



INEMI

International Electronics Manufacturing Initiative

DRAFT

**RFID Roadmap
for Item-Level Tag**

February 2008

**Advancing
manufacturing
technology**

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1. EXECUTIVE SUMMARY

The iNEMI Item-Level Tagging (ILT) Radio Frequency Identification (RFID) Roadmap is a use-case driven roadmap fundamentally based on in-pilot and commercially launched ILT RFID applications. This ILT RFID Roadmap is a living document that is consensus based and was written after completing a rigorous analysis. Stakeholder and value chain members were queried over a period of six months to identify the technical, business, and government related issues for market commercialization.

Roadmap Working Group members selected the following four use-case categories to guide the development of this document:

- Asset tracking
- Process validation
- Intra-company transactions
- Inter-company transactions

A situation analysis was performed for the RFID industry that highlighted 1) RFID tags, 2) RFID readers, 3) RFID market size projections, 4) current business drivers, and 5) barriers to adoption. The analysis in general concluded that the market potential remains attractive. The growth rate has been steady, but moderate, for the past few years but could potentially increase if specific gaps and needs were addressed.

The document highlights the gaps and needs that were identified for further deployment and diffusion of ILT RFID technology. While there are many related solutions that must be adapted to make full use of ILT RFID (e.g. materials planning systems), the focus of this document is primarily on those technologies that are directly related to ILT deployment. The identified attribute needs and gaps were articulated based on historical data as well as identified technology limitations presented in the public domain. They were further weighted based on their perceived constraint of RFID commercialization and ultimately ranked to define the following gaps:

- Tag (size, form factor, cost, read reliability)
- Reader performance (interference, dense RF environments)
- Infrastructure (cost, interoperability, open source middleware)
- Security/ privacy

- Adoption / commitment to standards

These gaps should be addressed to provide ILT RFID technology with the ability to continue to strengthen its business value based on a strong technology foundation. Suggestions were given to address these gaps with minimal disruption to existing industry development efforts that are presented in the roadmap.

Attribute needs requiring the greatest attention are given for 1) active RFID tags, 2) passive RFID tags (low functionality, high functionality), 3) RFID readers, 4) emerging RFID tag technology, 5) infrastructure, 6) software, and 7) security. For each of these attribute needs are presented for the state of the art (2007), mid term (2012), and long term (2017).

As an example, the attribute needs for RFID readers listed below were identified as requiring attention for continued RFID diffusion in existing revenue generating markets as well as adoption into new markets.

- Tag read speed
- Dense reader environment
- Radio frequencies supported
- Protocol supported
- Reader form factor
- Reader complexity
- Cost of a fixed reader
- Reader operation in RF challenging environment (metal, liquid)

Specific design criteria as well as operating parameters are presented based on industry projections aligned with future system attributes. A final section is included in an effort to address identified needs and gaps: Prioritized R&D Needs and Recommendations. This section attempts to prioritize areas requiring new as well as continued R&D investments and provides recommendations that can address these areas. Also, suggestions are presented for government and academic R&D efforts that will further strengthen the appreciation of RFID technology.

The Roadmap Working Group feels that the greatest value of this roadmap is to facilitate ILT RFID adoption and technology diffusion into the market. The group does recognize, however, that accurately predicting the emergence of a new technology is difficult. We are more confident in the projected trends that have been articulated. Moreover, the identified needs and

gaps can be integrated into strategies to achieve sustained business growth given stable market conditions.

2. INTRODUCTION

2.1 RFID Background

Radio frequency identification (RFID) is a technology that facilitates the identification of items or people, using radio waves as a data carrier, to a base station that connects to a database. It is similar to other auto-identification systems, including barcode and optical character recognition. However, being radio frequency based, it does not require a line of sight to read the identification number and can operate in environments where line of sight is not always practical. The technology provides for the identification of many items virtually simultaneously, allowing high-speed, automatic data collection. RFID technology has been around for quite some time, starting during World War II. However, several things are happening today to make this technology feasible for broader use. First, the cost of tags has come down dramatically and continues to fall. The other factor is hardware and infrastructure standardization. There is wide industry support to standardize the technology. For example, companies such as Wal*Mart, Target, Tesco, Best Buy, Boeing and Airbus, as well as the US Department of Defense, are solidly behind RFID and the current standards development initiatives.

An RFID hardware system requires an RFID tag and an interrogator, commonly called an RFID reader. The RFID tag consists of a microchip containing the circuitry for a miniature radio receiver/transmitter and an antenna mounted on a substrate. Chips can store data and a minimal chip can hold 64 to 96 bits, while higher functionality chips can hold kilobits of data. RFID tags can be classified into two types — active tags and passive tags — depending on how their internal radio is powered. Active tags have a constant battery source, whereas passive tags, which are more common, harvest the power from the radio wave transmitted by the reader. In ultra-high frequency UHF systems (defined below), the tag modulates and reflects the incident energy (modulated backscatter); and in low frequency (LF) and high frequency (HF) systems the tag load modulates the electromagnetic field.

The RFID reader is comprised of digital and analog electronics connected to one or more antennas that emit radio waves to the tag and receive transmissions from the tag. The reader then communicates the tag identity, plus any other data stored on the tag, to middleware

software that parses the data from readers and communicates the tag information to back-end computer systems for processing.

RFID systems use various radio frequencies and air interface protocols. Common frequencies used for battery-less tags (passive tags) are low frequency (LF), which is 125 KHz, 135 KHz; high frequency (HF), which is 13.56 MHz; ultra-high frequency (UHF), which ranges from 860 MHz to 960MHz; and super high frequency (SHF), which is 2.4 GHz or 5.8GHz. Common frequencies used for battery-operated tags (active tags) are 433 MHz, 2.45 GHz, and 5.8 GHz. Each frequency has its own radio characteristics that are suitable for different applications.

LF tags are typically used for access control and security, manufacturing process flow control, animal identification and in a variety of industries that utilize short read ranges. HF tags are used where medium data rates and medium read distances are required. Popular applications include: library tracking and identification, healthcare patient identification, access control, laundry identification, item-level tracking, etc. HF tags are small-profile alternatives to LF RFID tags as the HF tags enable printing antenna on the substrate or embedding antenna in the substrate. Despite read ranges that are shorter than UHF, both LF and HF waves can more easily penetrate walls and liquids.

UHF tags boast great read distances, high reading speeds and superior anti-collision capabilities. The primary application envisioned for UHF tags is in supply chain tracking. The ability to identify large numbers of objects as they move through a facility and through the supply chain, has enormous potential for inventory management in retail applications, reduction of out-of-stock inventory, and elimination of the human intervention currently required for successful barcode data collection. The larger read range (3 meters) makes passive UHF tags suitable for use in environments like warehouses, and they are being used for case and pallet-level tagging to comply with Wal*Mart and US Department of Defense (DoD) mandates. The big challenge, thus far, is for companies using passive UHF to read the tags in the middle of a pallet. This is exacerbated by liquid (UHF waves are absorbed by water.) or metal environments, which present challenges to RF propagation.

Microwave tags (SHF) are primarily used in active RFID systems. These tags offer long read ranges and high data transfer speeds, though at significantly higher cost per tag. Because of the cost, microwave tags are typically implemented in reusable applications such as railroad car tracking, container tracking, and automated toll collection.

One issue with UHF is that there are a multitude of government regulations around the world restricting the use of certain frequencies and power output. In the Americas the allocated frequency band for RFID is 902-928 MHz, while in Europe the frequency band is 865-868 MHz. In Asia, each country has its own or no regulations. Also, power output may be constrained, which impacts read range. Tags are generally tuned to be readable by any frequency within the 860-960 MHz UHF band.

Tags and readers can be RF coupled inductively, or electromagnetically. Inductively coupled tags typically operate at LF and HF frequencies. For HF frequencies an antenna coil of only a few turns is required, enabling the formation of a printed antenna structure to reduce the overall cost of the tag. For UHF tags, communication with a reader is based on electromagnetic backscattering of the incident reader signal.

2.2 Electronics Industry's Interest in RFID

Interest in the electronics industry can be described in two fundamental categories:

1. RFID-based electronics solutions that are designed, manufactured, and supplied by the electronics industry can be provided to the global marketplace. Industries served here include transportation, retail, medical, and defense.
2. RFID-based electronics solutions used by the electronics industry to improve the efficiency of its own electronics manufacturing supply chain and internal processes.

2.3 The Case for an ILT Roadmap

Significant progress has been made in the deployment of RFID at higher levels of tracking (e.g. containers, pallets, etc.). While more improvements are needed in these areas, a number of efforts are focused on making the necessary progress. Conversely, item-level tagging (ILT) is still in a nascent state with many remaining challenges and open questions. There are some efforts underway in the ILT area, but the focus seems to be primarily on retail scenarios with little emphasis on the infrastructure and technology issues that must be addressed if ILT is to be ubiquitous across the supply chain. In order to fully leverage the benefits of ILT, utilization should begin within the manufacturing process and be operational through storage, shipment, product integration, distribution, etc.

iNEMI brings together a number of firms that have manufacturing and logistics expertise for electronics hardware. The belief is that these skills will enable this consortium to add further clarity to the requirements for ILT by creating a technology roadmap. This roadmap will identify gaps that must be addressed in order to accelerate widespread deployment and thus achieve the desired improvements in quality, cost, and delivery. The electronics industry is uniquely qualified to provide leadership in this effort due to its rich history of advancing and leveraging technology for product development, manufacturing, and fulfillment.

3. STANDARDS EVOLUTION

Following a period of custom and proprietary solutions, RFID technology has now evolved to a point where standardized solutions are available. One key element requiring standardization is the wireless interface (air interface) protocol governing communication between the reader and the tag. Two major existing standards groups are involved in developing RFID standards: the International Standards Organization (ISO) and EPCglobal.

In ISO 18000, there are different standards based on frequency:

1. ISO 18000-2 Low Frequency (LF) < 135 KHz
2. ISO 18000-3 High Frequency (HF) 13.5 MHz (including two optional standards, Mode 1 & Mode 2)
3. ISO 18000-4 Super High Frequency (SHF) 2.4 GHz
4. ISO 18000-6 Ultra-High Frequency (UHF) 860-960 MHz (including three optional standards, Type A,B & C)
5. ISO 18000-7 433 MHz

EPCglobal has defined the following standards:

1. 900 MHz Class 0 Radio Frequency (RF) Identification Tag Specification
2. 860-930 MHz Class 1 Radio Frequency (RF) Identification Tag Specification
3. 13.56 MHz ISM Band Class 1 Radio Frequency (RF) Identification Tag Interface Specification
4. Class 1 Generation 2 UHF Air Interface Protocol Standard Version 1.0.9 (UHF Gen 2)

ISO and EPCglobal are looking at ways to converge to common standards. As an example of this ISO 18000-6C is an equivalent to the EPC Class 1, Generation 2 specification. Also, the

Class 1 Generation 2 protocol is intended to supersede the existing Class 0 and Class 1 EPC protocols.

Standard development activities continue at EPCglobal. As of the writing of this report EPCglobal is working on incremental improvements to the UHF Gen2 standard, which will be released as a version 2.0.0 document, and an HF (13.56MHz) specification called HF Gen 2 will also be published soon.

Many current RFID systems have proprietary air interface protocols, but there is a lot of momentum to move toward the standards listed above. However, under the right circumstances a proprietary system may be okay. Usually the issue of whether to use one of the standards deals with whether the application is “closed” or “open.” A “closed” RFID system is one that is totally under control of the company implementing it. It is within the “four walls.” An “open” RFID system is one where the tags need to be shared among many partners. For example, when a manufacturer tags product that is sent to a retailer, both parties must be able to read the tag, so a standard is imperative.

4. RFID SOLUTIONS/USE CASES

A number of companies are now offering electronics solutions that include the use of RFID technology. Participants in this business segment cover a fairly broad spectrum and include RFID tag suppliers (such as Tagsys and Avery), reader and printer equipment suppliers (such as Motorola and Zebra), software suppliers, and total system integrators (such as EDS and Sun Microsystems). While there are some fairly unique requirements for some of the industry segments, it is believed that much of the underlying technology can find broad applicability so that a viable business model can prosper. To date, heavy adoption of RFID solutions has been limited to application-specific solutions such as access control, vehicle immobilizers etc. Broad adoption in open loop supply change management and across industries has been slow and is only finding significant use where mandates have occurred (either by large firms such as Wal*Mart or by industry segments such as defense). Like many new technologies, early adoption is driven more by belief in the benefits and by strategic planning rather than detailed ROI analysis.

A thorough analysis of the use of RFID technology throughout industry today illustrates that the problems being resolved generally lie in four major areas (or super-clusters), namely:

1. Asset tracking
2. Process validation
3. Intra-company transactions
4. Inter-company transactions

Each super cluster is discussed in more detail below.

4.1 Use Case: Asset Tracking

In this use case something of value, for example an asset, is being maintained by the owner. The asset itself is not transformed in any way (made more or less valuable as the result of any transformational activity) but, rather, is monitored from a location, quantity, and (often) authenticity perspective. Typically, only when a genuine asset is not where it is supposed to physically be (Kanban, physical geographic location, storage location, etc.) is an out-of-boundary condition generated and acted upon. In many cases the RF tag is applied to a carrier of some sort (container, cart, tote bin), which is then associated with the asset itself. The tag holds the associated information within it. However, in other cases individual items are tagged. Both fixed and mobile readers are used, usually in the high frequency bands with either active or passive tags, depending on the application environment.

A typical electronics factory implementation is illustrated in Figure 1, and Table 1 provides examples of typical asset tracking for the following applications:

- Semiconductor assembly
- Package tracking (FedEx/UPS etc)
- Luxury item tracking (jewelry/high fashion etc)
- Pharmaceutical product tracking
- Human tissue (medical products)
- Automotive/airlines spare parts/spare assembly

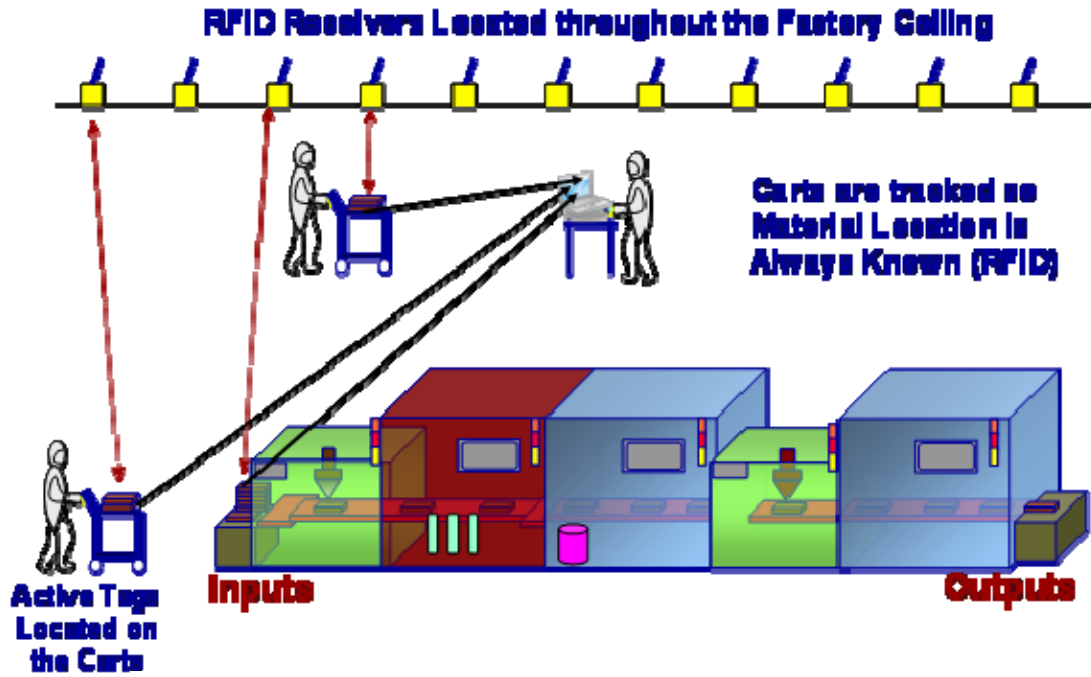


Figure 1: While on carts, active tags help to identify the exact two-dimensional location of semiconductor chips within the factory.

Table 1: Asset Tracking

Attributes	Asset Tracking					
Industry examples	Semiconductor assembly	Package tracking	Jewelry inventory	Pharmaceutical	Human tissue	Auto parts assembly
Security	Closed	Closed	Closed	Open	Closed	Closed
Carrier	Cart	Truck	Attached to jewelry	Label	Vial cap	Container
Asset	Wafer lot	Package	Jewelry	Drugs	Human tissue	Auto parts
Where	Equipment tracked	GPS, location in building	Storehouse/warehouse location	Case packing	Storage location	Mfg start / stop, Finished goods w/h Shipping
Business process	Path, assembly	Shipment	Retail sale	Providing compliance information	Stock control	Production order control via Kanban system
Validation	Needs to be where it is supposed to be	Package is not where it is expected	Stock by item validation	Authenticity validation	Identity validation	Where production order is in the process

Tag	Active	Passive	Passive	Passive	Passive	Passive – 13.56 MHz
Reader		Fixed or mobile	Fixed reader	Fixed	Fixed or mobile	Fixed
RFID functionality			Read only	Read only	Read only	Read only
Information		Package tracking	ID number		Tissue data	Tag ID #, carrier #, production order #

4.2 Use Case: Process Validation

In this use case, an asset is having value added to it through a transformation process. This transformation is often done by combining the asset with other assets in some way (processing, assembly, etc.), usually involves more than one step/station and is usually done in a controlled “factory” setting. In order to guarantee the proper value-add it is important that each transformational step happens in the proper sequence with the right materials, work instructions, machine programs, etc. If any of these prerequisites is missing, the process is stopped until corrections are made. Upon the successful exiting of the transformation process a detailed set of records is available and is usually catalogued for future use. Fixed readers are prevalent due to factory layouts (the asset is brought to the machine/station) and, typically, high-frequency passive tags are used. Figure 2 shows a typical factory implementation, and Table 2 gives examples of typical process validation across several industries.

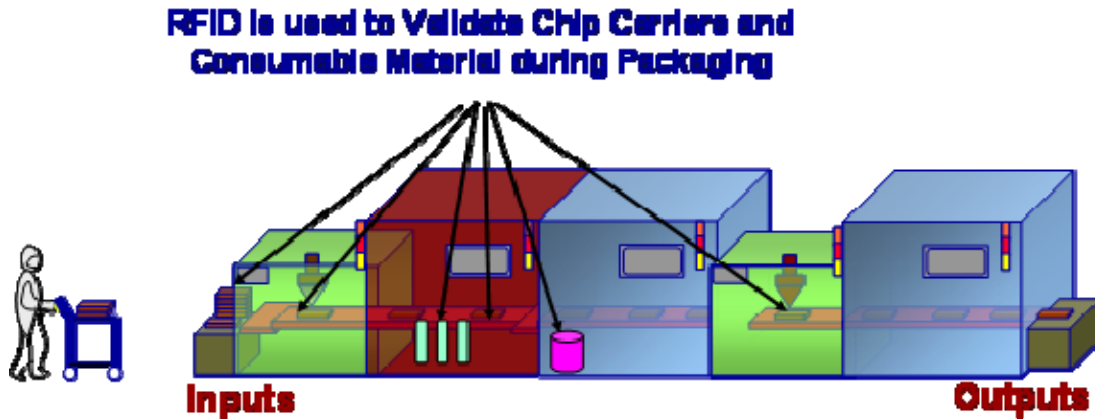


Figure 2: RFID used on chip carriers and consumable material containers helps to enable error-free production at assembly packaging factories.

Table 2: Process Validation

Attributes	Process Validation					
Industry examples	Semi wafer processing	System final assembly	Auto chassis	Cleaning service process control	Automatic garment dispenser	Silicone based product manufacture
Security	Closed	Closed	Closed	Closed	Closed	Closed
Carrier	FOUP, boat	Card	Skid	Garment	Garment	Pallet
Asset	Wafers	Subassembly	Chassis	Garment	Garment	Product
Where	Equipment station	In & out of Kanban	Equipment station	Equipment station or location (e.g. dock)	Dirty garment chute	Equipment station
Business process	Manufacturing process steps	Manufacturing process steps	Manufacturing process steps	Cleaning process steps	Dispensing clean garment	Manufacturing process steps
Validation	Proper machine, proper materials, proper process	Process flow & completeness	Proper materials with proper machine	Accelerate process flow & ensure accuracy	Validate WIP	Proper machine, proper materials, proper process
Tag	Passive	Passive	Semi-passive	Passive	Passive	Passive
Reader	Fixed, asset to reader	Fixed, asset to reader	Fixed	Fixed & mobile	Fixed (in chute)	Fixed and mobile
RFID functionality	Read only	Read only	Read only	Read/Write	Read only	Read only
Information	Serial number, lot, station number	Customer, product ID, subassembly configuration	Unique ID, color, process info.	Garment ID, apparel size, # of wash cycles, client name & address	Unique ID, apparel size	Unique ID

4.3 Use Case: Intra-company Transactions

With intra-company transactions, ownership of an asset changes within the company. This drives activity around basic business processes like order, shipment, credit, and debit, but in its simplest form, since this change occurs within a single company entity. The transfer is usually made on that company’s ERP system via virtual warehouse locations and/or various company entities. Nonetheless, accuracy in the order/ship/debit/credit process is vital to ensure proper control of valuation and location/quantity of assets within the company’s records. RFID is used

as a trigger that launches other events such as advanced ship notifications, invoicing, etc, often without human intervention. Upon completion of these transactions detailed records are available and catalogued. Fixed readers are prevalent due to the “dock-to-dock” activity and, typically, high frequency passives tags are used.

Table 3 shows typical intra-company transactions for several industries.

Table 3: Intra-company transactions

Attributes	Intra-company				
Industry examples	EMS	Garment	Construction	Bank	Air Cargo
Security	Closed	Closed	Closed	Closed	Closed
Carrier	Pallets or item-level	Item-level	Item-level	Money bag	Unit load device (ULD) and packages
Asset	Package	Trousers/ shirts	Reusable construction equipment	Cash	Package
Where	Docks	Dock to dock (factory to warehouse)	Warehouse to work site (and return)	Vault	Dock to dock
Business process	Internal order, ship, receive, pay	Tag, load, ship, receive	Tag, load, ship, unload	Credit, debit	Tag, load, ship, receive, unload
Validation	Sequence, receive and pay	Individual items sent from factory to warehouse	Amount sent, amount returned	Amount sent, time, carrier	Individual items sent, route, weight, origin, final destination
Tag	Passive and active: common solution	Passive HF	Passive HF	Passive HF	Passive EPC Gen2
Reader	Fixed, mobile/both	Fixed, mobile/both	Fixed	Fixed (vault)	Fixed (Symbol XRF400s)
RFID functionality	RO and R/W Functionality same across the supply chain	Read only	Read only	Read only	R/W to commission and RO
Information	License plate number and user data, transparent protocol	Source, item-specific data, destination	Item-specific data	Source, amount, destination	License plate (ULD), license plate (product), associate to airway bill #

4.4 Use Case: Inter-Company Transactions

Inter-company transactions are the first use case where the ownership of an asset changes between two or more companies — a purchase is made. Like intra-company transactions, activity is driven by basic business processes, such as order, shipment, credit, and debit, with a few key differences. One is that money is changing hands. This can involve more companies in the transaction (credit card, banks, etc.) and require more controls (proof of payment before the purchase transaction is allowed to be completed, for instance). The involvement of more companies also drives standardization on the business information level in addition to the technical standards normally in play in all use cases. Standardization typically drives compliance. The second major difference is that point of sale to end customers (people) also falls into this category. Cash becomes an asset in and of itself. This drives hundreds to thousands of possible transaction locations and a potentially high volume of transactions compared to the other use cases discussed thus far. It is in this use case that, again, accuracy in order, shipping, and payment are vital and cannot fail. Detailed records are kept at the conclusion of the transactions. Fixed and mobile readers are used with either active or passive tags depending on the application.

Table 4 provides examples of typical inter-company transactions across several industries, and Figure 3 shows both intra-company and inter-company interactions.

Table 4: Inter-company transactions

Attributes	Inter-company				
Industry examples	Supplier to retailer order fulfillment	Canned foods order fulfillment	Order fulfillment	Various subscriber order fulfillment	Gasoline pump order fulfillment
Security	Open	Open	Open	Open	Open
Carrier	Pallet or item-level	Pallet	Pallet	Cell phone	Key fob
Asset	Package	Case	Case	Cash	Cash
Where	Dock	In-line conveyor	Dock (automated)	Retail outlets	Filling station pump
Business process	Purchase order, ship, receive	Purchase order, ship, receive,	Ship, receive	Electronic payment	Electronic payment

		customer stock level			
Validation	Sequence, receive and pay, compliance	Order fulfillment, delivery validation, compliance	Order fulfillment, delivery validation, compliance	Financial debit/credit	Financial debit
Tag	Passive and active	Passive (assume)	Passive (assume)	Active HF	LF
Reader	Fixed, mobile/both	Fixed	Fixed	Fixed	Fixed
RFID functionality	RO and R/W	R/W (assume)	R/W	RO	RO
Information	License plate number and user data	Unknown	License plate, item summary, case count	ID, subscription information (credits)	Account number

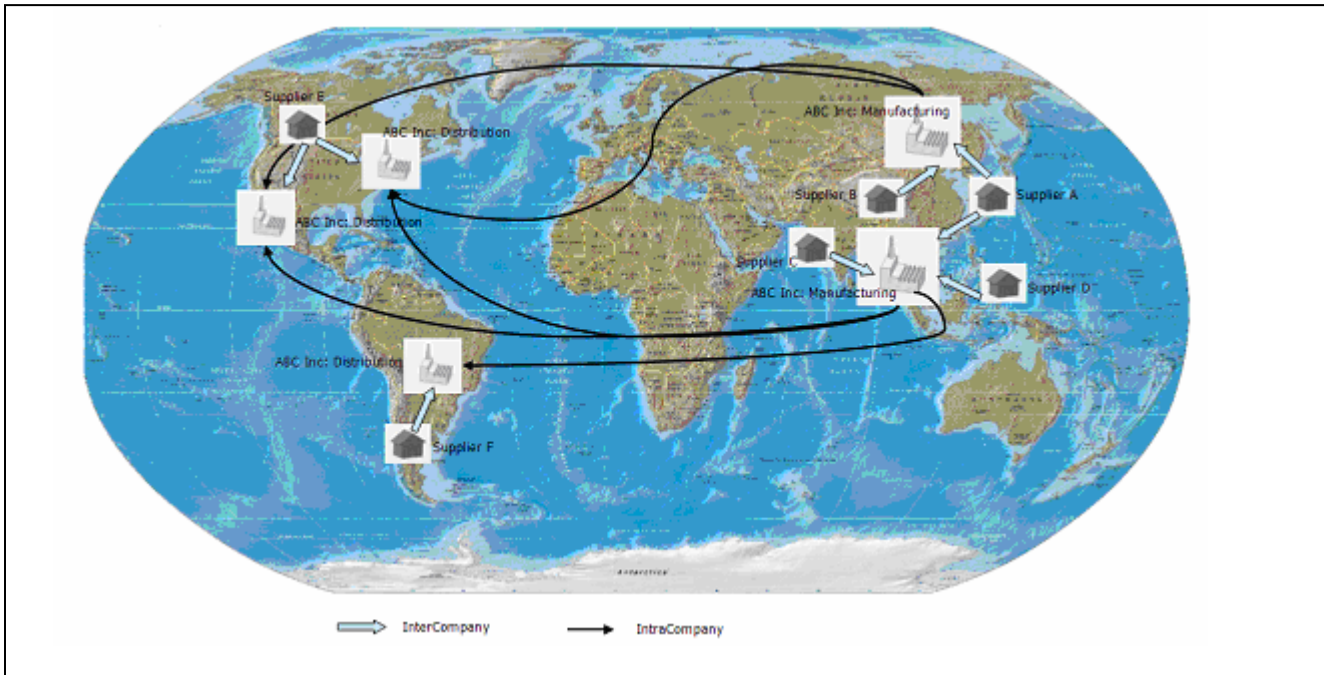


Figure 3: Inter/Intra-Company Transactions

5. SITUATION ANALYSIS

5.1 RFID Business

5.1.1 Market Size Projections

Several industry reports have been written over the past few years that provide significant detail as to the status of the industry and projections for future growth. In this section we focus on three specific topics that are of greatest relevance to the roadmap: 1) business drivers for historic adoption, 2) barriers to adoption, and 3) initiatives to address barriers to adoption.

RFID adoption today has been driven by mandates as well as microeconomic drivers which have resulted in an RFID market of approximately \$2B. The size of the market is projected to grow as definitive and strong returns on investment are captured and promoted to potential adopters (Table 5).

Table 5: RFID total available market projections

2007	2009	2011	2013	2015
\$4.96B	\$8.58B	\$14.30B	\$20.17B	\$24.45B

Data compiled from IDTechEx (<http://www.idtechex.com/>).

Presently, RFID has been adopted by several industries based on its bottom line financial benefits. The most often mentioned verticals and forward market projections are given below (Table 6).

Table 6: Tag value of several verticals within RFID market (US\$ Millions)

Vertical	2007	2009	2011	2013	2015
Air baggage	9.0	19.8	67.5	104.0	75.0
Animals/livestock	160.0	404.8	450.0	480.0	730.0
Military	24.0	180.0	405.0	560.0	828.0
Passports/ secure documents	171.0	205.2	208.8	234.0	280.0
Smart cards/ payment key fobs	1420.0	1367.0	1503.0	1645.0	1733.0

Vehicle clicker	47.0	49.0	51.0	53.0	55.0
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Data compiled from IDTechEx (<http://www.idtechex.com/>).

Another primary driver for adoption is the demonstration of a tangible return on investment (ROI). To date, tangible ROI capture has been application specific, and in many cases it has been difficult to attain data since companies associate a high net value to this data which in turn is considered as a competitive differentiator. More recently, efforts to articulate ROI propositions in different use cases have been initiated. Due to the lack of publicly shared data within the RFID industry, adoption drivers are typically classified into two broad categories: “faith based ROI” or mandate compliance. The general consensus is that the most definitive returns are captured when RFID systems are deployed for applications to prevent loss of valuable assets and to minimize the cost of poor quality associated with operators not following proper procedures.

The market will grow beyond mandate-led adoption as the gaps/needs outlined in this roadmap are addressed. Once addressed consensus among industry members is that great financial benefits will be realized upon the deployment of open loop applications and as a result of the lower costs for deployment due to the associated economies of scales.

5.1.2 Current Business Drivers

Specific attributes leading to adoption of RFID are typically discussed in terms of system parameters, RFID device type, operating frequency, etc. The most important of these are the following:

1. Level (item, case, and pallet)
2. Frequency of tag operation
3. Active or passive
4. Closed or open loop system
5. Inter or intra supply chain

To date, RFID has been successfully implemented at several points along the supply chain: item level, case level, and pallet level (Table 7).

Table 7: RFID tag value projections related to tag placement location (US\$ Millions)

Tag Location	2007	2009	2011	2013	2015
Item	2052	2986	4594	5891	7901
Pallet/case	49	196	1150	1650	1750
Other	90	298	216	176	120
Total	2191	3480	5960	7717	9771

Data compiled from IDTechEx (<http://www.idtechex.com/>).

In the past, RFID systems operating at 433MHz (vehicle clicker immobilizer) and HF (smart cards) were most often deployed. During the next 10 years, this trend will shift as UHF systems for pallets and cases are deployed (Table 8). Ultimately, HF tags will dominate as item-level tagging becomes ubiquitous.

Table 8: Distribution of tag sales as a function of frequency (percentage)

	2007	2012	2017
UHF	37.9	53.0	9.1
HF	49.7	46.6	90.8
LF	12.1	0.4	0.1
Other	0.3	0.0	0.0
Total	100%	100%	100%

Data compiled from IDTechEx (<http://www.idtechex.com/>).

To date, 77% of the tags that have been sold are passive tags with the balance being active tags. The application providing the majority of sales for passive tags is smart cards while the majority for active tags is vehicle clicker immobilizer.

Another RFID system attribute that drives adoption is whether the system will be used for a 1) closed loop application or 2) open loop. In the latter case, a well-developed ecosystem is required which is fundamentally anchored with mature consensus-based standards and well defined interoperability methodologies. Thus, the prevalence of closed loop systems is higher since deployment is not burdened by interoperability related constraints.

Examples of closed loop system applications where a single company and/or industry have been able to capture greater revenue or reduce expenses are as follow:

1. Asset tracking within a controlled facility where the cost of implementing the RFID system is a small fraction of the intrinsic value of the asset
2. Process validation/monitoring to reduce cost of quality, cost of yield/scrap (e.g. IC wafer fab)
3. Brand protection and authentication (grey/black markets)
4. Security and access control for applications such as remote access denial and corporate security to deny/control access
5. Library asset control (e.g. loss avoidance)
6. Duty payment control
7. Labor improvement and cost containment (e.g. process efficiency and process automation)

Yet another attribute that drives the decision to deploy RFID is the value of the interactivity to the supply chain: intra-supply chain versus inter-supply chain applications. Greater traction has been observed for groups deploying RFID for intra-supply chain applications (e.g. baggage tracking at airports, pallet tagging for work-in-progress tracking, tagging of casino chips, and beer keg tracking to ensure replenishment accuracy).

Inter-supply chain deployment tends to have greater barriers to adoption, such as lack of interoperability standards, and is typically a result of imposed mandates from powerful partners (Wal-Mart, Department of Defense). To date, the mandate-driven adoption has met with some resistance and, therefore, rollout has been slower than first expected. In addition, mandate-driven adoption has focused on case and pallet level applications with item-level applications being reserved for future discussion.

5.1.3 Barriers to Adoption

Several barriers to adoption exist of which the most significant are:

1. Standards, global harmonized regulations, and interoperability schemes (open loop)
2. Reliability in aggressive RF propagation environments (e.g. liquids, metals)
3. RF interference between readers and from external sources

4. Reading rogue tags
5. Difficulties with industry data sharing (e.g. sensitive information, demand data driven stock/product fulfillment)
6. Privacy (e.g. customer level of comfort for release of data for benefits, discounts, loyalty points, etc.)
7. Security issues (i.e. encryption, re-authentication/post-authentication, valuable data aggregation, sensitive company strategy information, etc.)
8. Cost and “who pays” (e.g. tag applier or user)
9. Speed of infrastructure rollout
10. Software for data integration into enterprise systems; middleware architecture for integration to tiers of software.
11. Source tagging and robust connection to databases

5.1.4 Initiatives to Address Barriers to Adoption

During the past several years, initiatives addressing the barriers impeding adoption of RFID have been established. Below are listed the ones that have been announced to the public:

1. **EPCglobal** (<http://www.epcglobalinc.org/>) — A working group was established to focus on item-level tagging within specific markets
2. Industry/government cooperation (<http://www.acq.osd.mil/dpap/UID/>)
3. Defense Procurement and Acquisition Policy <http://www.acq.osd.mil/log/rfid/index.htm>
4. iNEMI (<http://www.inemi.org/>) — A working group was formed in October 2006 to develop a roadmap identifying needs/gaps for item-level tagging deployment
5. International activities related to standards and regulations
6. State Radio Regulation Committee (SRCC), part of China’s Ministry of Information Industry (MII) (see article: “China Approves Requirements for UHF Bandwidth,” *RFID Journal*, <http://www.rfidjournal.com/favicon.ico>)
7. EU commission RFID cluster activity influencing future research directions and R&D call for proposal content

Beyond these initiatives there are ad-hoc groups comprised of multiple members of an industry value chain that have been formed to address specific issues with RFID adoption. Due to the perceived value of an RFID ILT deployment solution, by forming these ad-hoc groups the consensus is that they will establish a competitive advantage.

5.2 RFID Technology

5.2.1 RFID Tags

Active tags (which have a local power source on each tag) and passive tags (which have no battery source on the tag) each offer advantages for specific types of applications.

Active tags render much higher functionality than passive tags, such as:

1. Longer read range
2. Ability to integrate sensor or other device inputs
3. Data security through encryption
4. Ability to transmit in a noisy RF environment
5. Ability for tags to talk to other tags to form an ad-hoc network

Car immobilizers (clickers) are the most visible and highest volume active tag application for RFID so far, followed by active tags employed by military and defense for asset monitoring.

Active tags can operate at several different carrier frequencies based on the targeted application. At low frequencies, the RF beam floods an area, detecting tags behind obstacles; whereas, at high frequencies the beam is directed so that individual tags can be located in space. For applications like tagging intermodal shipping containers where, typically, metal environments are encountered, a frequency of 433 MHz is chosen to handle asset visibility. For non-stop road tolling or monitoring of railway carriages from gantries and bridges, where a high speed of interrogation is desired, a carrier frequency of 2.45 GHz or higher is selected.

Although passive tags have lower functionality than active tags, they offer a number of advantages over active solutions:

1. Inexpensive tags
2. Small form factor
3. Long operating life that is not dependent on battery life
4. Easy to integrate with product or packaging
5. Easy to deploy in the field with very little maintenance required throughout tag operational life

There is considerably more standardization of the passive RFID systems through ISO and EPCglobal efforts. Passive tags are best suited in applications like access control, animal identification, supply chain management, and item-level tracking (books, laundry, airline baggage, etc.)

Table 9: Types of RFID tags and key performance attributes

Attributes	Active		Passive			
	433MHz	2.4GHz	LF	HF	UHF	Semi-passive UHF—battery used to power IC, but not transmitter (uses backscatter)
Operation frequency	433MHz	2.4GHz	LF	HF	UHF	Semi-passive UHF—battery used to power IC, but not transmitter (uses backscatter)
Read range¹	<100m	<100m	<20cm	<3m	<7m	<20 m
Memory size	2kbits	2kbits	64-96bits	64-128bits	64-512bits	ID size ² sensor memory
Security	Encryption	Encryption	Encryption	Coding the chip, encrypted	Write, read lock, kill code, random number	Encryption
Form factor	Large >5cmx5cm	Large >5cmx5cm	0.5cm – 10mm	2cmx2cm – 4cmx10cm	2cmx2cm – 10cmx10cm	Passive ² sensor size
Cost	Expensive \$5-\$50	Expensive \$5-\$50	\$0.20-\$2.00	\$0.20-\$0.80	\$0.20-\$0.80	Passive tag ² battery ² sensor
Tag life	Based on battery life and usage 1-5 years	Based on battery life and usage 3-5 years	Up to 10 years based on tag environment	Up to 10 years based on tag environment	Up to 10 years based on tag environment	RF tag portion: up to 10 years, sensor life based on battery life; 1-5 years
Read rate			1-20 tags/sec	30-300 tags/sec	30-300 tags/sec	
Tag environment impact	Not severe in typical environments	Not severe in typical environments	Not severe in typical environments	Not severe in typical environments	Issues with metal and liquids	Potential issues with metal and liquids
Interoperability standards	ISO 18000-7 (433 MHz)	ISO/IEC 24730 (2.4 GHz)	ISO 18000-2	ISO-14443, ISO-18092, ISO 18000-3, EPC HF Gen 2	ISO18000-6 (Parts A, B & C), EPC Class 0, EPC Class 1 Gen 1 EPC class1, Gen 2	ISO-15693 (sensor tag)
Coupling	Electro –	Electro -	Capacitive/	Inductive	Electro - magnetic	Electro - magnetic

mechanism	magnetic	magnetic	inductive		backscattering	backscattering
Anti-collision	Yes	Yes	Yes	Yes	Yes	Yes

Table notes:

1. Read range depends on antenna size and power input to the reader
2. Not all features listed are available on standard products — table describes best-of-class features

5.2.2 RFID Readers

An RFID reader consists of a transmitting and a receiving section. The transmitting section includes a carrier frequency generator, signal gate, and an antenna circuit. The receiving section includes a peak detector, a signal amplifier/filter, a signal-collision detector, and a microcontroller for data processing. The reader also communicates with an external host computer to write new or updated information about the tags to the databases or network devices.

RFID readers can be of different types such as fixed, mobile and hand-held. The selection of a suitable type depends on the use case. A fixed reader is most appropriate when there are well-defined areas (e.g. choke point) through which the tagged items flow. With the fixed reader, it is possible to take advantage of the relatively consistent, repeatable process and further optimize with antenna orientation and placement. Fixed readers also have the advantage of human-free operation. A potential downside of the fixed reader is that there is a limited window of time in which to read the tags as they pass by, assuming the tags themselves are moving. Fixed readers are usually in a portal form or a tunnel form. A tunnel is typically used with a conveyor system. The tunnel forms an enclosure, which helps to contain and concentrate RF energy, thus reducing the power output requirements of the interrogator.

A mobile reader is a fixed mounted device on a mobile platform like a forklift. This configuration has advantages of the fixed readers, such as repeatability and human-free operation. It also relieves the time constraint for processing tags since the tags can continue to be read while the pallet is being held. One of the challenges associated with the mobile reader is to eliminate reading of stray or unintended tags (other than the tags on the pallet being held) while the reader is in motion.

A number of proprietary RFID system solutions have been deployed in closed loop systems that operate at various frequency bands and use different communication protocols. In an open loop RFID system, where the tagged items move through various points in supply chain, the tags and

RFID infrastructure needs to be interoperable among various vendors and users. Identifying this need for interoperability, some of the RFID suppliers have started to offer multi-frequency, multi-protocol RFID readers.

Table 10: Types of RFID readers and key performance attributes

Attributes	Fixed reader	Mobile reader	Hand-held reader	Ultra-compact reader (in mobile device) NFC
Read distance	Up to 6m	Up to 3m	Up to 3m	1-5 cm
RF output power	Typical: up to 4W High power: up to 20W	Typical: up to 1W High power: up to 20W	Up to 1W	Up to 1W
Tag read speed	Up to 300/sec	Up to 300/sec	< 100/sec	< 10/sec
Reader memory	128 KB – 1GB	128 KB – 1GB	Up to 64 MB	<32MB
Cost	\$\$	\$\$\$	\$\$	\$
Protocol supported	EPC Gen2, HF, LF	EPC Gen2, HF,	EPC Gen2, HF	ISO 14443
Data collection and analysis capability	Host or on-reader computer controlled	On-reader computer control	On-reader computer controlled	Host controlled
External interface	USB type 1 and 2, RS232, GPIO	N/A	Active sync	RS232
Network connectivity	Ethernet, RJ45	WiFi 802.11 a/b/g, WPAN	802.11/g, WPAN, Bluetooth	Ethernet
Temperature range of operation	-10°C to +50 C	-10°C to +50°C	-10°C to +50°C	-10°C to +50°C
Frequency response	LF: 125KHz-135KHz, HF: 13.56 MHz UHF: 860 MHz-960 MHz Active: 433 MHz, 2.4GHz	UHF: 860 MHz-960 MHz	UHF: 860 MHz-960 MHz	HF: 13.56 MHz

6. ROADMAP OF QUANTIFIABLE ATTRIBUTE NEEDS

6.1 Technology

RFID technology has been successfully demonstrated in niche applications and at large system levels (e.g. pallets and cases for retail application). However item-level RFID technology, which is expected to be a major driver for ubiquitous RFID deployment, is not as mature. Technology, business challenges and particularly cost have held item-level RFID back. The first phase of RFID technology penetration saw implementation of standard and proprietary passive tags with limited functionality. Tags functioned simply as serial number holding devices. Ruggedized passive tags for asset management with more memory and higher functionality have emerged since. The tag market is expected to bifurcate in the near future resulting in two distinct tag families and these families may embody very different technologies. One such family — “simple tags” — will be ultralow cost tags with deliberately constrained functionality suitable for disposable mass market applications. Such tags will use non-silicon based technologies. The other family — “complex tags” — will remain silicon based and will offer significantly higher functionalities, but at higher cost. Such tags may integrate sensors with the RFID tag for periodic monitoring of the tagged object’s condition/environment. Also, networks of various tags are envisioned in the future that will be able to communicate tag to tag and with the central system to form a distributed architecture.

6.1.1 RFID Tags

The present active and passive RFID tags are based on silicon ICs. The capabilities of these silicon IC based tags are evolving to enable higher functionality, higher security, enhanced reliability and lower cost. An emerging type of tag — referred to as a chipless tag — has non-silicon based circuit elements that function with chemical, electrical or acoustic modulation of the structure. A majority of these chipless tags are passive in nature. The following sections delve into the state of the art and future attributes of various types of tags.

RFID tags need to meet various operating conditions prescribed by specific applications/use cases. Table 11 lists extreme operating conditions in some of the representative applications.

Table 11: Extreme Operation Conditions

Application	Temperature	Humidity	Chemical	Other
Automotive	-55°C to 150C	85°C/85%RH	N/A	Vibrations, shock
Consumer electronics (e.g. Mobile phone)	-40°C to 85°C	70°C/85%RH		Mechanical shock
Electronic assembly process industry	-55°C to 250°C	85°C/85%RH	Alcohol based cleaning solutions, PCBA washing detergents, rework flux	
Access control, smart cards	-40°C to 70°C	5% to 95%	N/A	Flexing, bending
Autoclave	120°C to 200°C	0% to 100% RH	Application dependent	
Laundry	-55°C to 150°C	5% to 100% RH	Laundry chemicals, detergents	
Coldchain storage of grocery goods	0°C to 18°C ¹	85% to 95% RH		
X-ray/ionization radiation environment				Typical X-ray source energy: 0.5MeV to 6MeV Typical nominal dose per scan value above normal background level at centerline of target container: 4μR to 10μR ²
Logistics – storage and shipment	-40°C to 85°C ³	5% to 95% RH		

Table notes:

¹<http://usna.usda.gov/hb66/017grocery.pdf>

²<http://www.saic.com/products/security/pdf/Portal-VACIS.pdf>

³http://www.savi.com/products/SensorTag_673.pdf

6.1.1.1. *Active Tags*

Active RFID systems were initially driven by the commercialization of real-time location systems (RTLS) for asset tracking (containers, inventory, WIP), people tracking (hospitals, care homes, prisoners) and vehicle tracking (road tolling, warehouse, airport ground support). Future growth

in active RFID tags is projected to be in RTLS, RFID sensor systems, including smart active labels (SALs), and sophisticated multifunctional devices.

SALs are defined as thin and flexible labels that contain a sensor, an integrated circuit for RF communication, and a power source. A vision for smart active label is that of a product label with self-adjusting “use by” and “sell by” dates. These labels will consist of an RFID tag, a sensor and a display that indicates the date as it detects humidity, temperature and exposure time. Typical applications include:

- Shelf life monitoring of perishable items (e.g. meat, produce)
- Condition monitoring (e.g. containers of donated blood)

Battery life of active RFID tags becomes an issue with required longevity of the tags in the field. Sensor enabled RFID tags are beginning to find their way into environment monitoring applications such as natural habitat monitoring, and measurement of stress and strain in bridges and high-rise buildings. These sensors are typically battery powered and their useful life is limited by their energy supply. The energy density of low cost batteries is not expected to significantly improve in the coming years. Therefore, extending the useful life of a sensor is still a function of careful energy budgeting and recharging through energy scavenging or harvesting. Besides, ideally, these sensors should last as long as the environment they are monitoring; so no matter how much energy a battery starts out with, it will eventually run out.

There is significant economic opportunity in developing a sensor that can scavenge or harvest energy from its surroundings. Though recharge methods such as vibration, photovoltaic, and thermal differentials have been around for a while, these techniques are either too expensive for RFID application, too large, or too inefficient. Research is needed to develop an energy source that is small, low cost, and rechargeable.

As a multifunctional device, the active RFID tag will integrate functionalities like sensing and tracking to operate on existing wireless networks or short-range communication protocols such as WiFi, Zigbee, Bluetooth, NFC, GSM, UWB, etc. Examples of this include: an active RFID with Bluetooth to locate nurses in a hospital, an active RFID with GSM for tracking and recording people, and a WiFi-enabled active RFID for location tracking. Some of the active RFID tags integrate functionality of EPCglobal Gen2 passive RFID, RTLS, sensor link and data logging with an active RFID network at two different frequencies.

In addition to the existing network protocols, IEEE began work in February 2007 on a new networking standard called RuBee (IEEE P1902.1). This standard is based on long wavelength (below 450KHz) bidirectional, peer-to-peer, radiating transceiver protocol. The advantages of the long-wavelength technology are that the radio tags can be low in cost, near credit card thin (1.5 mm), and fully programmable using 4-bit processors. Despite their high functionality, RuBee radio tags have a proven battery life of 10 years or more using low-cost, coin-size lithium batteries. The RuBee protocol works with both active radio tags and passive tags that have no battery. The RuBee network standard will provide for asset visibility networking that fills the gap between the non-networked, non-programmable, backscattered, RFID tags widely used for asset tracking and the high-bandwidth radiating protocols for IEEE 802.11™ local area networks and IEEE 802.15™ personnel area and data networks. The IEEE1902.1 based tags are not affected by liquids and metals, and hence are attractive for item-level tagging applications like asset tracking, agricultural visibility networks, implantable medical sensors, etc. Since this is a recent initiative, there is a limited amount of information available in the public domain.

Table 12 Roadmap of attributes for real-time location systems (RTLS)

Attributes	State of the art (2007)	Mid term (2012)	Long term (2017)
Locate range	100m indoor 1000m outdoor	150m indoor 2000m outdoor	300m indoor 3000m outdoor
Location finding algorithm	Triangulation, TDOA, RSSI, proprietary location method	RSSI, TDOA	Novel accurate location finding techniques
Location accuracy	Zone tracking, item-level tracking 1.5m to 6m	Item -level tracking 1m to 3m	Accurate item-level tracking 0.3m to 1m
Solution for dense environment of tracking items	ISO 24730 based detection	Standards based, novel solutions to operate in dense environment	Standards based, novel solutions to operate in dense environment
Battery life	1-5 years	3-10 years	3-10 years, low cost printed batteries, energy harvesting (e.g solar cell)
Cost of the tag	\$30 -\$100	\$10 - \$ 50	\$1 - \$ 10
Networking	WiFi (802.11), ISO 24730, proprietary network, ultra-wide band GSM	WiFi (802.11), UWB, Bluetooth	A multi-protocol supporting system

Table 13 Active RFID tags: roadmap attributes for smart active labels

Attributes	State of the art (2007)	Mid term (2012)	Long term (2017)
Added functionality	Time & temperature sensing, source tracking	Temperature, time, humidity sensing, source tracking	Environmental sensing, display
Sensor integration	Sensor integrated on the tag with RFIC	Sensor integrated on silicon chip (e.g. MEMS)	Sensor integrated on silicon chip (e.g. MEMS)
Integrated EAS	No	Yes	Yes
Tag life	Dependent on battery life Single use, or multi-use tag	Dependent on battery life Single use, or multi-use tag	Single use tag
Security	Password protected data	Password protected data, encryption	Password protected data, encryption
Read range	1-10m	Up to 30m	Up to 100m
Battery life	Up to 1 year	Up to 1 years	Up to 3 years
Cost of the tag	\$4 - \$10	\$2 - \$5	Under \$1
Form factor	Credit card form factor	Credit card form factor	Label
Networking	EPC and ISO standard based, proprietary	EPC and ISO standard, Zigbee, proprietary	EPC, ISO standard, autonomous network
Tagged item location (RTLS)	No	No	Yes

6.1.1.2. *Passive Tags*

Innovative research is ongoing to reduce the cost of passive tag and to provide higher value with functionality greater than simple serialization. The cost of the tag can be reduced by reducing the component count (through integration), or by reducing the assembly steps to manufacture the tag. One company recently developed an RFID chip with an antenna embedded in the chip that operates at 2.45GHz frequency and has a 128-bit ROM. This chip can be easily embedded in bank notes, documents or other objects for authentication. Another company introduced an RFID tag that has a precision antenna coil-mounted directly on the chip surface. The chip itself is 2.5mm x 2.5mm in size, making it possible to be applied to any two-dimensional or three-dimensional object. The chip RF interface operates at 13.56MHz and storage capacity ranges from 128bytes to 4Kbytes.

The passive tag can provide higher value by integrating sensor functionality with the RF communication link provided by the tag. Several companies have sensors integrated with semi-passive tags to monitor the condition of food, blood, etc. The US military is investigating integration of MEMS sensors with RFID to track and monitor shelf life and the effects of environmental conditions on individual protective equipment (IPE). Integration of MEMS with RFID on the same chip or in the same package will enable small form factor, high functionality and low cost.

The field of application for passive RFID tags is vast, spanning from low-functionality license plate type tags for retail or logistics to high-functionality tamper-proof, high security tags for pharmaceutical applications. Two use cases — low functionality and high functionality — are considered here in order to outline the development roadmap of passive RFID tags.

Typical applications for low functionality passive RFID tags include:

- Closed-loop asset tracking (e.g. rental items)
- Fashion labels (e.g. marks and spensers)
- Retail consumer packaged goods
- Items to be read by mobile phones (e.g. Internet access)

High functionalilty passive RFID tags are often used for:

- Cold chain track and trace (e.g. temperature logging)
- Sensor tags
- Data logging tags
- Maintenance applications

Table 14 Roadmap of key attributes for ultra-low functionality passive tags

Attributes	State of the art (2007)	Mid term (2012)	Long term (2017)
Cost	Min. 12 cents	Min. 5 cents	Min. 1 cent
Memory size (License plate)	64-128 bits	64-256 bits	64-256 bits
Memory type	WORM	WORM/ RW	WORM/RW
Antenna type	Antenna and chip on inlay	Printed antenna - coupled to chip	Antenna integrated on chip
Attachment to product/ packaging	Label applied to product	Partially integrated into product, tag antenna printed on product	Totally integrated into the product
Chip type	Si	Si	Si or polymer
Read distance	1-2 m	1-2 m	1-2 m
Speed of reading	100 tags/sec	300 tags/s	600 tags/s
EAS	No	Yes	Yes
Password read	No	Yes	Yes
Proximity tags	Difficult to read	Readable	Readable
Power requirement at the tag	Up to 100mW	Up to 1mW	Up to 0.01mW
Tag on metal mounting	No	No	Yes

Table 15 Roadmap of attributes for high functionality passive RFID tags

Attributes	State of the art (2007)	Mid term (2012)	Long term (2017)
Cost	Min. 25 cents	Min. 10 cents	Min. 5 cents
Memory size (license plate)	256bit -2kbit	256-64kbits	256-64kbits
Memory type	RW	RW	RW
Antenna type	Antenna and chip on inlay	Printed antenna - coupled to chip	Antenna integrated on chip
Attachment to product	Label applied to product	Partially integrated into product, tag antenna printed on product	Totally integrated into the product
Chip type	Si	Si	Si

Read distance	1-3m	1-6m	1-10m
Speed of reading	100 tags/sec	300 tags/sec	600 tags/sec
EAS	Yes	Yes	yes
Password read	Yes	Yes	yes
Proximity tags	Difficult to read	Readable	Readable
Sensors (temp/pressure/humidity/light)	Connected	Integrated (MEMS)	Integrated (MEMS)
Selective killing of data on tag	No	Yes	Yes
Selective locking of data on tag	Yes	Yes	Yes
Partitioned read zones protected by passwords	Yes	Yes	Yes
Encryption	No	Yes	Yes
Tag networks - tag to tag communication	No	Yes	Yes
Memory write technologies	CMOS EEPROM	Ferro-electric RAM based high speed EEPROM	High speed EEPROM
Tag on metal mounting	No	No	Yes

6.1.1.3. *Emerging Tag Technology: Chipless Tags*

RFID tags that do not contain a silicon chip are referred to as chipless tags. The most attractive proposition of these tags is that they can drive the cost of RFID tags below one cent and can potentially be printed directly onto the package/product surface, thus replacing barcodes with a more versatile solution. There are a number of technologies that enable chipless RFID tags, such as: 1) acousto-magnetic, 2) specialty inks, 3) SAW (surface acoustic wave), 4) inductor-capacitor arrays, 5) synthetic aperture radar (SAR) and 6) thin film transistors (TFTs). Most of the chip-less RFID tags can store a limited amount of data on the tag, thus limiting their application to niche areas, although the data storage capacity is increasing with time. Of the technologies available only the acousto-magnetic based RFID tags for drug error prevention and for SAW devices for road tolling have been sold in large volumes. Printed TFT technology, printed electromagnetic inks and SAW technology appear to be the most promising chipless technologies because of their data storage, compatibility with chip-based infrastructure and

cost. Once mature, chipless RFID tags are expected to rapidly dominate the market because of the cost and integration advantages, although more complex applications like smart cards, real-time location systems, large data storage and active tags are expected to be based on the silicon chip-based tags.

Table 16 Types of chipless RFID tags with their advantages and limitations

Technology	Advantages	Limitations
SAW	Better tolerance for interference and potentially much longer read range than silicon RFIC based tags Fewer processing steps and less precision needed in fabrication, less expensive Inherent temperature sensing capability	No read/write option Brittle crystal leading to less mechanical rigidity Scale up to high volumes Need connection to the antenna
TFTs Printed electronics	Roll-to-roll processing makes it potentially very low cost RFID tags can be printed directly onto the product or packaging Meet existing open specifications Low frequency (13.56 MHz or lower) allows operation in metal/liquid environment	Circuits have large footprint Initial versions have low to modest memory Read/write functionality in early development stages Environmental reliability is a concern
Printed inks Electro-magnetic	Potentially lowest cost solution RFID tags can be printed directly onto the product or packaging Read range several feet	Read only tags, no read/write option Limited anti-collision capability Low memory content Large footprint of the tags

Table 17 Roadmap of key attributes for Printed TFT-based RFID tags

Attributes	State of the art 2007	Mid term 2012	Long term 2017
Operating frequency	LF to HF	HF	HF-UHF
On-board memory	4-32 bits	128 bits	1Kbit
Memory type	Read only	Write once read many (WORM)	Read/write many
Read range	<4cm	Up to 1m	Up to 3m
Infrastructure compatibility	Very little	Compatible with LF and HF infrastructure	Compatible with UHF infrastructure
Integration level	Discrete components: antenna, RF and memory	Integrated RFID tag as label	RFID tag (chip + antenna) directly printed on product/packaging
Physical size of the tag	4 cm ² - 25cm ²	2cm ² – 10cm ²	1cm ² – 5 cm ²
Anti-collision	Unavailable	Limited availability	Widely available

6.1.2 RFID Readers

The RFID reader is a key component of RFID hardware. Until recently, a large portion of the RFID readers were simple, inexpensive units that collected data from RFID tags and forwarded it to middleware for data filtering and aggregation. The middleware can become a point of failure in this case, and a robust middleware is required to guard against such occurrence. Increasingly, the trend is toward smart readers that have built-in low-level filtering that can reduce the network traffic by forwarding only relevant data to the middleware. With smart reader systems, middleware's role is reader management, provisioning and high-level filtering and aggregation.

With the advent of global RFID standards like EPC Gen2 and ISO 18000-6C, the readers need to be interoperable in the frequency spectrum of 860MHz to 960MHz with various protocols. Multi-frequency, multi-protocol RFID readers are being developed in the industry to meet the interoperability demands brought on by typical open loop systems at the global level. Recently some companies have reported development of several multi-frequency, multi-protocol readers based on software-defined radio (SDR) architecture.

The number of RFID readers being deployed per unit area is increasing as the RFID based solutions scale up to meet the business demands. For example, in a warehouse readers may be installed on dock doors, fork trucks and smart shelves, in addition to hand-held readers. Next-generation readers need to manage the limited RF spectrum efficiently to operate in this "dense reader" environment. The reader performance is being boosted with spectrum plan and channel masking technologies, which are also addressed in EPC Gen2 specifications. However, these technologies do not address challenges faced in environments with typically more than 20 readers. Other approaches are required to solve the dense reader issues.

Table 18 Roadmap of key attributes for RFID readers

Attributes	State of the art (2007)	Mid term (2012)	Long term (2017)
Tag read speed	100 tags/sec	300 tags/sec	600 tags/sec
Dense reader environment	Spectrum management by the reader protocols	Channel masking and spectrum plan 'Tag-talk-first' protocol to optimize spectrum utilization	Reader synchronization techniques
Frequency and protocol supported	Standards like EPC, ISO or proprietary	Multi-protocol readers	Multi-protocol readers
Reader form factor	Stand alone wall mount or floor mount reader	Integration in printers, smart shelves	Integration in wearables
Reader complexity	Readers with some data processing capability	Smart readers with data filtering	Smart readers with data processing capability
Cost of a fixed reader	\$1500 - \$3500	\$500 - \$2000	\$100 - \$1000
Reader in RF challenging environment (metal, liquid)	Limited solutions for metal or liquid environments	Near field UHF coupling technology for RF unfriendly environment	Near field UHF coupling technology for RF unfriendly environment

6.1.2.1. Emerging Reader Technology: Near Field Communication

The term “near field RFID” has been used to describe two entirely different RFID technologies. Near field communication (NFC) describes a short-range wireless RFID technology, operating at a frequency of 13.56MHz, mainly aimed at usage in mobile phones. The standards that define this technology were approved by the International Standards Organization on December 8, 2003. NXP, Sony, and Nokia formed the NFC Forum to advance and promote this RFID technology. The second use of the term “near field RFID,” emerged in 2006, when UHF proponents promoted the term “near field UHF.” Here, the term refers not solely to the proximity of the communication (as it does for mobile phone NFC operation), but rather to the basic physics of an electromagnetic field. The section below specifically addresses 13.56MHz NFC technology

Near field communication (NFC), which can be considered as an RFID-enabled mobile device technology, operates at 13.56 MHz and combines the functionality of an RFID reader device and an RFID transponder into one integrated module. Whereas a typical smart card is compatible with ISO 14443, NFC is compatible with ISO/IEC 18092, ISO/IEC 14443, and

ISO/IEC 15693. While the smart card can operate as a ticketing/payment vehicle in smart card emulation mode, NFC goes beyond that to enable a peer-to-peer communication and read-write operation from the host device. In general, NFC devices feature three modes of operation:

1. **Smart Card Emulation:** When using the card emulation mode, an NFC-enabled device emulates an ISO/IEC 14443 or 18092 compatible smart card. This mode enables, for example, the use of the NFC device as a contactless credit card or electronic ticket.
2. **Peer-to-Peer:** NFC devices use the peer-to-peer mode defined in ISO/IEC 18092 for data transfer, such as passing contact information or an electronic business card between devices (e.g. between a cell phone and an NFC-enabled desktop computer).
3. **Read & Write Mode:** This mode enables the NFC device to access data from an object with an embedded RFID tag. It enables the user to initiate data services such as the retrieval of information or rich content like trailers and ringtones.

Contactless applications for payment/ticketing technology are widespread in parts of Asia, while contactless payment applications based on the ISO 14443 standard are common in the US. Until the end of 2006, an estimated 1.2 billion ISO 14443 Type A chips had been sold, which can be read by 7 million ISO 14443 Type A compliant reader modules. An estimated 30 million contactless chips have been implemented in Japanese mobile phones supporting smart card emulation mode.

Table 19 RFID-enabled cell phones (NFC)

Attributes	State of the art (2007)	Mid term (2012)	Long term (2017)
Read range	4 cm	4 cm	4 cm
Battery life	Battery phone powered	Battery phone powered + field powered	Battery charged inductively
Cost of the tag	50 cents	20 cents	5 cents
Form factor	Smart card	Label	Printed tag
Networking	ISO 14443 + ISO18092	ISO 14443 + + ISO18092 + ISO 15693	ISO 14443 + ISO18092 + sensor tag
Security and privacy	Encryption, short distance read		
NFC antenna	Integration in the phone housing	Miniaturized antenna	Antenna integrated with short range comm. module, on-board antenna

NFC chip design	Stand alone NFC chip	NFC Bluetooth integration	Short range communication module
Data rate	106 kbps	424 kbps	424 kbps

6.2 RFID Infrastructure

The RFID infrastructure typically consists of readers, antennas, switches, the communication network, and the computing hardware. This infrastructure is needed to gather the RFID data and transmit it to back-end enterprise software applications that consume the data. This section covers both intra-company and company-to-company (also known as business-to-business) infrastructure capabilities and technologies.

6.2.1 RFID Infrastructure Components

There are four main components of the RFID network as shown in Figure 4. They are:

1. **RFID Hardware:** The RFID hardware consists of the combination of RFID tags and RFID readers.
2. **Middleware:** The middleware takes the data from RFID readers and makes it available to the applications connected with the RFID tag information. The middleware abstracts the RFID hardware to the data analytics system as RFID information.
3. **Data Analytics System:** The data analytics system consists of applications and databases that process RFID information related to the business processes they support. The data analytic system could also draw non-RFID information from ERP systems.
4. **B2B Integration:** Business-2-business integration enhances the usefulness of RFID by enabling the timely and secure sharing of information across business partners in a supply chain. Such sharing, for example, can be used to mitigate the bullwhip effect thereby reducing inventory carrying costs at the manufacturer and distributors without increasing out-of-stocks at the retailer. B2B frameworks, such as RosettaNet and EDIFICE, which were originally designed for barcode technology, can easily be used for RFID without any significant changes.

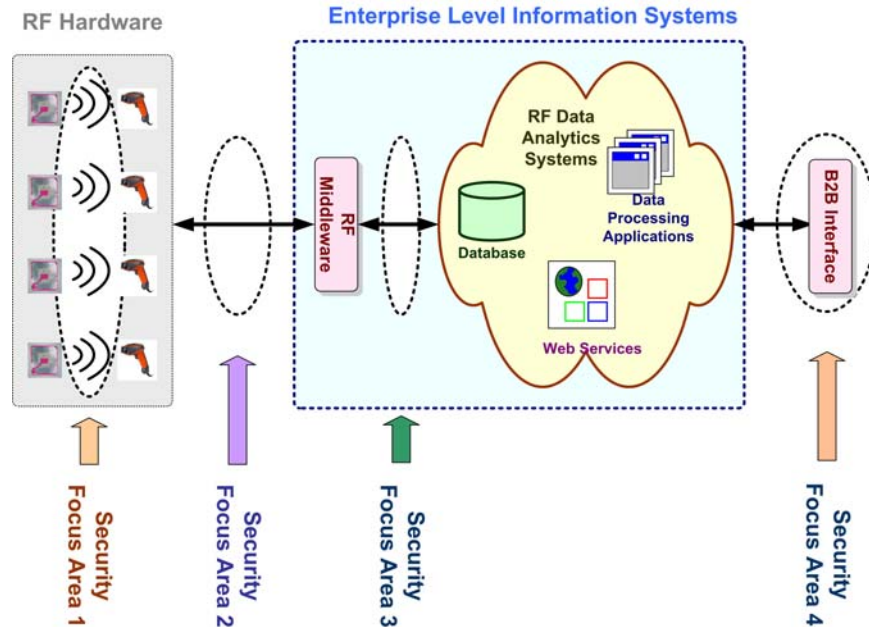


Figure 4 the RFID network architecture and components

The RFID middleware and the RF data analytics system jointly form the enterprise-level RF system.

6.2.2 RFID Infrastructure Network

There are four main network focus areas in an RFID network. They are:

1. **Focus Area 1:** This area is within the RFID hardware and is the wireless network between the RFID tag and reader. There are several options for wireless network depending upon the application type (LF, HF, UHF, super-HF, etc).
2. **Focus Area 2:** This area is between the RFID readers and the RF middleware. When located sufficiently close, the common link layer protocol used is the Ethernet Protocol (IEEE802.3). For longer distances, WiFi (IEEE802.11) is starting to emerge, the wireless link layer protocol. The area between the RFID reader to RF middleware network is called the edge processing network.
3. **Focus Area 3:** This is between the RF middleware and RF data analytics systems, an area traditionally supported with the Ethernet protocol. This connection is traditionally integrated within the company intranet.

- 4. Focus Area 4:** This is the communication between various business partners in a supply chain. Though the underlying network protocol is almost exclusively IP, the application layer continues to have a slew of protocols such as SOAP, XML, HTTP, FTP and others. These protocols tend to address various niche functional areas and may be used in conjunction with each other.

6.2.3 Infrastructure Challenges and Future Needs

Due to rapid technology innovation and standards compliance, the infrastructure is becoming easier to deploy and manage. However, the specialized skills and constant monitoring that is currently needed by the RFID infrastructure is more than can be handled by the IT department of a small or medium sized organization. These special needs increase the cost of ILT deployment and maintenance, and impede its adoption by a wider group of organizations.

Some of the important things that the RFID community must work on to accelerate adoption are:

- 1. Ease of Installation and Servicing:** The very nature of radio communication makes it hard to constrain an RFID reader's signals to within a desired space. The environment has an immense impact on the distance the signals travel, the shape of the coverage area, and even the reliability of reads in the desired coverage area. An antenna with an incorrectly selected power level and sensitivity may read tags from beyond its intended coverage area, or may not reliably read tags that it *should* within its coverage area. It currently requires highly skilled engineers and technicians to survey the environment and configure readers and antennas to achieve the desired effect. To accelerate acceptance of RFID, it is important to make it easier for organizations to set up and maintain their own infrastructures, very much like the way it is done for IT infrastructure such as WiFi, compute servers, and telephony. For instance, it would be much easier for a technician to simply specify the read zone in a graphical user interface and have the reader achieve that by automatically selecting the correct power levels for the different antennas. Though much research has been carried out on channel adaptive antenna arrays for wireless communication purposes, the benefits of the research have not yet been applied to RFID.
- 2. Remote Configuration of Devices:** To a large extent, it is already possible to remotely configure readers. Readers and tags must comply with a global standard such as ISO 27791.3 so that they have a standard interface for remote discovery and configuration.

6.3 Software Applications

Much of the benefit of RFID lies in the fine-grained and real-time data that is produced. To leverage that data, we need applications and enterprise systems that can extract useful information from it and in turn drive business objectives.

Important functions may be met by different applications including the RFID middleware, enterprise resource planning (ERP) software, warehouse management software (WMS), customer relationship management (CRM), manufacturing execution system (MES) and a host of other applications. Irrespective of where the functions are implemented, some of the important features required to fully realize the potential of an RFID infrastructure are:

1. ***Inventory Management and Disconnected Operation:*** When RFID is used in applications that require tagged objects to be scanned at locations without immediate network access to the enterprise applications, it may not always be sufficient to simply upload the data at a later time. For example, an application that forecasts demand based on the rate at which products are removed from the shelves of a retailer and the quantity already in different warehouses can easily be off the mark when a huge consignment is delayed at a shipping port. Such forecasting applications, or any relevant enterprise application for that matter, should be intelligent enough to know that its forecasting ability is curtailed or unreliable because it has not received an expected update from a large warehouse or huge consignment in transit.
2. ***Data Filtering:*** The ease with which RFID data can be collected is its strength, but could easily become a weakness if not controlled adequately. The large volumes of data can easily cripple a communication network or overwhelm enterprise applications and databases. It is important to filter the data so that either only relevant data is sent by the readers and edge systems, or the data is aggregated to a desired level. Currently, a large set of business rules are painstakingly created and applied to various devices in the RFID infrastructure so that only relevant information makes it past them. However, in a fast-paced world, businesses must be agile and tend to have constantly changing business rules. The RFID community must develop alternatives to rule-based systems or at least find a way to simplify or automate the task of creating or changing the rules across an organization or group of organizations.

3. **Data Mining:** The usefulness of the RFID data can go well beyond pure supply chain or facility management. Typically, the tag IDs are associated with other information such as product ID, date of manufacture, batch number, customer ID, current location and other information relevant to an organization. This rich data set can be mined for insights into what is really going on in the field. For instance, given the data, it is possible to find the correlation between different variables of the supply chain such as the percentage of increase or decrease in sales after a product was reviewed in a national newspaper or an online post such as cnet.com. Currently, it could take weeks or even months for such signals to trickle back to a manufacturer and, by then, the signal is usually attenuated due to noise from seasonal variances, introduction of other products, or rebate programs. This delay amplifies the bullwhip effect; getting a clear signal directly from the point of sale reduces the impact of this effect.

With the vast amount of near real-time data available for an RFID-enabled supply chain, an enterprise system can be programmed to automatically look for such correlations and alert management when something of interest is found.

4. **Exception Detection and Resolution:** There are primarily two types of exceptions that can occur: a) the RFID tag is read multiple times at a point; and b) a tag is read at a location where it is not expected to be. Most readers available on the market today can filter out duplicate reads of the same tag within a specified period of time. However, it is much harder for an enterprise system to comprehend what is happening if an RFID tag ID shows up unexpectedly at a location. This could happen for several reasons: the tagged object ended up in the wrong location; duplicate tag IDs have inadvertently been introduced into the system; or two read locations are co-located and a reader is picking up signals from tags in the read zone of another reader. The latter could happen, for instance, if the incoming and outgoing dock doors are close to each other and are not sufficiently shielded.
5. **Task Execution:** Current applications already allow companies to automate certain business functions by automating simple decision-making. These applications use sensor and event information as inputs to the decision and use predefined rules. However, with the explosion in the amount of fine-grained real-time data collected, it should be possible to push business automation to a much higher level of sophistication. Rules-based decision-making is good for simple and clear-cut inputs, but more often than not, the important decisions that impact the business' bottom-line are still heavily human-driven and complex.

This does not necessarily mean a human is better than a computer at making such a decision; it could just mean that we have not yet developed an algorithm that can do as well, if not better. Much more research must go into how the rich information set now available through RFID can be used to automate and speed up complex decisions.

6. **Modularity:** RFID can be applied in varying degrees by different organizations to meet different objectives. Not all features of a software application will be useful to an organization. Software vendors should start unbundling their software so that setting up the RFID infrastructure becomes cheaper and more organizations will begin to adopt it.

6.4 Security

RFID represents a technological advancement in auto identification and capture (AIDC) systems due to the key features that are not available in other AIDC systems, such as bar codes. These features are enabled by the use of radio frequencies rather than light which is required for optical AIDC systems. The key features of RF-based AIDC compared to optical-based AIDC are:

- Ability to penetrate some material without optical line of sight
- Ability to read tags quickly
- Ability to identify over greater distances
- Ability to store and possibly record information and events in the tags

While RF technologies provide significant benefits, they bring security challenges with them as well. As described in Figure 4, the complexity of RFID network security is higher at the edges of the intranet than the inside. This behavior is typical of all computing environments and infrastructure. The security needed for the areas depend upon the network technology used and the classification of the information sent from the RFID tags to the appropriate applications implementing the business process.

6.4.1 Components of Network Security

There are two aspects of network security. The first is maintaining system integrity as required by the design. Cyber attacks such as viruses, worms and denial of service are examples of capabilities that impact the integrity of the system. The second is intellectual property (IP) protection, which focuses on the information content carried over the network that drives

business processes. There are several techniques to capture IP. Loss of IP impacts the financial strength of the company.

6.4.2 Risks Associated with RFID Networks

There are four categories of risk associated with the RFID network environment:

- 1. Business Process Risk:** Direct attacks on the RFID network could impact the running of the day-to-day business processes.
- 2. Business Intelligence Risk:** Attacks by adversaries or competitors to gain unauthorized access to the RFID system, capture IP, and undermine the financial viability of the business.
- 3. Privacy Risk:** The RFID system may contain information that, when compromised, impacts privacy rights of individuals or companies.
- 4. Installed Environment Risks:** This category refers to the threat an RFID system may pose to non-RFID systems, assets and people. This is not within the scope of the document and will not be dealt with in any detail.

6.4.3 Security Focus Areas

As described in Figure 4, there are four areas of interest regarding security, and in each of these area, system integrity, IP, data and more must be protected:

1. **Focus Area 1: The RFID Hardware**

System Integrity: Ensure that only known devices are in the network and communicating only what they should be communicating

IP Protection: Ensure that the information between the tag and the reader cannot be read by any unauthorized device on the network

2. **Focus Area 2: The Reader to Middleware Communication**

System Integrity: Ensure that only known readers are in the network and are communicating with the middleware software with known protocols.

IP Protection: Ensure that the information between the reader and the middleware cannot be read by any unauthorized device on the network.

3. **Focus Area 3: The Middleware to RF Data Analytics Systems Communication**

System Integrity: Ensure that only known middleware servers are in the network and communicating with the data analytics systems with known protocols.

IP Protection: Ensure that the information between the middleware and the data analytics sections cannot be read by any unauthorized device on the network.

4. **Focus Area 4: Data Security**

Collaborative Data Sharing: In very much the same way an organization can obtain insights into its operations by analyzing its supply chain data, any affiliate with access to that data can do the same. For effective supply chain management, data must be shared between partners. However, this can easily expose the internal operations of an organization. It is important to have security measures in place that either restrict access to the raw data or summarize data in such a way as to provide only relevant information.

Information Gateway: The information gateway between organizations must support security rules that allow organizations to prevent the inadvertent sharing of certain data or combinations of data items that it considers as insightful. Summarization works a little differently in that the organization describes rules on how to obtain specific information from the underlying data. The organization then shares only that information with associates, rather than the entire data set. This ensures associates do not have access to the raw data that they can use to infer other information.

6.5 Emerging Trends in RFID Infrastructure, Software, and Security

Some of the emerging trends in RFID infrastructure are:

1. The importance of middleware software is expected to decrease as more enterprise level applications absorb its functionalities from one end and the readers themselves become smarter at the other end.

2. The cost of readers is expected to reduce significantly as manufacturers replace discrete components in those readers with integrated circuits. The sizes of the readers are also expected to reduce for the same reason.
3. The cost of reader management and enterprise information systems software is expected to reduce over the next five years as more open source efforts come to fruition. The open source software will not supplant incumbents, but rather fill unmet needs both in terms of feature set as well as cost points.
4. Multi-protocol multi-frequency readers will become more common as organizations deploy RFID on a global scale and for varied product lines.

7. CRITICAL TECHNOLOGY AND INFRASTRUCTURE NEEDS

Today, technology limitations are impeding the broad adoption of item-level tagging solutions across different industries and supply chains. These limitations occur in the areas of tags (active and passive), readers, infrastructure, and data integrity and are summarized below looking forward over a 10-year horizon.

7.1 RFID Tags

7.1.1 Active Tags

ILT applications using active tags or smart active labels (SAL) can offer valuable information in terms of an item's location and its environment. This data can be analyzed either in real-time or as stored data that can be reviewed in the future. This data is useful in many ILT applications but certain limitations such as the tag form factor, smart active label battery life, etc., impede its accelerated adoption. Table 20 provides a proposed roadmap and technology needs for active tags in real-time location systems (RTLS) and smart active label applications.

Table 20 Technology needs for active RFID tags: real-time location systems (RTLS)

	State of the art (2007)	Mid term (2012)		Long term (2017)	
Features	Attributes	Attributes	Technology needs	Attributes	Technology needs
Locate range	100m indoors 1000m outdoors	150m indoors 2000m outdoors	High sensitivity reader design Efficient antenna and RF front-end design for the tag	300m indoors 3000m outdoors	High sensitivity reader design Efficient antenna and RF front-end design for the tag
Location finding algorithm	Triangulation, TDOA, RSSI,	RSSI, TDOA		Novel accurate location finding	

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	proprietary location method			techniques	
Location accuracy	Zone tracking, item-level tracking 1.5m to 6m	Item-level tracking 1m to 3m	High accuracy location algorithms Operation in dense environment	Accurate item-level tracking 0.3m to 1m	High accuracy location algorithms Operation in dense environment
Solution for dense environment of tracking items	ISO 24730 based detection	Standards based, novel solutions for operating in dense environment	Solutions for operating in dense RF environment	Standards based, novel solutions for operating in dense environment	Solutions for operating in dense RF environment
Battery life	1-5 years	3-10 years	Efficient IC design for reduced power consumption High density battery technology Energy harvesting techniques for direct use or battery recharge	3-10 years, low cost printed batteries, energy harvesting (e.g solar cell)	Efficient IC design for reduced power consumption Energy harvesting techniques for direct use or battery recharge
Networking	WiFi (802.11), ISO 24730, proprietary network, ultra-wide band GSM	WiFi (802.11), UWB, Bluetooth	Ability to operate on more than one network/protocol	A multi-protocol supporting system	

Table 21 Technology needs for active RFID tags: smart active labels (SAL)

	State of the art (2007)	Mid term (2012)		Long term (2017)	
Features	Attributes	Attributes	Technology needs	Attributes	Technology needs
Added functionality	Time, temperature sensing, source tracking	Temperature, time, humidity sensing, source tracking	Integration of sensor with RFIC either in the tag or on single chip	Environmental sensing, tracking, message display	Integration of sensor on RFIC chip, integration of low-cost display with the tag
Sensor integration	Sensor integrated on the tag with RFIC	Sensor integrated on silicon chip (e.g., MEMS)	Design and integration of sensor on same silicon as RFIC	Sensor integrated on silicon chip (e.g., MEMS)	
Integrated EAS	Yes	Yes	Desirable to have backward compatibility with existing EAS infrastructure such as systems operating at 8.2MHz and 8.6MHz	Yes	
Tag life	Dependent on battery life Single use, or multi-use tag	Dependent on battery life Single use, or multi-use tag		Single use tag	Low-cost disposable sensor and tag
Security	Password protected data	Password protected data, encryption, mutual authentication	Low cost security technology development, very high security technology development	Password protected data, encryption, mutual authentication	Low cost security technology development, very high security technology development
Read range	1-10m	Up to 30m		Up to 100m	
Battery life	Up to 1 year	Up to 1 years	Efficient IC and sensor design for reduced power consumption High density battery technology Energy harvesting techniques for direct use or battery recharge	Up to 3 years	Efficient IC and sensor design for reduced power consumption Energy harvesting techniques for direct use or battery recharge
Cost of the	\$4 - \$10	\$2 - \$5	Low-cost sensor,	Under \$1	Low cost sensors

tag			RFIC and printed antenna		and displays (e.g. printed electronics based) Low-cost integration process
Form factor	Credit card form factor	Credit card form factor	Integration with product packaging	Label	Material compatibility Conversion process compatibility
Networking	EPC and ISO standard based Proprietary	EPC and ISO standard, Zigbee, UWB, proprietary	Ability to operate on various networks	EPC, ISO standard Autonomous network	Ability to operate on various networks
Tagged item location (RTLS)	No	No		Yes	Integration of hardware and software components on RFIC and reader infrastructure for real-time location

7.1.2 Passive Tags

Passive tags fall into one of two categories: high functionality or low functionality tags. There are significant differences in cost sensitivity and in use case requirements between the two categories. The technical limitations of each are outlined below. In addition, two emerging technologies that have the potential to radically lower the cost of ILT tags are summarized. These are chipless tags and TFT printed tags.

Table 22 Technology needs for high functionality passive ILT RFID tags

	State of the Art (2007)	Mid term (2012)		Long term (2017)	
Features	Attributes	Attributes	Technology needs	Attributes	Technology needs
Memory size (license plate)	256bit -2kbit	256-64kbits	Miniaturization of memory cells Novel memory structures Compression techniques	256-64kbits	Miniaturization of memory cells Novel memory structures Compression techniques
Memory type	RW	RW		RW	
Antenna type	Antenna and chip on inlay	Printed antenna - coupled to chip	Integration schemes	Antenna integrated on chip	Silicon integration schemes

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			Materials Fabrication process		Silicon compatible
Attachment to product	Label applied to product	Partially integrated into product Tag antenna printed on product	Material compatibility Conversion process compatibility	Totally integrated into the product	Customization of embedded tag
Chip type	Si	Si	Thickness and conformability Chip handling (e.g pick and place vs fluidic self-assembly vs vibration assisted assembly)	Si or printed	Materials Process Compatibility Attachment(silicon
Read distance	1-3m	1-6m	Higher efficiency Smaller antenna designs Improved algorithms on receiving side	1-10m	Higher efficiency Smaller antenna designs Improved algorithms on receiving side
Speed of reading	30 tags/sec	100 tags/sec	Protocol Dependant Frequency Anti-collision Error correction	500 tags/sec	Protocol dependant Frequency Anti-collision Error correction
EAS	Yes	Yes	Integration Backward compatibility Dual functionality Deactivate Detection accuracy	Yes	Integration Backward compatibility Dual functionality Deactivate Detection accuracy
Password read	Yes	Yes	Password management Simplified encryption approaches	Yes	Password management Simplified encryption approaches
Proximity tags	Difficult to read	Readable	Active tuning	Readable	Active tuning
Power requirement at tag	30 microwatts (e.g. NXP)	10X reduction	Power harvesting at the tag level Chip geometry miniaturization	Further 10X reduction	Power harvesting at the tag level Chip geometry miniaturization
Sensors (temp/pressure/humidity/light)	Connected	Integrated (MEMS)	Process compatibility Carbon nano tube sensors	Integrated (MEMS)	Process compatibility Carbon nano tube sensors

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			SAW Materials compatibility Active device interoperability schemes		SAW Materials compatibility Active device interoperability schemes
Selective killing of data on tag	No	Yes	New IC architecture Protocol? Reader architecture Password management Novel destructive means (e.g. RF, UV, uWave)	Yes	New IC architecture Protocol? Reader architecture Password management Novel destructive means (e.g. RF, UV, uWave)
Selective locking of data on tag	Yes	Yes	Lock with password Lock and unlock with password	Yes	Lock with password Lock and unlock with password
Partitioned read zones protected by passwords	Yes	Yes	Business transaction protocols Lock against read with password Lock against read and unlock with password	Yes	Business transaction protocols Lock against read with password Lock against read and unlock with password
Encryption	No	Yes	Shared keys Key management Algorithms Low power encryption techniques	Yes	Shared keys Key management Algorithms Low power encryption techniques
Tag networks - tag to tag communication	No	Yes	Master/slave networks/protocols Cascading	Yes	True tag to tag communication Protocols Power scavenging Permissions
Memory write technologies	CMOS EEPROM	Ferroelectric RAM based high speed EEPROM	CMOS Ferroelectric	High speed EEPROM	
Tag on metal mounting	Yes (high cost)	Yes (lower cost)	Antenna innovation Materials	Yes (low cost)	Antenna innovation Materials Frequency
False positive reads	UHF susceptible to unintended reading of distant tags due to multi-path wave propagation	Reduced false reads by 100x	Signal post processing/ New antenna designs	Reduced false reads by 10,000x	Signal post processing/ New antenna designs

	creating nulls & hot spots in the RF field (principle of stationary waves).				
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Table 23 Technology needs for ultra-low functionality passive IL tags

	State of the Art (2007)	Mid term (2012)		Long term (2017)	
Features	Attributes	Attributes	Technology needs	Attributes	Technology needs
Memory size (license plate)	64-128 bits	64-256bits	Miniaturization of memory cells	64-256 bits	Miniaturization of memory cells
Memory type	WORM	WORM/ RW	Materials (e.g. feroelectrics, polymer, etc)...	WORM/RW	Materials e.g. Feroelectrics, polymer, etc ...
Antenna type	Antenna and chip on inlay	Printed antenna - coupled to chip	Integration schemes Materials Fabrication process	Antenna integrated on chip	Silicon integration schemes Silicon compatible
Attachment to product/ packaging	Label applied to product	Partially integrated into product, tag antenna printed on product	Material compatibility Conversion process compatibility	Totally integrated into the product	Customization of embedded tag
Chip type	Si	Si	Thickness and conformability Chip handling (e.g pick and place vs fluidic self-assembly vs vibration assisted assembly)	Si or Printed	Materials Process Compatibility Attachment (silicon)
Read distance	1-2 m	1-2 m	Read reliability > x%	1-2 m	Read reliability > x%
Speed of reading	30 tags/sec	100 tags/sec	Protocol dependant Frequency Anti-collision Error correction	500 tags/sec	Protocol dependant Frequency Anti-collision Error correction
EAS	No	Yes	Integration Backward compatibility Dual functionality Deactivate Detection accuracy	Yes	Integration Backward compatibility Dual functionality Deactivate Detection accuracy
Password read	No	Yes	Password management Simplified encryption approaches	Yes	Password management Simplified encryption approaches

Proximity tags	Difficult to read	Readable	Active tuning	Readable	Active tuning
Power requirement at the tag	Up to 100mW	Up to 1mW	Power harvesting at the tag level Chip geometry miniaturization	Up to 0.01mW	Power harvesting at the tag level Chip geometry miniaturization
Tag on metal mounting	No	No		Yes	Materials Frequency

Table 24 Technology needs for chipless RFID tags

	State of the art 2007	Mid Term 2012		Long Term 2017	
Technology	Attributes	Attributes	Technology needs		Technology needs
SAW	Operation frequency: 2.46GHz Memory: up to 96bits	Lower cost, increased memory, improved anti-collision	Interoperability with existing infrastructure	Lower cost, increased memory, improved anti-collision	Interoperability with existing infrastructure Anti-collision capability
Printed functional inks Electro-magnetic (electrical, magnetic, optical functionality)	Operation frequency: above UHF Memory: 25-96bits Read speed: 1 tag per sec Anti-collision with 2-3 tags at a time Tested on paper and various polymeric materials used in packaging	10x increase in memory by, increased read speed, better anti-collision, programmability, better substrate technology for harsh environments	Interoperability with existing infrastructure, kill tag, password, encryption, size of the tag w.r.t bits, tag reliability over time, exposure to harsh environment	Further 10x memory increase, increased read speed, better anti-collision, programmability, better ink life	Compatible with RFID infrastructure Memory: 96 bits and higher Tag read speed: >100 tags per sec Anti-collision with several hundred tags

Table 25 Printed TFT based RFID tag technology needs

	State of the art (2007)	Mid term (2012)		Long term (2017)	
Features	Attributes	Attributes	Technology needs	Attributes	Technology needs
Operating frequency	LF to HF	HF	Higher performance semiconducting inks Low loss, thin profile dielectrics	HF-UHF	Higher performance semiconducting inks Reduction in TFT feature sizes
On-board memory	4-32 bits	128 bits	Increased circuit density	1Kbit	Increased circuit density
Memory type	Read only	Write-once-read-many (WORM)	Development of memory architecture, materials development	Read/write many	Development of memory architecture, materials development
Read range	<4cm	Up to 1m		Up to 3m	
Infrastructure compatibility	Very little	Compatible with LF and HF infrastructure	Establish interoperability standards	Compatible with UHF infrastructure	Establish interoperability standards
Integration level	Discrete components: antenna, RF and memory	Integrated RFID tag as label	Advanced manufacturing and converting processes, materials development	RFID tag (chip + antenna) printed directly on product/packaging	Advanced manufacturing processes, materials suite development
Anti-collision	Unavailable	Limited availability	Design tag circuitry to place burden on reader	Widely available	Design tag circuitry to offload some burden from reader

Source: Organic and Printed Electronics chapter, 2007 iNEMI Roadmap

The 2007 iNEMI Roadmap included — for the first time — a chapter on organic and printed electronics. The technology has matured in recent years, migrating from the lab to prototype production, and a supply chain is beginning to emerge. The iNEMI Roadmap attempts to develop a “schematic” for the supply chain. It provides an overview of the most critical technologies necessary for commercial launch and market diffusion of organic and printed

electronics-based products. It addresses technologies specific to functional inks, substrates, packaging, printing platforms, characterization tools, design and modeling, and reliability.

7.2 Readers

RFID tags (UHF or HF) are read by a single antenna or an array of antennas that are connected to a fixed or hand-held reader. A combination of correct antenna design, multi-frequency and multi-protocol (Gen1, Gen 2 UHF) capability, output power, cluster/array design, and antenna form factor are all critical elements to ensure minimal interference or collision with other antennas, high data rates, and 100% tag read rates.

Table 26 provides a proposed roadmap and technology needs for readers and antennas.

Table 26 Technology needs for readers

	State of the art (2007)	Mid term (2012)		Long term (2017)	
Features	Attributes	Attributes	Technology needs	Attributes	Technology needs
Tag read speed	100 tags/sec	300 tags/sec	Better tag to tag interference control or anti-collision algorithms (e.g. ALOHA V2) Better tag inventory schemes (Q) Improved reader to tag (PIE), tag to reader (Miller, FMO) modulation algorithms	600 tags/sec	Advanced tag to tag interference control or anti-collision algorithms (e.g. ALOHA V3) Advanced tag inventory schemes (Q) Advanced reader to tag (PIE), tag to reader (Miller, FMO) modulation algorithms
Dense reader environment	Spectrum management by the reader protocols	Channel masking and spectrum plan 'Tag-talk-first' protocol to optimize spectrum utilization	Master host coordination for better channel and spectral planning	Reader synchronization techniques	Master host coordination for better channel and spectral planning Increasing number of sessions supported
Frequency and protocol supported	Standards like EPC, ISO or proprietary	Multi-protocol readers	Option to connect the same reader to region specific antennas to meet power needs Impedance matching	Multi-protocol readers	Option to connect the same reader to region specific antennas to meet power needs Impedance matching

Reader form factor	Standalone wall mount or floor mount reader	Integration in printers, smart shelves	Small RF (amplifier/reader, controller) chipset footprint that can output ½ W and 1W power (UHF) to enable reader in a PCMCIA card	Integration in wearables	Small RF (amplifier/reader, controller) chipset footprint that can output ½ W and 1W power (UHF) to enable reader size equal to a US quarter
Reader complexity	Readers with some data processing capability	Smart readers with data filtering	Advanced reader controller chipset to perform modulation and advanced filtering	Smart readers with data processing capability	Advanced reader controller chipset to perform modulation and advanced filtering
Cost of a fixed reader	\$1500 - \$3500	\$500 - \$2000	Miniaturization of reader module so that it fits in existing PDAs. Development of hand-held readers with no Windows CE OS but scaled down LCD user interface	\$100 - \$1000	Miniaturization of reader module so that it fits in existing PDAs Development of hand-held readers with no Windows CE OS but scaled down LCD user interface
Reader in RF challenging environment (metal, liquid)	Limited solutions for metal or liquid environments	Near field UHF coupling technology for RF unfriendly environment	Tag antenna designs that can work in near field Reader antennas that can read in near field and far field	Near field UHF coupling technology for RF unfriendly environment	Tag antenna designs that can work in near field and far field. Reader antennas that can read in near field and far field

7.3 RFID Infrastructure

Deploying an RFID solution consists of a careful selection of the RFID Infrastructure. A typical RFID infrastructure involves selecting a suitable technology/frequency (UHF, HF, active, passive), RFID tag air interface protocol (EPC Global, third party proprietary), RFID hardware platform reader, antennas), purchasing or developing a reader management software for reader configuration/discovery, purchasing or developing a middleware solution that can filter event data, and developing APIs to feed event data from the middleware to high-level software solutions. This multi-tier deployment framework adds challenges to deploying an RFID solution and justifying ROI.

Table 27 provides a proposed roadmap and technology needs for RFID Infrastructure.

Table 27 Technology needs for infrastructure

	State of the Art (2007)	Mid term (2012)		Long term (2017)	
Features	Attributes	Attributes	Technology Needs	Attributes	Technology Needs
Infrastructure health monitoring	Remote device-by-device diagnostics and limited reconfiguration	Centralized equipment failure prediction and preemptive maintenance	Equipment performance and health analytics Failure prediction algorithms	Autonomic infrastructure management and failure recovery	Self-aware devices and infrastructure
Infrastructure features and capability	Conduit for data collection and exchange	Databases and information systems that can detect missing data or data errors and to take corrective action	Data analysis and outlier recognition algorithms	Dynamic quick-change information systems	Technologies that enable easy and rapid process changes without the need for extensive software reimplementation
Security	Proprietary encryption algorithms for tag-reader communication that depend on secrecy of algorithm	More secure tag-reader communications (when needed) Open encryption algorithms for multi-vendor compatibility	Open, standardized mechanisms that do not depend on algorithm secrecy	Prevent breach of security and privacy through inference	Inference engines that troll aggregate data and business intelligence to check if information can be inferred from shared data
Inter-company data exchange and compatibility	Limited or case-by-case compatibility	Compatibility between immediate trade partners	information exchange standards	Out-of-the-box compatibility between partners in the entire supply chain	Global information exchange standards
Infrastructure set-up	Requires highly trained RFID professionals	Human interfaces for set-up and maintenance made easy enough for regular IT staff	Read range self-configuration based on input criteria	Plug and play RFID devices	Automatic channel state comprehension

7.3.1 Data and System Security

RFID applications read data from tags, normalize/filter event data, and feed backend systems with rich data to enable business decisions. This tag data or filtered event dataflow can be restricted within a company or between business partners. In this data flow, format, consistency, accuracy and timeliness of RFID events and content are very critical. Due the nature of radio frequency identification (non line of sight), tag information could be read by an

unauthorized person. To ensure security of the data on the tag, encryption or a layered data model (no information on tag besides tag ID) is required.

Table 28 provides a listing of several critical data and system security needs within the RFID infrastructure. Each attribute listed in Table 28 could be applied throughout the system (e.g. tag, reader, application server, and database) dependent on the level of security required as well as the cost vs. benefit trade-offs and business requirements.

Table 28 Technology needs for data and system security

	State of the Art (2007)	Mid term (2012)		Long term (2017)	
Features	Attributes		Technology Needs	Attributes	Technology Needs
Encryption (authenticity, integrity, etc.)	Minimal encryption solutions deployed Most deployed encryption solutions are costly	Lower cost, lower functionality, encryption deployed at critical high threat infrastructure access points	Development of, and agreement on, standards Improved power management for tag Development of efficient computation algorithms Improved key management Development of hardware embedded cryptography for mutual authentication, data encryption, message authentication codes (MAC), message integrity code (MIC), and encrypted passwords	Low cost, higher functionality encryption deployed throughout RFID infrastructure	Development of, and agreement on, standards. Continued development of hardware embedded cryptography for mutual authentication, data encryption, message authentication codes (MAC), message integrity code (MIC), and encrypted passwords
Rogue-scanning	Few solutions presently deployed	Tag deactivation solutions User-authorized scanning offered via button control Symmetric key protocols deployed	Improve methodology for selection of symmetric key Develop low cost, easily controlled deactivation methods	Tag deactivation with secure reactivation functionality Public key protocols deployed	Develop authenticated reactivation methodology via symmetric-key protocols initially, longer term establish public-key protocols Continue research of several potential options: privacy bit, blocker tag,

					pseudonym tag, policy (soft blocker) tag
Eavesdropping	Eavesdropping on tag possible at a short distance Some singulation protocols vulnerable to long distance eavesdropping	Symmetric key protocols deployed	Develop improved tree-walking protocol for reader addressing or singulation of tags Develop improved prefix for tag identifier methodology Improve methodology for selection of symmetric key	Public key protocols deployed	Continue research of several potential options: silent tree walking, privacy bit, blocker tag, pseudonym tag
Identification	Readers unable to distinguish between tags to read vs. tags that should not be read	Few user intervention solutions deployed	Develop technology to link to previous events and associate with other information	User intervention solutions become ubiquitous.	Develop low cost, scalable solutions for mass deployment.
Authorization	Tags unable to distinguish between authorized and unauthorized readers.	Some solutions provided for user authorized scanning (e.g. button control for payment transactions)	Develop efficient provision for permission access according to security policy Develop methods and solutions for public-key protocol to authenticate reader and encryption of tag identified with reader public key	Authorization solutions become ubiquitous	Continue development of computationally efficient protocols (e.g. low overhead SSL with reader certificate)

8. GAPS & SHOWSTOPPERS

8.1 Gap Importance to Use Case Sectors

If one uses the requirements of the electronics manufacturing supply chain as a lens to focus on the technology needs discussed in the previous section, several gaps rise to the surface. Table 29 lists these gaps and weights them according to overall priority by use case (i.e. high, medium, or low importance). This ranking can help industry determine which segments will support the investments required to close the identified gaps.

Table 29 Gaps retarding ILT deployment

Gaps	Process validation	Asset tracking	Inter-company	Intra-company	Notes
Tag cost	M	L	M	M	
Tag size (x,y,z) and/or form factor*	H	L	M	M	
Tag read reliability (high read yield) ¹	M	L	H	H	
Tags vs metals and liquids ¹	H	H	M	M	
Tag detuning – close proximity	M	L	M	M	
Reader interference in dense reader environment	L	L	H	M	
Reading in dense tag environment (Swiss cheese) ¹	H	L	H	H	
Infrastructure Cost*	H	M	H	M	
Infrastructure interoperability	L	L	H	M	Multi-frequency/ multi-protocol reader Data formats Passwords
Open source middleware solutions	M	M	M	M	
Security/ privacy	L	L	H	M	Vulnerability to external attacks

Adoption / commitment to standards	L	M	H	M	Geo-political Other
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Table notes:

1. Significant barrier to adoption specific to the electronics manufacturing industry
2. L = low, M = medium, H = high

The requirements of the intra-company and inter-company use cases are largely the same for the electronics industry as they are for industry as a whole and the gaps that are relevant to these use cases are described briefly below. In the areas of process validation and asset tracking there are several specific factors that make implementation of these use cases especially difficult for electronics manufacturers. These factors are discussed in some detail.

8.2 Tag Cost

In order to compete with the current tag technology in use in industry today (1D barcodes) passive RFID tags will need to approach the same price point. A premium can be paid depending on the extra features available in the new technology but no more than 2-3x of current 1D tag costs.

Active tags are a different story. Their fundamental characteristics are different than current tag technology in use today and their premium can be justified via these extra features and the solutions they allow. Pricing for active tags should continue according to Moore's Law.

8.3 Tag Size

In all industries tag size is of great importance. The electronics manufacturing industry is no different.

Tag size is most critical in the printed circuit board assembly operation. Circuit boards vary in size anywhere from 1"x2" panels all the way up to 18" x 24" but regardless of the size, real estate is always at a premium. This drives a tag size requirement of no larger than 0.275-0.60" (width) x 0.75-2.36" (length). RFID tags will have to meet the same standard as the current barcode labels. The final size of the RFID tag is primarily determined by the size of its antenna. Typically, UHF tag antennas are designed in from of dipole are larger in size than HF tag antennas that are designed as coil windings. This UHF tag design also allows longer read range using far-field backscatter coupling. UHF tags can also be designed to operate in near-field mode like HF tags, and the antennas for UHF near-field coupling are comparable in size to the

HF tags. In addition, current tags are only 0.002" thick (in the z axis). This requirement for a thin tag is important due to the processing of the printed circuit boards through the solder paste screening process.

As for the size of tags that may be applied at the final product level, electronic products have requirements much the same as industry in general.

8.4 Tag Read Reliability

There are three major issues when dealing with tag read reliability within the electronics manufacturing supply chain: the abundance of metals and liquids, extreme environmental conditions, and the read reliability rate.

The electronics manufacturing industry consumes and transforms many liquids and metals as part of most production processes. As an example, in the printed circuit board manufacturing liquids (e.g. isopropyl alcohol for cleaning), metals (e.g. 1 ounce copper foil within printed circuit boards providing ground planes within circuits), or a combination (e.g. solder paste where metal particles are held in suspension) are in common use. This provides tremendous barriers for adoption as significant interference issues arise.

The second major issue comes with environmental extremes. In printed circuit board assembly temperatures as high as 260°C are common. Passive tags available today cannot withstand such temperatures. In the semiconductor sector pressures can exceed 66 psi at certain points in the production process, while air and hydraulic pressures can exceed 20 psi and 130 psi, respectively. Current tag technology will need to be extended or new tag technologies will need to be developed in order for ILT to flourish in electronics manufacturing facilities around the world.

The final issue is in the area of read reliability. Tags must deliver a high read rate (100%) so that production stoppages are not increased in the process validation applications with the introduction of this technology. The ability to attain a high read rate can be exacerbated by the number of tags in close proximity. Production runs can vary from as low as five to as high as 1,000 pieces per hour and are often optimized to use as little floor space as possible. Tag density in a production cell can be in excess of 300 per cubic foot.

Read rates of 100% are desired, which drives very low tolerance for tag defects in the process and for low read rates caused by interference (addressed in the Reader Performance section below).

8.5 Reader Performance

As discussed in the previous section, high tag read rates are a requirement of the electronics industry. In a dense tag environment read performance can be adversely affected by either constructive or destructive interference caused by the broadcasting of multiple tags. Readers and associated techniques or practices that can deal with this 'Swiss cheese effect' will boost the successful tag read rate significantly and would be a required element of any ILT implementation.

Heavy reader density (and, therefore, interference) is not anticipated in the electronics manufacturing sector as reader implementation can be optimized/minimized for any given factory floor layout (number and type). However, in other industry sectors, such as retail where multiple vendors may be in close proximity (each having a reader) and where the consumers themselves may also have mobile readers associated with mobility products, reader interference may be a significant issue. Interference issues caused by proximity, multiple frequencies, and multiple protocols will need to be assessed and addressed.

8.6 Infrastructure

Infrastructure is another area where minimizing cost / investment is a great concern for today's managers. Every company has made significant investments in ERP, MRP, B2B, shop floor control systems, etc., and the interfaces and protocols that run between each. It is within this overall system architecture that business information is amalgamated and from which business decisions are driven.

The introduction of a new technology like RFID ILT will lead to a new set of sensor based data being driven into the network, which will have to be re-architected to change this new data into actionable information.

One of the places where these investments will occur is at the edge of the network where the tags themselves interface with the readers that are deployed. Interoperability of all readers in the network will be a must so that multiple frequencies, communications protocols, data formats,

and perhaps even password protocols can be supported. A 'one reader fits all' solution is required to provide the robustness, flexibility and re-usability of any reader solution.

The second area of concern is in the layer that connects the reader layer to the existing enterprise layer within a company. Today, many proprietary 'middleware' or 'broker' solutions are available which are very specific to the architecture within which they reside and are costly. This layer also lacks a cohesive set of standards around which an open architecture and cost effective middleware solution could be developed.

The electronics industry encourages standardization in the middleware layer so that readers can essentially plug into an industry-standard 'socket' and that the sockets themselves in turn plug into enterprise architectures via standards based implementations.

8.7 Security / Privacy

As RFID tags are used more and more in industry, issues of security and privacy will arise, primarily on two fronts: transmitting/receiving and the information itself.

As the information (no matter what it may be) is broadcast over the communal atmosphere, signals can be detected and read by anyone. Corruption of the data itself via malicious intent (read, write something different in the original record's place) or reading the records and using the information for gain must be considered and eliminated as possibilities.

Also, as an increasing amount of information can be broadcast, there is concern about how rich the information available may be. The information contained on tags can include not only industrial information (part number, shop order, waybill # etc.) but also information about the customer or individual.

Data security and, in some cases, encryption will likely play a large role in the solutions in this space.

See References at the end of this document for sources of information about security and/or privacy and RFID tags.

8.8 Adoption/Commitment to Standards

Standards are the only thing that will drive broad industry adoption of RFID ILT, especially as it applies to inter-company solutions. Standards drive repeatability, ensure connectivity, and

minimize overall options, thus driving down cost by allowing companies to make investments that will be long lived. iNEMI strongly encourages industry to continue to adopt and commit to standards around the globe.

See References at the end of this document for sources of information about standards in the RFID industry.

9. PRIORITIZED R&D NEEDS

As we look at those gaps that require significant innovation to resolve, it is critical that industry work with academia and governments to coordinate the necessary research. This section highlights those needs in hardware, software, and systems integration. Investments in these longer term gaps will help to ensure that we can achieve ubiquitous ILT deployment over a wide variety of applications.

9.1 Tag Performance

Item-level tagging brings up a new set of challenges that are different from case-level or pallet-level RFID tags. Here, reliable reading of each individual tag becomes critical, despite the challenges of dense tag environments, high reading speeds, and non-friendly RF environments. Fundamental problems like antenna detuning in the presence of liquid or metal environments need to be addressed by the R&D community, along with practical problems like tag read reliability and application specific tag design. For active tags, development of low-cost energy harvesting, networking, and integration of higher functionality on single chip form the focus areas of research. The following tables list prioritized R&D needs in passive and active RFID tags.

Table 30 R&D needs for passive tags

Constraint	Current Scenario	Proposed Scenario
Tag length, width and antenna design	Most tags have an aluminum sheet metal stamped antenna. Tag size variation may require a new antenna design and, hence, new tooling. This leads to higher tag costs and higher lead times.	Printed antennas that will allow flexibility in tag length and width combinations without having to develop new tooling for tag manufacturing.
Tag thickness	Tag thickness at the chip location is 9-12mils. In some applications, tag thickness >2-3 mils is a concern if a relatively flat surface is required (e.g., PCBA stencil printing)	Tag thickness should be <3 mils, which is the current thickness of most PET substrate 1D/2D barcode labels. This will ensure full backwards compatibility of tags with existing processes.

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	operation).	
Tag read reliability	Tag orientation w.r.t readers is key for high reliability read rates, especially UHF. Custom tunnels, reader antenna array designs are required to reach Six Sigma levels.	Innovative antenna and reader designs that do not require extensive/ elaborate antenna arrays.
Liquids, metals, high temperatures	Current UHF and HF tags can detune when used on metals and liquids. UHF, HF tags require some separation to reduce effects of detuning. This may increase cost and will increase the thickness of the tag. Currently tags are designed for limited exposure to harsh environmental conditions like chemicals and elevated temperatures (up to 250°C)	Ability to work on metals and liquids with minimal separation to reduce effects of cost and higher thickness. Ability to operate tags at elevated temperatures and chemicals without having to design custom enclosures.
Memory writing speeds	Silicon RFICs have EEPROM based memories, which are slower in 'write' operation, limiting the number of re-writable tags a system can handle.	Memory architectures based on ferroelectric RAM (FeRAM) can significantly reduce 'write time.' (Typical writing time for FeRAM is 0.1us compared to 10 ⁴ us for EEPROM.)
Power consumption at the tag	Power consumption at the tag is of the order of 10 ⁴ uW, with the best-in-class low power transponders at 200uW.	Power consumption can be further reduced by efficient antenna and chip design. Also, technologies like MRAM and FeRAM, can reduce power consumption.

Table 31 R&D needs for active tags

Constraint	Current Scenario	Proposed Scenario
Location accuracy indoors	Most of the systems rely on IEEE 802.11 based systems for location determination indoors. This method can locate the tagged item to an accuracy of about 5m.	Accurate methods of location determination need to be developed for indoor environments.
Tag form factor	Tag is in rigid and bulky form factor due to the battery, antenna.	The tag can be made thin and flexible using printed batteries Miniaturize/integrate antenna with IC
Battery life	Battery life presently limited to 1-5 years, making it imperative to change the batteries or risk losing the tag.	Extended battery life through higher energy density of the cells. Harvest power for operation from solar energy, vibrations or other sources.
Sensor tag or smart active label	The sensor in a sensor tag or a smart active label is added as a separate component on the substrate that hosts RFIC.	The sensor, in the form of a MEMS or non-MEMS device needs to be integrated with the RFIC for miniaturizing the product.
Networking	Active RFID tags operate on proprietary networks, WiFi or ISO standard. Interoperability in various	A tag that can work on multiple networks (ISO, WiFi, GSM). The tag would also take inputs from

	environments is required to widen the application space.	environments like Zigbee sensor network, Bluetooth, EPC RFID network, etc.
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9.2 Reader Performance

Future reader developments will be driven by technology vendors striving to better address the needs and concerns of their customers. Today, customers are concerned about the cost of establishing a reader infrastructure, including the initial capital cost, installation and integration into their IT systems. Suppliers responding to this will strive to reduce reader cost, ease the process of reader installation/cabling and simplify the integration into customers' IT solutions. Customers will also favor suppliers able to achieve the same reading outcomes and performance with fewer readers. Once reader infrastructure is installed the customer's concern will transition from whether the technology works, to how to assure themselves that the reader infrastructure will continue to perform correctly and not degrade. This will require reader infrastructure to be able to monitor and report its health and performance. Ease of infrastructure maintenance will be a key driver of the reader market. Also, customers increasingly want to integrate readers into the existing environment in which they operate. Readers will be required to transparently assimilate into existing hardware and furniture. RFID enabled shelves, points of sale, mobile phones, cabinets and integration to a huge variety of other physical forms will drive readers and antennas to smaller and smaller sizes and more flexible shapes. Overlaid on all these factors are customer concerns that the reader infrastructure chosen will not become prematurely obsolete due to changes in technology, frequency choice, or regulatory amendments. Standards, interoperability and technology flexibility will be essential to reducing this customer concern. In addition to customers' concerns, which may limit the rate of technology adoption, new requirements from customers and demands for additional functionality will drive reader development (e.g., enhanced security needs or the use of sensor tags).

Table 35 outlines proposed R&D needs based on perceived new customer requirements and current reader technology constraints.

Table 32 R&D needs for reader infrastructure

Constraint	Current Scenario	Proposed Scenario
Reader cost	High powered readers are expensive for mass deployment.	Development of readers using chipset solutions. More modular design to offer appropriate functionality. As specific applications arise different reader paradigms will come into play – thin/dumb/numerous readers interacting with smart/fewer tags. Ultra low cost/ low functionality reader development.
Reader coverage	Achieve the same reading outcomes and performance with fewer readers.	Readers with both passive and active tag capability so it is possible to use fewer readers and active tags, Single readers managing many antennas. Mesh networks peer-to-peer networks. Tag vs reader differences may disappear in some cases (cf. NFC). Master and slave reader infrastructures.
Reader agility	Different RFID solutions operate at different frequency bands (LF, HF, UHF, microwave). Different regions around the world have different regulations. These regulations are currently in a state of change. Different communication protocols exist and will evolve.	More modular reader designs, able to be easily configured for different frequencies. Multi-frequency readers. Multi-region readers. Multi-protocol readers. Innovative antenna and reader designs that do not require extensive/ elaborate antenna arrays.
Reader performance (false positives)	UHF solutions tend to suffer from false positive reading of tags. The issue is due to the propagating nature of the UHF field and the presence of stationary waves that result in weak and intense zones in the RF field leading to unintentional reading of distant tags.	Data filtering techniques in readers to identify distant tags.
Reader performance (tag read rate)	With larger read zones there will be pressure to increase reader data rates. This will also be driven by the presence of richer data on the tags – from license plate to extended memory to supporting sensor tags – as well as data/communication requirements for additional tag security.	Improved anti-collision protocols, increased data rates. Improve reader sensitivity.
Reader interference	UHF solutions are inherently	Techniques for interference rejection.

	susceptible to electrical interference due to the power of the propagating wave at UHF. Readers can interfere with other readers. This will limit the scalability of UHF RFID.	Reader automatic synchronization.
Smaller readers with lower power consumption	UHF reader solutions have relatively high power consumption. This limits the use of the technology for mobile battery-powered applications	The development of more efficient reader circuits.
Assimilation of readers into objects/ furniture	Increasingly, readers will be integrated more deeply into systems, ultimately with limited visible manifestation. Standalone readers will turn into RFID enabled doorways, cabinets, shelves, tabletops.	Reduced power developments Reduced size. Wireless backend communications. Meshed readers. Antennas integral within objects.
Reduced cabling	The whole reader + antenna + cable design will become rare.	Integrated antenna/readers solutions. Wireless reader communications. Low cost power distribution.
Health monitoring	Reader infrastructure will need to be able to monitor and report its health and performance.	Monitoring networks. Self-diagnosing readers.

9.3 NFC Technology

NFC technology is currently targeting mobile payment and ticketing applications by integrating 13.56 reading capabilities into mobile phones. As with any technology being integrated into hand-held devices, modularization and miniaturization are keys for success. In addition, new applications will come up in the future, driving the need to support different communication standards as well as new features.

Table 33 NFC R&D

Constraint	Current Scenario	Proposed Scenario
Modularization	Current NFC chip designs are still limited in supporting all different ISO 14443 standards (A/B/Felica). One of the main obstacles to NFC integration into different phone designs is the current need of a large area loop antenna.	To enable the NFC technology to become a successfully deployed technology in a global mobile phone market, it is necessary to integrate the different ISO 14443 standards (A/B/Felica) into a single chip design. Combining this step with embedding it into the already existing Bluetooth module, will enable smooth hardware integration A new, smaller antenna design integrated into today's PWB layout would be a key advantage for product implementation.

Energy Efficiency	To realize the same behavior on NFC as on a smart card, the NFC function embedded in a mobile phone should be not depending on the battery status of the mobile phone.	Default service functions for ticketing, payment and access control should be provided even without any energy provided (no power mode). An integrated NFC module should be capable of charging mobile phone batteries by providing a wireless field. This would allow a standardized method for charging any kind of NFC device.
ISO support	The target applications for NFC at the moment are access control, payment and ticketing, which are all based on the ISO 14443 standard.	To extend these application areas, it will be important to also support ISO 15693 and any upcoming EPC HF standard. This will allow using NFC technology in enterprise scenarios as well as in a future retail environment.
Sensor functionality	Currently NFC technology is limited to passive RFID tags (ticketing, payment and access control). These applications are limited in creating “new” content at the edge.	Adding NFC wireless sensor support will open the door to new applications in e-health, monitoring and control as well as ambient assisted living scenarios. In the long term this will allow NFC technology to leverage the cost benefits of printed electronics sensors and tags.

9.4 Infrastructure

There are five top infrastructure related research and development needs that will foster quicker adoption of RFID:

1. Open source software solutions
2. Standardization of frequency usage regulations across the globe
3. Development of multi-protocol and multi-frequency readers
4. Better data acquisition and management methodology

9.4.1 Open Source Software Solutions

Even though the cost of tags has received a lot of attention, it is the software costs that are probably the most significant barrier to the adoption of RFID by small and mid sized organizations. A study by Open Source Innovations indicates that software can constitute up to 70% of the cost of an RFID implementation.

In order to foster innovation, organizations such as EPCglobal and ISO have intentionally stayed away from providing reference designs or implementations of the standards they ratify. As a result, companies must either develop their own implementations, or license software from a handful of well-established players. Both of these options are expensive.

With open source software, RFID vendors and customers can reduce implementation costs by reusing software libraries. There are also other significant benefits to open source software:

1. RFID products will have a quicker time-to-market since they need not be developed from scratch but, rather, built over what is already readily available.
2. The solutions tend to be more secure and robust since they are examined by a multitude of independent developers, testers, and systems integrators – more people than any one company can hope to involve in a project.
3. Open source software generally does not have restrictive licenses and, hence, companies have the freedom to pursue innovative business models. For instance, with open source operating systems, it is not uncommon for companies to provide the actual software for free and yet earn revenue from support services. This significantly reduces the upfront costs for the customers.
4. It acts as a catalyst to technical innovation.

It stands to reason that as open source software becomes mature, the cost of RFID implementation will reduce and will, in turn, spur a higher adoption rate. Industry and academia have realized the benefits of open source implementations of RFID standards and have begun several open source efforts that will implement the standards for middleware, reader management, and information services. There are also ongoing efforts to develop software for reader and network emulation and testing. However, the open source scenario is currently very fragmented with several organizations implementing very similar solutions, most of their products not yet ready for production. Some amount of consolidation is required to channel resources and to bring the products to the community much faster.

The community must also expand its scope of work and include the newly ratified standards. There are also emerging standards that must be implemented as they are ratified.

Some of the current open source efforts in the RFID space are:

1. RadioActive Foundation is currently working on three projects: Neutrino, Fusion, and Graviton. Fusion is a middleware that gathers data from tags and readers and delivers that data to enterprise information systems; Neutrino is a software suite that enables the exchange of EPC data between business partners; and Graviton is a simulator for RFID hardware from various manufacturers.
2. LogicAlloy is developing a middleware that implements the Application Level Events (ALE) interface. ALE is an interface standard from EPC Global that provides a layer of abstraction between the data providers such as RFID readers and the data subscribers such as enterprise information systems (e.g. Warehouse Management software).
3. FirstOpen is developing a middleware called Singularity Middleware and is also working on EPC-IS.

4. Pramari is developing a reader emulator called Rifidi. The emulator will enable rapid development of RFID applications by allowing developers to test their applications against emulated scenarios and hardware rather than real hardware.
5. The University of Arkansas is developing a middleware called TagCentric that collects data from a network of RFID readers and sends to a database.
6. Open Source Innovation has received a grant from the UK government to develop open source RFID solutions.
7. Several RFID vendors have joined together to develop the LLRP Toolkit – a set of open source libraries for the implementation of the Low Level Reader Protocol based applications.
8. Accada is a rapid prototyping platform that implements the EPC Network specifications.

Table 34 Open source software R&D

	Gaps	Development Needs	Timeline
EPC architecture	<ul style="list-style-type: none"> • Discovery services • Object naming services • Pedigree 	Development of non-license bearing, scalable software for adoption by EPC Software must demonstrate fault tolerant operation in a production/manufacturing environment	Short to medium term (1-5 years)
Business-to-business information exchange	Lack of open source production-ready business logic software	Software must be improved to meet production grade requirements of reliability, maintain-ability and security	Short to medium term (1-5 years)
Tag protocols	Lack of standards for 2.4 GHz and 5.8 GHz	Development and implementation of microwave air interface protocols	Short term (1-3 years)

9.4.2 Global Standardization of Frequency Usage Regulations

Currently, there is no standardization of UHF frequency allocation across countries. Local regulations differ from country to country, making it difficult to design and deploy RFID applications on a global scale. This is especially a problem for multinational companies that have operations across the globe, and for logistics companies that must ship goods and services across national borders. For example, the designated UHF frequency band in North

America is 902-928 MHz, while in the European Union it is 865-868 MHz. China, on the other hand, has approved bandwidth in the 840-844 MHz and 920-924 MHz ranges.

Apart from frequency, there are also varying regulations on transmit power, hop frequency, channel sensing and a host of other radio parameters. As an example, the US allows a maximum transmission power of 4 Watts while Europe limits transmission to 500 milli-Watts outdoors and 2 Watts indoors. These different power restrictions mean that a tag can be read from a farther distance in the US than it can be in Europe. International regulations covering the HF (13.56MHz) RFID frequency are significantly more harmonized than for UHF, and this has favored the adoption of HF solutions for global RFID applications to date.

Complying with the different regulations is both technically challenging and economically wasteful. First, the same UHF tags may not be able to be used globally since their antennas are designed to respond to a specific frequency range. Any attempt to use a frequency outside of that range will result in either poor performance or outright failure to read. Having different UHF transponders for different geographies will reduce the efficiencies of scale.

It is unrealistic to expect standardization of frequency allocation across the globe. Instead, the RFID industry must look for opportunities to leverage technologies that allow frequencies to be shared without adversely impacting the applications that have the original right of use. An example of such an attempt is that of electronics manufacturers requesting the US Federal Communications Commission to grant them permission to use the white space between TV broadcast channels for personal computing devices.

9.4.3 Development of Multi-protocol and Multi-frequency Readers

Due to the physics of RFID, no one single frequency band works well for all applications. For instance, even though UHF is being aggressively promoted for supply chain management applications due to the ability of signals at that frequency range to travel over several meters, it does not work very well for tracking objects that have high water content. On the other hand, HF works reasonably well with metals and liquids but the signals do not travel very far. To add to the complexity of frequency selection, there are very few frequency bands that are available for RFID use anywhere in the world.

Even within a frequency band, there tends to be a multitude of incompatible tag protocols. Several of the tag protocols in use today were developed by vendors before the industry ratified

standards. Further, some tag protocols were developed as extensions to the industry standards. The resulting incompatibilities necessitate the selection of tag suppliers as early as the design phase of an RFID implementation. This can also be a problem for manufacturers or distributors who supply products to retailers with different tag protocols.

Several reader manufacturers offer readers that are able to switch between protocols.

It has been harder to implement multi-frequency readers. For example, UHF, HF, and microwave frequencies have different antenna requirements. Microwave antennas use radiative-coupling and their form factors are generally a function of their wavelength. On the other hand, HF may use inductive coupling and is generally implemented as coils of conducting material. Some research has been done on antenna systems that can be dynamically tuned to a desired frequency using various methods such as using variable capacitive and inductive components as part of the antenna, and having antenna elements that can be switched on or off to change its effective length. However, these solutions work for a very narrow range of frequencies. More research into antenna theory and design is needed to develop antennas that are frequency tunable across a wider frequency range.

9.4.4 Better Data Acquisition and Management Methodologies

The constantly changing radio environment in warehouses and factories makes it very difficult to consistently obtain 100% read rates or to ensure that certain tags are read only when needed. It is almost certain that a small fraction of the data sent to databases is either incomplete or inaccurate. However, every read is important when it comes to item-level tagging since a tag not read is a product not shipped from a distributor or a product not paid for at the retailer, and has very real monetary impact.

Research is needed to develop databases and information systems that can detect missing data or data errors and to take corrective action.

9.4.5 Summary of Research and Development Needs

Table 35 Summary of R&D needs

	Gaps	Research Needed	Timing Target
Opens source software solutions	Current projects are not yet production-ready Not all areas/standards being implemented in open source	Consolidate projects and realign talent and effort to bring projects to fruition faster Close gaps in implementation	As standards become available
Global standardization of frequency usage regulations	Different regions of the world have assigned different frequency bands for RFID use Variations in restrictions on power output	Technologies that will allow the use of frequencies without impacting existing applications of those frequencies	Medium to long term (5-9 years)
Development of multi-protocol and multi-frequency readers	Several non-compatible air interfaces currently employed A single radio frequency is not suitable for all applications	Readers that can quickly switch between various protocols on an as needed basis Antennas that can be configured on-the-fly to support any of a broad range of frequencies	Short term (1-2 years)
Better data acquisition and management methodologies	Incomplete or inaccurate data in backend databases due to non-reads or multiple reads; especially impacts item-level tracking applications	Databases and business applications that are tolerant of incomplete or incorrect data Self-correcting databases	Medium term (3-5 years)
Development of low cost energy harvesting technologies for embedded sensors	New sensor applications are expected to collect and transmit data over extended periods of time; battery power will not be sufficient	Energy scavenging/harvesting technologies that are cost effective and have small form factors	Medium term (3-5 years)

9.5 Data and System Security

Data and system security is essential to the broad implementation of ILT. In section 6.1.8, four focus areas were defined for security: (1) the RFID hardware (2) reader to middleware

communication, (3) middleware to RF data analytics systems communication, and (4) data security.

Of these four areas, the one most vulnerable to data and systems security is the RFID hardware. The vulnerability derives from the fact that communications between tags and readers involve data being transmitted wirelessly across an air interface. These transmissions are potentially susceptible to unauthorized reading and changing of RFID data. Also, there is a higher propensity for tampering with tags than with other elements of the full IT infrastructure due to the quantity of tags in existence and the mobility of the tags where their physical security can rarely be guaranteed.

A further issue is that networked backend infrastructure already has extensive security protections in place, whereas security practices covering RFID tags and air interfaces are less developed.

For these reasons the RFID hardware is believed to present the most fertile area for prioritized R&D related to RFID data security.

There are a number of ways in which system security can be compromised at the tag and air interface level. These include skimming, eavesdropping, spoofing, cloning, data tampering, unauthorized killing of a tag, jamming and shielding. Below is a short description of the threat categories and the typical defenses used today to combat them.

1. **Skimming:** The unauthorized reading of a tag without the knowledge or approval of the tag holder. Defenses include the use of low range frequencies such as LF and HF rather than UHF such that unauthorized readers would have to be in the general vicinity of the tag, then securing the region for rogue readers. The use of password-protected read commands or the use of reader authentication protocols by the tag prior to tag data transmission. The practice of limiting data on a tag to non significant database pointers. Encrypting sensitive tag data. Monitoring airspace for unauthorized transmissions.
2. **Eavesdropping:** The unauthorized intercepting/listening to an authorized RFID data communication. Defenses include: limiting data on a tag to non-significant database pointers, encrypting sensitive tag data, limiting transmitting power of data, selecting communications protocols where the reader does not transmit/echo tag data, and using metal foil to guard RFID tags when not in an authorized read zone.

3. **Spoofting/Cloning:** The mimicking of an authentic tags' data or duplication of a tag and its data. Defenses include: employing anti-cloning techniques for the silicon chips, such as foundry programmable serial numbers and unique challenge response circuits on the ICs, encryption, and tag history logging to look for duplicate data and read location anomalies.
4. **Data Tampering:** The unauthorized erasing or writing of data to a tag. Defenses include the use of password-protected write and erase commands.
5. **Unauthorized killing of a tag:** The physical destruction of the tag or unauthorized activation of a tag kill command. Defenses include protecting the tag from physical destruction and employing password-protected kill commands.
6. **Jamming:** The use of an RF device to disrupt the reader function. Defenses include monitoring the reader environment for rogue RF devices.
7. **Shielding:** The use of a metal shield to impede the RF data communication. Defenses include use of LF and HF solutions to limit the interrogation region available to employ shielding techniques.
8. **Tag Displacement:** The removal of an authentic tag from its matched item and placement on an unauthorized item. Defenses include incorporation of the tag physically within the item being tagged.

Each one of these defensive techniques has its value and limitations. For example, encryption seems to offer a high degree of security but brings with it the overhead of tag complexity and cost and the network complexity of managing public and private key information. Another example is that jamming may be defeated by continual monitoring for rogue RF signals, but for time-critical activities the delay between identifying an interfering source and its removal may be unacceptably long.

Table 36 presents proposed security R&D needs based on customer requirements anticipated for the future and on current data security technology constraints.

Table 36 R&D needs for RFID system data security

Constraint	Current Scenario	Proposed Scenario
Skimming	Defense requires continual monitoring of airspace, or high tag complexity with password-protected read commands or encrypted data.	Low cost defense techniques.
Eavesdropping	Some applications allow for the use of non-significant data on tags which then points to firewall protected private data. Other applications do not have such flexibility and have to employ encrypted data. This adds significant system complexity and cost.	Low complexity/low cost encryption solutions.
Spoofing/cloning	Requires anti-cloning functionality on the tag or complex history logging.	Techniques to simply and “on-the-fly” identification of spoof and cloned data.
Data tampering	Requires password management systems for authorized tag writing. Security limited to password length and requires complex password management.	Improved defense against data tampering.
Unauthorized killing of a tag	Requires password management systems for authorized tag writing. Security limited to password length and requires complex password management.	Improved defense against unauthorized killing of a tag.
Jamming	Requires continuous monitoring of reader environment.	Improved defense against jamming.
Shielding	Issue particularly with EAS security gate applications.	Improved defenses against shielding.
Tag displacement	Significant threat for the wrongful identify of products.	Improve techniques to embed tags into products.

10. RECOMMENDATIONS

As can be seen in sections 8 and 9, there are a number of technology and infrastructure challenges that face the emerging RFID supply base and user communities. This section makes recommendations on those that are viewed as most critical to enabling ubiquitous deployment of ILT. These recommendations are structured in two categories: near term (1-4 years) and long term (5+ years). Timeframe is determined by both criticality of need as well as

difficulty expected to close the gap. Recommendations are targeted toward academia/research centers, industry, funding agencies, and standards bodies.

10.1 Near Term Recommendations

1. **Reading tags for difficult applications (e.g. liquids and metals):** Invest in fundamental research at academic institutions to develop a stronger appreciation for electromagnetic (EM) propagation theory as related to difficult environments. Identify centers of excellence for research with demonstrated expertise in EM propagation (e.g. resonance and detuning principles) and for developing commercially compatible solutions. Engage product development team with researchers to ensure proposed solutions are commercially viable based on design for manufacturing and other industry-wide standard operating procedures.
2. **Limited availability of open source middleware:** Form a working group that engages multiple active participants to organize efforts to develop a 'base' open source code that can be customized by users and others (e.g. value-added software providers). By developing a base open source the industry will benefit from having established a 'standardized' platform that enables universal interoperability for ILT deployment.
3. **Industry adoption of standards:** Providers must offer standards-compatible hardware/software. Today many providers do not offer a product platform that is compliant with existing standards. Strong appreciation for international regulatory policies is lacking; stakeholders must appreciate the international regulatory policies and develop interoperability solutions as required to help drive technology into the global marketplace.
4. **Complexity of RFID system deployment:** Deployment must be made simpler. The lack of individuals with the necessary engineering skill level to handle the complexity of RFID systems is impeding rapid deployment. In the instances where certification is required, the pool of skilled talent is small and, therefore, individuals with inadequate training are being 'certified.' The number of companies offering 'site survey services' is small and in many cases the RFID system that is being deployed may be operating in non-optimal conditions. By simplifying deployment (i.e. creating more of a 'plug and play' environment), skill levels required, start-up cost, and schedule can be improved. Thus, RFID deployment could become simpler and more predictable. Continued deployment of RFID infrastructure will require personnel and, although this recommendation is listed for the near term, it will extend into the long term as well.

Table 37 Recommended actions to address near term needs

Near Term Need (2008-12)	Recommended Action			
	University & Research Consortia	Industry	Funding Agencies (NSF, MITI, 5th Framework, etc.)	Standards Bodies
Reading tags for difficult applications	EM propagation theory centers of excellence	Guide university and consortia research & encourage deployment in product lines	Identify/fund centers for top research problems connected to the iNEMI ILT roadmap	N/A
Availability of open source software and middleware	N/A	Provide test beds to validate open source Identify and help close gaps Validate open source ROI Deploy in products and solutions	Fund test beds	Enable a strong portfolio of open source software closely linked to standards. Participate in test beds to validate both standards and open source software
Adoption of standards	N/A	Adopt standards in products Validate and help refine them based on lessons learned	N/A	Enable interoperability of products by harmonizing standards across all geographies
Deployment complexity	Train students to be RFID-savvy for both future research and commercial engineering	Drive standard, easy to use and configure solutions; Adopt open industry standards	N/A	Determine if plug-and-play philosophy can be built into the standards

10.2 Long Term Needs

- 1. Low cost technology solutions for ILT:** A stronger appreciation for ILT cost drivers is necessary. Specific elements in both hardware and software must be identified and the drivers discussed in detail to assess potential opportunities for cost reduction. The ILT community must agree to the functionality (attributes) required for ILT RFID (e.g. less memory capacity than Gen2 memory requirements to reduce total ILT cost).
- 2. Tunable antennas for challenging RF environments:** Perform environmental scan to identify academic institutions that have strong ongoing efforts in tunable antenna

technology. Invest in fundamental research. Engage industry product development teams with researchers to ensure proposed solutions are commercially viable.

3. **Tags for extreme environments:** Initiate efforts to identify ILT performance in aggressive environments (e.g. reflow temperature during PWB assembly, high temperature/humidity operation). Identify testing conditions to simulate aggressive environments and establish criteria for assessing performance.

Table 38 Recommended actions to address long term needs

Long Term Needs (2012+):	Recommended Action			
	University & Research Consortia	Industry	Funding Agencies (ex. NSF, MITI, 5th framework, etc.)	Standards Bodies
Low cost technology solutions for ILT	Create centers of excellence for low cost ILT technologies; Analyze and develop options for enabling commercialization	Participate in centers of excellence Enable the supply chain to commercialize and produce low cost ILT technologies	Fund centers of excellence to enable the iNEMI ILT roadmap	Match standards functionality with low cost price points by intelligently reducing requirements
Tunable antennas	Create centers of excellence for tunable antennas	Engage with Centers of Excellence and enable the development of commercially viable technologies	Fund centers of excellence to enable the iNEMI ILT roadmap	N/A
Deployment complexity	Train students to be RFID-savvy for both future research and commercial engineering	Drive standard, easy to use and configure solutions; Adopt open industry standards	N/A	Determine if plug-and-play philosophy can be built into the standards
Tags for extreme environments	Investigate materials and technologies that withstand extreme environments per roadmap	Adopt materials and technologies for extreme environments into product offerings; Drive for lower cost to enable use	Fund extreme environment materials and technology research	N/A

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12. Appendix A – Use Case Descriptions

The electronics industry has often been an early adopter of technology to help improve the efficiency of its manufacturing, supply chain, and logistics efforts. The industry has made significant investments in IT along with associated hardware solutions to better manage the flow of information, materials, and customer data. As outsourcing has evolved for the last 25 years, it has moved to a very distributed supply network that spans the product lifecycle (i.e. from product concept through end-of-life disposition). This distributed environment has driven a much greater need for efficient and accurate movement of information and materials. In the late 90s large investments were made to address these needs although returns on investment have been less than projected.

12.1 SECTION A.1: SEMICONDUCTOR USE CASES

Following are several semiconductor RFID use cases — viewed at the system level — that are considered successful (e.g. demonstrated positive ROI).

USE CASE 1 — Semiconductor Material Validation and Tracking

Application: Wafer and reticle carriers within a 300mm wafer fabrication factory

Overview: 300mm wafer fabs validate each wafer carrier before it is processed at each tool in the factory. This process is accomplished with an RFID tag on the carrier and readers located at the equipment load ports. This technology is used at nearly every 300mm wafer fab in production today, as well as some 200mm wafer fabs.

Fab Wafer and Reticle Carriers Tracking Description: As a result of semiconductor industry standardization undertaken with the 300mm wafer size transition, nearly all 300mm wafer fabs use an RFID tag to validate that the right material is being processed on the right equipment with the right instructions. When an RFID system is coupled with an automated material handling system (AMHS) and an intelligent manufacturing execution system (MES), the factory can run fully automated without humans moving materials or working directly at equipment. As shown in Figure 1, each FOUP (front opening unified pod) wafer carrier has a passive fixed read-only RFID, which stores, at minimum, a unique carrier ID number. Some fabs also equip their tags with read-write capability for additional material control and traceability data. In addition, each equipment load port within the fab has an RFID reader. Typical equipment has from two to four load ports and, therefore, two to four RFID readers. A mega fab with 1,000+ pieces of equipment might have 2,500 to 3,000+ RFID readers and 5,000 to 20,000 FOUPs with RFID tags.

Material Flow Description:

- Each FOUP with an RFID tag is pre-programmed with a unique six-digit code that is fixed.
- The FOUP carrier with wafers is inserted onto a material handling stocker load port. The ID is read and the FOUP is temporarily stored.
- The FOUP moves from the stocker via automated transportation vehicles to its next processing destination.

- When the FOUP is placed at the load port, its ID is read and transmitted to the manufacturing execution system. Once the carrier is validated to have the right wafers, the equipment automatically starts processing.
- After the equipment has finished processing, the FOUP is automatically moved to its next storage or equipment processing destination and the process repeats.
- If the material is invalid, it is automatically moved to an error location within the factory and a human is paged/dispatched to analyze and resolve the issue.

Industry Standards: A SEMI industry consortium standard (E99) defines the communication protocol between the tag and the reader. This same concept was also deployed in some older generation 200mm wafer size fabs, although with far less frequency.

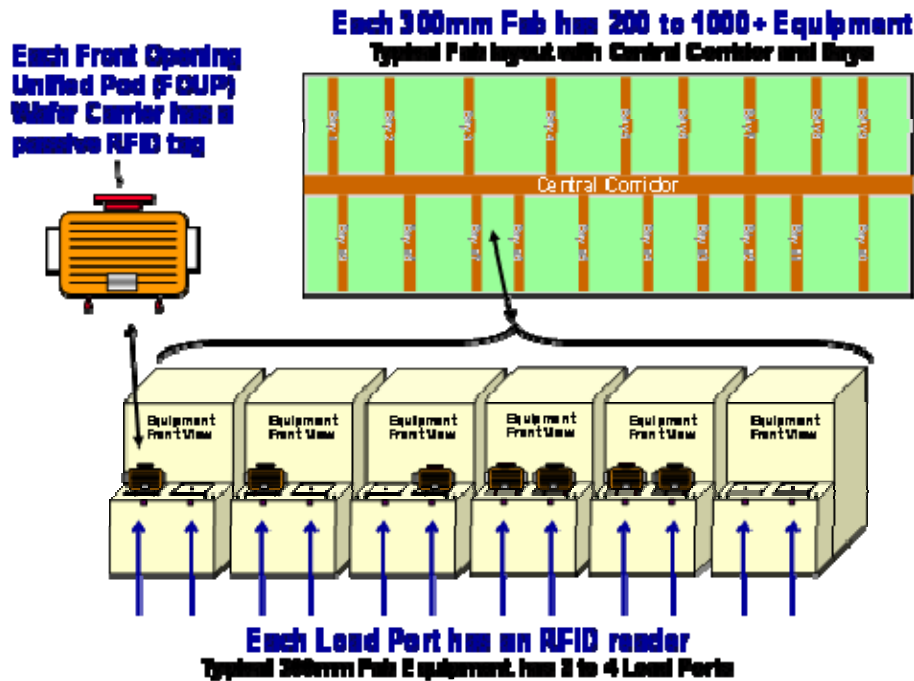


Figure 1: FOUP and equipment having RFID tags and readers help to enable fully automated material movement, validation and processing for 300mm fabs.

Desired Impact: The desired impact is cost reduction by reducing occurrences where wafers are misprocessed and scrapped, and to enable material tracking throughout the factory so that the location of each wafer carrier is always known.

USE CASE 2 – Semiconductor Real-Time Location Tracking

Applications: Carts and WIP in an assembly packaging and testing factory

Overview: Several assembly packaging and test factories are investigating the use of RFID tags to track the physical movement of WIP on a real-time basis.

Real-Time Cart Tracking Description:

- Active RFID tags are placed on each WIP cart and receivers are positioned on the ceiling throughout the assembly packaging factory, as shown in Figure 2. This ensures that the carts can be tracked to any location within the floor in real-time.
- When a factory worker needs a particular lot, he/she goes to a user interface (UI) and selects the lot to be found. The RFID system looks up the cart ID associated with the lot and proceeds to find the tag attached to that cart. The system then displays a 3D view of the factory showing the location of the cart (and hence the lot).
- As the cart moves, its position on the UI factory map is updated automatically so that its location and the location of all carts are known real-time. The main benefit of this system is the ability to rapidly find the right materials that must be processed next without requiring a more expensive material storage or handling solution.

Real-Time Cart Tracking Process Flow:

- A cart RFID tag is pre-programmed with a unique code that is fixed and does not change.
- As the cart moves through the factory, its location is transmitted and triangulated by the RFID receivers located on the factory ceiling.
- The carts are parked with chips until needed for their next process step.
- Once the material is actually needed, a human operator searches for its location on a factory user interface. Its location is instantly displayed and updated if the cart is in motion.
- The human operator retrieves the cart and moves it to the next equipment step in the manufacturing flow.

Industry Standards: Industry standards do not exist for this application. If used more prevalently, industry standards might be created to enable 'mixing and matching' of tags and readers from multiple suppliers.

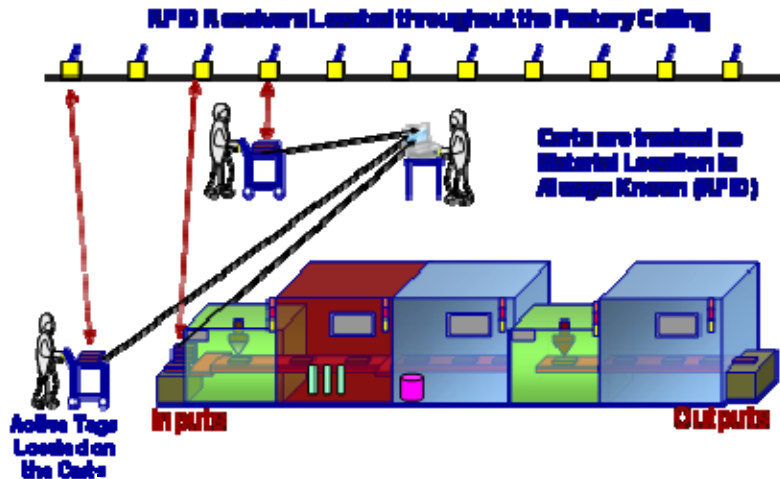


Figure 2: While on carts, active tags help to identify the exact 2 Dimensional Location of Semiconductor chips within the Factory.

Desired Impact: The objective is to improve manufacturing cycle time by enabling rapid discovery of where each cart and its material is in the factory, so that operators can quickly move it to the next processing step.

USE CASE 3 – Semiconductor Material Validation

Applications: Chip carriers and material containers within an assembly packaging and testing factory

Overview: Some assembly packaging and test factories are investigating the use of RFID tags to validate material in order to prevent excursions.

Material Validation Description (Figure 3):

- The assembly packaging and test factory material validation use case is very similar to the 300mm fab use case, with the exception that material validation is done for chip carriers (similar to the FOUP use case) as well as for consumable materials used during packaging. (See Figure 3.)
- A passive RFID tag on each carrier is used to identify the carriers as they arrive at the load port of a module. The tag ID (or carrier ID) is associated with data such as the lot the carrier belongs to, a count of the units it has, the operations performed on its units and where it is headed. A station controller validates that the carrier entering the module belongs to the correct lot, the carrier has met the processing pre-requisites (such as sit time) and that the correct consumables will be used during the processing of this carrier.
- Validation and traceability of consumable materials is performed in a similar fashion. A passive RFID tag attached to the material container will contain information such as material part number, lot identifier and expiration date. As the material is loaded to the tools in the module, a station controller reads the tag and validates that the right material is used for the right product. If a mismatch or error occurs, the line is stopped and a human is dispatched to correct it.

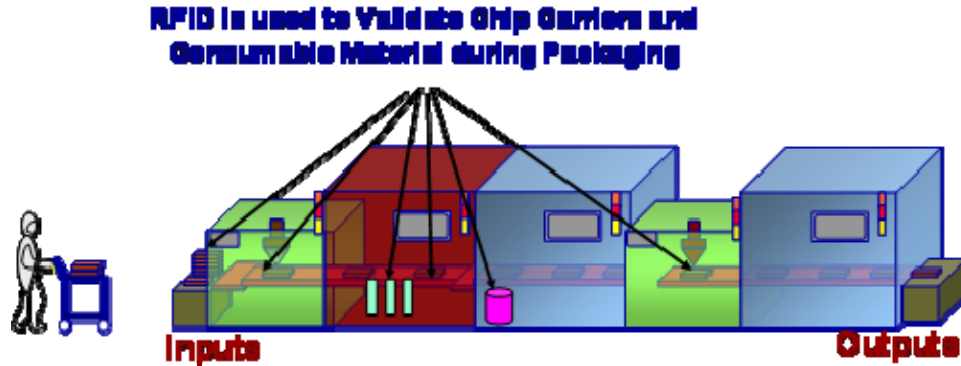


Figure 3: RFID is used on chip carriers and consumable material containers help to enable error free production at assembly packaging factories.

Material Flow Description:

- Each batch of material used during chip assembly is given a unique RFID tag (e.g. epoxy, flux, etc.).
- A lot/carrier of chips is moved to the equipment, identified, and starts processing.
- The batch of material being used at the equipment for processing the chips is validated against a database of instructions and materials for that lot of chips.
- If the material matches the database information, then processing starts and executes normally.
- If the material does not match the database information, then processing is halted and an error condition occurs which prompts factory operators to determine the cause of the error. Since no material is processed, no damage or losses occur.

Industry Standards: No industry standards currently exist to allow ‘mix and match’ of RFID tags and readers within the factory. This is a potential area of focus moving forward if the technology becomes widely used and ubiquitous.

Desired Impact: The desired impact is cost reduction by reducing occurrences of chips being misprocessed and scrapped due to the use of incorrect materials during the assembly process.

12.2 SECTION A.2: EMS USE CASES

Following are several EMS RFID use cases —viewed at the system level — that are considered successful (e.g. demonstrated positive ROI).

USE CASE 1 – EMS Intra-Company Tracking between Sites

Applications: Cases and pallets tracking

Overview: The EMS business stream consists of many different manufacturing facilities — from facilities that specialize in the manufacture of PCBA to facilities that complete the final assembly

prior to shipment to the end customer or the end customer's customer (usually located in Europe or the Americas). At present, shipment and tracking of cases and pallets moving from Asia (PCBA manufacturing) to the Americas is done via an electronic data interface (EDI) that indicates the PO number, pallet ID, product and quantity being shipped from Asia to the receiving site (one-way transmission). When the receiving site receives the material, they check the manifest and manually update the enterprise resource planning (ERP) systems to confirm the receipt of the cases/pallets. Updating of the ERP system can happen several days after the receipt of the pallets and cases.

RFID Process:

- Passive RFID tags are applied to the cases and pallets at the shipping location. When the products leave the facility an advanced shipment notification (ASN) is sent to the receiving site. When the cases and pallets arrive at the receiving location, they are received via an RFID portal where the case and pallet RFID tags are compared automatically against the receive ASN. (This process is completed in a matter of seconds).
- Upon confirmation that all the cases and pallets match, the RFID middleware software automatically sends a file back to the shipping location to inform them that the cases and pallets have been received. The shipping location can then start the invoicing process.
- Typical equipment used will be passive (UHF Class 1 Gen II) RFID tags that do not use the EPCglobal tag data format. The equipment on the shipping side will consist of RFID printers, fixed and mobile RFID readers. At the receiving area are fixed and mobile RFID readers, and middleware software will be used to send an e-mail notification or file back to the shipment location.

Transaction Level Description:

- Scan case, product and pallet IDs into RFID software tool.
- Confirm that the case and pallet IDs are linked and generate the RFID labels (done via RFID software tool).
- Apply RFID labels to cases and pallets and confirm that they can be read.
- Send ASN from ship location to receiving location when cases and pallets leave the facility (done via RFID software tool).
- Ship product by air or sea to end location.
- Receive cases and pallets at receiving location and compare the RFID tags on each case/pallet with the data received in the ASN (done via RFID software tool).
- Send auto-receipt acknowledgement back from receiving location to the shipment location via e-mail (done automatically via software tool).
- Shipping location invoices the receiving location.

USE CASE 2 – EMS Inter-Company Tracking

Applications: Case and pallet tracking

Overview: EMS businesses build and ship products based on customer demands. When products (cases and pallets) are shipped, the customer is notified in a variety of ways (e.g. EDI, e-mail, etc.). The data that is sent by these methods is usually the PO number, pallet ID, product name/ID and quantity (although every customer has a specific requirement). When customers receive products, they check the manifest and manually update their ERP to confirm receipt of the cases/pallets. The ERP system will 'run' every few days, which mean that the EMS business is not informed that the cases and pallets have been received until several days after receipt; hence, the EMS business cannot invoice the customer.

RFID Process:

- Passive RFID tags are applied to the cases and pallets at the shipping location. When the products leave the facility an ASN is sent to the customer.
- When the cases and pallets arrive at the customer's location, they are received via an RFID portal where the case and pallet RFID tags are compared automatically against the receive ASN (process completed in a matter of seconds). Upon confirmation that all the cases and pallets match, the RFID middleware software automatically updates the ERP system that the products have been received.
- Receipt of the products automatically starts the invoicing process within the ERP system and a file is sent to the EMS business informing them that the cases and pallets have been received. The EMS business can then start the invoicing process.
- Typical RFID tags used will be passive (UHF Class 1 Gen II) RFID tags that use EPCglobal tag data format. The equipment on the shipping side will consist of RFID printers, and fixed and mobile RFID readers. At the receiving area are fixed and mobile RFID readers, and middleware software will be used to pass the data collected by the RFID readers to the ERP system.

Transaction Level Description:

EMS Process

- Scan case, product and pallet IDs into RFID software tool.
- Confirm that the case and pallet IDs are linked and generate the RFID labels (via RFID software tool).
- Apply RFID labels to cases and pallets and confirm that they can all be read.
- Send electronic serialized ASN that includes the RFID identifiers to customer as soon as the case and pallets leave the facility (via RFID software tool).
- Ship product by air or sea to end location.

Customer Process

- Upon receipt of ASN, the ERP system checks ASN against PO issued to supplier.
- ERP automatically updates PO (differences between ASN and PO resolved).
- Cases and pallets are pulled through an RFID portal at the receiving location.
- The case and pallet RFID tags are compared automatically against the received ASN (completed in a matter of seconds).

- RFID middleware confirms that the correct products have been received and automatically updates the ERP system, which automatically sends receipts for the items.
- Auto-receipt acknowledgement sent back from receiving location to the shipment location via EDI.

USE CASE 3 – EMS Higher Operational Efficiency in Final Assembly Operations

Applications: Product tracking

Overview: Increasingly OEMs are outsourcing their final assembly of systems to EMS organizations. These final assembly systems consist of multiple subassemblies, which are configured according to the end customers' requirements (each unit being configured to order). Each subassembly is built to a basic specification and then configured with different hardware and software revisions. As each subassembly is unique, this means it has to have its own production routing (i.e. build sequence and functional tests).

Currently a paper-based Kanban system is used to ensure that each system is configured correctly. Each basic subassembly unit is given a Kanban card, which moves with the product through the production line. The Kanban card indicates the customer, product ID number, the subassembly configuration and the production routing (i.e., tests) that the subassembly must follow. On completion of each stage in the process an operator updates the shopfloor control system. Once all the subassemblies have been configured, the final system is assembled and tested.

RFID Process:

- Passive RFID tags are used in place of existing paper Kanban cards. These RFID tags are used as data carriers and hold all of the production information (e.g. customer, product ID number, the subassembly configuration, etc.). To ensure that the Kanban system operates as designed, the production details are printed on the RFID Kanban card. The RFID Kanban cards move through production in the same way as paper-based Kanban cards.
- The RFID Kanban tag communicates with readers throughout the manufacturing process, allowing the operations team to understand what stage each subassembly has reached. The RFID Kanban cards are read at each stage, enabling production data to be viewed (e.g. production drawings, etc.) or production process to be started (e.g. print-outs of test check sheets, test cycles, etc.).
- Reusable passive high-frequency RFID tags are used. The RFID tags are cleaned, printed and programmed using an RFID printer. The RFID tags will be interrogated using RFID readers at each stage of the production process and the data on the RFID tag will be used to start processes (e.g. generate print-outs, display data and test equipment).

Transaction Level Description:

- Enter production data into system and generate RFID Kanban cards.
- Data printed on the RFID Kanban card and programmed into the RFID tag includes customer name, product ID number, subassembly configuration and routing.
- RFID Kanban card is associated with subassembly (basic configuration).
- RFID Kanban card travels with the subassembly and is scanned at each step of the process.
- The RFID readers are linked to printer, VDU or test units and automatically start the production process once the RFID Kanban card has been read.
- Once the subassembly has been associated to the final unit, the RFID Kanban card is collected and reloaded into the RFID printer.
- The RFID Kanban card will be wiped clean of data, both on the tag and visually, when it is next printed.

USE CASE 4 – EMS Automotive Tracking

Applications: Chassis manufacture

Overview: Automotive assembly processes are conducted in harsh environments where temperatures can exceed 230°C and paint is added to the product. In addition, it is vital that all the robots used in the assembly process have accurate work instructions and are correctly positioned when a chassis arrives at each assembly operation. Any failure at this point can cause production delays or incorrect products to be built. Thus large amounts of time are currently spent ensuring that all tasks are performed correctly the first time.

RFID Process: An RFID tag capable of withstanding extreme temperatures and harsh environments is attached to the skid. The RFID tag communicates with readers throughout the manufacturing process, allowing the operations team to understand what stage each chassis has reached. The use of RFID tags enables production instructions to be communicated to the manufacturing robots, ensuring that each product is built to the correct customer specification (i.e. correct color). Reusable semi-passive RFID tags are used. A battery supports the additional memory these RFID tags have, but the communication protocol between the tag and reader is passive. The RFID tags are interrogated by RFID readers at each manufacturing stage and this data is used to control the robots.

Transaction Level Description:

- Each tag is encoded with a unique ID number that is associated with a specific chassis and contains information such as intended color of chassis and production process information.
- The RFID tag is affixed to the side of the skid and is carried down the production line by a conveyor system.
- Fixed readers are positioned along the line and scan the RFID tag at each production stage.
- The readers are linked to programmable logic controllers, which monitor and control the robots that are used to perform the various manufacturing operations.

- Once the skid has been used, the RFID tag is removed to be reused on the next chassis.

12.3 SECTION A.3; OPERATIONAL LEVEL USE CASES

This section discusses several use cases as viewed at the operational level (e.g. querying or dipping into a directory or other repositories for identity-related information such as user identity, vehicle identity, RFID, e.164, profiles, and more). Event sequencing is presented for each use case. In all of these use cases the underlying integration architecture could be: a) leveraging an identity management solution for workflow and provisioning between multiple repositories or b) directly linked via federation manager (SAML) and access manager agents, or c) a combination of the two (most likely) to offer this integration.

USE CASE 1 – Asset Tracker

Applications: Latitude/longitude for mapping, buddy tracker, phone service.

Description: This application provides business users with the ability to manage their assets. This use case ties in RFID to a wireless carrier's GPS functions.

Pre-Event Activity: An RFID tag tracks the movement of an asset through the supply chain. A need to map the asset to the transportation vehicle is necessary.

Triggering Event: The asset is off-track by delivery time. The user is delivered an event. Selecting the event presents the user with a message and options, as listed below.

Event Message & Options:

- Present a map pinpointing the vehicle containing the asset.
- Launch a phone call to the truck.
- Present a map locating the fleet. (This is a variation of buddy tracker — the user can select one or many trucks, or buddies, in the fleet.)

Table 1: Event sequencing for asset tracker.

Component	Comments/Notes
Web service to event queue	'Package not delivered' event is sent to user
Notification manager to user	Light goes on
User action to go to queue	User goes to event queue
User reviews queue	All queued events are presented
User selects asset tracker alert	Using arrows to position and OK to select, the user selects this event
User presented with 3 options	1) Pinpoint asset, 2) call the truck, or 3) show fleet
User selects 'pinpoint asset'	Using arrows to position and 'OK' to select
Map application is launched	User is presented with map of truck location
User selects 'call the truck'	Using arrows to position and 'OK' to select
Phone call to truck	Phone call to user ends web service interaction
User selects 'show fleet'	Using arrows to position and 'OK' to select
Map application is launched	User is presented with map pinpointing his fleet of trucks

Assumptions:

- User and device are running an AuthN user session with an IDP (such as an HLR or HSS) that interacts with an event-based orchestrator.
- ENUM mapping is available to map e.164 numbers to different caller destinations (e.g. cell number, vehicle phone number, instant messaging address, etc.).
- RFID repository tracks assets and vehicles used.
- ID-based location services tracks vehicles locations based on vehicle IDs.
- Event-based messaging system also handles orchestration and choreography.

USE CASE 2 – Security Camera

Applications: Webcam, phone service

Description: This use case describes a business opportunity for remote monitoring of an elder relative or remote home monitoring. For purposes of this discussion, the application will be called NanaCam. The relative (Nana) could either be in a care facility or located at home with the appropriate monitoring equipment. At the time users subscribe to the service, they identify the information necessary to have notices of triggering events sent to them.

Triggering Event: Service provides patient telemetry (blood pressure, heart rate, blood sugar, etc). If this telemetry goes outside a preset tolerance, an event is posted to the event queue and the user is notified. It can also be a motion sensor that detects movement in an unoccupied home.

Event Message & Options:

- Launch webcam to view relative
- This view contains a refresh option to pull the current image
- Launch a call to the doctor or security service – the phone number for this Nana’s doctor or security company is pre-populated.
- Call 911 — the emergency phone number for this Nana is pre-populated.

Table 2: Event sequencing for security cam

Component	Comments/Notes
Application to event queue	Telemetry out of bounds
Notification manager to user	Light goes on
User action to go to queue	User goes to event queue
User reviews queue	All queued events are presented.
User selects ‘NanaCam alert’	Using arrows to position and ‘OK’ to select
User presented with 3 options	1) Launch webcam to view relative or unoccupied room, 2) launch a call to the doctor or security company, or 3) call 911
User selects ‘launch webcam’	Using arrows to position and ‘OK’ to select
Webcam application is launched	
User selects ‘call doctor’	From phone book, or part of configuration for this service and number is already part of the option. Using arrows to position and ‘OK’ to select
Phone call is launched	
User selects ‘call 911’	Using arrows to position and ‘OK’ to select
Phone call to 911	

Assumptions:

- User and device are running a AuthN user session with an IDP (such as an HLR or HSS) that interacts with an event-based orchestrator.
- ENUM mapping is available to map e.164 numbers to different caller destinations (e.g. cell number, vehicle phone number, instant messaging address, etc.).
- RFID repository tracks assets and vehicles used (including webcam asset IDs).
- Event-based messaging system also handles orchestration and choreography.

USE CASE 3 – Mobile Diner

Applications: new application (Mobile Diner)

Description: This use case identifies a business opportunity for someone to act as a broker for restaurants in an area. The consumer subscribes to this service and gains mobile access to many restaurant options and menus via a handset application. For purposes of this discussion, this will be called the “Mobile Diner” service.

Starting the Application: The Mobile Diner application allows the user to establish a schedule of reminders, which are sent to the user via the event manager. The user can also select the application from the list of applications.

Triggering Event: The Mobile Diner application sends a notification to the user.

Event Message & Options:

- Order
- No order
- Selecting 'order' fires the Diner helper application.
- The user is presented with the restaurants that this service brokers: Applebee's, On The Border, Outback Steakhouse, etc
- The user selects a restaurant; menu entrees and prices are presented.
- The user selects one or many items.
- The user is given the option to go back or proceed to checkout.
- Once the user has completed the order, he/she selects the 'checkout' item. The checkout item returns a summary of the order with the total price.
- The user is given the option to purchase or go back.

Table 3: Event sequencing for Mobile Diner

Component	Comments/Notes
Using Mobile Diner	User sets the calendar event for the reminder
Calendar event fires	Event is put into the user's event queue
Notification manager to user	Light goes on
User action to go to queue	User goes to event queue
User reviews queue	All queued events are presented.
Using arrows	Using arrows to position and 'OK' to select, user selects 'dinner helper' alert and gets the following options: <ul style="list-style-type: none"> • Order • No order
User selects order	Use arrows to position and 'OK' to select
Mobile Diner application fires	The restaurant options are presented: <ul style="list-style-type: none"> • Applebee's • On the Border • Outback Steakhouse •others
User selects restaurant	Using arrows to position and 'OK' to select, the user selects a restaurant
Application responds with menu items	The user is presented with the menu items associated with that restaurant
Using the arrows, the user selects the entrees	Using arrows to position and 'OK' to select the user selects one or many
Once complete, the user goes to checkout	Checkout option on the phone
Checkout	
The user is presented an order summary	The order summary and total price are presented with the option to complete the order
The broker sends the order to	Restaurant receives order

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the restaurant	
The broker sends a confirmation to the user with order pick-up time	Event placed on event queue
Notification Manager to User	Light goes on
User action to go to queue	User goes to MI Event Queue
User reviews queue	All queued events are presented.
User selects alert	Using arrows to position and 'OK' to select, the user selects this event
Event pops up with options	2 options are presented: <ul style="list-style-type: none">• Set event in my calendar• Done
User selects 'set event in calendar'	Using arrows to position and 'OK' to select; the calendar is updated.

Assumptions:

- User and device are running an AuthN user session with an IDP (such as an HLR or HSS) that interacts with an event-based orchestrator.
- ENUM mapping is available to map e.164 numbers to different caller destinations (e.g. cell number, vehicle phone number, instant messaging address, etc.).
- RFID repository tracks assets and vehicles used.
- ID-based location services tracks vehicles locations based on vehicle IDs
- Event-based messaging system also handles orchestration and choreography with location, presence and payment services.