Technologies in Object Tracking System

Until today, technologies in tracking system have been being invented to help human to track objects moving in space more precisely and accurately. It is apparent that tracking system becomes more crucial for most organizations, institutions and corporations to prevent their valuable assets from unexpected losses as well as improving the level of visibility and awareness of the assets.

In addition to that, the tracking system can help the adopters in manufactures to reduce unnecessary incurring costs in the process of identifying, classifying, locating, inventorying and safeguarding the assets. From those reasons, the technologies in this particular area are significantly developed and improved over time to give the technology adopters the safety needs corresponding to the second layer of "deficiency need" pyramid proposed by Abraham Maslow in 1943[1].

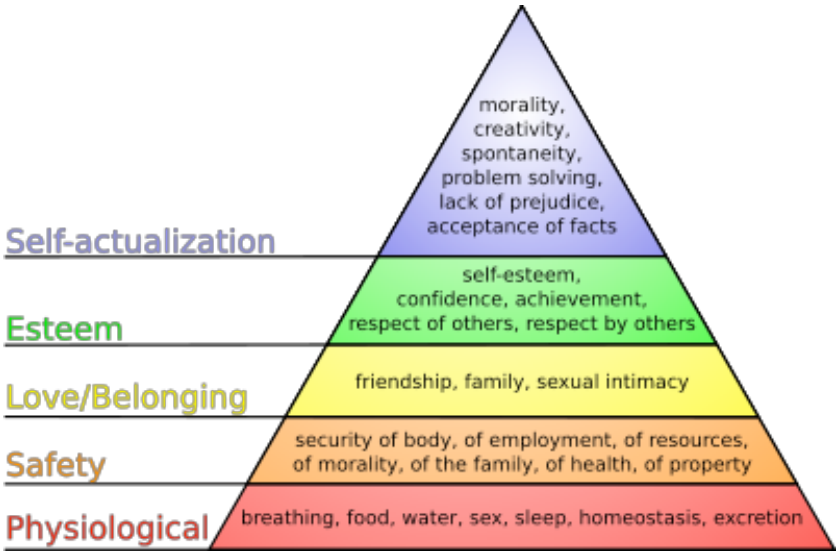

Diagram 1: Maslow's hierarchy of needs, represented as a pyramid

There are several technologies behind the tracking systems. One of the world's most widely used technology for tracking system nowadays is Radio-Frequency IDentification (RFID). This technology uses radio wave to identify and track an object. RFID tags are usually attached to the objects targeted to track. Data in the RFID tags are stored and retrieved wirelessly from another device in the system called RFID transponder. This technology is extremely used in enterprise supply chain management,

[1] http://en.wikipedia.org/wiki/Maslow%27s_hierarchy_of_needs

which leads to the increasing market size as the technology is going mature and become a standard of many gigantic manufactures and department stores.

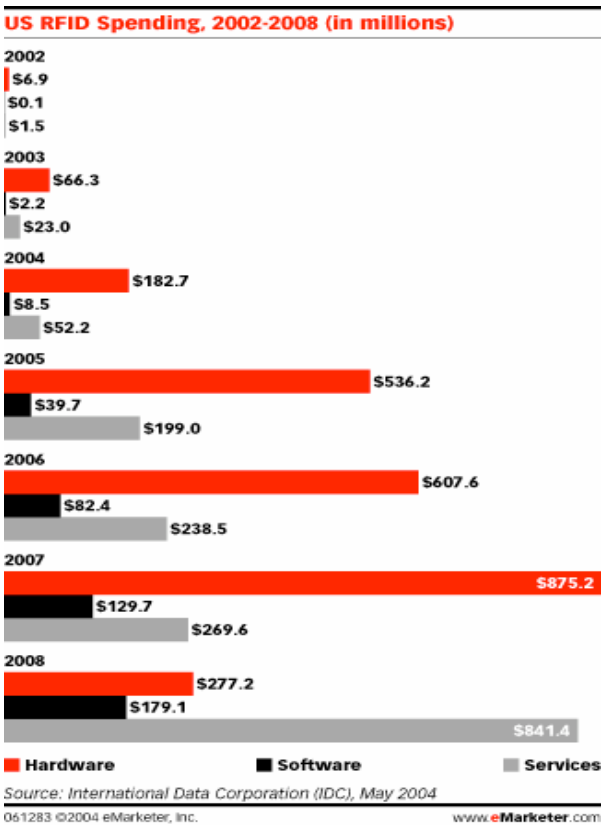

Figure 2: US RFID Spending[2]

According to the figure 2, the estimated US RFID spending in 2008 would reach $280 billion for RFID hardware and 180 for RFID software. This trend seems to correspond to the estimation of Canada RFID revenue, which would reach $61 million in 2012 shown in figure 3. The conformity of these 2 market forecast shows a potential exponential growth of the technology needs in this decade.

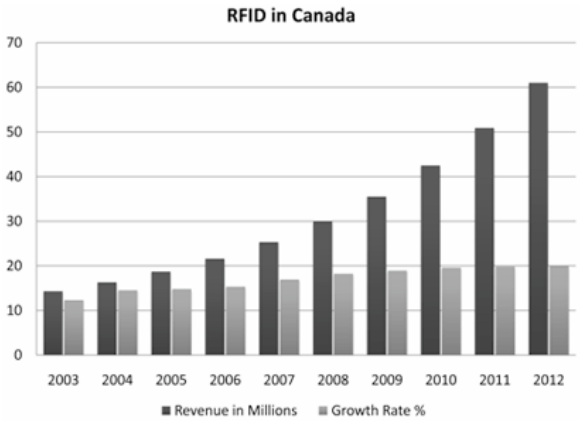

Figure 3: RFID revenue in Canada[3]

[2] http://www.santella.com/RFID%20Spending.gif

[3] http://www.privacyconference2007.gc.ca/workbooks/Terra_Incognita_workbook8_E.html

In the space of remotely tracking system, several key parameters that are often used to characterize technologies consist of:

Battery Life

As the system can be divided into 2 parts, two of which are RFID tag/receiver and RFID transponder, battery life usually refers to the lifetime of RFID receivers, which has an effect on system maintenance cost.

Read Range

The read range is one of the most important keys of RFID technology. With this unique capability, the data in RFID tag can be read from distance although there is an impediment in the way of data transmission. However, the distance and type of the impediment between RFID tag and RFID transponder affect the data readability of this technology. As a result, the "read range" attribute could limit possibility of some technology applications.

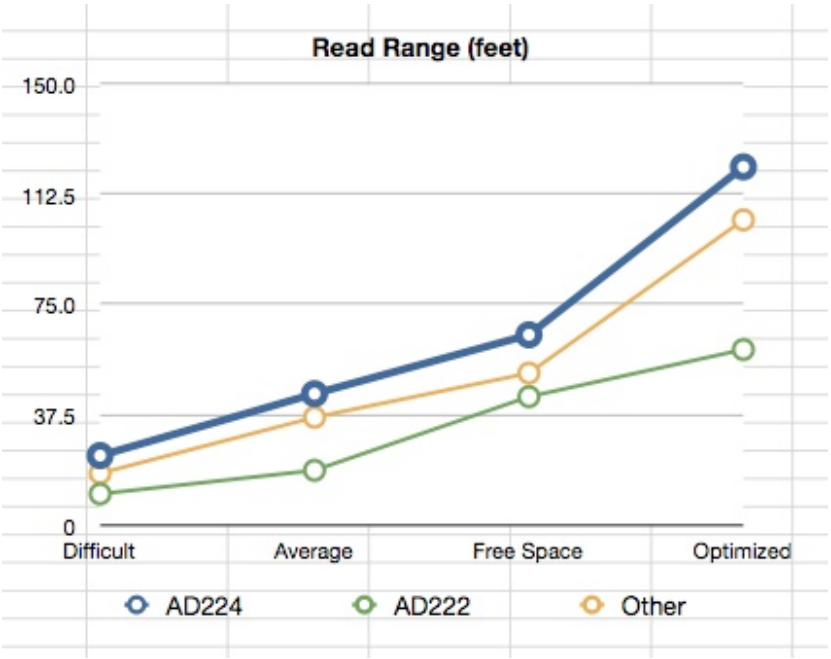

Chart 4: Read Range of RFID tags[4] in various conditions

[4]http://www.rfid.averydennison.com/us/products_portfolio.php

The read range depends on the circumstances. As illustrated in the graph[5], "difficult" conditions usually mean there are liquids or metal as obstructions in the RFID reading direction while "average (max)" condition reflects the average range in general situations. Free space condition is the minor optimized situation. For example, installer ensures tags are facing readers and give clear line-of-site while "optimized" condition is the maximum range of RFID tags.

Security of Information

As the information written in the RFID tag could be sensitive or confidential for the manufactures, the exposure of non-disclosed information in the system becomes another attribute to consider as a key parameter.

Safety

Some people believe that biological tissues can be harmed by radio wave because there was a report about increased incidences of tumors on nerves that connect the ear to the brain and in the UK, convincing that radio wave from mobile phones can damage human cells[6]. As RFID is developed on the radio wave, it could raise the same safety concerns.

Reliability

Sometimes radio frequency based technology cannot provide 100% reliability because of the noises in some particular areas, which result in signal lost or distortion. This attribute is also one of the key performance indicators used to evaluate tracking system performance.

Data Reading Speed and Writing Speed

Last key parameter is the speed of exchanging data between RFID transponder and RFID tag. As RFID tag usually holds a few bytes of information, the data speed and writing speed is fast enough for wide-range application. However, recent RFID tags introduce the better read and write speed.

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[5]http://blog.simplyrfid.com/2008/07/read-range-how-far-can-we-track-you-with-passive-rfid.html

[6]http://www.safekids.co.uk/MobilePhoneHarmChildren.html

The key trade-offs inherent in this technology is laid between the read range and the data reliability. Basically, the more the RFID workable range is, the less accurate the RFID transponders can provide. From that reason, the technology trade-off draws the boundary of RFID applications, which eventually result in the limited performance envelope if there is no either RFID tag and transponder improvement or identification technique enhancement involved in the application level. The read range can be presented in term of the system capability while data reliability reflects the system quality.

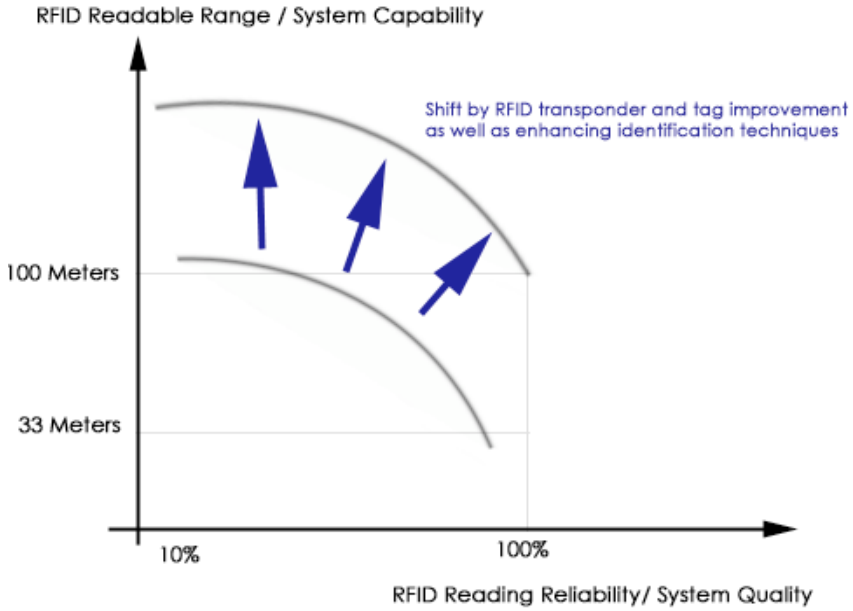


Figure 6: Trade-Off between Read Range and Reliability

Thanks to several initiatives to extend the capabilities of RFID tags over time, two key parameters, which are readable range and reliability, have been improved dramatically. For instance, "Chipless" tag has been created to deal with the physical limitation of radio frequency detection. "Chipless tag can be more easily applied to metal and liquid or embedded in items like paper"[7]. Another example is the "Tag Packaging", which involves with the improved process of printing tags on an object's package while maintain the RFID capabilities. This invention introduces new possibilities of RFID applications as well as pushing the technology envelope further. From these examples,

[7]http://www.developer.com/java/web/article.php/3494591

it could be seen that the two parameters (read range and reliability) relating to the RFID performance have been evolving over time after the technology started to become widely used by many companies.

There was a report in 2003 saying that the longest readable range was 30 meters[8] while the longest readable range becomes 10 meters at the object's speed of 100 kilometers per hour[9] recently. From that reason, the innovation trajectory of RFID technology significantly depends on the new breakthroughs and techniques to allow the RFID transponders to detect a RFID tag in long distance and information accuracy can be still obtained from the RFID tags in the distance.

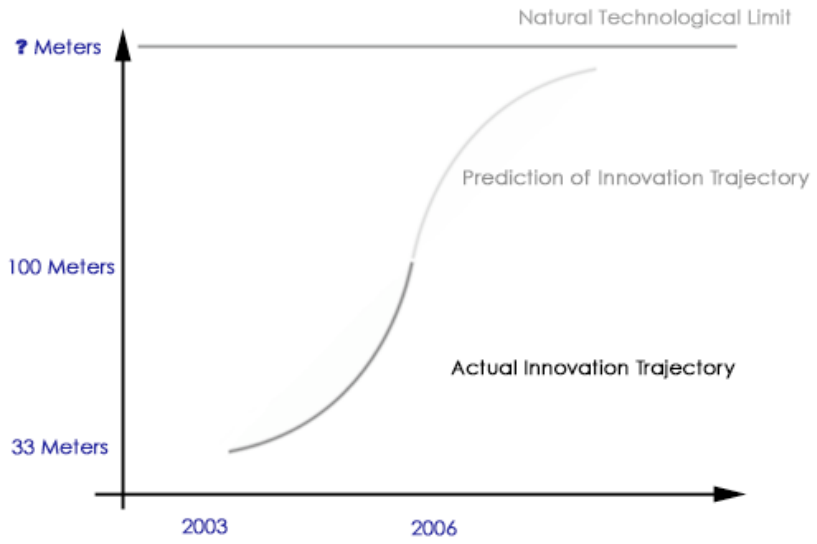


Figure 7: innovation trajectory of RFID technology

Although the RFID is the promising technology for object tracking system, the RFID technology needs to compete with the existing Barcode technology, which has been used for several decades. As the cost of using Barcode is much cheaper than using RFID, many companies in developing countries believe that they can afford the Barcode technology but not RFID at this time. Plus, most companies around the globe still use

[8]http://www.wi-fiplanet.com/tutorials/article.php/3292521

[9]http://www.electrocom.com.au/rfid_hyperx.htm

Barcode as a mean to track things because the Barcode technology offers acceptable tracking ability as well as not requiring changes in the companies' existing systems.

	RFID vs. Barcodes	
	RFID	Barcodes
Line of sight needed	No	Yes
Tag's Capabilities	Read/Write Capable	Read Only
Reusable	Yes	No
Cost of Tag	Expensive	Inexpensive
Security	Data can be read by any RFID System	Data is not held on label

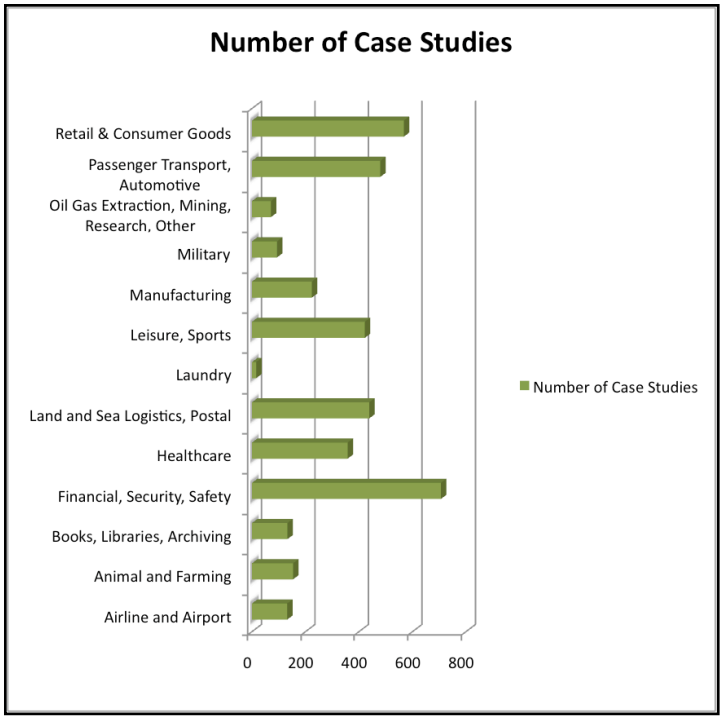
As shown in the table, both RFID and Barcode technologies have their own advantages and disadvantages. RFID provides a possible way to track things wirelessly in longer distance than Barcode. Also, RFID tags can be detected although there is not line of sight. However, the security and cost becomes the drawbacks of RFID when comparing to Barcode technology that has a cheaper tag and more secure. In near future, RFID would become more dominant than barcode because the price of a RFID tag will be cheaper since more companies tend to adopt the technology. Along with the solid technology standards, the RFID will be widely acceptable by big companies that want to improve their efficiency in logistic and supply chain management, which are considered huge company expenses for a long time.

Anyway, read range and reliability are expected to improve ever more over time, as they are the key parameters that leverage RFID technology to reduce asset management costs while increasing business values in term of object tracking. RFID is believed to stay in the game for at least a decade because one of the biggest players in retail chain like Wal-Mart still supports and pushes the technology adoption to their suppliers. However, the tendency of RFID to reach "natural technological limits" in the future is high because RFID cannot provide accurate location once the RFID tags and transponders are far from each other more than some specific length. Other technology like GPS might become a better choice if the object tracked is very much far away from the detector.

Technologies in Object Tracking

Technological advancements in tracking an object in space have been growing rapidly due to the increasing market demands for better asset management. It is observable that customer groups in several industries are now aware of substantial benefits introduced by RFID technology as well as its promising value added. Since those various groups of industries also perceive the RFID technology as a competitive advantage for their business, no wonder why there have been a number of research projects to continuously push the technology envelope in order to increase new possibilities of the technology applications. For example, new RFID tags are designed and improved over time to provide a longer RFID read range, which allow possibility to appropriately handle hazardous materials from a distance. Plus, direct contact to the hazardous materials can even be avoided by using this contactless identification technology.

According to The RFID Knowledgebase[1], there are 3,690 case studies in which 3,741 companies in 110 countries around the world are covered. It is apparent that top 3 industries that have adopted RFID technology so far are: financial, security and safety; retail; and, passenger transport and automotive.



This finding corresponds to the top 3 emergent RFID application areas consisting of:

- Asset Monitoring and Control

[1] http://www.idtechex.com/knowledgebase/en/nologon.asp

- Item tracking and tracing
- Inventory monitoring and control

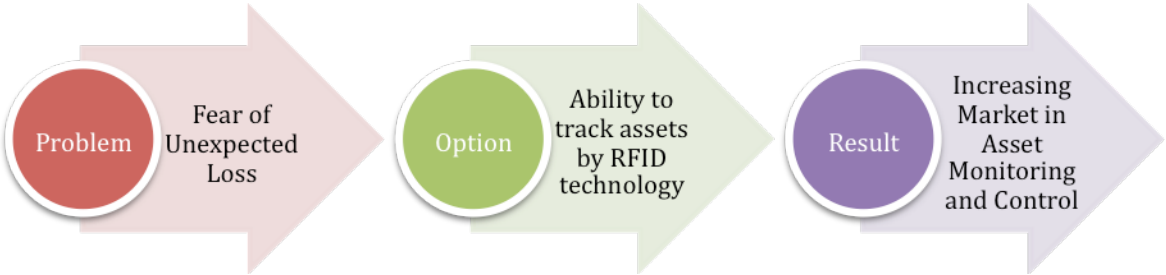
Asset Monitoring and Control

Key Value Added to technology adopters: Asset Security

Thanks to RFID technology key feature, which is ability to track an object in space without physical contact, many prevalent RFID applications could be implemented to keep track on assets automatically and accurately.

It is perceivable that many RFID technology adopters have a strong need in securing their valuable assets that might be easily stolen or lost. The fear of unexpected loss becomes a key driver to make this customer group invest in preventive systems using RFID technology to allow them to protect their own asset effectively. This condition is similar to the Lexar's successful case where Lexar's technology promises meet the needs of selected customer segments. Specifically speaking, Lexar's customers, who mostly are professional photographers, valued "click to click" time when taking successive pictures. From that reason, the speed of taking pictures easily drove photographers to adopt in Lexar's technology.

To make RFID technology becomes successful like Lexar in the market, insights about "expected values of target customer segment' must be revealed. As RFID technology promises to bring customers tracking ability, customer segments that fear of asset loss would have the highest probability to adopt RFID technology. With the strong relationship between fear of loss and RFID tracking ability, customer groups in financial, security and safety become top technology adopters in this particular area.



Key customer segments, potential applications and RFID contribution to customer jobs under this application area can be summarized in the following table.

Key Customer Segments	Potential Applications	RFID technology contribution
Fleet management companies such as Enterprise Fleet Services, Wheels, ARI, Players and LeasePlan USA	Fleet Monitoring and Management	• Automates logging process for fleet entering and departing[2] • Allows vehicle maintenance to be automatically recorded and tracked[3]
Car Rental Companies such as Enterprise, Dollars, Hertz and Alamo	Car Monitoring	• Provides visibility of all cars in the lot • Automatically notify when car enters or leaves[4]
Universities	Physical Computer Asset Monitoring	• Controls and manages the computers and other expensive equipment throughout campus.[5]

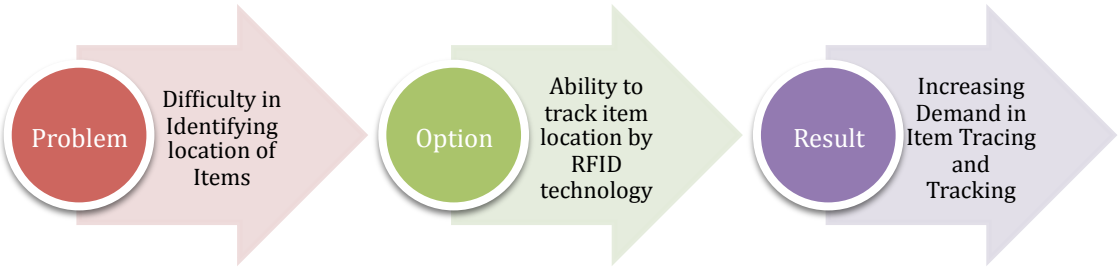
Item Tracking and Tracing

Key Value Added to technology adopters: Object Location Awareness

Problems in locating an object in space occur in almost all industries. Since RFID tags allow items to be tracked and identified wirelessly in any directions, this distinctive technology characteristic offers technology adopters item location information while those tracked items are moving. With better technology tracking and tracing capability, RFID would soon replace the barcode and dominate existing barcode market. Furthermore, as there is a tight link between problems of identifying a right object and ability to immediately locate an object offered by RFID technology, barcode customer groups, who perceive the value of near real time information on

[2]http://www.rfidnews.org/2008/07/25/australian-city-uses-rfid-for-fleet-management
[3]http://www.activewaveinc.com/applications_fleet_maintenance.php
[4]http://www.gaorfidassettracking.com/RFID_Asset_Tracking_Applications/RFID_Car_Rental.php
[5]http://www.morerfid.com/details.php?subdetail=Report&action=details&report_id=2192&display=RFID

the tracked item location, are the most likely to switch to RFID technology.



Key customer segments, potential applications and RFID contribution to customer jobs under this application area can be concluded in the following table.

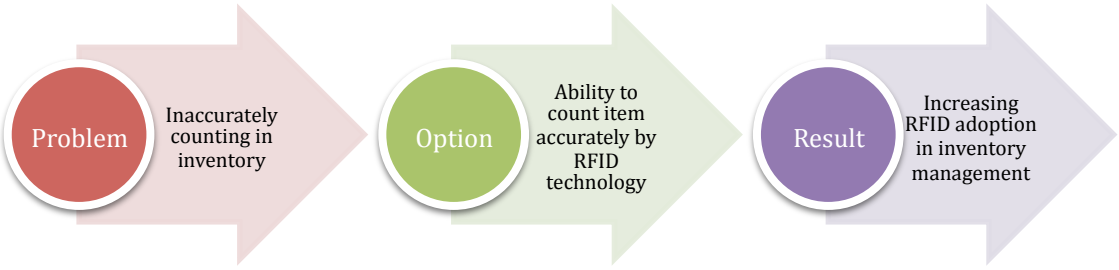
Key Customer Segments	Potential Applications	RFID technology contribution
Hospital	Patient Care and Management	• Provide real-time tracking of the location of doctors and nurses in the hospital • Track a patient's location (some Alzimer's patients may not be able to identify themselves, RFID tags will help doctor and nurses to identify them without asking) • Offer a means to rapidly verify information concerning patient allergies, prescription history, etc. to prevent surgical errors[6]
Shipping Companies such as UPS and FedEx	Package Tracking System	• Identify the right shipping containers[7] • Speed up dispatch process of goods[8] • Allow customer to check the location of the package shipped
Retail Stores such as Wal-Mart, Office Depot and CVS	Smart Shelves	• Accurately locate the items from shelves • Allow stores to track product packages that are "expired" on the shelves[9] • Ensuring that products (e.g., pharmaceuticals) are authentic and have not been altered in any way[10] • Report out-of-stock products to the procurement department to order

[6] http://www.privcom.gc.ca/fs-fi/02_05_d_28_e.asp
[7] http://www.rfid-weblog.com/50226711/rfid_for_shipping_containers_security_and_efficiency.php
[8] http://www.informationweek.com/news/mobility/RFID/showArticle.jhtml?articleID=54200114
[9] http://www.rfidjournal.com/article/articleview/4109/1/1/
[10] http://www.privcom.gc.ca/fs-fi/02_05_d_28_e.asp

Inventory monitoring and control

Key Value Added to technology adopters: Object Countability

As a RFID tag brings ability to count items in inventory immediately and accurately, the key customer segment that has a high tendency to adopt the technology in this particular area is customer groups who carry burdens from manual inventory management as well as manual data collection process. It seems that manual inventory management prone to date errors, which leads to either inventory shortage or inventory excess, lack of inventory space and unnecessary safety stocks. These inventory problems become more critical to business success in long run. As a result, accurate object countability is considered as an important part for inventory manager.



There is a coherent relationship between the inventory problems and counting feature provide by RFID technology, which increases the overall demand in several key customer segments as shown in the table below.

Customer Segments	Potential Applications	RFID technology contribution
Airplane and Automobile Manufactures	Parts Inventory Management	• Accurately identify aircraft parts in repairing and maintenance process[11] • Allow car makers to track parts from their suppliers[12]
Distribution Centers	Product Distributing Management	• Save time in order reconciliation and item inspections

[11] http://www.rfidjournal.com/article/articleview/3819/1/1/
[12] http://www.autoindustry.co.uk/news/19-09-06_7

		• Redirect the cases and pallets towards proper destination[13]
Manufactures in Supply Chains	Supply Chain Management	• Monitor and control the flow of goods from raw materials through to finished product, from manufacturer to consumer[14] • Improve collaborative planning with supply chain partners[15] • Enable automatic replenishment of parts and products from suppliers[16]

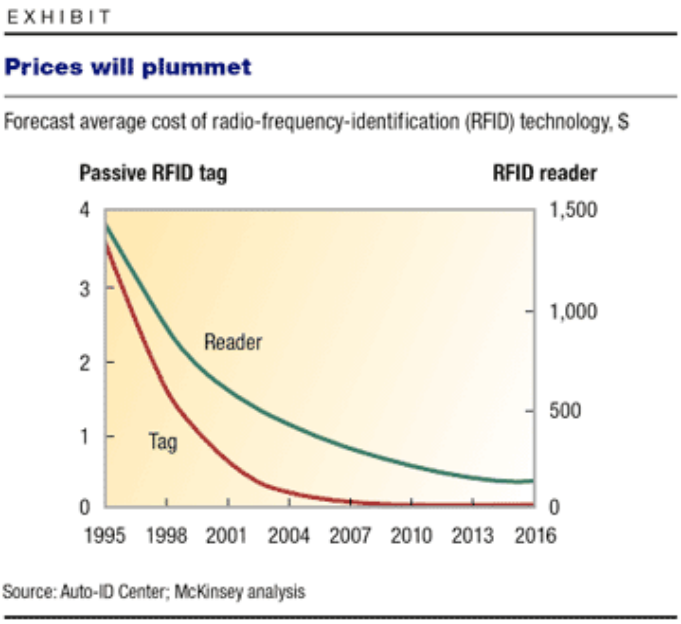
It is interesting that customer needs in RFID technology has been evolved over time. They can be classified as a heterogeneous group who change needs and values when in-depth information about RFID technology is available. At first, they might not know the entire benefits of RFID technology, which result in taking whatever solutions proposed by RFID suppliers. As time goes by, the RFID adopters learn and gather experiences in RFID technology, which allows them to design their solutions while having suppliers to implement those solutions. From that reason, there are a variety of demand opportunities for the RFID technology in both device level and application level.

It is important that many key factors in RFID domain need to be satisfied before speeding up the diffusion and adoption rate. In today's situation, the most important key factors can be described as follow.

[13] http://www.abrfid.com/rfid/articles/rfid-technology-distribution.aspx
[14] http://www.decisioncraft.com/dmdirect/pdf/rfidapplications.pdf
[15] http://www.allbusiness.com/company-activities-management/operations-supply-chain/5533894-1.html
[16] http://www.allbusiness.com/company-activities-management/operations-supply-chain/5533894-1.html

Cost of RFID system[17]:

One worrisome aspect of RFID technology is about the tag cost. RFID technology adopters have to balance between benefits that RFID promises to give and overall cost in setting up a RFID system. There are many types of RFID tags in the current market, the price of which vary from 10 cents to 50 dollars depending on the RFID tag type and the order volume. Moreover, RFID readers are a bit more expensive than a tag. As a result, the overall cost of a RFID system may be still too pricey for most potential RFID technology adopters in this decade. So, the adoption and diffusion still need to wait until the mass productions of RFID tags occur, which will low down RFID tag cost.



Average Cost of RFID Technology[18]

RFID Technology Reliability[19]

There were some stories about the technology reliability issues that affect the confidence of RFID technology adopters to implement RFID projects in their companies. Although the cost of RFID devices started to fall down to an acceptable level by many companies, most of the companies still decide to keep using barcode

[17] http://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=4281599&isnumber=4281390
[18] http://www.santella.com/news&views.htm
[19] http://www.usingrfid.com/news/read.asp?lc=q13985bx662za

technology, as the bar codes are cheaper, easy to be reproduced and more reliable at this stage.

Even though there are two key factors that define technology diffusion and adoption in the today's market, another two factors seems to affect the rate of RFID technology adoption and diffusion in the future. Those two key factors are:

Technology Standard[20]

The issue on various standards of RFID is anticipated to become a main concern for all potential RFID adopters because it would be too risky for a company to invest in new technology that may not meet technology standard of customers, partners and suppliers. Unlike RFID technology, barcode technology has the same standard for all countries, which allows adopters to easily use barcode as a mean to identify products instead of RFID. From this reason, this key factor heavily delays the rate of RFID adoption and diffusions in overall.

Technology Compatibility

Technology compatibility issues could be the most crucial to RFID adopting companies in the future if the RFID system is adopted without following the global standard for the RFID technology. It is due to the fact that there is no single global standard for RFID technology yet. Although the RFID technology can bring benefits as promised, it would be useless if the invested RFID systems cannot work with other existing technologies either inside or outside the company. Company may need to spend more money in making other non-RFID systems work with the RFID ones, which could make the system more complicated and require a lot of changes in the company.

Although there are 4 key factors that influence the RFID adoption rate and diffusion rate, smart RFID suppliers can still develop their marketing strategy to attract RFID customers. Those RFID suppliers must penetrate the most likely adopting companies first. It is observable that early RFID technology adopting companies, who decided to

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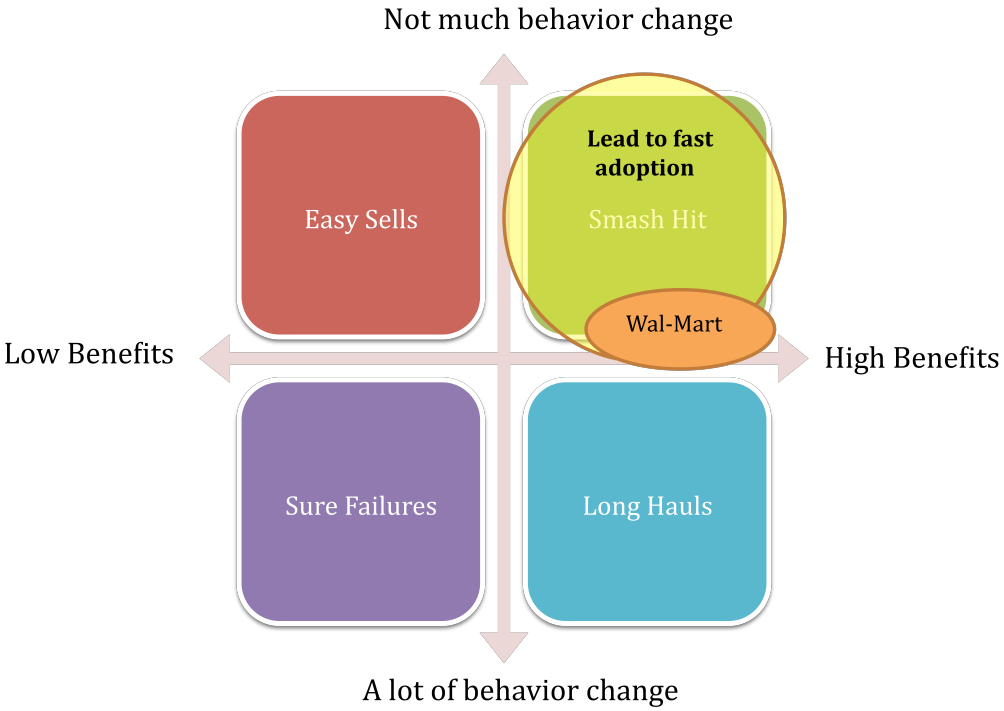
[20] http://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=4281599&isnumber=4281390

take risk to switch to RFID technology, usually see great benefits of the technology and have enough willing to spend effort changing their organization structures to be suitable for the technology. For example, Wal-Mart is one of the very first few companies who decided to utilize the benefits of RFID technology because Wal-Mart can save about $1.3-$1.5 billion, which is about 6-7% of annual cost[21]. Unfortunately, Wal-Mart needs to accept the fact that universal use of RFID tags is going to take some time[22] to change their suppliers in their chain to adopt the RFID technology, which require moderate behavior change. So, Wal-Mart could be located in the area of the graph below.



To increase the adoption and diffusion rate, a currently popular strategy is to have "an incremental pilot project[23]" in real working environment to prove the RFID system functionalities and capabilities step-by-step. At the same time, adopters should avoid any "radical technology transition project" as it can shift from "Smash Hit" area to "Long Hauls" area. This incremental pilot project approach also

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[21] http://news.cnet.com/Wal-Mart-to-throw-its-weight-behind-RFID/2100-1022_3-1013767.html
[22] http://osdir.com/ml/culture.it.newsscan/2003-11/msg00005.html
[23] http://www.informationweek.com/news/showArticle.jhtml?articleID=46802517

corresponds to some insights from Everett Rogers's five product-based factors, which can be explained in great detail below.

Relative Advantage: With a "pilot" strategy, the final decision maker in the organization would have a chance to perceive the relative advantages of RFID technology. The positive system perception will help the decision maker to adopt this technology easier as he/she has a better understanding about the tool.

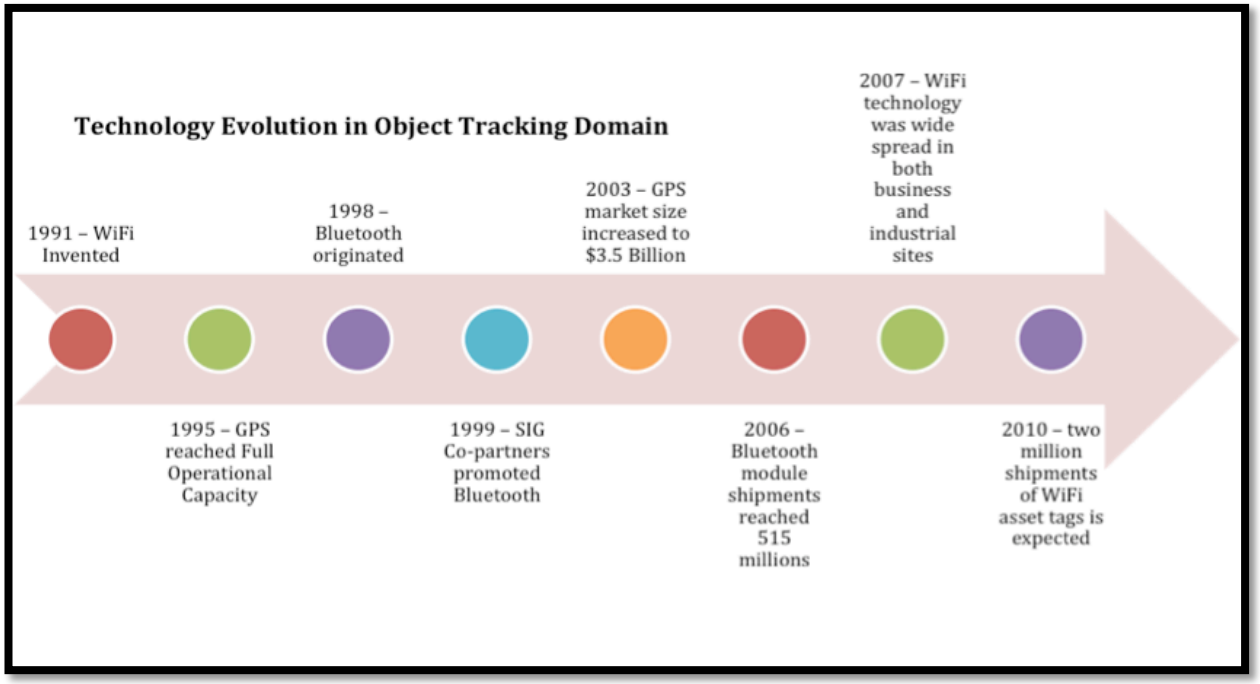
Compatibility: The "pilot" strategy will help RFID project development team to recognize the potential incompatibility problems before full implementation and integration occur. Plus, RFID implementers would gain understanding on what component is missing to ensure that the "pilot" RFID system could seamlessly integrate into the company existing systems in the company. The compatibility to the existing company systems will lead to greater technology diffusion.

Complexity: New RFID systems from the "pilot" strategy will not create any complexity to the users because users will incrementally learn over time and eventually become familiar with the technology.

From these factors, RFID technology would be adopted and diffused faster than ever when the "pilot" strategy is executed in companies across various industries.

The Technology Evolution in Object Tracking Domain

Object tracking technologies have an extensive history although many people might perceive that most of object tracking technologies are relatively new to the world. There are 4 outstanding technologies in object tracking domain that have been highly adopted and still being developed to extend their capabilities. They are global position system (GPS), Wi-Fi, Bluetooth and Radio Frequency Identification (RFID). Even though it may be a bit difficult to trace accurate starting points of time when these 4 technologies have firstly been invented, a brief of technology origins and their timelines are introduced to present a rough picture of technologies evolution in this particular domain.



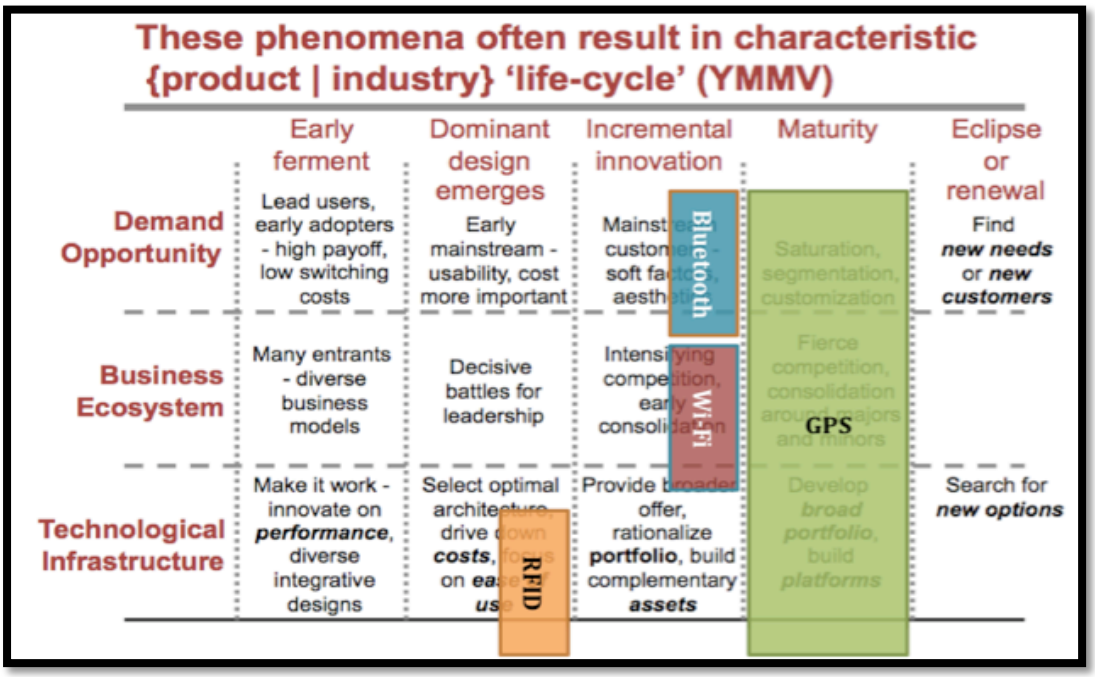
GPS was initially developed by the US department of Defense to obtain location of military personnel and transportation units. It was not until July 17, 1995 that GPS could reach full operational capacity because a minimum of 24 satellites was required to be in space[1]. Following that, the revenues in GPS were about $3.5 billions and 4.1 billions in 2003 and 2004 respectively according to Frost and Sullivan's North American GPS Equipment Market Report. Because of the stable platform and numerous adopter demands, GPS is considered to reside in "maturity" stage in technology life cycle (by Michael Davies).

Similarly, Wi-Fi was firstly invented in 1991 for cashier systems by NCR Corporation and AT&T. With the strong need of connecting to the Internet, Wi-Fi enabled devices has been produced tremendously. As of 2007, Wi-Fi technology has spread widely in both business and industrial sites[2]. With a tracking software and WiFi tags, adopters and users can utilize their existing wireless network to track objects. From that reason, **WiFi tracking system** becomes more popular in recent years. It is estimated that almost 2 million WIFI

[1] http://illumin.usc.edu/article.php?articleID=137
[2] http://en.wikipedia.org/wiki/Wifi#History

asset tags (used for WIFI location tracking) shipments will be reached in 2010[3]. From the ubiquitous WiFi enabled devices, it is apparent that the WiFi technology is in "maturity" stage while WiFi tracking technology is still in "incremental innovations" stage due to moderate numbers of available WIFi object tracking applications in the market[4].

Developing in parallel with GPS and Wi-Fi, Bluetooth was originated and introduced by Special Interest Group (SIG) in 1998 in order to rapidly transfer voice and data. By December 1999, founding SIG co-partners Nokia, Toshiba, IBM, Intel, 3Com, Lucent, Microsoft and Motorola had join the Promoter group, which were willing to spend money to hype the Bluetooth[5] as a communication standard among electronic devices. With increasing needs of better Bluetooth capability, SIG began a major overhaul of the Bluetooth specification with the announcement of version 2.1 in 2003. Interestingly, Bluetooth 2.0 + EDR (Enhanced Data Rate) was introduced in 2004, which led to big hit in market in 2005[6]. Plus, Bluetooth module shipment increased from nothing to $515 million in 2006. Furthermore, Bluetooth is incorporated in most cell phones and laptops, which allow Bluetooth adopters to track other Bluetooth objects easily. Like WiFi tracking, **Bluetooth object tracking** is still in "incremental innovations" stage due to moderate number of case studies to use Bluetooth for object tracking although Bluetooth technology is prevailing in market[7].



Note that although Bluetooth and WiFi are considered in "incremental innovations" stage, they almost shift to the "maturity" stage. They just need to satisfy some technological conditions before shifting. Similarly, RFID almost shifts to "incremental innovations" stage in a next few years.

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[3] http://www.electronicsweekly.com/Articles/2006/04/16/38190/wifi-tracking-will-grow-fast-says-analyst.htm

[4] http://itmanagement.earthweb.com/mowi/article.php/3789256/Tracking-Shoppers-with-Wi-Fi-and-RTLS.htm

[5] http://www.gsmfavorites.com/documents/bluetooth/history/

[6] http://www.bluetomorrow.com/content/section/11/38/

[7] http://electronics.howstuffworks.com/bluetooth-surveillance2.htm

Surprisingly, **RFID** technology that many people perceived to be a relative new technology in the object-tracking domain is the oldest technology when comparing to the other mentioned 3 technologies. It has its origins in 1940s, when the fundamental technology underlying modern RFID system was developed. The fundamental technology is **radio frequency** technology. The primary reason of the invention was to identify and discriminate between allied aircrafts and enemy aircrafts. Allied aircrafts installed transponders generally broadcast a unique radio signal so radar can detect the right aircrafts. This *Identify: Friend or Foe* (IFF) system became the basis of today's RFID technology[8].

Thanks to Continuous Wave (CW) Radio that was first introduced to the world in 1906 by Ernst F.W. Alexanderson, the beginning of modern radio communication occurred and grew dramatically. Based on radio technology, the radar was then invented to detect and locate an object by using radio wave reflection in 1922. This radar technology allowed the position and speed of an object to be determined. Although fundamental technologies existed at that time, it was not until 1950 that RFID-related technologies were heavily explored to provide object identification capability. As a consequence, the first commercial RFID implementation, which was the electronic article surveillance (EAS) equipment to counter theft, began in 1960. This made EAS became the first and most wide spread RFID commercial uses.

The full RFID implementation actually happened in 1980 when there was a great RFID proliferation in transportation, personnel access and animal tracking. Subsequently, RFID technology proved its promising benefits by being adopted to collect tolls in United State and several countries in African, Europe and Asia. With the growing interests of RFID technology in object tracking and item management along with the barcode technology, the number of companies that enter this marketplace is increasing exponentially. Major RFID events can be summarized into the following table[9].

Decade	Event
1940 - 1950	- Radar refined and used, major World War II development effort
1950 - 1960	- Early explorations of RFID technology, laboratory experiments
1960 - 1970	- Development of the theory of RFID - Start of applications field trials
1970 - 1980	- Explosion of RFID development. - Tests of RFID accelerate. - Very early adopter implementations of RFID
1980 - 1990	- Commercial applications of RFID enter mainstream
1990 - 2000	- Emergence of standards. - RFID widely deployed. - RFID becomes a part of everyday life

[8] http://www.shepardcomm.com/RFID-whitepaper-wp.pdf

[9] http://www.rfidconsultation.eu/docs/ficheiros/shrouds_of_time.pdf

Currently, RFID is considered in the "Dominant Design Emerges" as it still requires a global standard to increase the adoption rate. Also, the cost of RFID tags must be cheaper for most adopters to acquire. These two constraints are expected to be overcome by 2010.

RFID Product Dominant Design

A simple RFID system consists of 4 main components[10], which are a RFID tag, a RFID reader (interrogator), an antenna and software for data processing. Although numbers of RFID devices have been produced, there is no dominant design for RFID tags, RFID interrogators and antennas as they depend on the chip designs available in the market[11]. Also, each type of application may require different tag and interrogator designs. For example, RFID tags in personnel access applications should look like a key fob for easy carrying while RFID tags for logistic applications would look like a label.

RFID Key Fob

RFID Coin-Shaped Tag

RFID Clamshell Card[12]

From that reason, forms of RFID devices are characterized by their original chips and target applications. More importantly, since there are many existing air interface protocols (the way tags and readers communicate), data structure (the way data is organized or formatted), and application (how standards are used on shipping label) in the market, a common standard is strongly needed to allow RFID components from various RFID device manufactures to seamlessly interoperate with others. There are two dominant standards that have a strong potential to become a global standard.

International Organization for Standardization (ISO) has developed the first dominant standard for automatic identification and item management, known as 18000 series in which the major frequencies used in various RFID systems around the world are covered. The series are listed as follow[13]:

- 18000–1: Generic parameters for air interfaces for globally accepted frequencies
- 18000–2: Air interface for 135 KHz
- 18000–3: Air interface for 13.56 MHz
- 18000–4: Air interface for 2.45 GHz
- 18000–5: Air interface for 5.8 GHz
- 18000–6: Air interface for 860 MHz to 930 MHz
- 18000–7: Air interface at 433.92 MHz

[10] http://www.geneng.cc/rfid-faq.htm#Q2

[11] http://channel.media.mit.edu/ict4d/content/brainstorming-rfid-tag-design

[12] http://www.rfidconsultation.eu/docs/ficheiros/shrouds_of_time.pdf

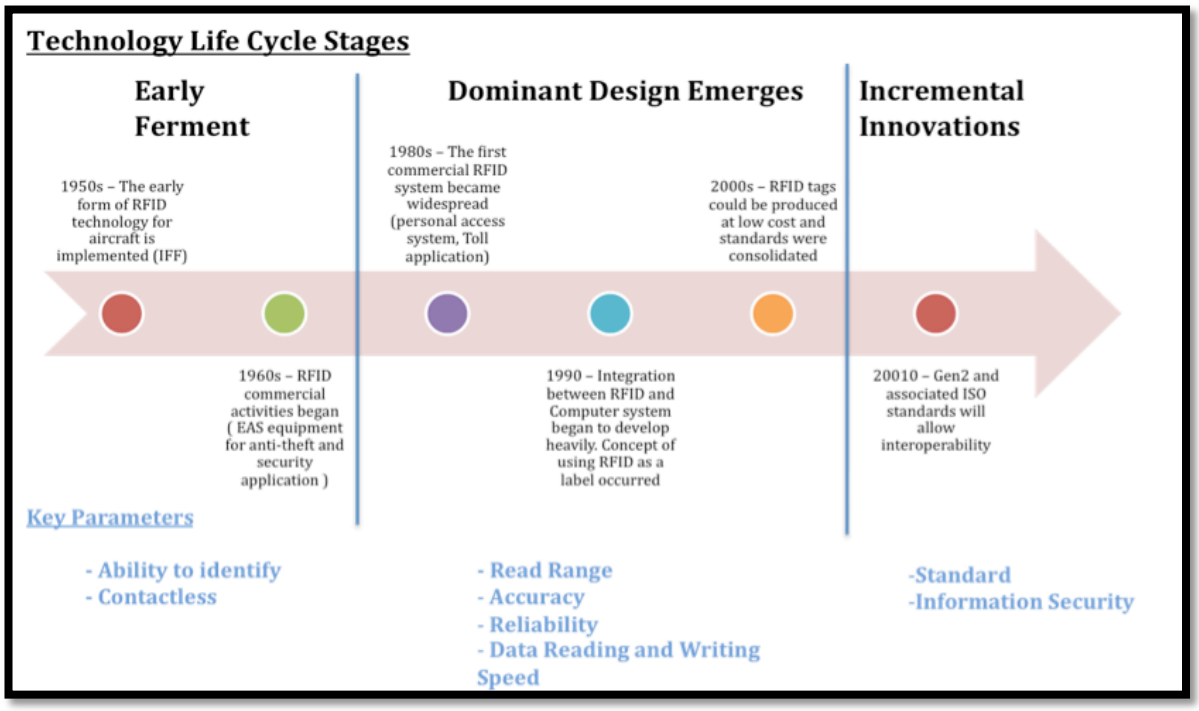
[13] http://www.rfidjournal.com/article/view/1335/3

The second promising standard is originally created by Auto-ID Center, which is a non-profit collaboration between private companies and academia that develop an Internet-like infrastructure for tracking goods globally through the use of RFID tags carrying Electronic Product Codes. The Auto-ID Center developed its own protocol and licensed it to EPCglobal, a non-profit organization who have been setup associated organizations working on Barcode standards, to make the protocol available to manufactures and end users on a royalty-free basis. Because of incompatibility with ISO standards for RFID, EPCglobal began developing a second-generation protocol (Gen2), which would to create a single, global standard aligned with ISO standards. As soon as the Gen2 was approved in December 2004[14], many RFID vendors in supply chain arena had adopted Gen2 standard and produce RFID devices accordingly. Thanks to the on-going cooperation between ISO and EPCglobal, Gen2 standard could be aligned with ISO 18000-6 standard, which would be a common solution RFID adopters in near future.

Indeed, many big consumer product manufactures (i.e., DHL, Michelin[15] and Kimberly-Clark[16]) and the biggest retailer in US Wal-Mart have already adopted this **Gen2 standard**. As a consequence, the strong demands, supports and widespread acceptance from those stakeholders will characterize Gen2 (along with ISO support) as a dominant standard for all future RFID device designs.

RFID Objective Parameters along the Technology Evolution

Along the evolution of RFID technology, each stage in RFID technology life cycle has different prevalent objective parameters, which can be illustrated in the following picture.

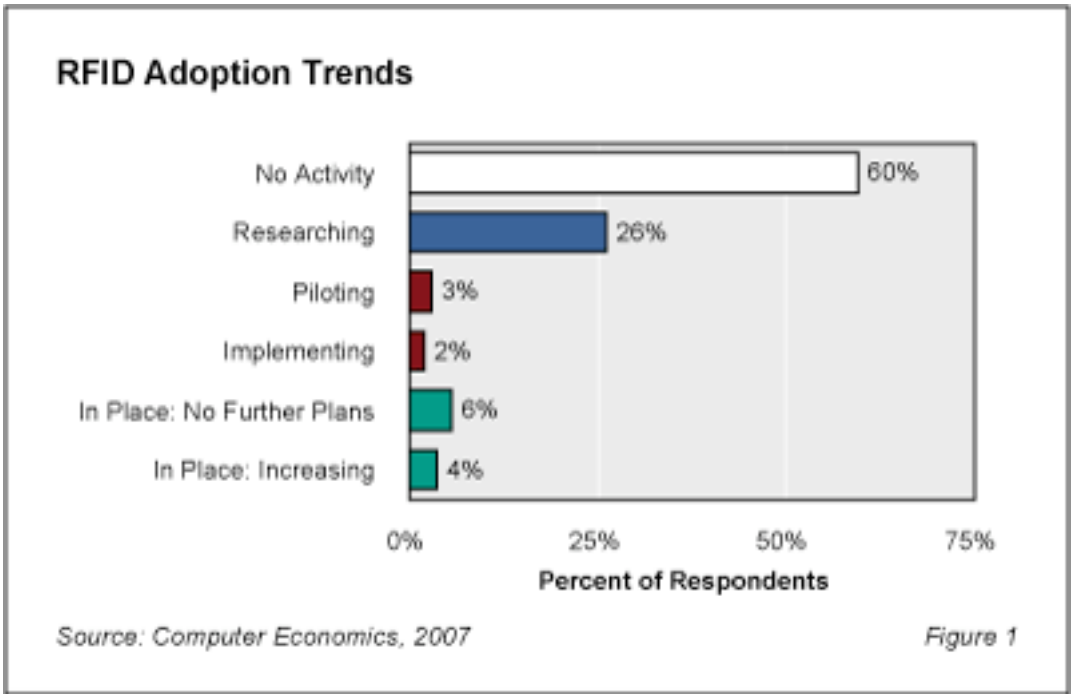


[14] http://www.rfidjournal.com/article/view/1335/1
[15] http://www.eweek.com/c/a/IT-Management/Gen-2-Spec-Gets-Major-Acceptance/
[16] http://www.rfidjournal.com/article/view/2161/1/1

In the early ferment stage, one of the objective parameters was the **ability to identify object in a distance** because the main objective of first RFID form (which is IFF at that time) was to identify the allied aircrafts not enemy aircrafts. Electronic article surveillance also needed this key technology parameter to prevent shopliftings in shopping stores. When RFID overcame these 2 key parameters, new 4 objective parameters were expected to be fulfilled because they would allow RFID technology to provide promising capabilities in greater extent. Specifically speaking, RFID has been widely used in identifying static objects at that time but the accuracy in identifying mobile objects and read range of the interrogators were problems that limited its applications. From that reason, many researches have been conducted to address those key objective parameters (which are read range, accuracy, reliability and data reading and writing speed) that would take RFID to the end of "dominant design emerges" stage and starts transitioning to another stage, which is "incremental innovations" where it is obvious that the key objective parameters are **standard** and **information security** (privacy). Those 2 key parameters need to be enhanced in order to make RFID become a part of everyday life like cell phone and laptop. It is believable that Gen2 and associated ISO standards will become a global standard by 2010.

Technology Adoption Rate

Unfortunately, a variation of RFID standards is still one big impediment that temporarily delays RFID technology adoption. Without standard, data among various applications cannot be exchanged, which freezes the growing rate of RFID applications and usage patterns. Also, the devices made for RFID cannot be interoperable, which limits choices of RFID adopters. At the same time, information security and privacy issues are also not fully addressed and solved, which results in fears of adopting RFID technology. From several concerns, the rate of adoption seemed to slow down in 2006. According to the executive summary report on computereconomic.com, it showed that 60% of companies in the survey had no activity while 26% of the companies were still in researching. Only 2% of the respondents are implementing the RFID projects.



Source: Computer Economics, 2007 *Figure 1*

Key Player Responses

Several key players in RFID technology are struggling by unpredictable circumstances. As a subsequence, they always need to take a prompt, deliberate and smart course of actions to gain competitive advantages and the promising benefits by RFID technology.

It can be seen from the history that key players have accordingly responded to events in the RFID technology evolution. Since the key players can be categorized into 3 groups which are RFID suppliers including service providers and chip manufacturers, lead adopter group and regulator group, some examples of key players' actions are shown in the following matrix.

	Early Ferment	**Dominant Design Emerges**
RFID Suppliers	In 1970, **Sensormatic** saw business opportunity from basic RFID implementation so they started building a simple electronic article surveillance (EAS) equipment for anti-theft and security applications[17]	Many suppliers jumped to this market because there was increasing awareness about the RFID technology promising benefits in automatic object tracking
Lead Adopters	Shoplifting cost an estimated $26 billion in lost revenues in the United States in 1981. As a consequence, **retailers** were beginning to adopt system that prevents shoplifting but might also reduce theft by in-store personnel	Based on case studies, US, UK, Japan, Germany and China were among the top countries that have adopted this technology to improve supply chain and inventory as the RFID technology in this stage allows objects to be tracked automatically[18]
Regulators	Data **not** available in this stage	The market has been looking for a global standard. So, EPC global and ISO are developing a suitable standard that will satisfy this market needs

[17] http://www.fundinguniverse.com/company-histories/Sensormatic-Electronics-Corp-Company-History.html
[18] http://www.idtechex.com/knowledgebase/en/breakdown.asp

Key niches, Key Players and Key Leaders within RFID business ecosystem

The concept of business ecosystem has been applied to business strategic analysis and planning since the early 1990s[1] as it can provide companies better awareness and understanding about their stakeholders and relationships in any business domain in order to make deliberate management decisions that then lead to smarter actions. Like other business domains, there are a number of key organizations including suppliers, business associations, standardization organizations, solution providers, governmental institutions and even competitors from other technologies that reside in the RFID business ecosystem in which each of the RFID stakeholders is more or less shaping the direction of this versatile technology. Although there are various stakeholders in the RFID business ecosystem as seen in the figure below, only some of the stakeholders are key niches and key players within the business ecosystem at a single point of time.

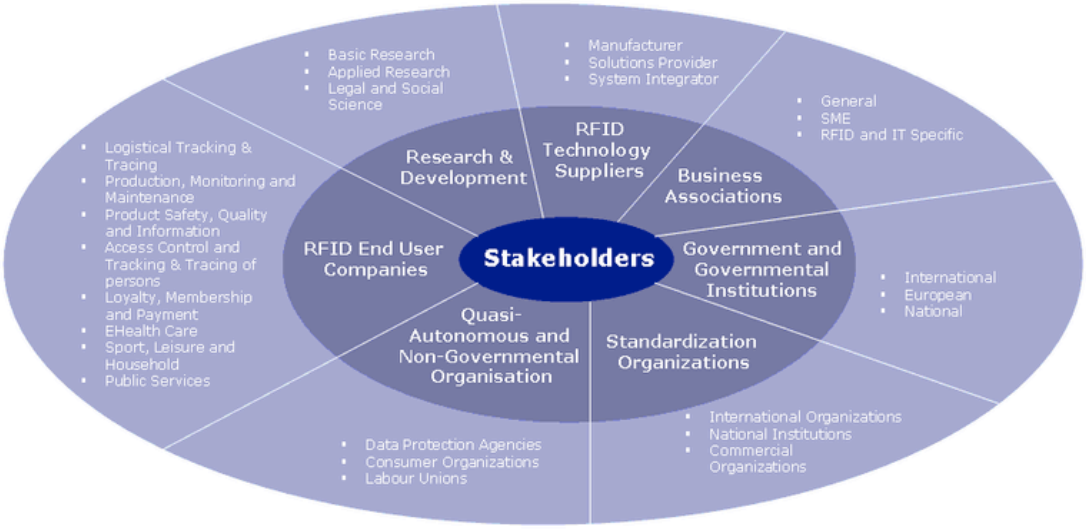


Figure 1: RFID Stakeholder Model[2]

It is observable that the key niches, key players and key leaders change over time since they significantly depend on the superior technological infrastructure of RFID pushing the performance envelope, which lead to a new space of applications. The key niches also rely on RFID manufactures, RFID solution providers and system integrators who foresee the potential RFID applications (in that new space) bringing value added to end users, mutually develop new workable solutions with lead users who have unique needs deviating from the ordinary RFID adopters and implement those commercial solutions that can satisfy both expressed and latent needs of the users better. From that reason, key players can be classified into four categories, which are RFID technology suppliers, RFID research & development, Standardization Organization and End Users (both government sector and non-government sector).

It appeared that the initial RFID niches were electronic article surveillance (EAS), users which used this technology to counter theft in the 1960s. The key RFID leading suppliers at the time were Sensormatic, Checkpoint and Knogo. All of which were considered specialists of the RFID technology domain in that time period. It was not until 1973 that Raytheon, RCA and Fairchild, which were followers in this epoch, became the other

[1] http://en.wikipedia.org/wiki/Business_ecosystem
[2] http://www.rfid-in-action.eu/public/results/rfid-stakeholder-model

three RFID suppliers of the Electronic Identification System[3]. To be precise, Raytheon developed "Raytag" in 1973 while RCA developed an electronic identification system in 1975. At that time, it seemed that most original attentions were paid to **theft prevention**, which highly attracted retail stores to become technology early adopters. In 1970s, the Port of Authority of New York and New Jersey brought another possibility of RFID applications in transportation, which are electronic toll collections. Big companies including General Electric, Westinghouse, Philips and Glenayre offered their testing systems to the Port of Authority of New York and New Jersey to test and the results were favorable. Thanks to Los Alamos and other research institution like Northwestern University, several studies about the RFID technology were explored and published more. One of the notable works was "Short-Range Radio Telemetry for Electronic Identification Using Modulated Backscatter" in 1975. In the same epoch, RFID technology was adopted for animal tracking and factory automation in which Alfa Laval and Nedap appeared to be important players in Europe. From these facts, the second attentions were heavily paid to **vehicle tracking, animal tracking and factory automation**, which require a relatively longer read range of RFID when compared to electronic article surveillance (EAS).

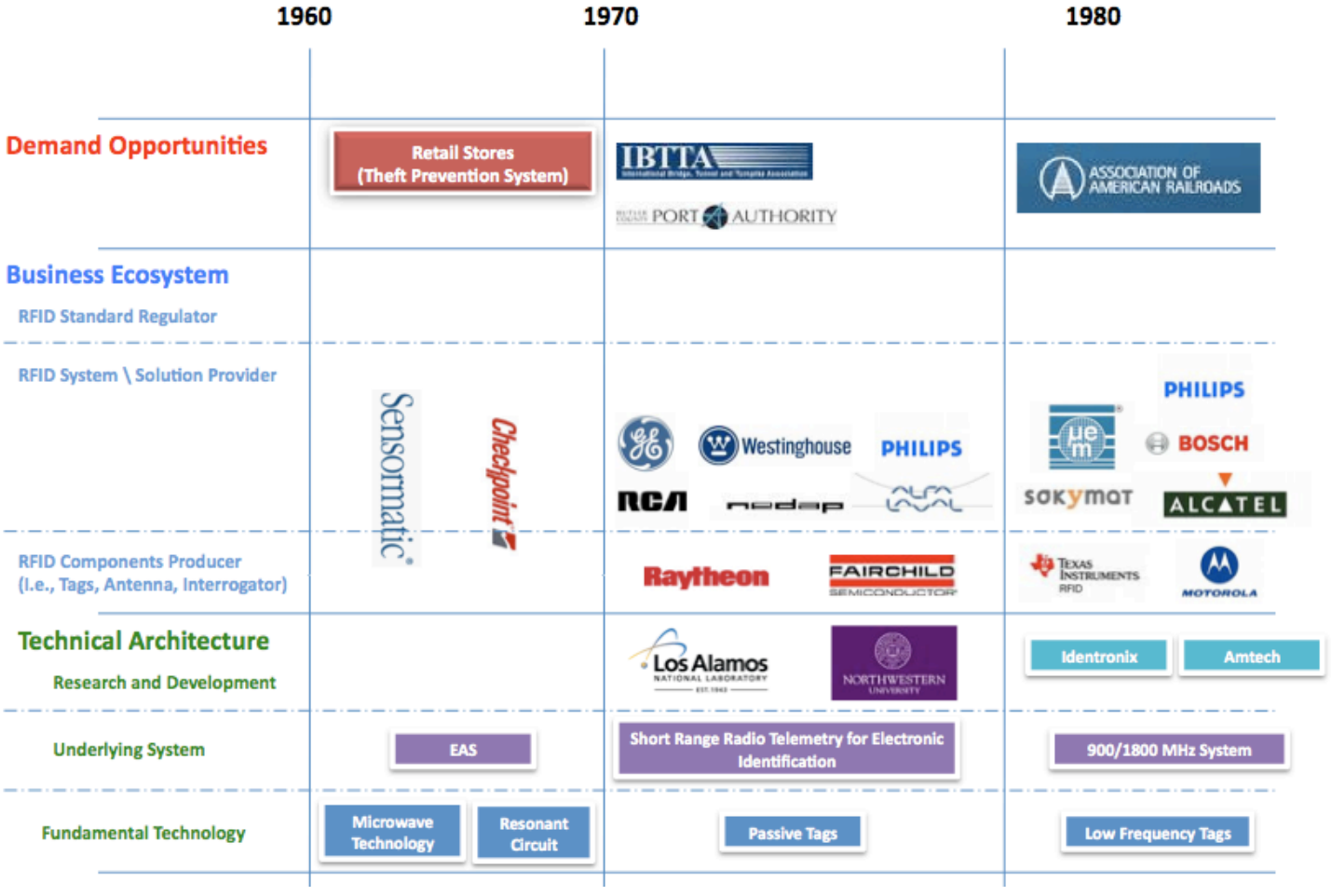


Figure 2: Architectural Ecosystem Map of RFID technology (1960-1980)

A divergence of RFID applications was more obvious in various parts of the world when the technology became more mature in 1980s. Specifically, great RFID interests in

[3] http://www.rfidconsultation.eu/docs/ficheiros/shrouds_of_time.pdf

United State were for transportation and personal access while the greatest interests in Europe involved with short-range systems for animal, industrial and business applications. In the Americas, the Association of American Railroads and the Container Handling Cooperative Program, who seemed to be key leaders in this episode, were active for RFID initiative[4] because of disastrous attempt to use Bar Code technology to keep track of rolling stock. Meanwhile, research by Identronix and Amtech was conducted based on 900 MHz and 900/1800 MHz[5], which can send signal longer distance than higher frequency. A number of companies in Europe, which comprise Alcatel, Bosch, EM Microelectronic, Sokymat and Philips, mushroomed corresponding to the growing demand of RFID technology. In this epoch but in a different episode, Texas Instruments applied RFID technology to the vehicle-part level. They took initiatives in new RFID applications for **vehicle engine control, dispensing fuel, vehicle access**, for example.

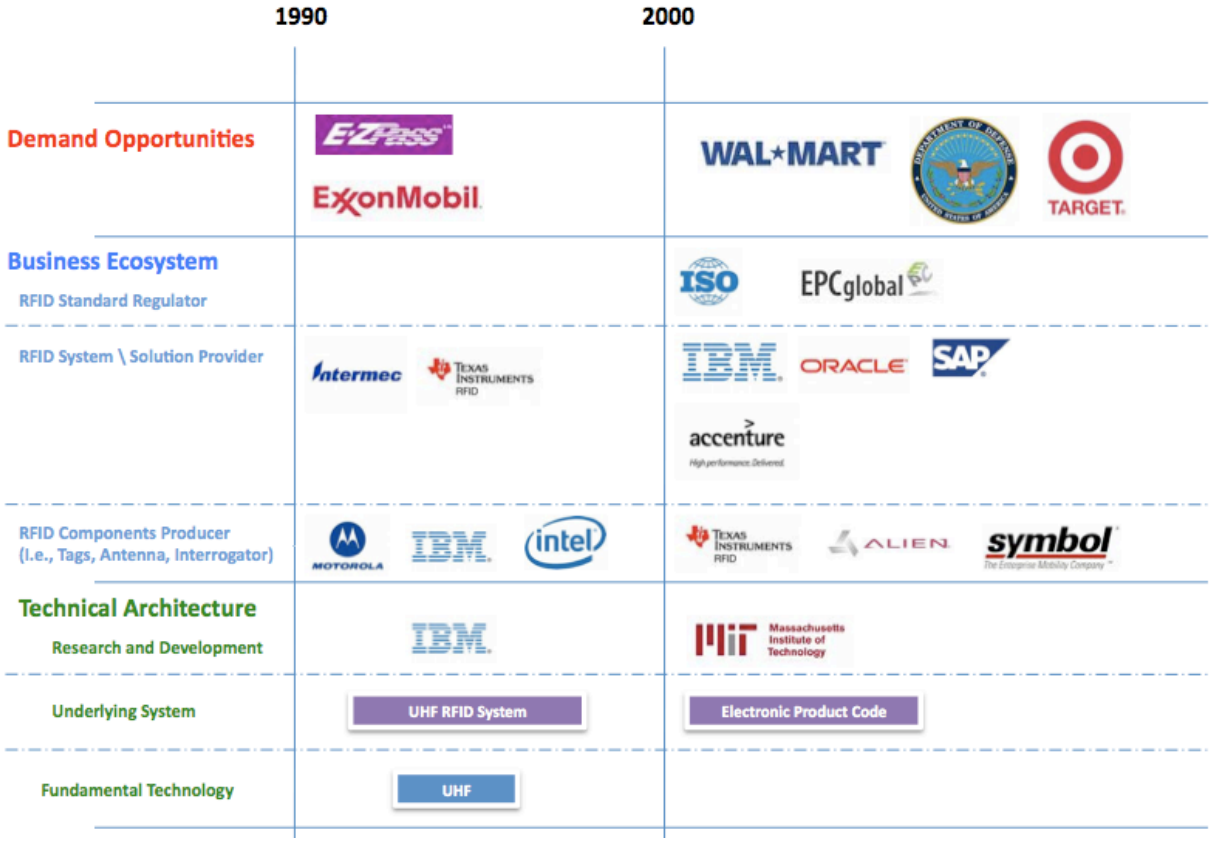


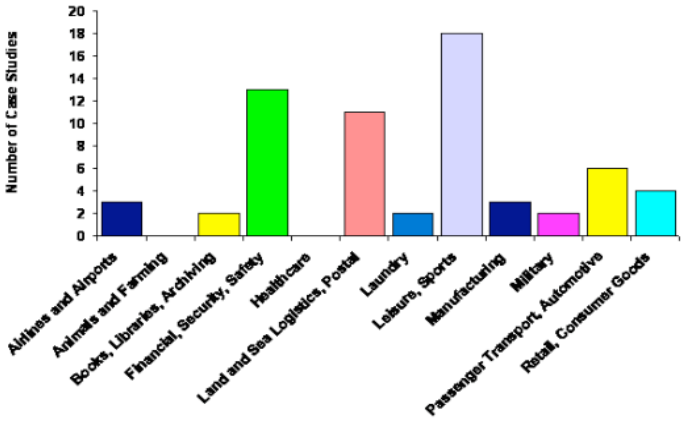
Figure 3: Architectural Ecosystem Map of RFID technology (1990-Present)

By the middle of 1990s, RFID system was pushed one step further by Regional toll agencies. One example was E-Z Pass. In this meantime, Texas Instrument developed a new specific application for dispensing fuel such as ExxonMobil's Speedpass[6] while IBM engineer developed and patented UHF RFID system, which offered longer read range and faster data transfer. Because of the financial trouble in the mid 1990s, IBM sold its patents to Intermec who was a bar code system provider. Intermec has installed various applications from warehouse tracking to farming[7]. Furthermore, the chipmakers

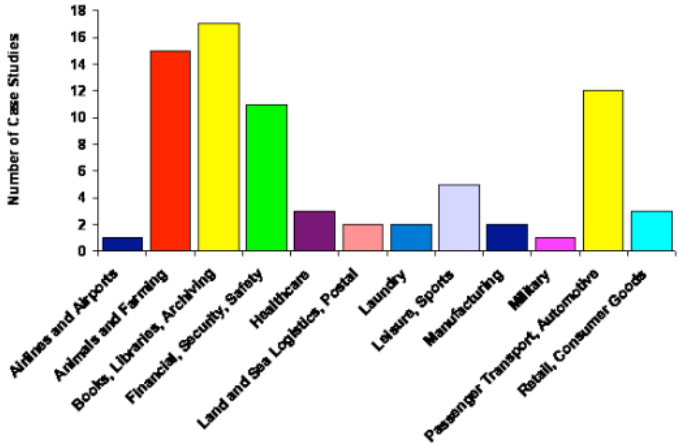
[4] http://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=01549751
[5] http://members.surfbest.net/eaglesnest/rfidhist.htm
[6] http://ks.utc.sk/casopis/pdf/III2008/michalek_vaculik.pdf
[7] http://www.rfidjournal.com/article/view/1338/2

consisting of Motorola, IBM and Intel could produce cost-effective tags, which lead to the beginning of **"smart label"** tests in this decade. The Auto-ID center at MIT was established in 1999 to work on open standards of RFID technology called Electronic Product Code (EPC), which was planned to be complement barcodes.

In the early of 2000s, the technology main focus was shifted to address issues in the **supply chains** due to the extreme interests in RFID applications of Department of Defense (DoD), Wal-Mart and other retail chains who are the key niches of RFID technology in this time period. This epoch had big demand in cross-platform RFID system[8] that can read standardized RFID tags defined by ISO and EPC Global. This standardization enabled RFID suppliers to develop new applications to satisfy those extraordinary needs. For example, DoD wanted to move toward what it calls *Knowledge-Enabled Logistics*[9] as they expected to have a better and effective supply chain process that allows logistics jobs to be done faster. Similarly, Wal-Mart shared this same vision and started testing their RFID system with other 8 suppliers[10] including Gillette, Hewlett-Packard, Johnson & Johnson, Kimberly-Clark, Kraft Foods, Nestlé Purina PetCare Co., Procter & Gamble and Unilever. Wal-Mart RFID system was planned to provide key competitive advantage in **supply chain process and inventory management**, which still have tremendous interests nowadays. Based on the news report on Nov 22, 2006, IDTechEx said that **financial, security and safety** became another market niche in Australia while Netherland was active in applying RFID in **sport segment** where they used RFID cards for entering soccer matches[11].



RFID Applications in Netherland
(Published Nov 22, 2006)



RFID Applications in Australia
(Published Nov 22, 2006)

Figure 4: New RFID Niches in 2006

In this episode, a survey of RFIDUpdate announced that the most recognized RFID providers were Texas Instruments, Symbol Technologies and Alien Technologies while IBM, Texas Instruments, and Alien Technologies were perceived to be RFID industry leaders[12]. Owing to the technology maturity, there were several unprecedented companies such as RFID consulting firms and RFID integrators appearing in the ecosystem. Examples of those companies include Accenture, IBM, HP, Oracle and SAP who provides either consultancy on RFID technology adoption or implement Enterprise

[8] http://www.tompkinsinc.com/publications/competitive_edge/articles/02-04-RFID_Pharma.asp
[9] http://www.shepardcomm.com/RFID-whitepaper-wp.pdf
[10] http://www.rfidjournal.com/article/articleview/926/1/1/
[11] http://www.idtechex.com/research/articles/hot_countries_for_rfid_00000505.asp
[12] http://www.rfidlowdown.com/2006/06/rfid_industry_l.html

Resource Planning (ERP) system that integrated inventory management through RFID usage for end users.

Figure 5: Key players in RFID consulting firm and RFID Integrators[13]

Interestingly, a new market research by IDTechEx just reveals some surprising new large niches[14], which come from nowhere, not extrapolations of past trends. They are:

- The South Korean Ubiquitous Sensor Networks USN projects backed by the South Korean government for monitoring natural disasters and for many other uses
- The tagging all patients, staff and assets in **healthcare facilities** worldwide for error prevention and other reasons
- **Antiterrorism measures in global logistics**
- Meat and **livestock tagging** in the face of new legislation against disease
- Tagging of high value banknotes and drugs for anti-counterfeiting

The research also stated that the highest volume application of RFID would occur when it could replace barcode technology. Although experts have discussed this possible replacement for a long time, it is difficult to make it happen in reality due to two main problems, which are the lack of RFID standard and the cost of a RFID tag. Two of which are expected to be overcome by the end of 2000s.

Corresponding to the IDTechEx market research, Tompkins Associates stated that RFID technology is perceived to provide benefits in **healthcare and pharmaceutical industries** such as reducing product diversion and decreasing dispensing errors[15], it is

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13 http://www.unisys.co.uk/eprise/main/admin/corporate/doc/AMR_Research_REPORT_17019_-_RFID_in_Consumer_Products_Which_Service.pdf

14 http://www.packagingdigest.com/contents/pdf/A%20Unique%20RFID%20Market%20Analysis.pdf

15 http://www.tompkinsinc.com/publications/competitive_edge/articles/02-04-RFID_Pharma.asp

likely that **healthcare and pharmaceutical industries** will be another market niche in today's world due to increasing interests and demand.

Key companies that shapes the evolution of the overall system and its architecture

It is fair to say that there is no single company who could shape the RFID technology evolution and its architecture. Instead, institutions that developed technical infrastructure, RFID component producers, RFID application solution providers and end users have all been involved with the system evolution over time since 1960. The matrix below shows a summary table of all the key niches, players and leaders in RFID ecosystem from 1960 onwards[16].

Time Interval	Key Niches	Key Players	Key Leaders	Specialist	Follower
1960s	Theft prevention	Sensormatic, Checkpoint and Knogo	Sensormatic, Checkpoint	Sensormatic, Checkpoint	Knogo, Raytheon, RCA and Fairchild
1970s	Electronic toll collections	General Electric, Westinghouse, Philips, Glenayre Alfa Laval and Nedap	Alfa Laval and Nedap	Alfa Laval and Nedap	General Electric, Westinghouse, Philips and Glenayre
1980s	Vehicle engine control, dispensing fuel, vehicle access	Alcatel, Bosch, EM Microelectronic, Sokymat, Philips and Texas Instruments	Texas Instruments Philips, Sokymat and EM Microelectronic	Texas Instruments	N/A
1990s	Smart label	IBM, Intermec, Texas Instruments, Motorola, Intel and MIT	Intermec, Texas Instruments, Intel and MIT	MIT, Intel, Motorola and Texas Instruments	IBM
2000s	Supply Chain and Asset Management	Wal-Mart, DoD, Target, Tesco, ISO, EPCGlobal	Wal-Mart, DoD, Texas Instruments, EPCGlobal and ISO	EPCGlobal and Wal-Mart	Target, Tesco
2005	Healthcare Facilities and Pharmaceutical	Pfizer, GlaxoSmithKline, Hewlett Packard, IBM, Samsung, Systech, McKesson, Impinj, Symbol Technologies and Tagsys	Pfizer, GlaxoSmithKline, IBM, Symbol Technologies and Tagsys	IBM, HP, Symbol Technologies and Tagsys	N/A

Figure 6: A summary table of Key stakeholders (1960-present)

[16] http://www.transcore.com/pdf/AIM%20shrouds_of_time.pdf

Successful Business models

One of the successful RFID business models appears in the sector of RFID consulting firms. As many IT-originated consulting companies such as IBM, HP, Unisys and SAP and accounting-originated consulting companies including Accenture and Deloitte are already well known consulting firms that have both brand equity and "enterprise" customers in hands, they can simply add a RFID consulting service into their service line to extend their service offerings to their existing customers[17]. Because most of the enterprise customers have to manage their assets or inventories, RFID consulting is unavoidable for the enterprises to ensure their success of technology implementation as well as the return of investment of their projects. Along with experiences in consulting industry for decades, it is not difficult for those consulting firms to generate revenue from their RFID consulting service. What the companies need to do is to only provide trainings for their personnel to become RFID experts contributing back to community.

Furthermore, some IT-originated consulting companies can make additional income from the related services. For example, IBM worked with Metro group to develop a "smart" solution for retail that tailors in-store merchandising messages by tracking product movement in real time. In this project, IBM could make money from the proprietary software such as IBM WebSphere Application Server and IBM WebSphere MQ and supporting services[18].

Value Capture in the Evolution

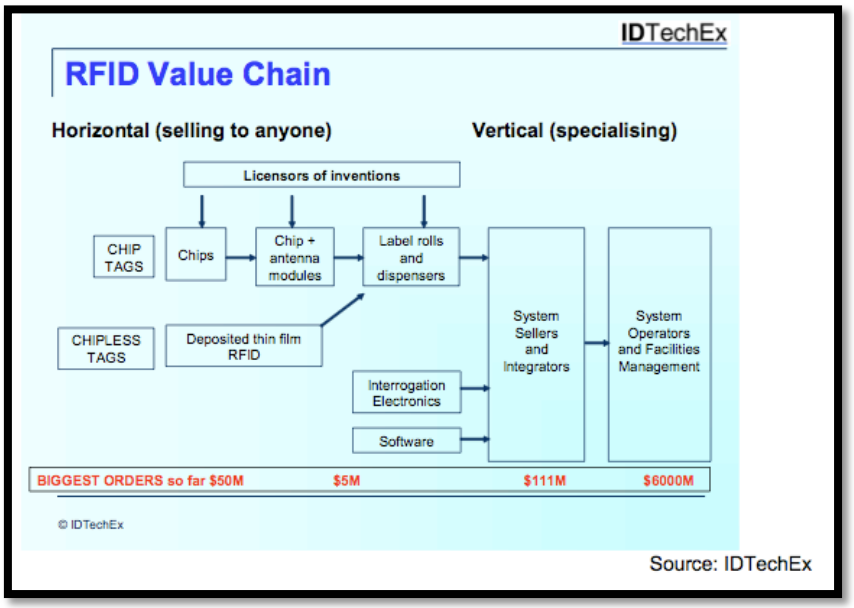

Figure 7: RFID Value Chain[19]

According to the figure above, all the stakeholders in the RFID value chain are all beneficial from the RFID technology. A large proportion of money tends to be in system operators and Facilities management, which partially flows to system sellers or

[17] http://www.rfidjournal.com/article/view/613
[18] ftp://ftp.software.ibm.com/software/solutions/pdfs/ODC03116-USEN-01a.pdf
[19] http://www.packagingdigest.com/contents/pdf/A%20Unique%20RFID%20Market%20Analysis.pdf

integrators afterwards. Then, the RFID software developers and interrogation electronicians would receive money from the system sellers and integrators as they usually integrated all pieces together (software and electronics) into a system. Likewise, producers of chips, antenna modules, label rolls and dispensers will gain money from the system seller and integrators. In parallel, the licensors of RFID inventions can acquire "loyalty fees" from their intellectual property in a period of time. Although there are still some key players changing over time in RFID evolution, it has not had any impact on the basic components in the value chain. So, the structure of value chain still remains the same regardless how evolution in the future will be.