R F I D….*will always remain an incomplete story*

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Modified from: Han Pang Huang, National Taiwan University

What is *'new'* about RFID ? Evolution of RFID

1940	1950	1960	1970	1980	1990	2000
RFID born out of Radar effort (WWII)	**RFID crawls out**	**Theory of RFID, field trials planned**	**Early adopters implement RFID**	**Commercial RFID endeavors sprout**	**Many RFID standards emerge**	**RFID hype, peaks**
1948 Harry Stockman invents RFID. Publishes paper, "Communication by Means of Reflected Power"	1950 D.B. Harris patents RFID. "Radio transmission systems with modulatable passive responder" 1952 F.L. Vernon "Application of the microwave homodyne" 1959 Identification of Friend or Foe (IFF) long-range transponder system reaches breadboard demonstration stage.	1963-1964 R.F. Harrington advances theory with "Field measurements using active scatterers" and "Theory of loaded scatterers" 1966 Commercialization of EAS, 1-bit Electronic Article Surveillance	1973 Raytheon's "Raytag" 1977 RCA develops "Electronic identification system" 1975 Los Alamos National Lab (LANL) releases RFID research to public sector, publishes "Short-range radio-telemetery for electronic identification using modulated backscatter" 1976-1977 LANL RFID spin-offs Indentronix and Amtech 1975-1978 Raytheon, Fairchild & RCA develop RFID	1982 Mikron founded; bought by Philips 1987 First RFID road toll collection implemented in Norway	1991 TI creates TIRIS to develop and market RFID 1992-1995 Multi-protocol traffic control and toll collection implemented in Texas, Oklahoma, and Georgia (USA) 1998 David Brock and Sanjay Sarma of MIT publishes an idea: 'Internet of Things' 1999 Auto ID Center created at MIT. Retailers drive to standardize EPC	2003 UPC and EAN forced by US retailers to promote EPC 2005 Wal-Mart and US DoD fuels the hype curve by demanding suppliers use passive RFID and EPC.

Vast number of RFID companies and 'short-sight' enters the market.

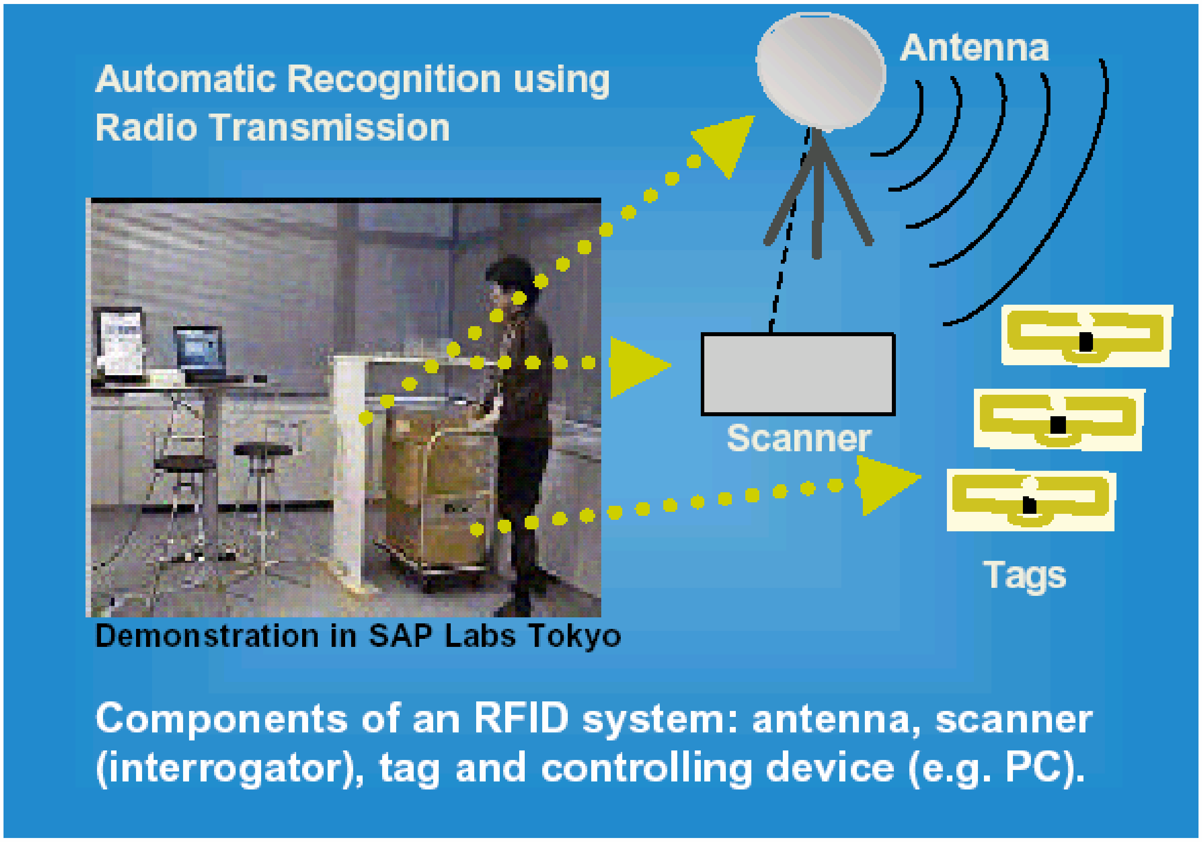
Partial Source: Shrouds of Time – The History of RFID

RFID: Still 'new' after 60 years?

What is RFID ?

Radio frequency identification (RFID) of objects (Coke can, vial of Aspirin, component of an aircraft engine) uses small paper-thin labels (tags) consisting of a small silicon chip (less than 2 mm sq) with an integrated antenna. Depending on the type of tag, several kilobits of data can be stored on one tag (expiration date of Aspirin, for example). Data exchange, both reading and writing, takes place via radio waves. Therefore, it is possible to read many tags simultaneously, even if the tags are not within line of sight. Unlike handheld barcode readers, RFID readers automatically record RFID data and can be integrated with ERP as well as SCM applications. Integrating RFID data with SCM offers significant improvements in operational efficiency, ease-of-use and enables rapid adaptive responses based on real time location (track and trace) of material, goods and objects in the supply network.

RFID systems include tags (also referred to as transponders), handheld or stationary readers, data input units and system software. RFID tags are the backbone of the technology and come in all shapes, sizes and read ranges including "smart labels" which can be laminated between paper or plastic. RFID creates an automatic way to collect information about a product, place, time or transaction quickly, easily and without human error. It provides contact-less data link, without need for line of sight even in harsh or dirty environments that restrict other auto ID technologies such as bar codes. RFID is more than just an ID code, it can be used as a data carrier, with information being written to and updated on the tag. RFID has been applied in dozens of industries, for example, in vehicle and personnel access control, anti-theft systems, asset tracking and supply chain automation.

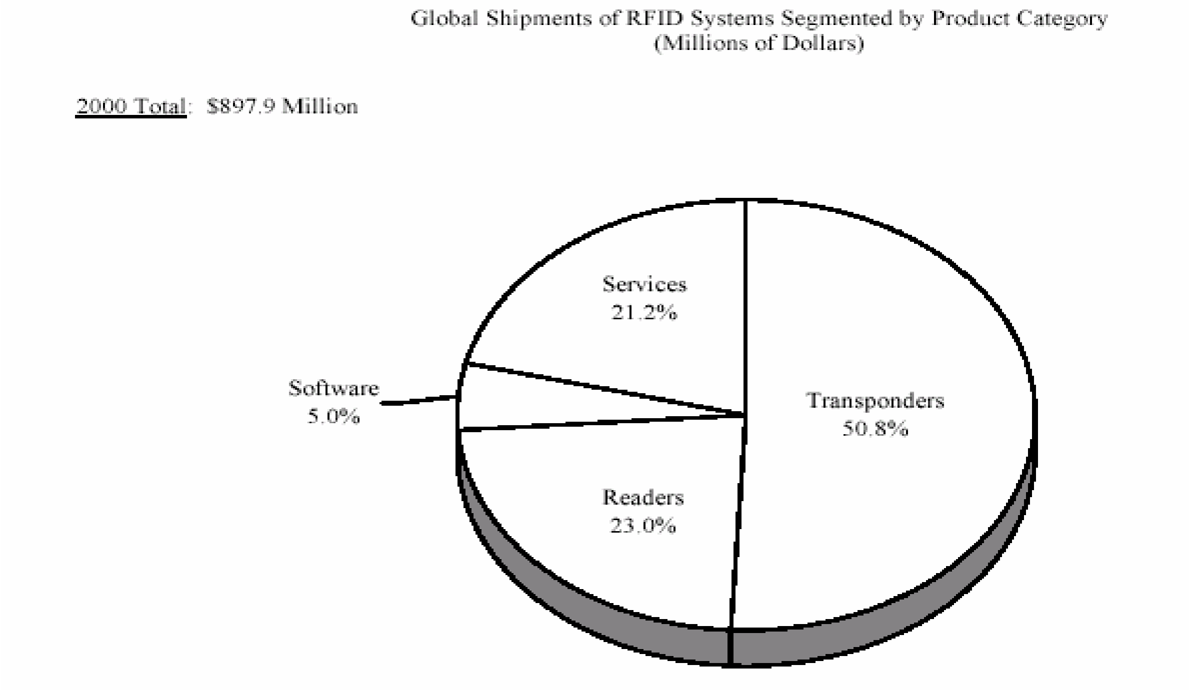


RFID Market (from Venture Development Corporation)

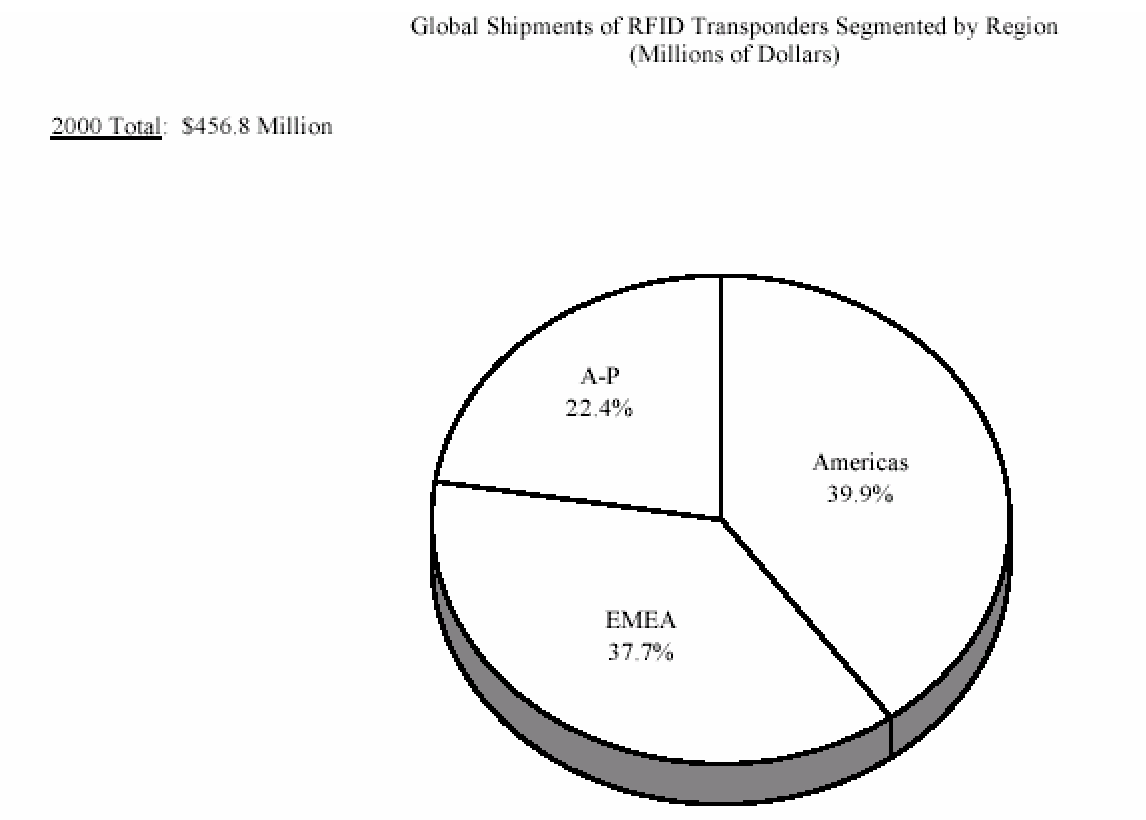
According to Venture Development Corporation, global market for RFID has grown to nearly $900 million in supplier revenue in 2000 (9% lower than market projections from Venture Development Corporation's 1997 RFID study). Rapid expansion has been limited by the lack of industry and application standards as well as saturation points of traditional RFID applications (security/access). The most significant RFID development in 2000 was the number of implementations across several industries (libraries, hospitals, laundries, automobile manufacturers now use RFID for material management). Penetration into vertical industries occurred as a growing number of systems integrators and software companies who serve these industries began to form relationships with RFID vendors. RFID manufacturers began to partner with solutions providers who specialize in logistics services, warehouse management, asset management and industrial automation. Over the next 5 years, end-user awareness of RFID technology and benefits may foster wider adoption and increase demand (particularly with proliferation of high volume, consumer applications such as transportation ticketing). While the market may not be prepared for explosive growth immediately, it has established itself within enough vertical markets and applications to sustain a 24% annual growth rate (higher than other auto identification technologies). While hardware and software revenues comprise nearly 80% of the market, several factors may be attributed to services claiming one-fifth of overall RFID revenue:

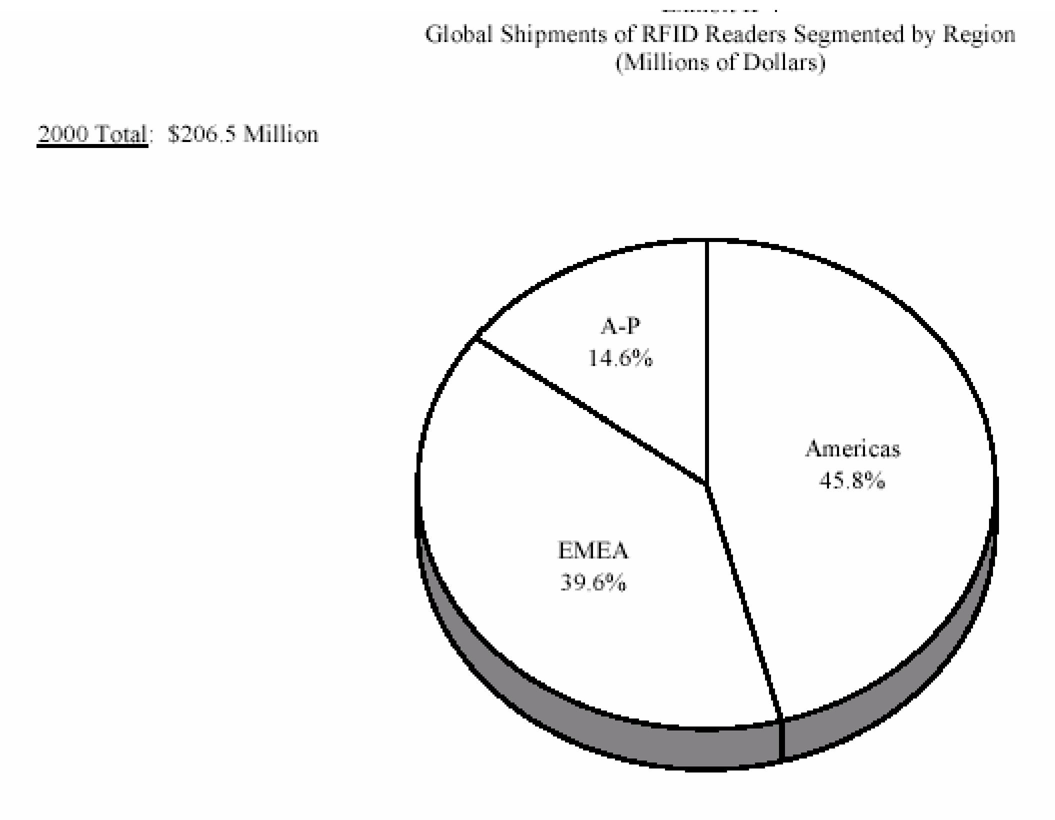
• RFID industry lacks experienced systems integrators and resellers able to provide end users with the level of support and service they require for an RFID system installation/application (vendors are left to integrate, support and maintain their products at the end-user)

• maintenance contracts have also generated substantial RFID service revenues for vendors, particularly those providing toll collection systems (Transcore, Combitech Traffic Systems), which require greater maintenance given the number of transponders (tags) and readers involved per installation.



In 2000, vendors shipped 298 million units of RFID hardware (297 million transponders and 520,000 readers. Currently, 443:1 is the ratio of transponders to readers (1997 data 292:1). Increase in number of transponders per reader suggests more applications with higher transponder-to-reader ratios are being implemented, such as public transportation ticketing, traffic management systems and security/access. In these applications, a small number of readers are utilized to read a large number of transponders.

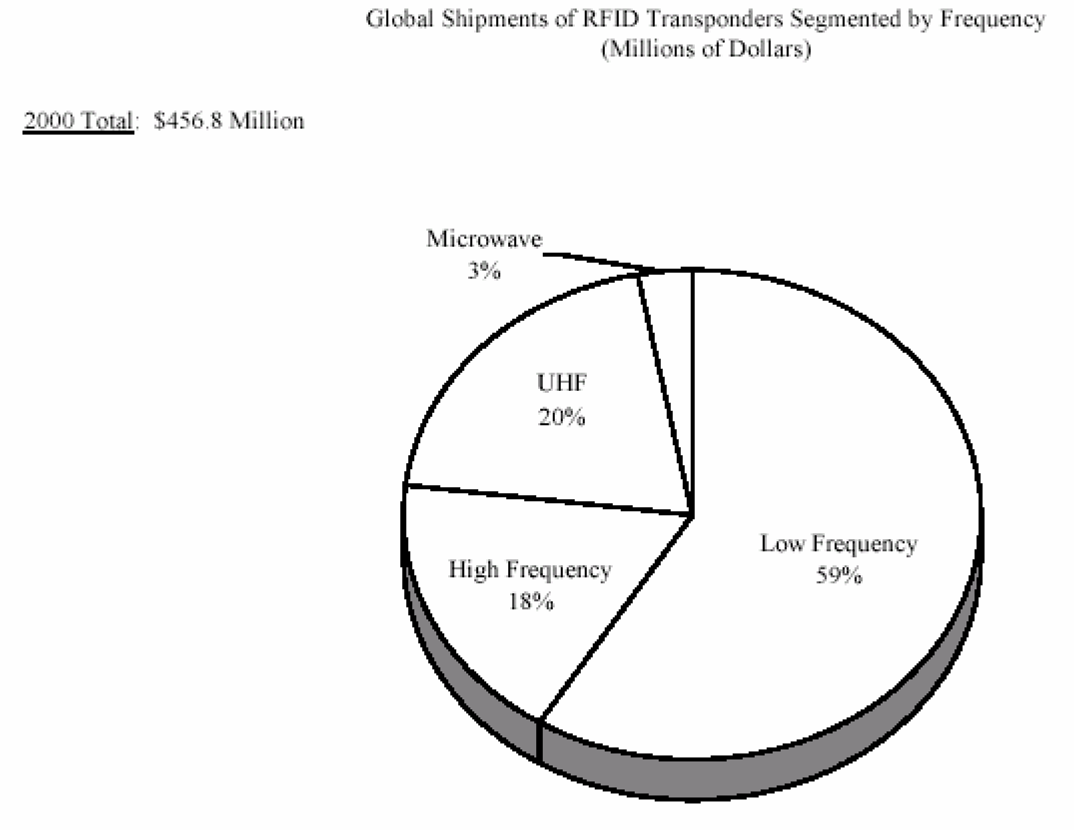




Frequency continues to impact the industry. Almost as varied as potential applications are frequency ranges to support RFID. Significant competition exists throughout the industry but few standards and/or regulations guiding frequency usage exist (www.autoidcenter.org). The use of a specific frequency traditionally has been based upon degree of control or regulation of a specific frequency, data transmission, power requirements, distance of operation and cost. Currently, RFID systems are classified into four primary frequency ranges:

- low frequency (less than 135 KHz; primarily 125 KHz)
- high frequency (13.56 MHz)
- ultra-high frequency (UHF) 300 MHz to 1000 MHz (primarily 900-915 MHz)
- microwave frequency (above 1GHz; particularly 2.45 GHz [BlueTooth] and 5.8 GHz)

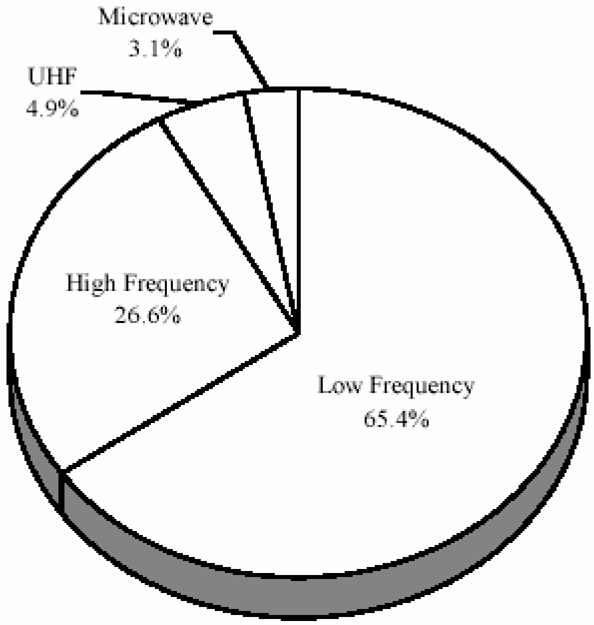
UHF and microwave frequencies support applications which require higher data transmission rates and may be susceptible to harsh environmental conditions (noise, temperatures, moisture). Higher frequency systems are regulated and may require user licenses. Through supplier relationships (Philips, Intermec and Gemplus) RFID products aimed at supply chain has produced developments in 13.56 MHz technology. Furthermore the smart card market (contact-less applications) using 13.56 MHz has also driven high frequency RFID volumes. As RFID matures, narrowly defined applications are moving toward specific frequencies. For example, low frequency systems (primarily 125 kHz) are widely used to support automobile immobilization, security/access control, WIP tracking, logistics and animal identification applications. High frequency systems (13.56 MHz) are used for applications using smart labels (such as library systems) and smart cards (public transportation ticketing). Depending on the region and frequency regulations, the UHF band is utilized for applications such as rail car identification and electronic toll collection. The primary disadvantage of microwave systems is their inability to transmit through water or human bodies. The issue of frequencies and their connection with certain applications has slowed the maturation of the RFID industry. In fact, discussions over operating frequencies have been the root cause for much debate and conflict during the standards development process. Ideally, desired frequencies would be defined by end-user groups and vendors should develop systems according to their specifications. However, given the highly competitive, highly fragmented state of the RFID industry, this has not been the case. In the absence of standards and end-user requirements regarding frequency, several suppliers have begun to broaden their RFID product offerings to include products for different frequencies.



VDC's analysis of segmentation of frequencies utilized in RFID systems reveals a high degree of concentration in the low frequency bands, primarily at 125 kHz. Low frequency transponder revenue accounts for 60% of the total transponder market while low frequency reader revenue totals 71% of the global reader revenues. Similarly, low frequency transponders and readers comprise the majority of global RFID hardware shipments. Low frequency transponders hold 65% of transponder shipments but low frequency readers possess 88% of the total reader shipments. Global UHF transponder revenue equals roughly 20% of the total market and their shipments total nearly 5%. The disparity between UHF transponder revenue and shipments results from the high cost of UHF transponders (most UHF transponders today are active) and the restricted use of UHF frequencies in select countries (915 MHz cannot be utilized in EU; UHF banned in Japan). UHF readers carry the most costly average selling price. Therefore UHF draws 9% of the global revenue while UHF reader units represent only 3% of the market. High frequency transponders netted 18% of transponder revenue and approximately 27% of unit shipments in 2000. This correlates to the low cost (in comparison to other frequencies) and high volume of high frequency transponders being shipped globally. High frequency readers received nearly 13% of global reader revenue and 6% of unit shipments. Microwave transponders comprised below 3% of total transponder revenue and a little more than 3% of unit shipments. Microwave readers total 7% of global reader revenue and over 3% of unit shipments. Like UHF, average selling prices for microwave readers increase given the long range, faster data transmission and greater complexity associated with RFID systems operating at higher frequencies.

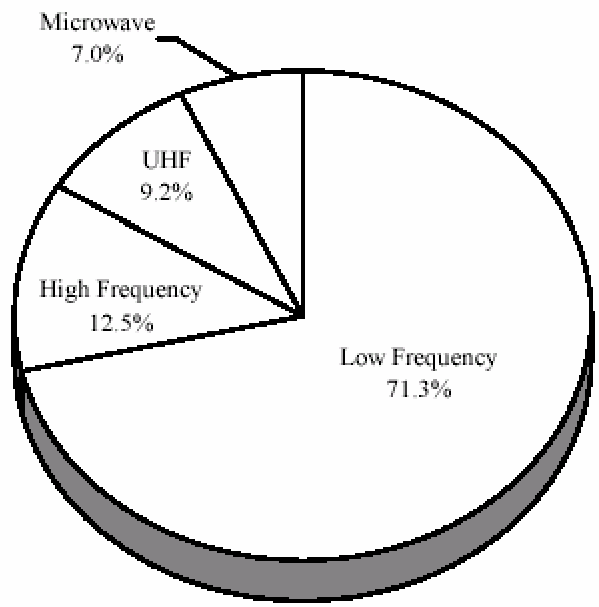
Global Shipments of RFID Transponders Segmented by Frequency
(Millions of Units)

2000 Total: 297.2 Units



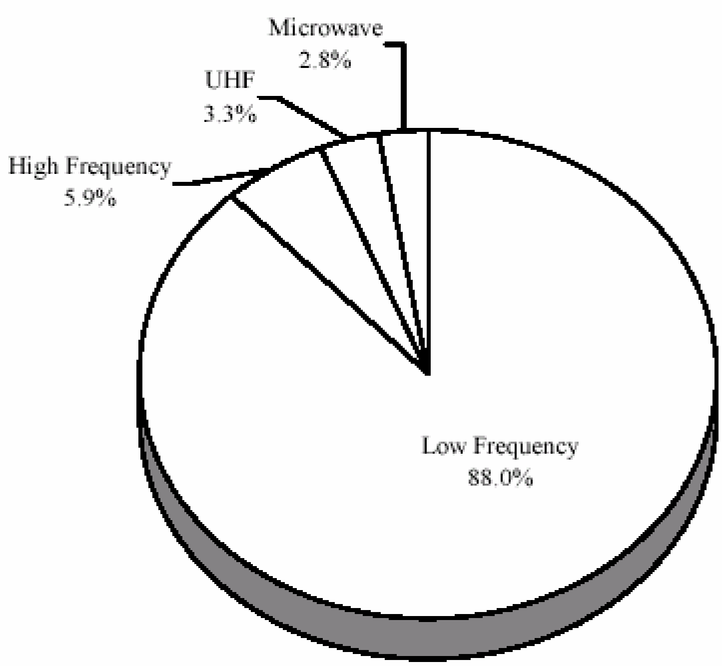
Global Shipments of RFID Readers Segmented by Frequency
(Millions of Dollars)

2000 Total: $206.5 Million



Global Shipments of RFID Readers Segmented by Frequency
(Thousands of Units)

2000 Total: 524.6 Units



With the broad spectrum of applications within the RFID industry, products covering various frequency ranges are necessary. For each frequency, operating characteristics and regulations differ, making each frequency appropriate for particular applications. For example:
• low frequency RFID systems, 125 kHz, were first used in high volume for industrial manufacturing and automobile immobilization applications (range upto 1 meter). It can be used worldwide without license and has become the frequency for many applications including several supply chain management applications
• 13.56 MHz is an ISM (Industrial, Scienctific, Medical) frequency and can be used worldwide. High frequency systems operate at a distance of approximately 1 meter with data transmission rates of up to 100 kbps and are unaffected by harsh environmental conditions. The market is experiencing a shift from contact-less smart card applications to supply chain management applications using 13.56 MHz smart labels.
• UHF RFID systems lack an industry standard regulating its use, but have the advantage of long read range. Under US regulations, UHF can achieve reading distances of 2-3 meters). EU regulations reduce the reading to distance to under 1 meter and do not allow use of 915 MHz. The entire UHF range cannot be used in Japan.
• microwave RFID systems have greater read range (2-15 meters), high storage capacity and temperature resistance (up to 250°C). These systems are used in automobile assembly, electronic toll collection and real-time location applications. They cannot be exposed to water and fail to transmit through human bodies.

Majority of RFID (tag) transponder revenue and unit shipments were passive transponders that lack internal power source for data transmission. While active transponders offer longer read and write ranges, passive transponders have a long operating life-span and are cheap. Passive transponders are anticipated to account for the overwhelming majority of shipments and revenues over the next 5 years. This will be driven primarily by increased adoption of higher frequency systems (UHF and microwave) with longer read/write capabilities. Primary drivers and/or characteristics of active and passive RFID systems include the following:
• active transponders achieve greater read/write ranges due to power provided by included battery (bulky)
• passive transponders do not have an internal power source for communication and require readers to transmit the initial communication signal
• design of passive transponders are simple with the antenna design determining the read range (based on the relationship between antenna size and strength of magnetic field)
• active transponders may cost more than $20 (justified by high-value asset tracking, rail car id)

Global transponder (tag) revenue segmented by (packaging) form factor shows highest current revenue, 44%, in plastic housing. In terms of volume, smart cards hold 27% of the current market. Over the next 5 years the growth in terms of revenue and volume will be enjoyed by smart labels and cards. However, transponders housed in plastic will generate the most revenue even though there will be fewer shipped in comparison to smart cards and labels. To better understand the relationship between revenues and unit shipments, below is a breakdown of the current and forecast average selling prices of transponders segmented by form factor:

Global Average Selling Prices of Transponders Segmented by Form Factor

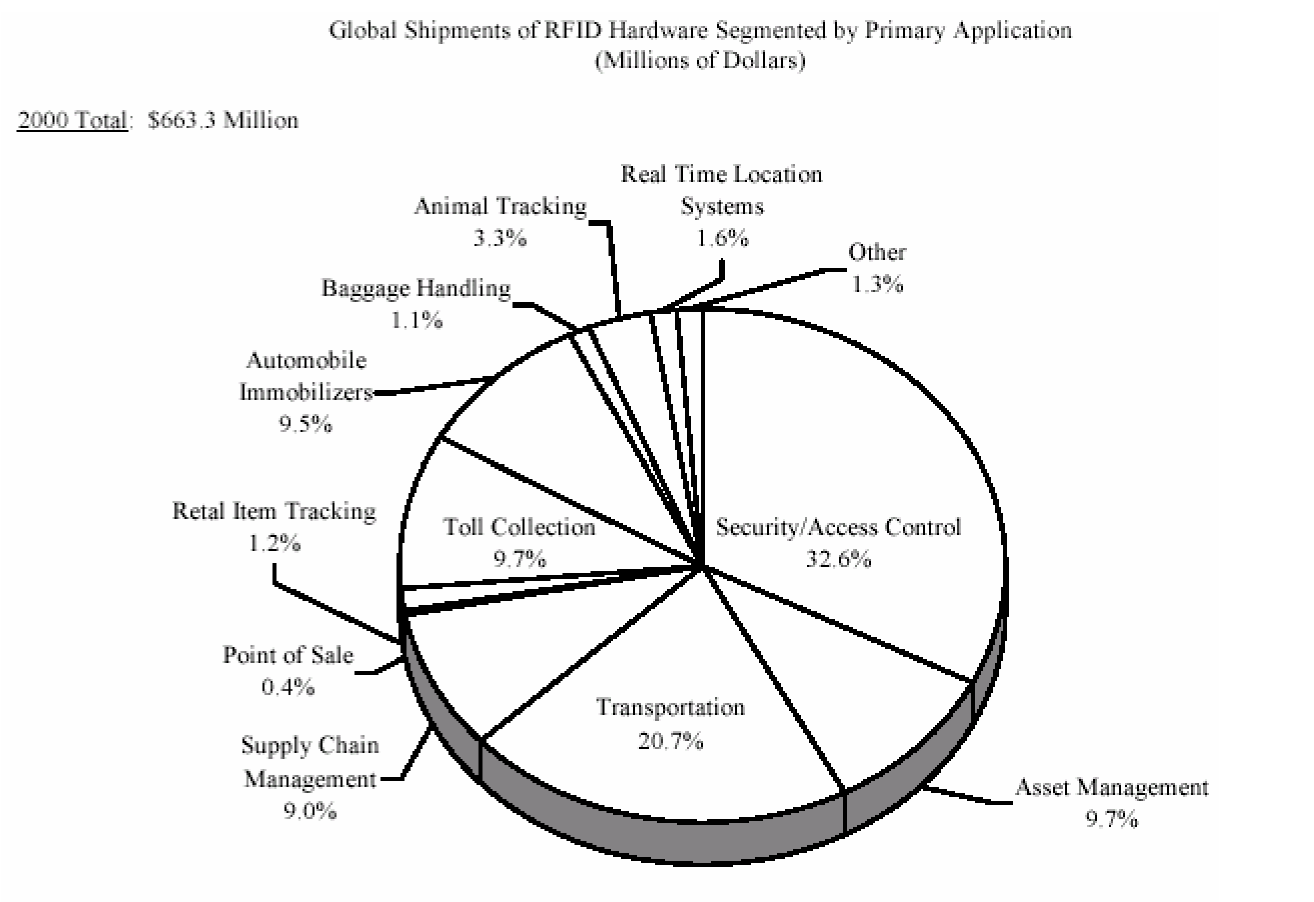
Form Factor	2000	2005	% Decline
Smart Cards	$1.00	$0.66	- 34.0%
Smart Labels	$0.99	$0.58	- 41.4%
Plastic Housing	$2.62	$1.47	- 43.9%
Glass Housing	$1.41	$1.26	- 10.6%
Key FOB/Car Key with Immobilizer	$1.31	$1.16	- 11.4%

Outside of falling price points, other factors impacting the growth of specific form factors may be:
• glass housing transponders will grow relative to growth of animal id and automobile immobilization
• key FOB transponders will grow partly in relation to the number of new automobiles produced each year, the shift from simple immobilization to solutions with integrated functionality like remote keyless entry
• volume of smart labels is expected to grow to support growing applications such as airline baggage handling (long term), track & trace, supply chain management
• growth of smart cards is partly dependent upon increasing numbers of security/access control and ticketing

End-User RFID Applications in Different Industry Sectors

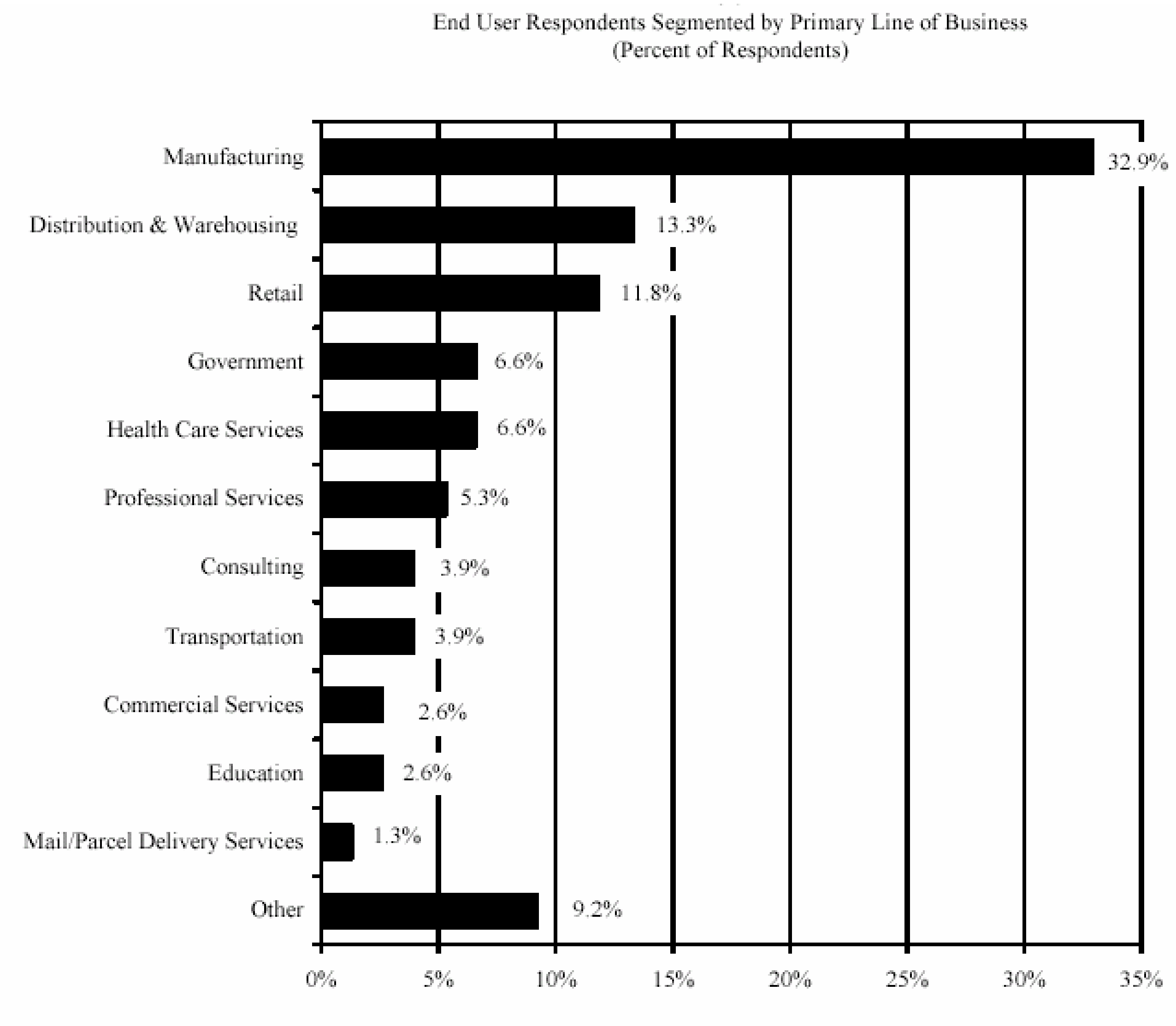
In 2000, RFID hardware revenues were concentrated among manufacturing and transportation, distribution and warehousing organizations. While these two economic sector applications may account for a good percentage of RFID hardware revenues in the near and long term, their growth will be slower in comparison to the annual growth of security, health care, commercial and retail industries. Evaluating global shipments by specific economic sector trends reveal:

- overall, RFID systems adopted by transportation, distribution and warehousing organizations typically utilize higher cost RFID systems, such as higher frequency, active, read-write hardware to support applications such as yard management, rail car id and container tracking
- increased usage due to significant developments in supply chain management and logistics applications, particularly in automated processes such as automobile assembly
- symbiosis between transportation, distribution, warehousing as manufacturers outsource logistics to 3PL
- the development of the smart label segment is expected to increase within the industrial sector to support growing applications such as baggage handling and high speed sorting
- interest is increasing among health care organizations to support applications such as waste management, high-value asset tracking, record/document tracking and real-time location systems (essential gas cylinders)
- adoption of RFID systems in retail environments has been limited due to cost
- developments within the retail sector are largely concentrated in creating smarter EAS (Electronic Article Surveillance) transponders to support, for example, the storage of pertinent product information within a retail item (such as warranty information)
- consumer applications to grow (automated payment, libraries, rental item tracking, re-usable media)
- tracking systems within government organizations (US DOD Total Visibility Program)



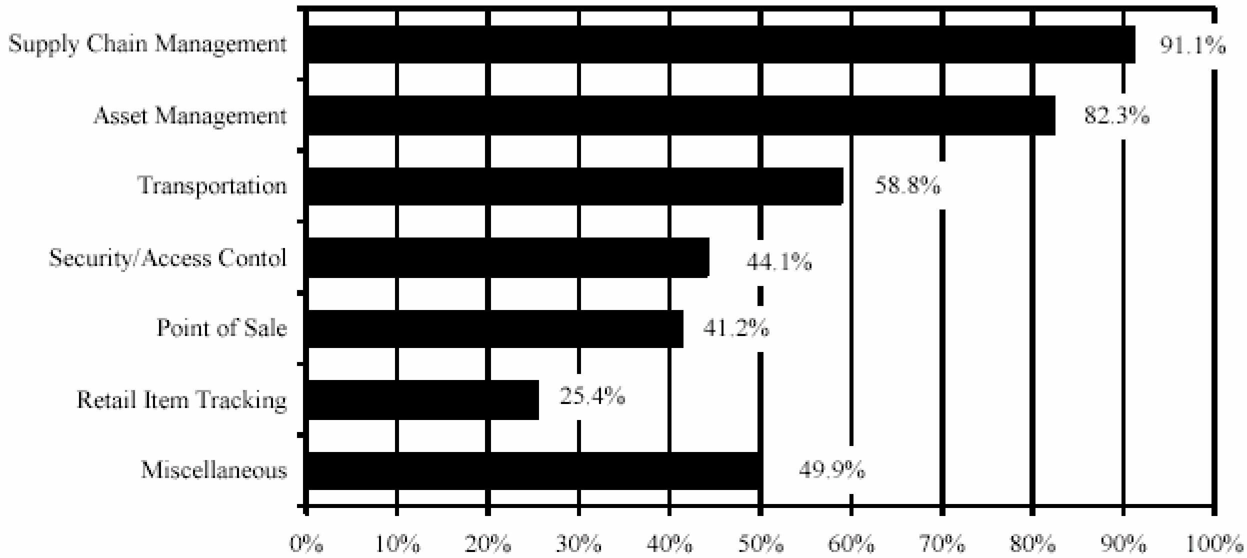
Since its introduction, over 60 years ago, RFID technology has not found a “killer” application. Vendors and end users are waiting for a “killer app” to emerge (SAVI’s security?). Regardless, the benefits of RFID are being realized across a multitude of applications and industries. The trend may continue if tag prices drop and adoption increases with new applications emerging from usage of low cost tags (transponders). While the potential for RFID applications appear limitless, few applications have translated into consistent profitable opportunities because the price is often the barrier. The most mature and developed systems include security/access control, transportation applications such as rail car tagging, asset management and electronic toll collection (these 4 application clusters comprise nearly 73% of global RFID hardware revenue).

Long term revenues opportunities are strongest within the supply chain management segment supporting applications such as WIP tracking, container id, “cradle to grave” or product life cycle tracking and location. POS applications such as EAS and self check-out comprise a small fraction of RFID hardware revenues in 2000, but the market for these types of applications are expected to grow considerably, particularly as the cost of transponders decrease and as individual item level tagging becomes more prevalent in the next decade. The demographics of the end user respondents, indicates that RFID is reaching into organizations of varying sizes, revenue classifications and lines of business. About 20% of respondents currently use RFID, 25% are actively evaluating the technology and 55% are not using or evaluating the technology.

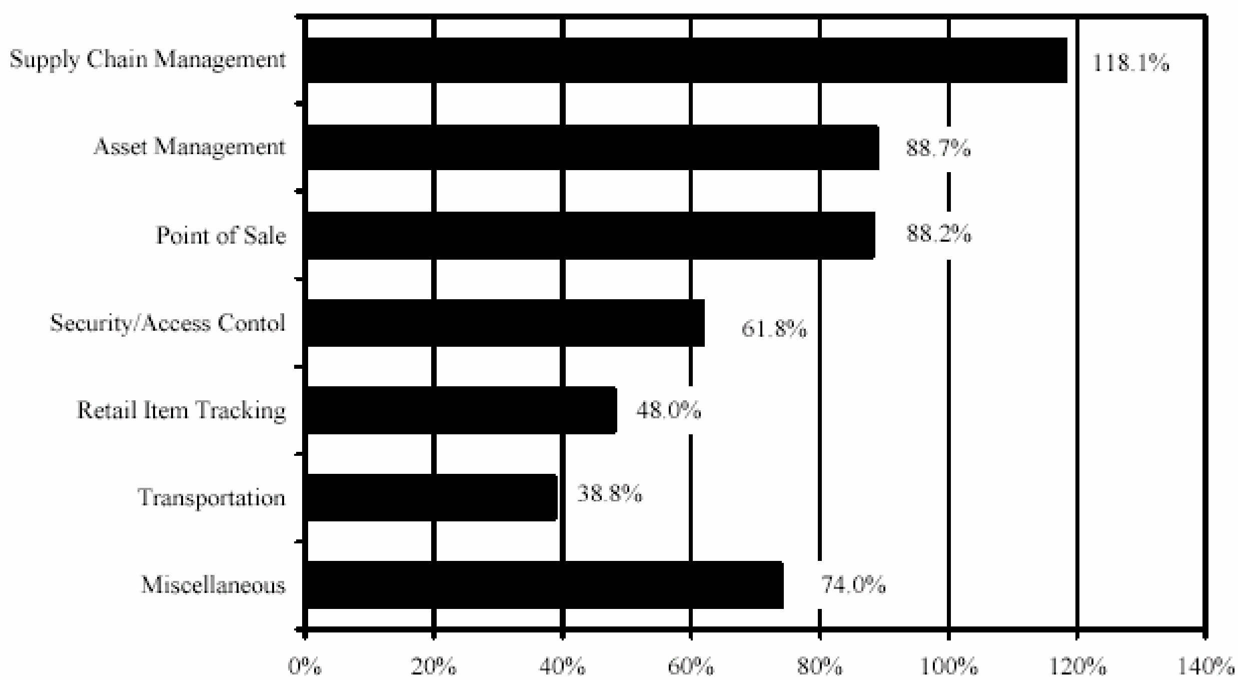


Respondents currently using RFID are concentrated in asset management, equipment tracking, aircraft id, ransportation ticketing, weigh stations. Users are supporting emerging applications such as, security, POS installations for self-checkout and EAS (theft, counterfeit protection). Rental item tracking applications and the benefits of RTLS to track assets are gaining grounds. **End users who are evaluating RFID**, are exploring to improve **supply chain management**. End users indicate limitless possibilities for RFID applications. End users believe in accelerated adoption as RFID technology develops, standards emerge and tag prices get cheaper.

Current RFID End Users Segmented by Application
(Percent of Respondents)



Current RFID Users and Evaluators Segmented by Application
(Percent of Respondents)



Note: Percentages sum to over 100% due to multiple responses.

While specific applications vary, most end users consider applications within the following general categories:

• Supply Chain Management: ideally used for the identification of (high unit value) products moving through an assembly process to DC and retail. RFID offers the durability essential for permanent identification of product carriers such as boxes, crates and pallets. Other applications within supply chain management include WIP tracking and delivery.

• Security/Access Control: movement and use of valuable equipment and resources can be monitored through transponders (tags) attached to tools, computers or embedded in credit card security badges. Home security call systems and building access are two types of security/access control applications.

• Transportation: transponders are attached to vehicles (aircraft, cars, trucks) which contain information about the vehicle and its contents. Transportation applications include aircraft, rail and shipping container tracking, public transportation ticketing and weigh station applications.

• Toll Collection: involves a transponder attached to a vehicle which transmits a code for a prepaid account.

• Point of Sale: electronic article surveillance, forgery prevention and tagging individual retail items.

• Baggage Handling: airline luggage/baggage is tagged with RFID transponders such as smart labels to allow airlines to track baggage from the moment a traveler checks in to his/her final destination.

• Asset Management: includes applications to monitor the flow of equipment within a building, terminal to tighten control over assets and hold accurate inventory of items, including individuals. Specific applications within asset management include records/document tracking, yard management and equipment tracking.

• Automobile Immobilization: an ignition key contains a tag. When the ignition key enters the ignition lock to start the vehicle, the reader is activated. Data exchanged with tag in key determines authenticity of the key.

• Rental Item Tracking: items which are available for circulation such as library books, video, DVD, can be tagged with a transponder which monitors the location of the item and contains data pertaining to the item.

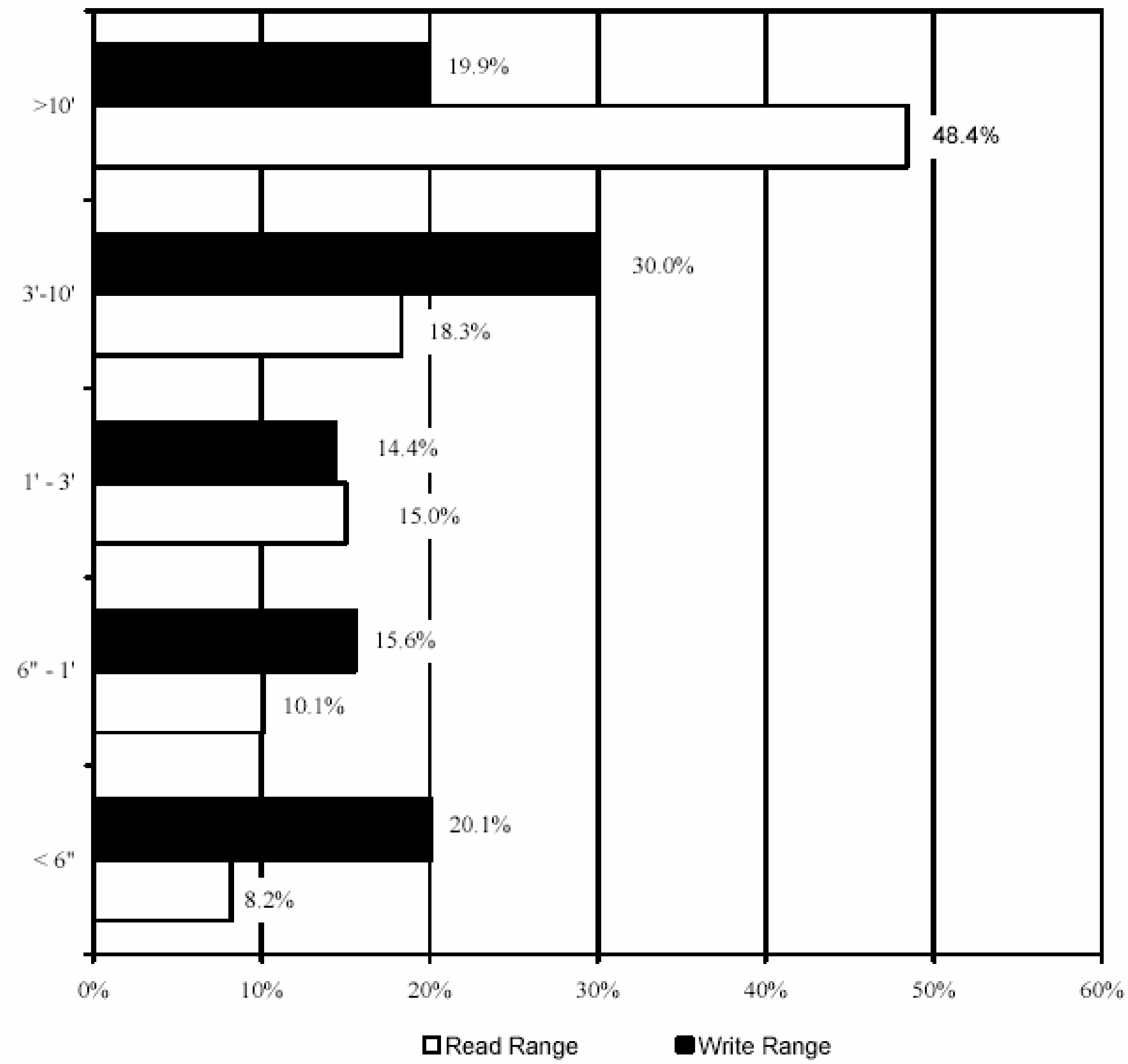
• Animal Tracking: breeding stock, laboratory animals involved in lengthy and expensive research projects, meat and dairy animals, wildlife and pets, present unique identification problems helped by RFID solutions.

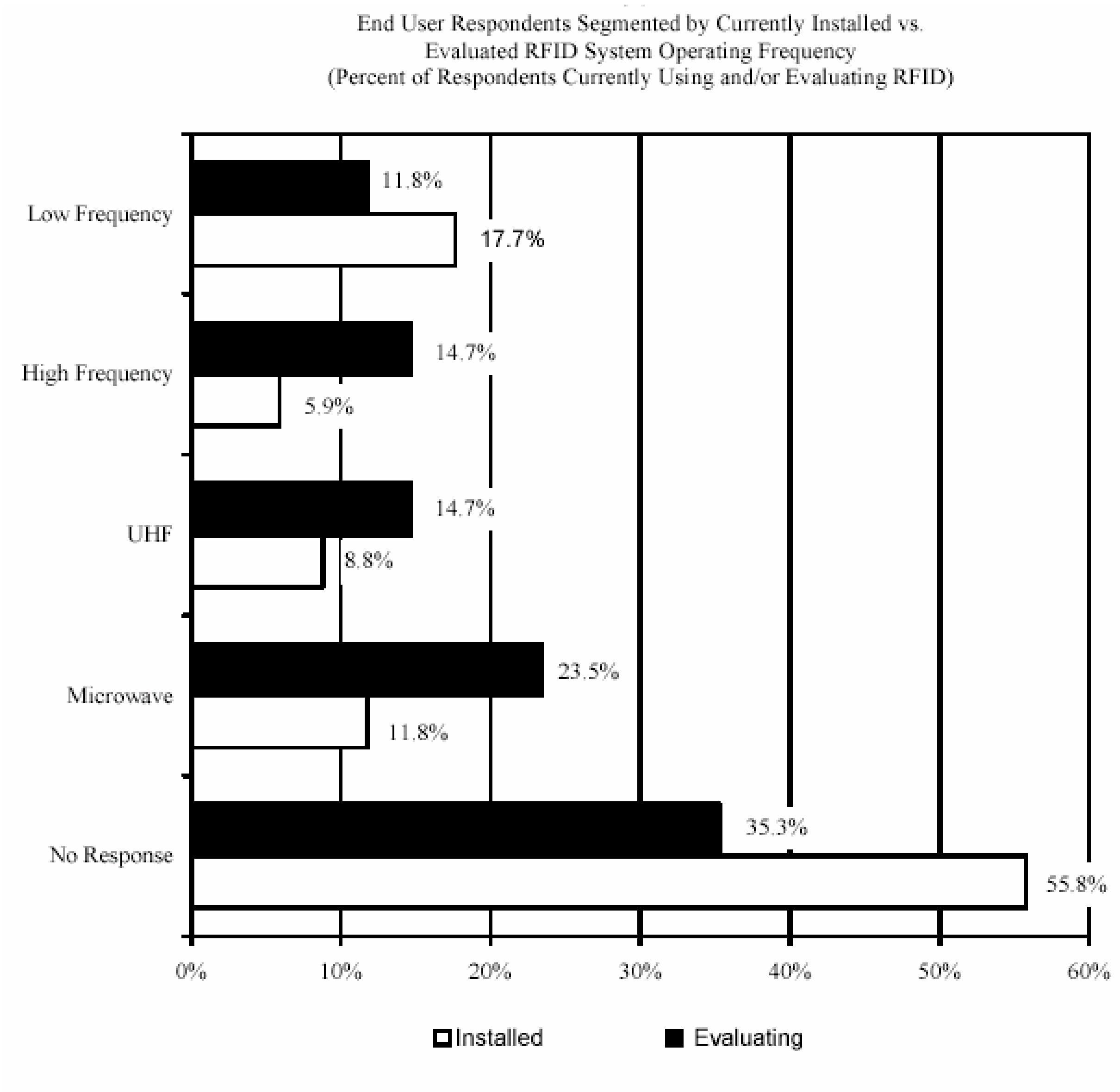
• Real-Time Location Systems: RTLS applications track items or individuals in real time to provide the most up-to-date location of an object along with any relevant data (generally expensive: about $50 per active tag).

Specification of RFID system is an integral decision for end users and depend on operating environment and application. Frequency regulations are important for international operations. Read-write range is correlated to power output, which is also subject to regulations, antenna size and interference. Current and potential end user read-write range requirements differ from application to application and influences the selection of frequency and technology. Other factors influencing the selection of an RFID system include:

• type and number of item(s) being tagged
• surface types of the items being tagged
• number of reads required during a transponder's life
• read rate
• operating system
• environmental conditions
• if using smart labels, the type of smart label and adhesive requirements.

End User Respondents Segmented by Current Read and Write Range Specifications
(Percent of Respondents Currently Evaluating RFID)





One of the largest obstacles to widespread adoption is the cost of an RFID system. The threshold of what end users are actually willing to pay for RFID system components (tags, readers, software, services) remains a mystery. Cost per tag is dropping and less expensive readers with greater functionality may be soon available. End users prefer that prices drop further. For example, compared to the average purchase price of hand held and fixed-position readers of current RFID users, end users evaluating the technology require lower price.

End User Respondents Segmented by Average Purchase Price for RFID Technology
(Percent of Respondents Currently Using and/or Evaluating RFID)

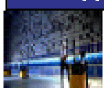
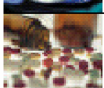
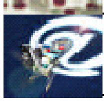
	Installed	Evaluating
Transponders	$0.70	$0.72
Hand Held Readers	$530.00	$370.00
Fixed Position Readers	$2,900.00	$1,980.00

Source: Venture Development Corporation (Harvard Business School) October 2001

RFID Integration Strategy

SCM applications are affected by product and events data transparency from RFID integration. Applications such as advanced planning tools, decision support systems and event management will derive greater efficiency. Pervasive storage of information (Business Intelligence) will improve SCM, CRM (POS data for campaign management) as well as PLM (spare parts; mean time between failure). Other beneficiaries are WMS, logistics and PLM that track and trace assets (field replacable units, capital repairable parts).

In brief, SCM functions, are dependent on information about inventory (raw materials, components, finished goods, replenishment), location of goods in transit and end-user demand (forecast). At each point of these business processes (cycle counts, goods receipt, pick, pack, delivery) there is human intervention for data collection (bar codes). RFID integration eliminates inaccuracies and offers the possibility of real-time data that could fine tune retail processes such as cross-docking and trans-shipment. Raw data converted to information (Business Intelligence) feeds transactions. These data feeds act as “monitoring agents” within the Intelligent Agents scheme for an emerging adaptive supply-demand management business network.

Application area		Applications	
	Warehouse Management	- Goods Receipt Management - Forklift Operation Records	- Picking - Automated Inventory Management
	Transportation Management	- Container/Palette Management - Confirmation of Transportation Status	- Sorting Processes
	Production Site	- Process Management - Material Management	- Production Control
	Linen Supply	- Merchandise Duration Management by Number of Cleaning Cycles - Merchandise Turnover Rates - Order/Delivery/Checking of Merchandise with Suppliers	
	Automotive Industry	- Vehicle/Customer management by Serial no.	
	Pharma Industry	- Lot Control - Expiry Date & Storage Condition Management	
	Retail Management	- Point-of-Sales (POS)	

To illustrate how specific processes may be affected or enhanced from RFID data transparency, the following selected [1] retail and [2] supply chain related event management processes are used as examples. The impact of RFID may be much more widespread than outlined in the table below. Business processes may evolve (BPR) as a result of RFID data transparency. This may introduce new nodes, eliminate or modify current processes, as we know now.

Select Retail Processes	Impact of RFID Integration ?
Supply Chain Management: Distribution Planning	
Plan & Design Distribution Network	Location of DC closest to key customer and maintaining JIT inventory to prevent stock-out may be based on aggregate forecast. RFID tagged products (pallet, case or item level) will improve forecast and could help re-design network based on accurate demand.
Definition of Stock Keeping Strategies	Loss from stock out may be prevented from accurate forecast possible with RFID integration.
Set Decision Rules for Network Optimization	RFID data feed to monitoring agents (Intelligent Adaptive Agents) could set rules as well as trigger new rules that may be necessary due to seasonal or local changes in consumption.
Operational Expense Tracking	Lower carrying costs due to accuracy of forecasts from RFID data could reduce operational expense.
Supply Chain Management: Inventory Management	
Retail & Cost Method Valuation	
Stock Management	Greater transparency of product consumption and stock at hand will improve stock management.
Physical Inventory	Close approximation to “inventory-less” scenario possible from accuracy gains based on RFID data.
Logistical Variants	
Multiple Transaction Quantities	Fine tuning possible.

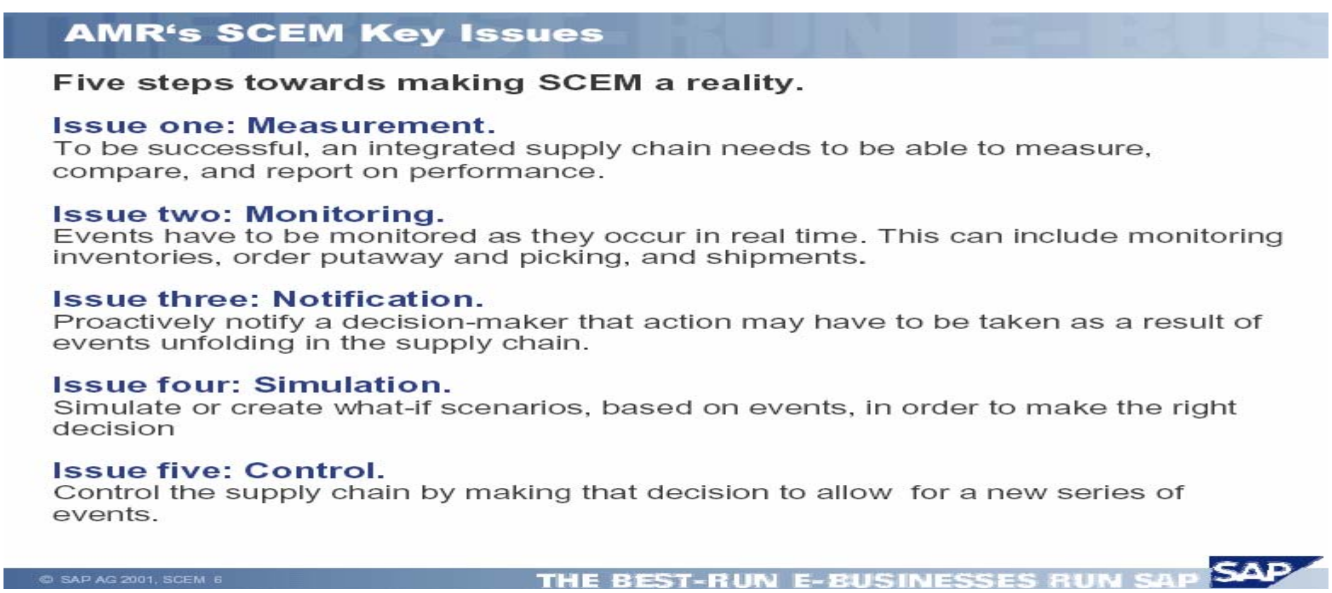
Select Retail Processes	Impact of RFID Integration ?
Supply Chain Management: Warehouse Management	
Goods Receipt Planning & Processing	Automated process reduces errors and human costs.
Cross Docking & Flow-Through	Key impacts on this dynamic process and on its extension (trans-shipment) due to RFID data that may be obtained in real-time and coupled with event manager (SCEM Transport) to optimize delivery.
Workload Forecasting & Scheduling	Better understanding of goods consumption allows better planning and scheduling.
Storage Management & Direct RF Enabling	Eliminates bar code usage and improves efficiency.
Robot Control	Can be programmed to learn and adapt based on real time data.
Handling Unit Management	
Supply Chain Management: Shipping & Transportation	
Plan & Optimize	Improved visibility of finished and unfinished goods in the supply chain enables cost effective (TL v LTL) planning.
Transportation	Improved visibility of finished and unfinished goods in the supply chain enables cost effective (TL v LTL) planning.
Route Scheduling	Real time RFID data could dynamically re-distribute goods based on requirement.
Carrier Tendering	
Yard Management	Active RFID tags and RTLS systems may offer solutions.
Delivery Process & Tracking	Vastly improved by RFID.
Picking & Packing	Improves accuracy.

Select Retail Processes	Impact of RFID Integration ?
Supply Chain Management: Replenishment	
Stock Planning with Safety Stocks & Presentation Quantity	Cycle count accuracy and real time inventory data offers precision planning capabilities.
Scheduling of Replenishment Frequency	Cycle count accuracy and real time inventory data offers JIT replenishment and adaptive response if consumption level changes (Adaptive Agents).
Optimization & Rounding	Improves
Collaborative Replenishment & VMI	Accurate picture of product flow-through at retailer enables better management of inventory and replenishment by vendors.
Sales Channels: Store Business	
Store Inventory Management	Accurate product flow-through at retailer enables better management of inventory. Reduces stock-out and loss of opportunity.
Store Replenishment	Accurate product flow-through at retailer enables rapid replenishment. Reduces over-stocking as well as stock-out.
Sales Order & Billing	
Staff Management	
Space Management	"Smart" shelves improves retail visibility of product flow (eg: cosmetics wall at P&G).
Returns & Repair Management	RFID tagged individual items will carry accurate POS data & warranties or other service info.
Sales Audit	
Cash Register Integration	POS data from RFID tagged objects may be stored in data warehouse to manage future campaigns/promotions. Missing object from shelf not correlated with POS may indicate theft or breakage.

Select Retail Processes	Impact of RFID Integration ?
Sales Channels: Store Business	
Tender Management	
Down Payments & Discounts	Data analysis of product sales (BI) could create instant discounts to promote goods.
Mobile Devices	Could be used as RFID readers.
Promotion Management	POS data from RFID tagged objects may be key (BI) to manage successful promotions.
Sales Channels: Catalog Sales	
Campaign Management	POS data from RFID tagged objects may be key (BI) to manage successful campaigns.
Integrated Product Catalog	
Catalog / Layout Processing	
Telesales	"Push" strategy could be focused from analysis of buying habits (POS data).
Order Execution	
Profitability Analysis	
Procurement: Forecasting & Allocation	
Forecasting	Accuracy of forecasting is a key benefit derived from RFID use.
Collaborative Forecasting	Accuracy of forecasting is a key benefit derived from RFID use.
Causal Analysis	
OTB Management	
Allocation Management	

The application components and RFID interfaces must seamlessly integrate with RFID hardware based on open architecture. Hardware agnostic interface eliminates proprietary protocols of RFID hardware, making it possible to integrate RFID applications in a manner that is back-end software agnostic. Several processes core to supply chain event management may be affected and enhanced by RFID integration. There may be some overlap of these business processes with planning tools and decision support solutions. Select examples of RFID integration possibilities with SCEM are discussed below. The importance of RFID-SCEM is strengthened by the analysis that SCEM could expect an 88% growth rate over the next 5 year period.

RFID inclusion offers accurate identification of objects associated with events (shipping, receiving). Such data analysis may generate useful information that has associated business value (event management). Decisions based on such information regarding next or prior steps (purchase, response to tenders) in supply chain or supply chain events may make business processes (goods production) adaptable to market demand.



RFID integration aids SCEM key issues for greater efficiency and accuracy of SCEM functionality:
[1] measurement metrics on performance (shipment, delivery, handling)
[2] monitors with precision (whole counts instead of inventory cycle counts, pick/pack, assortment)
[3] notification and alerts based on real time product/goods location (ASN; Inventory Early Warning Agent)
[4] simulation scenarios can use RFID data (from BI) for "what if" analysis
[5] control and management through "management agents" that can use RFID data.

Speed is driven by real time information, such as automated data entry from RFID integration (as opposed to manual checks and bar-code scans). RFID data feeds "intelligent monitoring agents" to respond immediately by creating alerts or notifications that is "aware" system wide rather than restricted by process specificity.

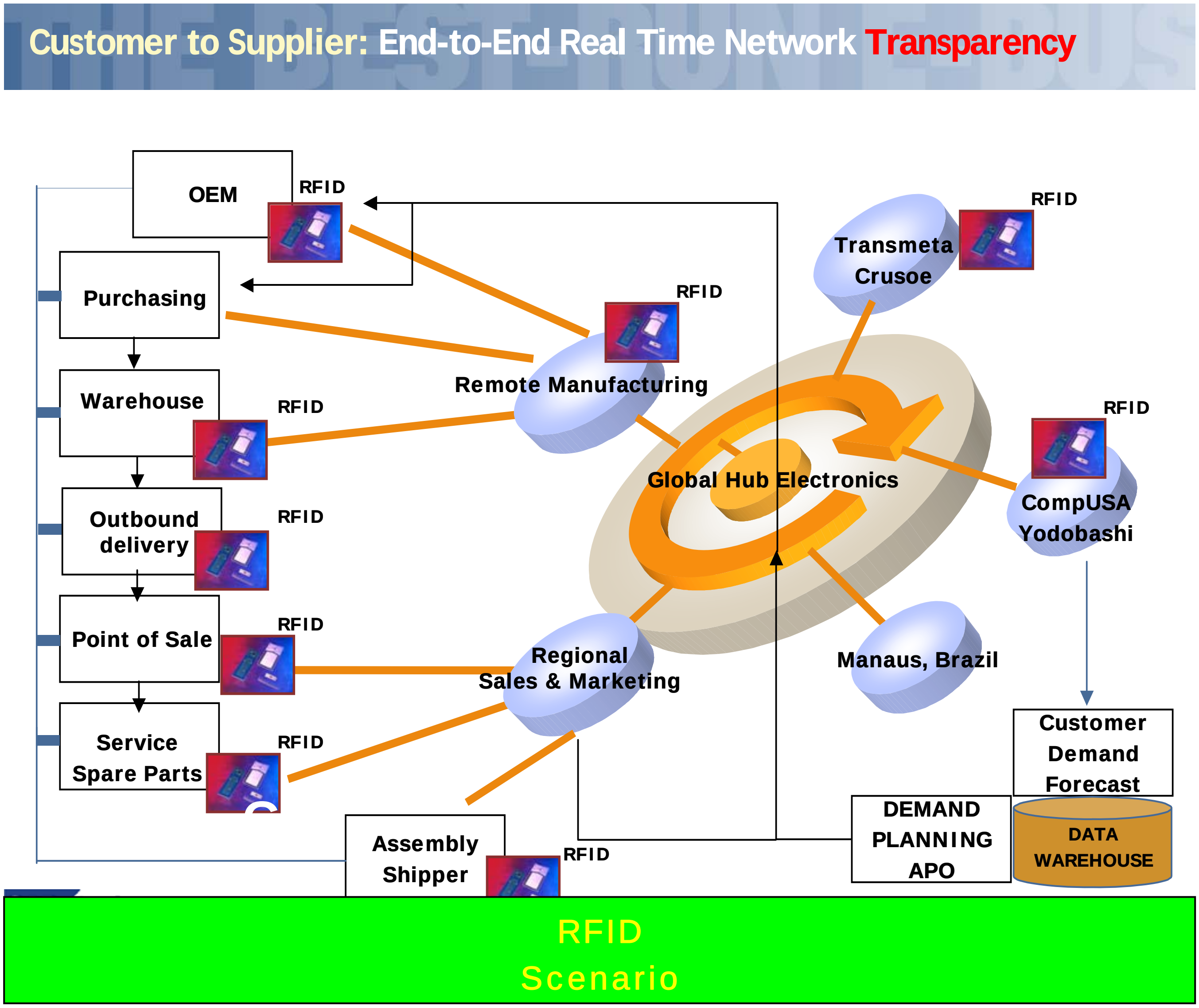
RFID tags push product information out at steps designed to receive RFID data. Customers in "attendant-less" environments (for example: **e-commerce**), are still being "served" through automated data collection that may be used (BI) for service (repair, warranty) without the hassle of receipts and bills. The virtual 1-2-1 attention is relevant with **mass customized** goods when costs for human attention increases overhead.

Transparency of product movement (DC to retail, storage to shelf, POS) data is possible with real time RFID data being shared with the members of the suuply **network** (partners and vendors) and is particularly key for VMI. Dynamic flow of critical information is severely restricted if bar-code scanners and other human-based systems are used.

In the networked environment and demand management, data is the primary layer that drives information, above, (through filters, Agents, rules) to the application layer (business logic, execution). Real time and accurate data from RFID is an enabler (Information Agent) of collaboration, fulfillment. Demand planning is highly reliant on such data and its aggregated accuracy. The ripple effect of greater transparency of goods and products among the network of suppliers, manufacturers, distributors, retailers and consumers influence procurement and manufacturing as well as elements in supply chain coordination, planning and execution.

Positioning systems (RFID, UWB RTLS, GPS, GIS) coupled with Intelligent Agents (monitor, coordinate, control manage) are catalytic in the paradigm shift from traditional supply chain management concepts to adaptive network strategies. To monitor events and notify, requires information about goods or products (RFID). To notify systems about changes, requires the action of an “Adaptive Agent” that bases its decision, in part, to create an alert or notification based on data from an information agent (RFID). Adaptive Agents (AA) include new information in a continual learning process that augments its ability to adjust. Transparency of data (key source of real time data is RFID) empowers collaboration that delivers greater business value. RFID data (as Event Handlers) feed Event Manager Engine and may be regarded as information agents to Event Processor which ultimately influences Rule Processor output (alerts, responses, performance).

Real Time RFID data brings business value across entire Supply-Demand Network



MIT Auto ID Center (www.autoidcenter.org)

Auto-ID Center at Massachusetts Institute of Technology is [1] "creating the next wave of the e-commerce revolution by linking the physical world to the Internet". The basic concept is to assign a number or ID to every physical object. Data on this object can than be looked up on the Internet with the ID number as a reference. There are three main initiatives to achieve this:

- **ePC - Electronic Product Code:** A numbering scheme designed to be able to identify all physical objects.
- **PML - Physical Markup Language:** A language to describe any physical object (PML is sometimes also referred to as *Product Markup Language*). Based on XML.
- **ONS - Object Naming Service:** A lookup service to link an ePC to corresponding page ("Object Home Page") with the data about the object.

ePC - Electronic Product Code

"The Electronic Product Code (ePC) is a numbering scheme that can provide unique identification for physical objects, assemblies and systems. Information is not stored directly on the RFID tag - the ePC code serves as a reference for networked (Internet-based) information. In other words, the code is an "address" which tells a computer where it should go to find information on the Internet."[1]

The ePC is a 96-bit number with a fixed 8-bit header field. This header is used as a version number defining how the other 88 bits are partitioned into data fields. In the proposed ePC configuration, the remaining bits are divided (unequally) into 3 data fields:

Header	Manufacturer	Product	Serial

A fact sheet [2] about ePC on the Auto-ID Center's Web page and a white paper [2] at the same site contain two slightly different definitions for data field names as well as for the size of individual fields, although the semantics are the same. The white paper numbers are more relevant at present.

Fact Sheet	White Paper	White Paper	White Paper
Header	Header	8	256
Manufacturer	ePC Manager	28	> 268 million
Product (SKU)	Object Class	24	> 16 million
Serial Number	Serial Number	36	> 68 billion

[1] Definition taken from http://auto-id.mit.edu/research/epc_code.html

The white paper's terms are generic, while the fact sheet uses terms applicable in retail industry (P&G is founding sponsor of Auto ID Center). They define a hierarchical system to assign & manage individual ePC. Each manufacturer can assign ID's autonomously to its products and then again serial numbers for all individual instances of each product. Who would be the authority to assign the manufacturer ID's is not defined, but likely this would be an industry organization like the UCC [4], who is currently responsible for assigning the ubiquitous UPC barcode numbers.

Adopting the ePC is no problem if UCC accepts it as standard[2]. Switching from the UPC-12 or EAN-13 codes used today would be easy, since ePC is a superset of the UPC/EAN codes, also distinguishing between Manufacturer ID and Product ID.

The data fields are large enough to satisfy the goal that each individual object can be identified. This will be possible for the foreseeable future without need to reuse previously assigned numbers. A few calculations show that this should be the case.

Sidebar

UPC : Universal Product Code

The UPC code is the most common standard in the US for product barcodes. It is a numeric sequence consisting of four sections:

Section	*#Digits*
Numbering System	1
Manufacturer ID	5
Product ID	5
Check Character	1

Variants of the UPC-12 code include the EAN-13 and EAN-8 code. For more information see [5], [6], [7].

- As per the Annual Report '00 [8] of the largest bottler in US, Coke sold 3.8 billion "unit cases" of drinks. One unit case is 192 ounces and 42% of all sales are Coca-Cola / Coca-Cola Classic. If Coca-Cola and Coca-Cola Classic is one product and assume that all Coke was sold in 16 ounce cans (there are other containers; bottles of various sizes), the serial number space as defined in the fact sheet is large enough to last for 57 years.
- The Perrier [9] bottling plant produces 3 million bottles of Perrier per day. Using the name space size as defined in the fact sheet, this would last for over 1000 years.

The examples above consider only serial number. Even if the size of the serial number should become a problem, a manufacturer still has enough product numbers to cover for this. In the worst case, a manufacturer may apply for additional manufacturer ID (for example to distinguish between regions or even single factories).

Product Mark-Up Language

According to the Product Mark-Up Language fact sheet [10], the Product Markup Language (PML) is a standard "language" for describing physical objects based on the eXtensible Markup Language (XML). Data about object will be stored in PML. Development of PML is in progress[3], but it is intended to handle following types of data:

- Static data: Data that doesn't change during an object's life time (name, production date, expiration).
- Dynamic data: Data that changes during an object's life time. Examples are temperature and pressure as well as relations to other objects (e.g., bundling and packaging with other objects). It is unclear however how objects can keep this information up to date. This is only possible while the object is close enough to sensors and equipment connected to the Internet, which could be a problem for frequently changing data like temperature during transportation[4].
- Instructions: Instructions tell other machines how to process an object. This could be a cooking recipe for a food item that the microwave oven uses to cook the product, or instructions for industrial robots that tell the robots what the next work items for an "unfinished" product are (car in assembly line).
- Software: Programs to show how an object behaves (for simulations), "driver" software (printer driver) and other software necessary to interact with the object. Instructions may be provided in program form.

[2] Note that the UCC is one of the sponsors of the Auto-ID Center.

[3] That is probably the reason why PML is referred to as *Physical Mark-Up Language* in David Brock's white paper [11].

[4] It is though possible to store a temperature history locally with the object, and transmit the whole history data whenever a network connection is available, as shown with the "IceCube" used in the Aware Goods project [12].

In order that data stored for an object can be used by as many applications as possible and to enable analysis across several objects of different type, the nomenclature used for single fields in PML will be generic, just defining an abstract concept. Abstract field names can easily be converted to better understandable names for a specific application domain (‘configuration’ construct with ‘timestamp’ interpreted as “assembly time” for a car or “harvest time” for produce). The same applies for measurement units. While basic PML should use SI units [13] to avoid ambiguities, transformations to other systems (transformation from meters to feet) can be achieved through software. Note that the transformators for such data and field name conversions are also accessible and shareable over the net (in the form of XSLT stylesheets).

PML will be able to show hierarchies (BOM or a truck (object) with pallet (objects) load containing boxes). As is obvious in case of truck, not all data for an object is stored in one PML file (information is distributed). The manufacturer of the truck (or current owner) stores a PML file with basic information and hyperlinks to PML file describing the pallets currently on the truck, which in turn contain hyperlinks to the product on the pallets. The PML files for products are stored at the site of product manufacturer and can contain hyperlinks for product parts from third party suppliers. Common information about a product can be stored in a single file (or database). Only information specific to singular object is stored with ePC containing a hyperlink to the common product information. From the Coke example: common product information (name, ingredients) can be shared, while only data (production date, current location) may be stored individually with ePC.

Object Naming Service

ONS links ePC with associated PML files (tell computer systems where to locate information on Internet about any object that carries an ePC[5]). ONS works similar to DNS (Domain Name System). While the DNS translates domain names into IP addresses, ONS translates ePC’s into URL’s. Both are structured hierarchically in order to be scalable. ONS is essentially a DNS with a configuration script file. Scalability is the main problem to be solved to make ONS viable. It is easy to see that by deploying ePC and ONS widely, it would be far bigger than the Internet is today[6]. AOL serves about 10 billion web pages daily [15]. ONS must be capable of much bigger workload. Being able to resolve billions of ePC’s daily for trillions of objects may not be trivial.

Data on Net vs Data on Tag

The MIT Auto-ID Center approach is elegant and compelling. Having all information on network and linking to it from physical objects results in a conceptually simple way to identify things and link information together. The research community in general has favored this approach (see also [17], [18]). In the real world the approach of storing necessary data on the tag itself is more common. Scenarios presented by RFID vendors at FrontLine Solutions 2000 conference [19] favour writing information to the tag for commercial self-interest. One reason for skepticism is that network availability cannot always be guaranteed. The MIT Auto-ID Center approach “enables minimal performance tags to be used while increasing the robustness, scalability, and flexibility of the system.” [20] While it is certainly true that “all data on the net” approach makes it possible to use low-cost tags and leads to maximum system flexibility, it deserves more testing and analysis in view of:

- Connectivity: An online connection is required for all real-time applications.
- Security/Availability: "Object Home Page" must be accessible through firewalls.
- Safety/Data Consistency: Data contamination (database contamination)
- Performance: Access to data over network is bandwidth-dependent.
- Scalability: Homepage for every object could result in trillions of pages (generated dynamically).

AIDC suggest that true read-only chips can be used. Tag ID is set by the chip manufacturer. WORM (“Write Once, Read Many”) chips are needed. ID can be programmed with ePC at the point where the tag is applied.

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[5] From the ONS Fact Sheet [14]

The opportunities and flexibility of ePC-PML-ONS is so great that it is suited to be a global standard. The ePC should replace the current EAN/UPC codes. At first, however, the serial number field of ePC might often not be used, but manufacturer and product fields can be easily adopted from current EAN/UPC codes. Later, it may not be necessary to track every individual item (soft drink can). General product information identifiable through the product id may be suitable. In other scenarios more critical information than just ePC should be written on tags (expiration date for drugs, batch number of chemicals). Business process critical information that needs to be available locally, without network connection, may be on tag, while other data on network. This mixed approach may evolve to become the most powerful approach, since it gives offers flexibility without negative effects regarding performance [25].

The adoption of ePC-PML-ONS could mean the following for ERP and business application software vendors:

- Systems must handle ePC. Such a change is more than switching from material numbers to UCC numbers
- Systems must process PML. This includes both generation of PML for objects managed in ERP as well as "understanding" the information in PML files received from other systems over network. This may be achieved with trans-coding between data formats (with Business Connector such as WebMethods).
- The future RFID framework must have components for processing ePC, PML and access data via ONS. This would enable local process control and improve scalability.

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Early Users - Case Studies:

[0] Example of ROI

[1] Gas Company

[2] Ford Motor Company

[3] Cell Phone Manufacturer

[4] Seagate: Disc Drive Manufacturer

[5] Newspaper (News Print)

[6] Meat Processing Plant

Example of ROI

Activity	Area	Benefit of RFID over Barcode Operation	% Cost Reduction
Storage	Supplier	Automated, accurate inventory management	28
Despatch	Supplier	Automated checking process	26
Claims Management	Supplier	Automated, accurate data recorded decreasing claims generated	18.5
Cross-docking	Hub	Automated checking plus reduced paperwork decreasing administration	18
Receipt	RDC	Automated checking	9.4
Claims Management	RDC	Automated, accurate data recorded decreasing claims generated	20.8
Despatch	RDC	Automated checking process	5
Storage	RDC	Automated accurate inventory	21.7
Receipt	Retail	Reduced paperwork	2.8
Storage	Retail	Automated inventory management	16.3
Replenishment	Retail	Improved efficiency	4.5
Losses	Retail	Reduced loss (due to out of code, overstocking) from inventory visibility	11
Inventory cost	All	Reduced inventory due to visibility through chain	Average 55%
Improved asset utilisation	All	RTP improvements in utilisation	Average 30%

Total savings from a RFID linked supply chain cost structure compared to barcode driven supply chain cost structure **8.1**
(Includes all implementation costs associated with RFID solution using Philips i-Code chips and related hardware)

Note: Benefits shown represent total savings achieved for activity (capital and system development costs of installing RFID solution are included). It is **62% cheaper to receive at RDC using RFID. W**hen implementation cost of RFID (readers, tags, software) are included, the cost benefit is 9.4% in terms of RFID ROI. Information contained here is from an actual customer implementation case study. But RFID 802.11b is not a panacea!

Gas Company

A major gas company operates numerous gas substations throughout an environmentally harsh region. Within the substations are many valves regulating flow and pressure of natural gas through pipelines. The technicians visit various substations and examine numerous valves to check on maintenance requirements.

- Physically examine each valve and fill out technical/maintenance checklists (condition of each valve)

- Write maintenance notes and call office for valve repair history, maintenance requirements.

- Wait to receive data and subsequently perform the necessary repairs or services. Write final report.

Technician returns, submits report to document maintenance (human error). To affix paper history document to the valve itself would be inappropriate due to harsh environment.

Application Requirements:

Simplify valve maintenance:

- Implement tracking and identification system that would remain on the valve

- Make it unnecessary for technician to contact main office for valve maintenance

- System must withstand harsh environment

Solution:

Mount HMS-150HT tag (50mm) on valve to scan with hand-held HMS814-PC2000 Passive Read-Write.

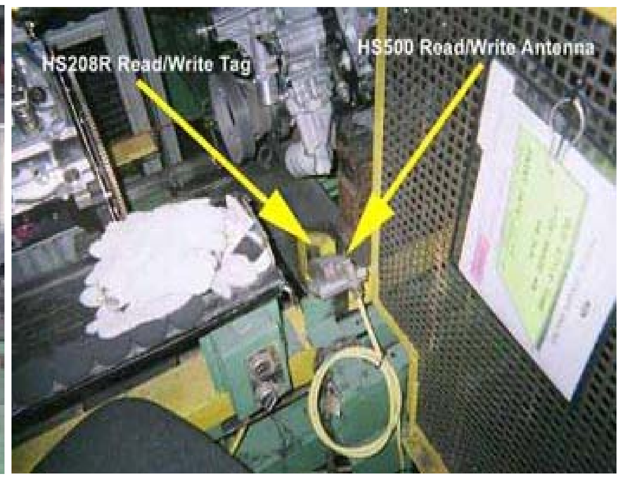
Benefits:

- Immediate access to valve data.

- Eliminate possibility of human error during manual administrative documentation

Ford

Ford Motor's Essex Engine Plant, in Windsor, Ontario, Canada, manufactures eleven different engines (manual versus automatic, 3.8 L vs 4.2 L, 98 vs 99 model year and South American vs North American). In order to maintain quality control of the approximate 700,000 engines produced at Ford Essex annually, an automatic data capture system was required to ensure product traceability and quality. Ford needed a tracking and identification system that could store build information (eg: whether a piston was installed correctly or a nut was torqued correctly).Tracking mechanism had to endure the same conditions as the machined engine parts (rinsed in hot soapy water, dried at 140 F and sprayed with oil).



After an in-depth analysis of the various automatic identification capture technologies in the marketplace, Ford Essex decided RFID was the solution. RFID tags are bracket mounted directly onto the engine block after the engine has completed the piston bore station. Communicating to the tags are Read/Write Antennas. At the onset of the manufacturing process, the antennas transmit such data as serial and model numbers. As the engine is transferred to the assembly line, where multiple lines converge (for example: cams and pistons), the data on the engine tag is transferred to another RFID tag which is mounted on the engine pallet. One antenna reads the data off of the engine tag and transmits this information to a controller. This same data is then transmitted via another antenna to the engine pallet tag.

As the engine travels through each of the approximate 2000 work stations, manufacturing process data is transferred to the tag as Pass/Fail. As each station is completed, an antenna writes manufacturing data to the RFID tag. As the engine pallet approaches the next station, an antenna reads the tag to confirm the engine successfully completed the previous station. If the tag has a "Fail" reading, the engine continues through the process but without being worked on at subsequent stations, until it reaches the repair bay. Ford Essex was able to use the RFID system to streamline the engine repair process. If an engine failed the final test, engineers no longer had to tear apart the engine to determine the problem. Instead, the engineers were able to analyze the stored build data in the RFID tag to pinpoint the step where the defect was. Ford used bar codes to track engines several years ago but the labels had difficulties surviving in this harsh environment and data cannot be written on to a bar code label.

Cellular Phone Manufacturer

Description:

The phones are placed in totes and are cycled through 15 stations every five minutes, with the totes communicating to a robot at each station.

Application Requirements:

The end user required identification and tracking system:

• to be extremely durable since the id system will need to perform several thousand communication operations

• have a large memory capacity since tags will be used to carry detailed information (internal manufacturing id codes, information gathered from previous station, number of bad or good assemblies and routing information).

Solution:

Sixty Readers/Writers used for the final assembly of cellular phones. Readers communicate the build and routing information to over 175 Read/Write RFID tags (mounted on pallets carrying phones).

Benefits:

• RFID tags enable the end user to make dynamic changes to the assembly process

• Perform approximately 3000 Read/ Write operations per shift

• Retain data from the previous workstation which assists in WIP tracking

SEAGATE

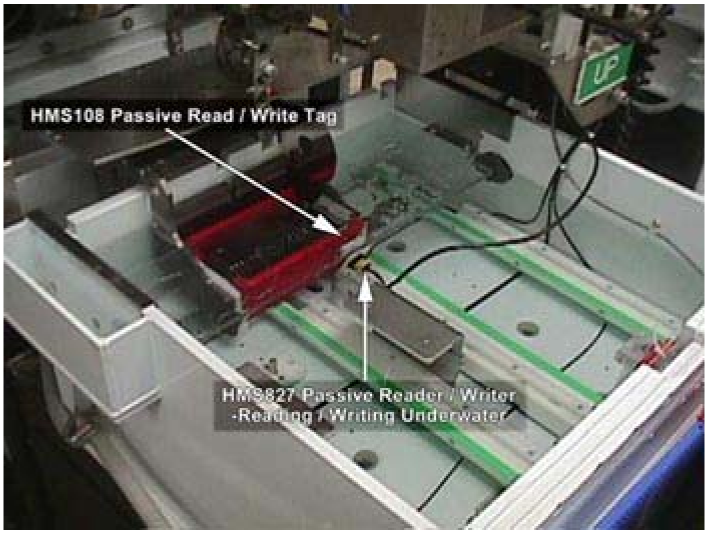
Seagate is recognized as the world's largest manufacturer of disc drives, magnetic discs, read-write heads and an innovator in tape drives. The $7 billion dollar Silicon Valley giant employs 86,000 people and has numerous production sites world-wide. One such site is the Seagate Recording Media Group (RMG) in Milpitas, California, responsible for producing discs, which are the media used for storing data in Seagate's disc drives. RMG facility manufactures approximately 100,000 discs per day (customers HP, Dell, Compaq).

"Product Traceability" project goal was to ensure each media disc is monitored at every step of the production process. This meant monitoring the thousands of cassettes, which are the carriers for the media discs, as they are transported throughout the production facility. Each cassette is tracked and identified as it moves through the various processes. It takes 48 hours for the cassette to complete all of the approximate twenty processes. With thousands of cassettes undergoing critical processes simultaneously, over a fairly long period of time, it was imperative that a durable and reliable Product Traceability system was implemented.

Initially Seagate used paper travelers with bar code labels for tracking and identifying the thousands of cassettes which are moved around the RMG facility each day. Traceability was not accurate because tracking using paper travelers involved human intervention. In addition, the issue of paper travelers contaminating the Class 10 clean room environments was a concern. At RMG facility certain areas have particle counts as low as ten particles (0.5 micron or less) per cubic foot (a Class 10 environment). It is critical that contamination sources are eliminated. Removing paper traveler removes a contamination concern.

Seagate wanted racking and identification system to store production information (completion of various processing stages) on the cassette itself. The ID system had to be able to confirm that each cassette (before entering a given processing center) had successfully been processed through all the preceding operations.

After an in-depth analysis of the various automatic identification capture technologies in the marketplace, Seagate decided RFID was the solution. In Seagate's application, the RFID tag is mounted on the cassette.



Newspaper

Application:
Paper Tracking
Maintenance Records

With an average market penetration of over 1.7 million readers, the Atlanta Journal-Constitution (AJC) newspaper has the second highest readership in USA. Tracking all the paper being handled is a task.

Using only a manual “pencil and paper” tracking system, targeted rolls of paper (2000 lbs) were delivered to their proper printing station. Different qualities of paper, such as glossy, newsprint and front-page need to be delivered to specific machines. Tracking the quantity of paper that is on the print floor at any given time is also key. With the printing press operators arbitrarily using paper rolls as necessary, there was no accurate way to track this information accurately.

Solution: tracking system that could identify the workstations where the paper was required and exactly how many rolls of paper were on the print floor at any given time(100% accuracy).

In order to achieve the specific tracking needs for this application, it was decided to mount the Active RFID Read/Write tags underneath and in the center of the 16”W x 30”L steel carts that are used to transport the various paper rolls throughout the printing facility. Written to each tag is a specific cart id number which identifies which type of paper is on that cart, as well as the most recent maintenance date for the cart. This information is logged into the main database every time a cart passes a specific antenna zone. Also, whenever a cart is taken in for maintenance, the maintenance information is written to the tag, keeping all records current. Antennas were mounted inside pre-existing holes in the ground. A phenolic insert was placed in each hole to help protect the antenna from debris, as well as to help shield it from any interference from surrounding metal in the area. The antenna was mounted underneath a concrete and metal shelf, about 1” off of the floor. The antennas were located along all the travel routes of the various paper rolls (storage warehouse to press). As the carts loaded with paper rolls pass over the antennas in the floor, the cart id number stored on the tag is read by the antenna and transferred to the database (locates where the carts are at all times). This enables to track and see if the correct type of paper, verified by the cart id number is at the correct printing press. Also, since there must be a specific number of carts out on the printing floor at one time, as the tags are read by the antennas, paper roll usage at any given time can be accurately determined. Another benefit of using an RFID system is the ability to track the consumption of different types of paper on specific machines (different machines work better with one type of paper as opposed to another). AJC can determine which specific paper type is going to which specific printing machine and calculate just how long paper rolls last on each machine. This helps to minimize waste and increase output of each workstation. It helps determine inventory levels.

Meat Processor

Application Description:

Improve product tracking process. Bar coding was out of the question, since the processes involved intense heat and extended refrigerated periods.The processed meat is packed in stainless steel metal tubes. The tubes are stacked on a mobile rack for easy transport from the blast area to the smoke house to the cooler room, and then to be sterilized. With 250 racks in one plant it is crucial for the end user to know exact location and stage in the meat processing cycle. It is important for the end user to have accurate weight information, since throughout the process, packaged meat is susceptible to moisture loss which will affect volumes and profit. In order to monitor weights, the end user used a manual written process. A cardboard checklist was attached to the rack and each time the rack was re-weighed, someone had to write the weight on each card. This process was both time consuming and error prone. If the tracking card was misplaced, the entire rack of processed meat must be destroyed, since the "best before" date of processed meat is crucial for safe consumption.

Application Requirements:

• Provide instant product identification and stage of processing information.

• Highly accurate and rugged tracking devices which are easy to operate.

• Tracking devices able to withstand quick cool down and extended cool temperatures over long periods

• Tracking devices able to withstand intense heat sterilization process

Solution:

RFID tags mounted on mobile racks scanned by hand held Reader/Writer. Rack location, meat type and weight data is transferred to the tag.

Benefits:

• RFID tags withstand the high and low temperature requirements (bar code labels unusable)

• Reduce moisture loss from processed meats

• Provide exact meat location and type of meat information.

• Determine shipping order of meats based on tracking the "Best before" dates

Economic Growth from RFID and Nanotechnology in the 21st Century

Must learn from the 19th century technological trajectory of the electric dynamo.

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Clayton Christensen's innovative marketing of the term "disruptive technologies" may be a clever rehash of general purpose technologies or GPT's (discussed below). The **wisdom** from the diffusion of the electric dynamo in manufacturing may be a necessary lesson for global leaders who may wish to prepare their national economies to benefit from nanotechnology. The **lesson** from electrification fits like a hand in glove with respect to automatic identification technologies (radio frequency identification or RFID and ultrawideband or UWB). RFID proponents are stumbling to show the business value (ROI) from pervasive implementation of auto-id technologies because commercial quick-fix "slap-ship" strategies are analogous to the pre-1920 mindset of adding on electric motors to the existing equipment. Post-1920's investment to include the unit drive in the infrastructure called for operational or process transformation that yielded 76% manufacturing growth of the domestic US economy in just one decade (1919-1929).

The following is a condensed version of selected excerpts from the paper (below) prepared by Shoumen Datta, MIT.
General Purpose Technologies and Productivity Surges: Historical Reflections on the Future of the ICT Revolution
by Paul A. David and Gavin Wright in *The Economic Future in Historical Perspective (*Oxford University Press, 2003)

We reflect on the relevance of early 20th century American experience for understanding the more general phenomenon of recurring prolonged swings in the TFP growth rate. After a productivity pause of some three decades, during which gross manufacturing output in the US grew <1% pa relative to inputs of capital and labour, TFP in this sector expanded >5% pa between 1919 and 1929.

This remarkable discontinuity has largely been overlooked by modern productivity analysts and economic historians alike, yet it contributed substantially to the absolute and relative rise of US domestic economy and in many respects may be seen as the opening of the high-growth era that persisted into the 1970's.

The shift in the underlying technological regime that is implied by this statistically documented discontinuity can be traced to critical engineering and organizational advances connected with the electrification of industry. These developments marked the culminating phase in the diffusion of "the dynamo" as a general purpose technology (GPT) that made possible significant fixed-capital savings, while simultaneously increasing labor productivity. Yet, a narrow technological explanation of the post-WWI industrial productivity surge proves to be inadequate. It neglects the concurrence of those developments with important structural changes in US labor markets and fails to do justice to the significance of complementarities that emerged between managerial and organizational innovations and the dynamo-based factory technology, on the one hand, and, on the other, between both forms of innovation and the macroeconomic conditions of the 1920's.

We explore the more complex formulation of the dynamics of GPT diffusion by considering the generic and the differentiating aspects of the US experience with industrial electrification in comparison with that of the UK and Japan. The cross-national perspective brings to light some differences between leader and follower economies in the dynamics of GPT diffusion and its relationship to the strength of surges in productivity growth. The Anglo-American comparison serves also to underscore the important role of the institutional and policy context with respect to the potential for upgrading the quality of the workforce in the immediately affected branches of industry.

The historical break was heavily though not exclusively concentrated in the manufacturing sector. Kendrick estimates decadal growth of TFP around 22% for the whole of the private domestic economy, while the corresponding figure for manufacturing was 76% and for mining was 41%. At the heart of the story was manufacturing, where the discontinuity was particularly marked. Evidently the post-1919 industrial productivity surge reflected broad, generic developments that were impinging widely upon US manufacturing activities. What sorts of forces were sufficiently pervasive and potent as to have these far reaching effects?

1st, the culmination of the dynamo revolution that had been underway as a technological trajectory since the 19th century but which did not realize its engineering potential for major productivity gains until 1920's.
2nd, the restructuring of US manufacturing labour markets in the wake of the closing of mass European immigration after 1914.

Each of these developments had its own prior history but the productivity surge reflected the confluence of these two largely independent streams of development. The transformation of industrial processes by electric power technology was a long-delayed and far from automatic business. It did not acquire real momentum until after 1914 to 1917, when the rates charged consumers by state-regulated regional utilities fell substantially in real terms and central station generating capacity came to predominate over generating capacity in isolated industrial plants. Rapid efficiency gains in electricity generation during 1910 to 1920 derived from major direct investments in large central power plants but also from the economies of scale realized through integration and extension of power transmission over expanded territories. These developments were not simply matters of technology, but also reflected political and institutional changes that allowed utilities largely to escape regulation by municipal and town governments, facilitating the flow of investment capital into holding companies presiding over centrally managed regional networks. Together these supply-side changes propelled the final phase of the shift to electricity as a power source in US manufacturing, from just over 50% in 1919 to nearly 80% in 1929.

But the protracted delay in electrification was not exclusively due to problems on the supply side of the market for purchased electrical power. The slow pace of adoption prior to the 1920's was attributable largely to the lack of profitability of replacing still serviceable manufacturing plants adapted to the old regime of mechanical power derived from water and steam. Coexistence of older and newer forms of capital often restricted the scope for exploiting electricity's potential.

Prior to the 1920's, the group drive system of within-plant power transmission remained in vogue. With this system (in which electric motors turned separate shafting sections, so that each motor drove related groups of machines) primary electric motors often were merely added to the existing stock of equipment. When the favorable investment climate of the 1920's opened up the potential for new, fully electrified plants, firms had the opportunity to switch from group drive to unit drive transmission, where individual electric motors were used to run machines and tools. Advantages of the unit drive extended well beyond savings in fuel and in energy efficiency. They also made possible single-story, linear factory layouts, within which reconfiguration of machine placement permitted a flow of materials through the plant that was both more rapid and more reliable. Rearrangement of the factory contributed to cost savings in materials handling operations, serializing machines and thereby reducing or eliminating back-tracking.

The package of electricity-based industrial process innovations could well serve as a textbook illustration of capital-saving technological change. Electrification saved fixed capital by eliminating heavy shafts and belting, a change that also allowed factory buildings themselves to be more lightly constructed because they were more likely to be single-story structures whose walls no longer had to be braced to support the overhead transmission apparatus. The faster pace of material throughput amounted to an increase in the effective utilization of the capital stock. Further, the frequency of downtime was reduced by the modularity of the unit drive system and the flexibility of wiring. The entire plant no longer had to be shut down in order to make changes in one department or section of the factory. Henry Ford's transfer-line technique and the speed-up of work was a contributory element of the high throughput manufacturing regime, as were the new continuous process technologies that grew in importance during this era.

The diffusion of the dynamo has served as something of a paradigmatic example for economists working in the spirit of the new growth theory who have sought to generalize the idea of general purpose technologies with applications in diverse sectors of an economy. GPT's are enabling technologies, opening up new opportunities rather than offering complete or final solutions. For example, the productivity gains associated with the introduction of electric motors in manufacturing were not limited to a reduction in energy costs. The new energy sources fostered the more efficient design of factories, taking advantage of the newfound flexibility of electric power. Similarly, the users of micro-electronics benefit from the surging power of silicon by wrapping around the integrated circuits their own technical advances. This phenomenon involves Innovational Complementarities, that is, the productivity of R&D in a downstream sector increases as a consequence of innovation in GPT. These complementarities magnify the effects of innovation in the GPT and help propagate them throughout the economy.

The interest in generalization has in turn stimulated efforts to consolidate our understanding of the defining features of GPT's and to extend the list of historical examples. According to the most carefully developed criteria, GPT's are technologies that share four characteristics:
(1) Wide scope for improvement and elaboration
(2) Applicability across a broad range of uses
(3) Potential for use in a wide variety of products and processes
(4) Strong complementarities with existing or potential new technologies

Using these criteria, Lipsey and his co-authors identify an extensive list of historical and contemporary GPT's from power delivery systems (waterwheel, steam, electricity, internal combustion) and transport innovations (railways and motor vehicles) to lasers (silicon lasers) and the internet. They also extend the concept to organizational technologies as the factory system, mass production and flexible manufacturing.