, test, storage, delivery, on-site, inventory, installation, inspection statuses) (Wang et al. 2007).
Quality control (5)	Identifier data: Component IDs and main features (Yabuki et al. 2002)*, batch number, ID number of tag/truck, (Peyret & Tasky 2004). Technical data: Quality parameters (i.e., proportion of each component, asphalt fabrication rate of the plant, bitumen temperature, asphalt temperature, bitumen weight for each batch) and quantity parameters (i.e., weight of the material batch for each truck, weight of the empty truck), and type of mix design (Peyret and Tasky 2004)*. Historical data: Advices and warnings of senior inspectors to juniors and recent inspection data of each facility or member (Yabuki et al. 2002)*, periodic temperature measurement of concrete samples (O'Connor, 2006b). Location data: Tag's location and its depth within the concrete during concrete curing (O'Connor 2006b).	Historical data: Measured data, digital photographs, digital sounds, information about inspection routes on PDAs, all the inspected data, document and drawing files in local office computer (Yabuki et al. 2002)*, results of tests conducted with concrete samples (e.g., compression test status, inspection status, curing status) (Wang, 2008), reports and statistical analysis about concrete samples (On the Move, 2004).

4.2 Aerospace Industry

Aerospace industry is observed to be employing the additional data storage on RFID tag approach widely within its applications, where eleven cases among seventeen, in other words about 65% of its applications, preferred this concept. It is observed that all of these eleven cases that stored additional data on RFID tags benefited from the informational function (Table 4.3). Type of information stored on RFID tags that serve the information function are the identifier information data within (1) baggage handling applications (e.g., name and route of the passenger, ID number of the carrier airline, date, time, passenger's mobile number, flight information), (2) lifecycle information tracking of parts and tools applications (e.g., part number, date of manufacture, serial number country of origin, maintenance information), (3) (e.g., object's technical ID code and equipment ID) and (4) RFID-enabled passport application (e.g., name, date of birth, photograph).

Table 4.3 : Number of cases in terms of benefited functions in aerospace industry.

	Informational function	Documentational Function
Baggage handling (airline-wide)	4	-
Baggage handling (airport-wide)	1	-
Lifecycle information tracking of aircraft parts and tools	4	4
Other applications	2	1
Total	11	6

Documentational function, on the other hand, is observed only within the lifecycle information tracking of parts and tools applications (O'Connor, 2006c; Url-11; Url-12; Url-13) and the fire shutters maintenance application at the airport (Legner and Thiesse, 2009). Type of information groups that are stored on RFID tags to serve the documentational function are history, shipping, routing and customs information of aircraft tools, maintenance and repair service history of aircraft parts, and as well as the date, time and duration of the last maintenance of fire shutters.

Temporary storage function and decentralized control function are not observed within the investigated aerospace industry applications, since battery-powered tag usage on commercial aircrafts has not yet been approved by air transportation authorities (O'Connor, 2006c). Thus, these cases could not take the advantage of tags that can monitor environmental conditions, as well as tags that can process data on their memories, communicate with each other and make calculations on their own.

4.3 Defense Industry

There are nine cases that followed the integrated data storage approach within the defense industry, eight of which applied the integrated data storage concept, while only one case stored data on RFID tags. All of these nine cases, nearly 56% of the entire retail industry cases, benefited from the informational function of the concept of additional data storage on tag (Table 4.4). U.S. DoD, as well as NATO and allied nations, are using their global supply chain networks to track their shipments throughout the world, where these networks mainly utilize RFID technology, along with the GPS and satellite technologies. Within these networks, active RFID tags integrated with environmental sensors are employed on shipping containers and they are read at several fixed reader portals which are deployed at ports on their way from army depots to the foxhole throughout the globe. Tags that are deployed on containers store the information related to the content of the containers, as well as their consignment and shipment details. At the point of reading at the portals, new data can also be written on tags. This ensures a complete and accurate electronic manifest of each container to be tracked from the time a container leaves its origin, through the ports around the globe, till the time it arrives at its final destination. This serves the documentational function. Additionally, these tags monitor the environmental conditions of the container during its transport, thus it serves the temporary storage function. There are three cases that applied the integrated data storage concept within their implementations.

Table 4.4 : Number of cases in terms of benefited functions in defense industry.

	Informational function	Documentational Function	Temporary Storage Function
RFID-based supply chain/logistics networks	2	2	2
Asset/equipment tracking	3	1	3
Materiel tracking	1	-	-
People tracking	1	1	-
Object localization	1	-	-
Security applications	1	-	1
Total	9	4	6

These cases utilized active RFID tags that are integrated with several sensors, which enable the temporary storage function of tags. One of these applications of active tags helps an army depot in vehicle management process, where the tags store maintenance data of vehicles, as well as speed, mileage and impact data obtained from sensors (Url-25). Another similar application tracked and recorded the number of firing of tanks, which is temporarily stored on tags until the tank returns to depot (Burnell, 2008). Third application utilized sensor enabled active tags for monitoring environmental conditions of Deployable Medical System (DEPMEDS) containers that include necessary medical supplies and equipment required for rapid deployment into the field of operation (Url-24). Another utilization of active tags integrated with sensors is in security area, where intrusion sensors are used to detect any breach on shipping containers (Url-21). Only case that utilized passive tags in an integrated data storage application stored information such as date of manufacture, service or maintenance records, or other specifications related to survival equipment (e.g. life jackets, life rafts) as well as clothing, on tags.

Only data-on-tag application is related to tracking injured soldiers which was conducted during the war in Iraq where information related to their injury as well as their treatment is stored on tags (Yoshida, 2003). This type of usage of RFID tags serves both the informational and the documentational functions.

4.4 Retail Industry

Retail industry cases mostly utilized the data-on-remote database approach, and only 25% of the cases (i.e. four out of sixteen) utilized the integrated data storage concepts. As summarized in Table 4.5, all four cases utilized active tags with sensors, and benefited from informational function and the temporary storage function of additional data storage on tags.

There are no cases that applied the integrated data storage approach within the item-level or pallet-level tracking categories. Instead, this concept is applied only in container-level applications to track their environmental conditions during shipment process and to track the conditions (e.g., temperature) of perishable goods (e.g. fish, ice cream, etc.) during their transport as well as at stores.

Table 4.5 : Number of cases in terms of benefited functions in retail industry.

	Informational function	Documentational Function	Temporary Storage Function
Item-level tracking	-	-	-
Pallet-level tracking	-	-	-
Container-level tracking	1	-	1
Tracking environmental conditions	3	-	3
Total	4	1	4

4.5 Manufacturing Industry

Only 24% of the cases within the manufacturing industry (i.e. four out of seventeen) applied the additional data on tag approach, only one of which is a data-on-tag case while other three cases followed integrated data storage on tags. All of these four applications benefited from the informational function. None of the cases within the manufacturing industry took advantage of temporary storage on RFID tags since active tags are not integrated with sensors in any of the manufacturing applications (Table 4.6).

Table 4.6 : Number of cases in terms of benefited functions in manufacturing industry.

	Informational function	Documentational Function
Identifying and tracking the production processes	3	-
Object localization	-	-
Inventory and warehouse management applications	-	-
Lifecycle information tracking	1	1
Total	4	1

The only case that applied the data-on-tag approach is in the lifecycle information tracking category, where a tire company embeds read/write passive tags into tires to be able to identify the manufacturer's name and plant, as well as to store vital identification information (i.e. time and date of manufacture, tire dimension and pressure specifications). Storing these information items on tags serves the documentational function, along with the informational function.

Other three applications that followed the integrated data storage approach are in the category of identifying and tracking the production processes (Diekmann et al., 2007; Banks et al., 2007; Wessel, 2009b). In one of these cases, a combination of active and passive tags is used, while active tags are utilized to locate the containers that carry the parts used in the production process, the passive tags carried information related to parts (e.g. supplier code, part number, lot number, date of production) (Wessel, 2009b). Other two cases stored the information related to the production processes of disk drives (Banks et al., 2007) and cars (Diekmann et al., 2007), where passive and active tags are utilized respectively. For instance, in the car case, customization details and the motor configuration are loaded onto the tag. At each work stations, necessary production steps and quality controls are read out and acknowledged on the tag. Additionally, the time and date of each stage is stored on the tags and this collected information is then transferred to the central system.

4.6 Healthcare Industry

Only five cases which is the 38% of the entire healthcare industry (i.e. five out of thirteen), followed the integrated data storage approach. This enabled all of these applications to take advantage of informational function (Table 4.7).

Table 4.7 : Number of cases in terms of benefited functions in healthcare industry.

	Informational function	Temporary Storage Function
People tracking	3	-
Equipment tracking	2	2
Mobile object localization	-	-
Stationary object localization	-	-
Tagging pharmaceuticals	-	-
Total	5	2

Two of these cases utilized active RFID tags integrated with environmental sensors, to monitor the electronic and medical equipment, and benefited from the temporary storage function. The temperature data are stored on the tags and then sent to the computers of the facilities for enabling the staff to track them. Other three applications that leveraged the integrated data storage approach utilized passive tags to store patient related information (e.g. patient’s name, medical record or ID number, date of birth, gender age, doctor’s name, blood type, patient’s picture) on RFID-enabled wristbands (Bacheldor, 2007; Url-43; Url-44). RFID enables the important information related to the patient travels with the patient wherever he/she goes and ensures the patients are treated properly (i.e. given the right medicine and the correct blood type, etc.).

Remaining eight cases that preferred the data-on-remote database approach are distributed among the object localization, people tracking and pharmaceutical tagging applications. Drugs that are tagged with passive RFID tags encoded with EPC numbers are aimed at figthing against the drug counterfeit.

4.7 Discussion on the Results

It is observed that in RFID applications, data storage is not required if the only purpose in applying the technology is to identify and track the location of an object. However, there are applications where data such as historical information (e.g., quality control and maintenance activity records) related to an object needs to be tracked and documented. Similarly, applications related to monitoring of the environmental conditions within an area (e.g., cargo container), require data storage. RFID technology can be used as a means of data storage in such cases.

The application environment is an important factor in situations where data needs to be stored. It influences the selection of data storage concepts in RFID technology implementations. Closed and controlled environments such as supermarkets and manufacturing plants, allow the implementers to deploy a network and maintain its accessibility throughout the time an object spends inside these places. On the other hand, in uncontrolled and dynamic environments, such as construction sites and battlefield, it is relatively harder to install a network and provide a seamless connection to the data stored on the network. That is why the retail and manufacturing industries, as well as the healthcare industry, generally preferred using the RFID tags solely as a means of identification. Because, they are able to store the relevant information on remote computers in retail stores (e.g., supermarkets, shops), in production plants (e.g., production area, warehouse area), and in hospitals, all of which are closed and controlled areas. Thus, in retail and manufacturing industries, inventory levels of tagged objects can automatically be tracked in the network by deploying fixed RFID reader portals between the production area, the warehouse area, and the sales area. However, due to the industry's dynamic nature, applications where additional data are stored on RFID tags are more frequently observed in construction industry when compared to retail, manufacturing and healthcare industries. Due to similar reasons, defense industry also requires additional data storage on RFID tags, rather than those indsutries.

Another factor in deciding the method of data storage in RFID applications is the results of the cost-benefit analysis of the implementation. A typical RFID tehcnology implementation cost includes the cost of the readers, either fixed or mobile, and the cost of the tags that are attached to each object. However, the cost of the middleware that aggregates, sorts, filters and manages the tag data needs to be included in the total cost of the RFID applications where data-on-remote database approach is being followed. Cost of the tags are another issue in deciding the data storage concept. For instance, since there are lots of pieces of products that need to be identified and tracked in retail and manufacturing industry, less expensive passive tags are required to ensure an affordable application. High cost of the active tags with large memory capacities is a barrier in front of the wider utilization of active tags, thus it is observed that the cheaper passive tags with lower data storage capacities are preferred when a cost-efficient application is targeted.

Other factors that affect the method of data storage in RFID applications are observed to be the number of parties involved in the business, as well as the number of locations that a particular business takes place. When multiple parties and multiple places are involved in an application, data ownership issues arise, in terms of the owner of tha data and the manager of the data. In such cases, data related to an item that changes places and parties during the application, needs to be stored directly on the item itself. Hence, data can be made available to everyone who has the item in hand, and no data management and ownership problems occur. Also, connection to a database might not be provided in every phases that an object goes through during the business. Thus, the necessary data should be stored on tags and made available to the ones with RFID readers, where no network connection installed.

In some cases, another factor in deciding the method of data storage can be the characteristics of the application itself, thus the type of information to be collected and stored. Example to such kind of utilization of RFID systems can be the applications that require the data to be stored and collected at the point of action, thus a data-on-tag approach to be applied. For instance, when the environmental conditions are needed to be monitored, utilization of sensor (e.g., temperature, humidity, etc.) integrated active RFID tags are required. These tags can store the data related to the environment of the object (e.g., cargo containers, perishable goods, etc.) that they are attached to. This kind of utilization of RFID tags is a typical example of the additional data storage on tags, where the sensor data are temporarily stored on tag memory and then transferred to a remote computer to make use of the collected data for further interpretations. Some retail chain companies (e.g., Metro, Migros), and the U.S. DoD use this approach to track the conditions of their containers during their transportion. When a reading point is reached, the sensor data on the tag is then used to monitor the traveling conditions (e.g., temperature throughout the transportation) of the goods. Moreover, these sensor-enabled tags can also detect the theft and pilferage attempts on cargo containers. This information is also stored on tags and transferred to a reader when a reading point is reached, and enables the user to see the number and time of the attempts.

Requirements of RFID applications affect the method of data storage in RFID implementations, as well as the type of tag to be used. For example, active RFID tag usage on airplanes has not yet been approved by the authorities in aerospace industry, passive tag usage on planes is a must. But the aerospace industry's requirement for large memory capacity led the technology suppliers work on producing passive tags with larger memories, such as 32 to 64 Kbytes (Bacheldor, 2009; Burnell, 2009).

Another factor when deciding the method of data storage on RFID tags, is the need to document the history of an object (e.g., maintenance records). This kind of applications require the data to be stored directly on the tag to ensure the data are moving with the object throughout the lifetime of the object. Thus, different parties can retreive the necessary data without the need to connect to a database. Aerospace industry typically applies this kind of approach in RFID applications, where information related to aircraft parts and tools are written on tags. This ensures the relevant information is travelling with the part itself, and can be retreived when needed by one of the multiple service suppliers of aircraft parts throughout the the world. Similarly, hospitals and their staff may need the personal and medical information of a patient to be moved with the patient him/herself. In such applications, data can be read with a handheld reader immediately from a tag formed as a wristband.

Table 4.8 : Distribution of applications among the industries, summary of the data storage concepts and the type of tags used in each case.

Applications		Industries
Object tracking (64)	**People (9)**	- Construction Industry: 1 integrated data storage: active (N/A), - Aerospace Industry: **1 data-on-tag: passive tag (HF);** *1 data-on-remote DB: passive (HF)* - Defense Industry: **1 data-on-tag: passive (HF)** - Healthcare Industry: *2 data-on-remote DB: 1 passive (UHF); 1 active (UHF);* 3 integrated data storage: 3 passive (UHF)
	Equipment/Asset (11)	- Construction Industry: **1 data-on-tag: active (UHF);** *2 data-on-remote DB: 1 passive (UHF); 1 active (UHF)* - Defense Industry: *2 data-on-remote DB: 2 passive (UHF);* 3 integrated data storage: 1 active (UHF); 1 active (N/A); 1 battery-assisted (UHF) - Healthcare Industry: *1 data-on-remote DB: 1 passive (N/A);* 2 integrated data storage: 1 active (UHF); 1 active (microwave)
	Materiel/Material (10)	- Construction Industry: **3 data-on-tag: 1 active (UHF); 2 passive (HF);** *2 data-on-remote DB: 1 passive (UHF);1 active (UHF);*3 integrated data storage: 1 passive (HF); 1 active+passive (N/A); 1 N/A - Defense Industry: *1 data-on-remote DB: passive (UHF);* 1 integrated data storage: passive (HF)
	Product (21)	- Retail Industry: *12 data-on-remote DB: 9 passive (UHF); 1 passive (HF); 1passive (N/A); 1 active (UHF);* 4 integrated data storage: 4 active (UHF) - Manufacturing Industry: *2 data-on-remote DB: 2 passive (UHF);3* integrated data storage: 1 active (N/A); 1 passive (HF); 1 active+passive (UWB+HF)
	Baggage (10)	- Aerospace Industry: *5 data-on-remote DB:5 passive (UHF); 5* integrated data storage: 1 passive (HF); 3 passive (UHF); 1 passive (N/A)
	Pharmaceuticals (3)	- Healthcare Industry: *3 data-on-remote DB:1 passive (HF); 1 passive (UHF); 1 passive (N/A)*
Localization (16)	**Mobile object localization (2)**	- Construction Industry: *2 data-on-remote DB: 1 active (microwave);1 active (UHF)*
	Stationary object localization (12)	- Construction Industry: **2 data-on-tag: 2 passive (N/A);** *1 data-on- DB: 1 active (UHF);* 2 no data stored, tag type N/A - Defense Industry: *2 data-on-remote DB: 1 passive (UHF); 1 active (microwave);* 1 integrated data storage: active (microwave) - Manufacturing Industry: *2 data-on-remote DB: 3 active (microwave); 1 active (UWB)* - Healthcare Industry: *2 data-on-remote DB:2 active (UHF)*
Lifecycle information tracking (10)		- Construction Industry: **3 data-on-tag: 2 active (UHF); 1 active+passive (N/A);** *1 data-on-remote DB:1 passive (UHF)* - Aerospace Industry: **4 data-on-tag: 1 passive (UHF); 3 passive (N/A);** *1* integrated data storage: 1 passive (UHF) - Manufacturing Industry: **1 data-on-tag: 1 passive (UHF)**
Construction/progress management (6)		- Construction Industry: *5 data-on-remote DB:2 passive (HF); 1 passive (UHF);2 N/A;* 1 integrated data storage: 1 passive (HF)
Quality control/management (5)		- Construction Industry: *2 data-on-remote DB: 1 passive (N/A); 1 N/A;* 3 integrated data storage: 2 active (UHF); 1 active (N/A)
Supply chain/logistics network (2)		- Defense Industry: 2 integrated data storage: 2 active (UHF)
Inventory/warehouse management (7)		- Manufacturing Industry: *7 data-on-remote DB: 2 active (microwave); 4 passive (UHF); 1 passive (HF)*
Security (3)	**Securing cargo containers (1)**	- Defense Industry: 1 integrated data storage: active UHF)
	Access control (2)	- Defense Industry: *2 data-on-remote DB: 2 passive (N/A)*

Written in bold: data-on-tag application, *written italic: data-on-remote database application,* written underlined: integrated data storage application
HF: High Frequency, UHF: Ultra High Frequency, UWB: Ultra Wideband, N/A: Not available

This data needs to be dynamic (i.e., read/write tags are used) to enable the storage of up-to-date data related to the object (e.g., patient, aircraft parts, construction tools), thus tags with read/write capabilities are required. Another similar approach is observed in RFID-enabled passport application, where all the personal data are stored on a passive tag. This ensures the security of personal data only available to the authorized officers in charge who are equipped with proper RFID readers, instead of being available over a network.

Summary of the distribution of RFID applications among the investiaged industries, as well as the data storage concepts they applied and the type of tags utilized, are given in Table 4.8.

5. DISCUSSION AND RECOMMENDATIONS

One hundred thirteen RFID cases, both from academia and the real-life applications from six industries, are investigated and data storage needs are examined for each case. It was observed that among all industries, additional data storage on RFID tags is preferred within about 44% of the entire cases (i.e. fifty out of one hundred thirteen cases). 30% (i.e. thirty-four out of one hundred thirteen cases) of which consists of the cases that preferred integrated data storage approach, while the remaining 14% (i.e. sixteen out of one hundred fifteen cases) applied the data-on-tag approach. Passive RFID systems usage is about 53% (i.e. sixty out of one hundred thirteen cases) among the six industries, while active RFID systems are used within about 33%. Most of the active tag usage is integrated with environmental sensors that monitor several conditions such as temperature, humidity, intrusion, speed, etc. Tag type utilized in the remaining eighteen cases was not available.

Among the investigated applications of six industries; aerospace, defense and construction industries more widely deployed the concept of additional data storage on RFID tags, where the percentage of utilization of this approach is about 65%, 56% and 50%, respectively.

In construction processes, network accessibility, might not be always provided throughout the lifecycle of a component and an existent network may not work efficiently due to dynamic and harsh conditions at a construction site. Data being stored on the network would easily become inaccessible in such circumstances. Thus, storing all of the case/object-related data in a network may result in interruptions in data flow when performing the construction work. This is similar to a battlefield environment within the defense industry, where sometimes it is impossible to deploy and maintain a network. In such conditions, storing data on the tag is a more reliable method. If this is not possible, then at least an integrated data storage approach should be followed and the information needed when the object is out of the range of a network must be stored on tag, while the rest can be stored on a remote computer to be accessed later.

Storing additional data on RFID tags must be preferred within applications where RFID tags will stay with the object during its all lifespan. This approach would be particularly helpful when the tags are used to store maintenance information of objects. Also it is observed that the additional data storage on tags serves the informational function and bring identifier data about the object. This is useful within all phases of construction, since it ensures the accessibility of data without the need to connect to a database.

In construction, when multiple parties (e.g., manufacturer, contractor, inspector) in multiple places (e.g., production plant, storage yard, construction site) are involved in a life-cycle of an object and the need the object-related data at different times, it is useful to store the object-related information on the tag, and make it available from the object itself. For example, quailty control results can be written on the tag that is attached to a building component, for the different service providers to get this information from the object, at the facility management phase. In such case, RFID tags serve the documentational function, and provides up-to-date object-related data directly from the object. Contrarily, when multiple parties involved in a process need the object-related information at the same time, data should be made available on the network to meet this requirement.

It is observed that when RFID is utilized solely for determining the exact location of an object, centralized management approach is required, and thus data-on-remote database approach is more generally applied. Active RFID tags are preferred in such cases, due to their long reading ranges and self-signaling features since they work on their own batteries. Location of the tags are needed to be monitored and tracked on a computer, thus the data-on-remote database approach is preferable in object localization applications.

Future Work

As given in detail in Section 2.2.2, when RFID tags are used for additional data storage, it is possible to benefit from several functions, namely (1) informational, (2) documentational, (3) temporary storage and (4) decentralized control functions. Decentralized control function differs from other three functions, where the tags should have the capability to process their data and make their own decisions to serve this function. An example to this kind of sophisticated utilization of RFID tags can be seen in some applications, as in a factory of the oil company BP (Collins, 2006). BP is implementing sensor integrated RFID tags in a pilot project where various rules are deposited on the tags (Collins, 2006). One of these rules is for preventing chemicals that could potentially react with each other to be stored too close to each other. If this rule is broken, an alarm is set off.

Decentralized control function requires active RFID tags since they would perform some actions without receiving any power from a reader. Additionally, it carries the RFID system one step further from its traditional utilization where sensor integrated tags become sensor nodes. These sensor enabled tags then create a network, where they can communicate with each other and can make local processing of the data being stored on their own memories.

An approach similar to the utilization of RFID tags as in BP is envisioned to be used in construction industry. It is aimed to prevent faulty connections where wrong components (e.g., steel columns and beams) are connected to each other, and/or wrong connection elements (e.g., bolts) are used.

Using the right pieces of components in the right manner in a construction is of vital importance, where it can result in fatal accidents, as experienced in several constructions previously (Houser and Ritchie, 2007). It has been observed that, even the nuts used for a connection of steel pieces in a construction of a building can lead to accidents and cause the death and injury of workers when unproperly used (Barnes, 2002). As illustrated in Figure 5.1, the envisioned approach can help ensuring the proper pieces are connected to each other, by using the necessary connectors, in the correct manner.

In the proposed system, sensor integrated active RFID tags, that are pre-written with several rules to prevent wrong connections, are attached to construction components. The information related to a component, such as its ID number, specifications, and instructions are written on the tag's memory. Additionally, the ID numbers of other components that it should be connected to, are written on the component's tag. As a result, each component is aware of its adjacent component/s that it is supposed to connect with. As shown in Figure 5.1.a, while being moved to connect to each other, an RFID tag attached on a steel column and another tag attached on a steel beam start communicating. They transmit critical information related to themselves (e.g., ID numbers, specifications, instructions, etc). Each tag processes the data that they receive from each other. According to the results of this processing, the tags alert the worker by turning the lights located on themselves, if not the right pieces of components are being connected (Figure 5.1.b). This kind of utilization of an RFID system can serve all of the four functions mentioned in Section 2.2.2.

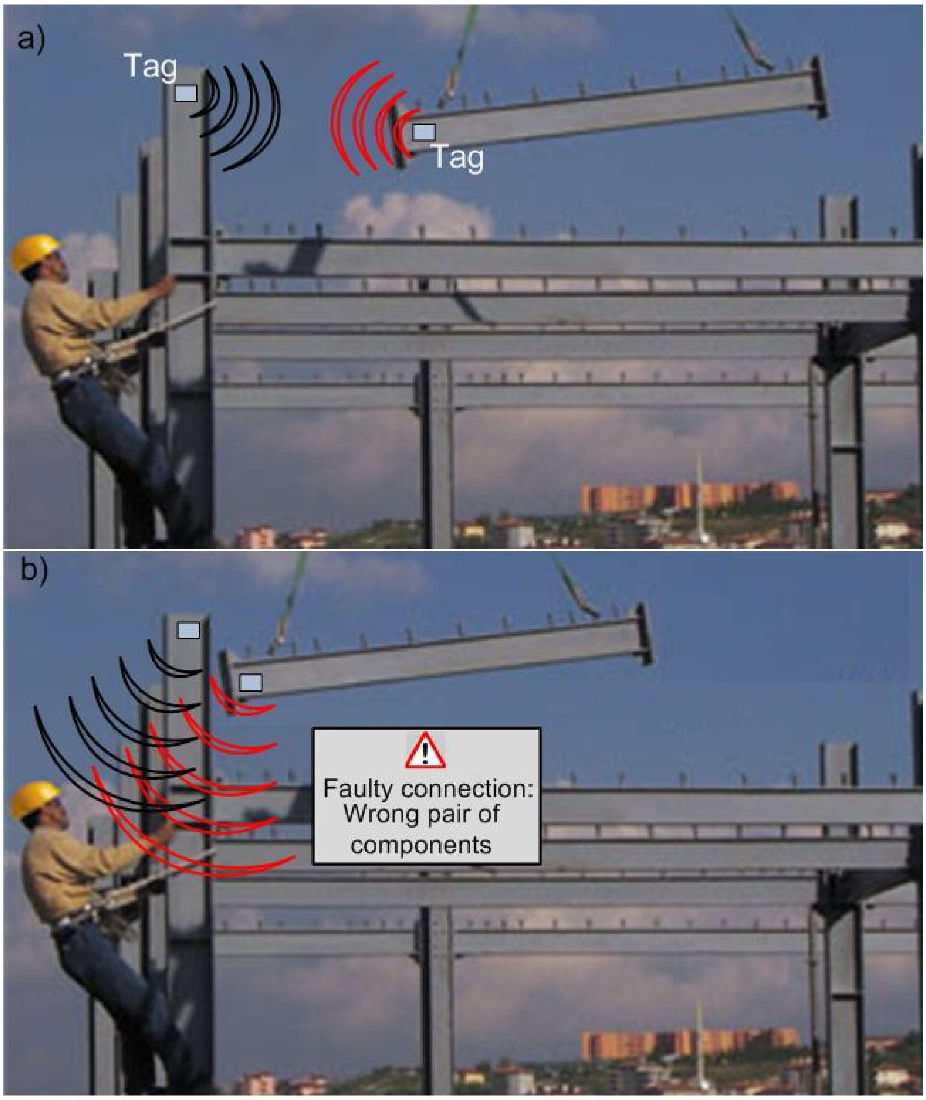

Figure 5.1 : a) Components communicating their specifications and instructions via RFID tags, b) Tags alerting the worker in case of a wrong connection.

6. CONCLUSIONS

The main goal of this thesis was:

- to identify what types of data are being stored in RFID cases that are applied in construction industry and other industries, and
- to determine under which conditions storing data on the tag is more appropriate for the construction industry.

To reach the goal of the thesis, the contexts of specific cases were needed to be known to identify the specific conditions that require different data storage approaches. Therefore, an extensive literature review related to RFID technology usage both in construction industry and other large industries was conducted to identify under which specific conditions each data storage approach was selected.

First of all, RFID cases in construction industry, both the research studies and the industrial applications, were investigated in terms of the characteristics and data storage needs. After the RFID cases are divided into groups, the data storage approaches followed in each type of application was analyzed. According to this analysis, it is observed that the half of the cases preferred additional data storage on RFID tags within the construction industry. These cases typically benefited from the informational and the documentational function of the additional data stored on tags. For example, in life cycle information tracking applications, mostly historical data (e.g., maintenance and inspection records) were stored on tags. Information items related to components (e.g., engineered-to-order components, fire valves) that include the manufacturer and owner information, as well as the handling, storage and installation instructions are stored on tags. In material tracking applications data stored on tags were mostly related to the identification and receiving process of the materials (e.g., purchase order number, release number, requisition number, client number, quantity ordered) during the delivery and receipt processes of pipe supports, pipe spools, steel components, etc.

These information items were stored directly on the component because this information is needed at multiple places (e.g. production plant, storage yard, construction site) by multiple parties (e.g. manufacturer, contractor, inspector) throughout the lifetime of the component. Network accessibility cannot always be provided in all stages of a construction component throughout its lifetime. Thus, it is necessary to store related data on the component itself to make sure that the data (e.g., maintenance history, handling and installation instructions, delivery and receipt information) is available at multiple places and accessible by multiple parties.

The reason for some cases in construction to follow an integrated data storage is that the data that is stored on the tags was needed to be transferred to a central database to be used in making further interpretations or computations about the objects on remote computers. Another method in following the integrated approach was making the most necessary information immediately available on the tag and keeping the rest of the information on a PDA or on a remote computer, server, etc.

On the other hand, most of the cases that stored data on remote databases (e.g., company databases, portal) in construction industry, were related to construction/progress management applications, localization of objects and equipment tracking . These cases utilized RFID tags for identification of objects and stored object-related data (e.g., status of the object, GPS data of objects, their locations) on remote databases. These information items are already present on the object itself when one is next to the object in the field. Thus, it is not additionally needed to store this data on the tag. Instead, this data should be made available to the ones who are not on the jobsite and not next to the object. Also, in some cases, the current status of the components was updated in the 3D model, as well. These information items were stored in a central database since they need to be made available to multiple parties working at different locations at the same time. PDA integration was also observed in the applications that stored data on remote databases, since PDAs enable uploading up-to-date data immediately to the network to improve the decision-making processes.

In applications that stored additional data on tags in construction industry, active tags were used in seven applications while passive tags were used in six applications. Active tags, due to their larger data storage capacities, are more suitable for applications where additional data needs to be stored on tags. However, passive tags also have user memory and read/write capabilities, which allow the implementers to store data that does not hold a large place (e.g., data related to material written in text format). Thus, passive tags were preferred when only a small amount of data, such as the identifier data (e.g. description of components, type of material) was needed to be stored on tags. Another reason in using the passive tags is their short reading ranges that requires a person to be close to the tag, thus to the object, to perform read/write processes. In this way, passive tags ensure that a person who is in charge of an activity which requires him/her to be in close proximity of an object (e.g., quality control inspection) performed that activity.

Passive tags, on the other hand, were more frequently used in data-on-remote database cases (i.e., eight out of fifteen) than active tags (i.e., four out of fifteen), since only a little data storage capacity is needed for data-on-remote database approach. Another reason for using the passive RFID systems was to have a more affordable application, since it is less expensive than active tags. Consequently, if cost was an important issue, passive tags were used and additional data on tags was not stored due to low data storage capacity of passive tags. For the remaining three cases that stored data on remote databases, information on the tag type was not available. If no other information is stored on active tags, the reasons for using active tags were the need for longer reading ranges or self-signaling tags that can only work on their own batteries, particularly in localization applications.

Following the construction industry, five large RFID-adopter industry were examined in terms of the data storage concepts they applied and their characteristics. Similar to the construction industry, defense industry, along with the aerospace industry, were observed to be typically storing additional data on RFID tags. This was due to the characteristics of the environments of these industries (e.g., battlefield area), as well as the needs of their applications (e.g., maintenance records on parts). United States Department of Defense is one of the early adopters of the RFID technology, also the long-time user of large memory active tags that still have the largest memory available today (i.e., 128 Kbytes). They attach these tags on containers, and write the content of the containers on the tags. This ensures the military to retrieve data about the container without opening the container and without waiting for a network connection. They benefit from the informational, documentational and the temporary storage function served by the method of additional data storage on RFID tags.

Aerospace industry is another industry where RFID has been used nearly over two decades, typically for storing maintenance and service history of aircraf parts, and history, shipping, routing and customs information of tools. Thus, they mostly benefited from the documentational function served by the additional data storage on tags. The need for the additional data storage on RFID tags in aerospace industry can be explained by the fact that the mechanic does not always have the access to Internet. Also when they want to loan, borrow or exchange parts, they immediately need to know if a certain part is interchangable on their plane (O'Connor, 2006c). Moreover, since the utilization of active RFID tags on airplanes has not been approved by the aerospace industry authorities, there are several advantages of sensor integrated active RFID tags yet to be experienced in this industry. For example, the sensors would provide insights into the conditions to which parts are exposed during a plane's journey, where this information can be used to improve the designs of aircrafts.

Retail and manufacturing industries, on the other hand, are different than the construction industry due to their relatively controlled and stable natures. Thus, they are suitable for applications where a network can be deployed successfully and access to a database is provided throughout the entire phases of the products. Moreover, the RFID mandates of large retail chains (e.g., Wal-Mart) are entailing the manufacturers, as well as the retailers, to apply the EPC compliant passive tags on their products to meet the mandate rules.

Healthcare industry is utilizing RFID tags to track employees and patients, and to determine their location, where generally active tags with long communication ranges and self-signalling capabilities are used. Also boxes of pharmaceuticals are being tagged with passive RFID tags to prevent counterfeit of drugs. Data-on-remote database approach was applied more generally in healthcare industry, unless it was needed for the patients, and the blood bags to carry the relevant information on themselves, for instance on wristbands.

As a result of the investigation of the cases that are applied in different industries, the types of information items being stored in RFID cases were grouped into seven, and then the cases were interpreted in terms of the information items they stored on tags. It was observed that all the cases that preferred storing additional data on tags, either in a data-on-tag or in an integrated data storage approach, benefited from the informational function. In this context, the identifier information (e.g., serial number, production number, manufacturer information) was stored on RFID tags in such cases. Other types of information groups were identified as the technical features information, historical information, location information, status information, task-related information and the environmental conditions information.

Additional data storage on RFID tags were observed to serve informational, documentational and temporary storage functions in construction industry cases. A further usage of RFID tags, can be utilized within the construction industry where they are integrated with sensors that can deploy a network and communicate with each other. An approach for this kind of utilization of RFID systems is envisioned where components themselves are able to communicate with each other and prevent any possible faulty connection by alerting the workers.

Construction industry, similar to others that store data on RFID tags within RFID applications (i.e., defense industry and aerospace industry), was suitable to follow the data-on-tag approach due to its dynamic nature where it is not easy to deploy a network. The need to store the relevant data directly on the object itself is great, due to multiple number of parties and multiple places involved in construction processes. The advantage of storing object history within maintenance and service applications through the facility maintenance phase is another need, where the history of the object is made available with the object itself. In addition to the data-on-tag approach, the integrated data storage approach can also be applied, when network connectivity is partly employed.

It has been shown that, construction industry needs tags/storage mediums with large memories but currently, most of the tags have memories less than needed. Moreover, the results show that, there is a need for tags/storage mediums that are specially designed for construction industry, having larger memories to store data related to components and equipments on the job site, as well as to store the records of their operation and maintenance histories.

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