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From Light Frequency Identification (LFID) to Radio Frequency Identification (RFID) in the Supply Chain

by Farhad Moeeni, Arkansas State University

Conceivably one of the most successful technologies in the history of retail supply chain has been bar code identification along with the Universal Product Code (UPC) symbology and numbering system (Larurer). The first item with a UPC bar code, taken to a cashier for scanning by a customer, was a 10-pack of Wrigley's Juicy Fruit chewing gum. It happened on June 26, 1974, at Marsh's supermarket in Troy, Ohio. Which retail store will make a similar historical hallmark with respect to radio frequency identification (RFID) and Electronic Product Code (EPC) in the U.S.? Answering this question is hard because there are many technological as well as social obstacles that should be resolved first. Perhaps a more sensible question to ask is how would the RFID technology evolve, will RFID offer a strategic advantage for adopters, and where is the ROI?

For a meaningful analysis, one needs to understand the current status of *automatic identification* technologies and the corresponding standards as they relate to supply-chain applications. They include bar coding (Exhibit 1), Global Trade Item Number (GTIN, a superset of UPC) (Exhibit 2), RFID (Exhibit 3), and EPC (Exhibit 4).

Understanding bar coding may also help better anticipate the future of RFID. Interestingly, from a technological standpoint, both rely on the electromagnetic (EM) energy for data transmission. Bar coding uses light or infrared frequencies, but RFID uses radio or microwave which has lower frequencies than light in the EM spectrum. Using an analogy similar to RFID, we may refer to bar coding as *light frequency identification*, or LFID, which inspired the title of this article. LFID seems to be more meaningful and inclusive than bar coding as Exhibit 1 indicates because some of the so-called "bar code" symbologies do not have bars; they have dots instead.

Automatic Identification

Automatic identification (or auto-id) means identifying, capturing, and transferring data to a PLC, microprocessor, computer or network by means *other than* keyboard or manual notation. Several technologies have been developed over the decades to include bar coding, magnetic stripe, IC or smart card, RFID, biometric scanning, and many others. Some technologies such as magnetic stripe, IC cards, and biometric scanning are suitable for identifying and processing people, and some others are mainly used for physical objects (including animals) such as bar coding and RFID.

The initial benefits of auto-id technologies are the *accurate* and *timely* identification and data collection. However, the ability, ease, and low cost of collecting masses of data in real time should potentially enable organizations to produce unprecedented levels of business intelligence. Figure 1 compares the traditional methods versus the auto-id data entry (Fales, 2005).

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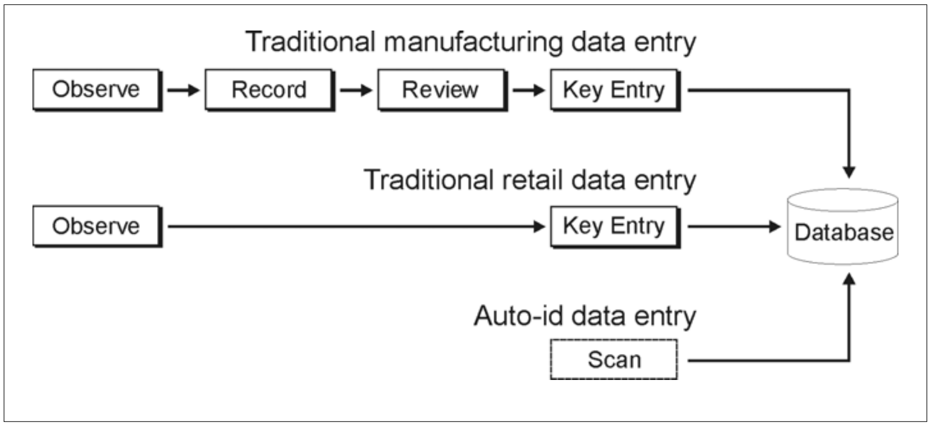

Figure 1: Comparing the traditional and the automatic identification data entry.

As the figure indicates, every activity in the traditional data entry process (solid boxes) is an opportunity for error due to human intervention in significant ways. Only auto-id data entry (the dashed box) such as bar code or RFID scanning is error-free because either the scanning process does not need human touch (e.g., bar code or RFID scanning of items on conveyors) or human intervention occurs in an insignificant manner (e.g., pointing a laser scanner at a bar code label). By referring to the figure, one may also compare the efficiency of updating a database in the traditional versus the auto-id environment. Note that the dashed box can represent a bar coding or an RFID system.

While I'm not aware of any published research article that quantifies the amount of time saved or errors prevented when an auto-id technology replaces the manual keying, experts believe that both are significant. One unpublished study (Fales, 2005) indicated that in a laboratory environment, bar code scanning produced one error in three million labels scanned. On the other hand, undetected error by good typists amounted to an average of one character per 300 characters typed. Another benefit reported by practitioners is that the point-of-sale (POS) implementation of bar coding within grocery stores reduced the number of checkout stations roughly from 13 or 14 to about 8 or 9. Experts generally believe that the payback period of implementing bar code technologies in most cases is a few months.

The Current Excitement over RFID

The RFID technology has been used in niche applications for more than 20 years. These applications use proprietary technologies and are closed-loop for they do not interact with other systems or adhere to any broad-based standards. Successful examples include access control, highway toll payment, real-time locating systems, and many others. Depending on applications, various frequency bands and tag types such as passive, semi-passive or active (Exhibit 3) are used.

What is new is the massive use of an open RFID system for supply chain transactions. The wide-spread excitement over the RFID technology began in 2003 when Wal-Mart issued a mandate to its top 100 suppliers to affix RFID tags to cases and pallets by 2005. The requirement has since been extended to several times that number and a deadline of 2007. Other companies such as Target, Best Buy, Tesco and Metro, some government agencies, and several others also devised their own plans to implement RFID within their supply network.

It is natural, in my opinion, for Wal-Mart to be the torch bearer of RFID experiment among U.S. retailers. First, Wal-Mart mastered the use of bar code technology for a near real-time sharing of its POS transactions to backrooms, distribution centers, logistic systems, and suppliers. The use of RFID is an extension of that vision. Second, Wal-Mart does not face a total financial risk for experimenting with the RFID technology. It invests only in readers and infrastructure. Suppliers pay for the cost of tags, which is a significant and *recurring* part of the total cost.

It is also up to the suppliers to generate ROI by using the *tags* and its data within the internal operations. While the search for identifying a business case and ROI continues, most suppliers have adopted a "slap-n-ship" policy just to comply with the customers' demand.

Besides the lack of sound business cases, major drawbacks of implementing RFID included high system cost, especially for tags, and lack of standards. Paradoxically, the cost of producing tags would go down only if the consumption went up. In my opinion, the pilot RFID implementation by first-movers broke this potential deadlock to some extent. In addition, the ratification of the first global tag standards for the supply chain in late 2004 eliminated another major source of uncertainty. This stimulated a segment of the technology sector including tag producers, reader manufacturers, software companies, system integrators, consultants, and education/training organizations. Many technology giants such as TI, IBM, Microsoft, Sun, SAP, Oracle and many others have since entered the market or expanded their ongoing activities.

It is interesting to know that bar coding implementation in the retail supply chain faced a similar uncertainty thirty years ago but for different reasons. Certainly, standards were not a hurdle because the UPC standards were in place before the first retailer adopted the technology. Even though the cost of bar code scanners and their primitive technology and effectiveness were perhaps comparable to the RFID readers today, bar code labels were cheaper 30 years ago compared to the price of tags today. Nonetheless, bar coding technology

Bar coding systems

Major components include scanners and labels. Scanners use one of several technologies such as laser or charge-coupled device (CCD). The label stores data in the form of bars and spaces of various widths printed or etched on paper, metal, etc. Bar code languages are called *symbology*. Each symbology has a unique pattern of bars and spaces for encoding data. Some symbologies such as UPC (note that UPC is also a numbering system) only encode numbers and some can encode the entire ASCII characters set such as Code 128.

Two dimensional symbologies provide substantial data capacity. One type uses multiple rows of very short linear bar codes stacked on top of each other, e.g., PDF 417. Another type uses dots, instead of bars, in a matrix structure, e.g., Aztec and Data Matrix. *Composite* symbology combines linear and 2-D symbologies into one label. The need to store more data and limited space on pharmaceutical and electronic components motivates the technology.

Scanners read labels by illuminating them and then analyzing the spectrum of the reflected light for patterns, intensities, and duration. After a successful read, most scanners supply the decoded data in the form of ASCII characters to the host applications. Bar code scanners are programmable to read various symbologies and to perform data filtering.

Exhibit 1: Components of bar code systems and symbologies.

faced a "chicken-or-egg-first" phenomenon, too. Manufacturers were reluctant to affix bar code labels on products when retailers did not have bar code scanners. Retailers, on the other hand, were reluctant to invest in scanners when products didn't have bar code labels.

Automating the Supply Chain

The EPC initiative is based on an idea originated at the MIT's Auto-ID Center to create an "*internet of things*" similar to the Internet of computers,

> which all electronic devices are networked and every object, whether it is physical or electronic, is electronically tagged with information pertinent to that object…. The realization of our vision will yield a wide range of benefits in diverse areas including supply chain management and inventory control, product tracking and location identification, and human-computer and human object interfaces. [Sarma et al, 2000]

The goal has been to automate identification of physical objects and products and sharing of data about them throughout the supply chain. Several other universities around the world, along with a large number of sponsors ranging from technology users to technology providers, and standard organizations also joined the effort for the global deployment. A coalition of the Auto-ID center, the Uniform Code Council, users group, and technology developers has been named EPCglobal to oversee the development of the EPC network and standards.

As a part of the EPC network, RFID readers are responsible for discovering RF tags, which are in their EM field, and report their EPC numbers to the host application. It is assumed that the EPC number of the tag accurately identifies the item, case, or pallet that it is attached to. The host application then issues a query to search a database for retrieving the product information. This process is identical to the current retail bar coding systems. The UPC (GTIN) and the EPC numbers act as pointers to information stored in a database. One distinction is that the EPC numbering system allows mass serialization of consumer-level items which is not possible under UPC or GTIN (see also Exhibit 2 for SGTIN). For example, two identical bottles of shampoo can have different identities under EPC.

Another difference is that in the current UPC system, the information is usually contained in a local database. When EPC network is operational, the information can be anywhere on the Internet. If the local database does not have the product information associ-

Global Trade Item Number (GTIN)

GTIN combines the structure of UPC and EAN (European Article Number) into a 14-digit global identification numbering system. The middle 12 digits identify country, company, and product. The most significant digit (leftmost) identifies the packaging level such as consumer level, case or pallet, and the least significant digit is a calculated check digit to verify the previous 13 digits. GTIN uniquely identifies the class of an item (SKU) but not each instance of it. A version called Serialized GTIN (SGTIN) is defined for use with RFID and the EPC network and can assign a unique number to each instance of the product.

Organizationally, the Uniform Code Council and its European counterpart (EAN) transformed into GS1. Today, every country in the world has a GS1 organization (e.g., GS1-US) that manages the GTIN numbers assigned by that country. GS1 offers other services to complement GTIN for global e-Commerce.

Exhibit 2: GTIN numbering system and its relation to the UPC and EAN codes.

ated with an EPC number, a systematic and hierarchical search is automatically performed to find the information and to update the local database. Thus, the EPC network architecture relies on an elaborate infrastructure, including the Internet, to facilitate such flexible, scalable, automatic, and distributed information sharing mechanism (Exhibit 4), allowing organizations to trace and track items perpetually.

RFID versus LFID

In my opinion, the role of RFID in the EPC network will evolve in two phases. The two phases map to the class definition (Engles et al, 2005) as presented in Exhibit 5. Note that there are no complete specifications or ratified standards for class 2 and above.

Phase one corresponds to the capabilities of Class 1 tags. This class defines minimum functionality such as passive backscatter and limited memory to minimize the tag cost. In this phase, RFID primarily acts as "electronic bar code" and attempts to replace current bar coding applications by offering increased efficiencies. At this level of functionality, RFID readers read, filter, and pass EPC numbers to the host application. How to use the data intelligently after it is captured is independent of the data capturing method. In other words, it doesn't matter how the EPC number is collected, either through an RFID, a bar coding system, or something else. Note that Code 128 or 2-D symbologies (Exhibit 1) can encode EPC numbers as bar code labels.

The most important features that favor RFID in this contest with bar code include an additional level of automation by reading multiple tags almost simultaneously, eliminating the need for operators and line-of-sight. The most important features that favor bar coding, on the other hand, include highly developed and mature technology, well accepted standards, and cost. Bar code labels are almost free.

Phase Two corresponds to Class 2 tags and beyond (Exhibit 5). These classes of tags create functionalities outside the current capabilities of bar coding. Most imaginative and unprecedented applications of RFID systems are expected to happen during this phase. Many researchers are envisioning a time that ubiquitous low-powered networks of RFID readers and active and semi-passive tags are integrated with all kinds of sensors. Through the Internet, they share and report digital data from temperature and air quality at a particular intersection to the expiration date of a given bottle of milk to the imminent failure of a pacemaker and the location of the patient to the nearest ambulance.

Regardless of the phases and tag functionalities, RFID may not completely replace bar coding in the foreseeable future. There are certain products such as jet turbine blades that must operate in extreme temperatures. The size, form factors, or materials used in the manufacturing of current tags do not make them suitable for such application. On the other hand, it is possible to engrave bar codes directly on such products using laser technology. RFID technology will dominate some applications, bar coding will dominate certain other applications and, in the majority of applications, the two technologies will coexist on the same physical object.

RFID systems

Major components include readers and tags. Readers have radio transmitters and receivers, processors, and memory. They also have antennas. Readers communicate with tags through antennas in order to read data from or write data to tags. A tag also has antenna and a tiny microchip with memory, processor, and communication circuitries.

Reading mechanism depends on the type of tags. *Active* tags carry their own power source and broadcast their own signals to communicate with readers. *Passive* tags, on the other hand, should be within the EM field of the reader's antenna in order to receive sufficient power for broadcasting data. This transmission mechanism is known as *passive backscatter. Semi-passive* tags contain a tiny battery for logging the data received from connected sensors. These tags also use passive backscatter method to communicate and transfer the logged data to readers. Supply chain applications of RFID systems currently focus on passive tags that operate in the UHF band (860-960 MHz). Readers are programmable and can perform a variety of data filtering.

Exhibit 3: Components of RFID systems.

Where is the ROI

Making a business case for bar coding to substitute manual data entry has relatively been obvious (Figure 1). Yet, it took years for many companies to gradually adopt bar code technology. In many cases, the customer (such as Wal-Mart) forced some suppliers to affix bar code labels on their products. There are many countries, companies, and applications yet to adopt bar code technology. For example, the healthcare sector has been very slow in the widespread use of bar coding within the patient-care system, even though thousands of lives are lost every year due to medical errors.

On the other hand, making a business case for RFID may not be so obvious, at least at the moment. In the only known large-scale research experiment (Hardgrave et al, 2005), it took seven months of data collection, 24 Wal-Mart stores (12 with RFID implementation and 12 without), and substantial resources to investigate a potential business case for RFID. Without disclosing any cost-related information, the preliminary results showed that RFID-enabled stores had much fewer numbers of shelf out-of-stocks. More analysis may be needed to assess what proportion of the improvement could be attributed to RFID, and what portion to the process change. Further analysis is also needed to determine whether or not bar coding could be used instead of RFID.

To produce reasonable ROI, many technological challenges should be resolved. Components of the EPC network are under development and no standards yet exist except for C1G2 tags. The technology is very primitive but evolving. One hundred percent tag read rate, in every situation, is ambitious because metal and liquid (not favored by UHF radio band) are commonly present in products, especially grocery items. On social issues, public concerns and debates on the right to privacy may be delayed indefinitely as long as RFID remains out of the sales floor and behind the impact doors of retail stores.

On the positive side, Moore's law favors RFID. The cost of UHF tags has continuously declined and the capability of readers has improved over the last few years. The business value of RFID is expected to increase when the EPC network becomes operational. The value of the EPC network itself will increase, according to Metcalfe's law, as more organizations join the network. It is hard to believe that, for gaining strategic advantage, the original sponsors of the EPC network would prevent others to join. Like any infrastructural technologies (railroad, Internet, etc.), EPC network would offer far more value when shared than when used in isolation (Carr, 2003). Transforming masses of shared RFID-generated data into knowledge would be the key to creating strategic advantage.

Conclusion

RFID is only one technology within a family of technologies generally known as automatic identification or auto-id. Academia in general and business schools in particular have not included auto-id related topics within their curricula. The current market excitement over RFID has stimulated some busi-

EPC Network Architecture

Components of EPC network (Leong et al, 2000) include the Electronic Product code (EPC), Savant, EPC Information Services (EPCIS), and Object Name Service (ONS). Strictly speaking, RFID readers are also part of the network but they were presented separately.

Electronic Product Code (EPC) format has the following fields:

Header	EPC Manager	Object Class	Serial Number

Header specifies the format of the tag. Currently, there are 64-bit, 96-bit, and 256-bit tag formats. EPC manager uniquely identifies the producer. Object class uniquely identifies each type of product. Two identical boxes of cereal have the same object class number. The serial number uniquely identifies each instance of the same product type.

Savant is a generic name for middleware between readers and upper layers of the EPC network. A part of the Savant functionalities may be performed by readers.

EPCIS is a set of interfaces for data exchange and specifications of data itself. It facilitates the exchange of all kinds of data about products (e.g., tag read events) with the internal enterprise system or with queries coming from authorized applications outside the company. In cases when EPCIS does not know the location of the needed information, it may ask the ONS to find the address of such a resource.

ONS identifies the address of the servers that contain information about products (e.g., EPCIS). It resolves an EPC number into a complete URL of the source. The process of finding the needed URL may extend beyond the LAN and go up to the root ONS. The design of the ONS followed the Internet DNS (Domain Name System).

The following figure exemplifies the structure of an EPC network within a company or LAN. Local EPC networks may exchange information with each other through the Internet.

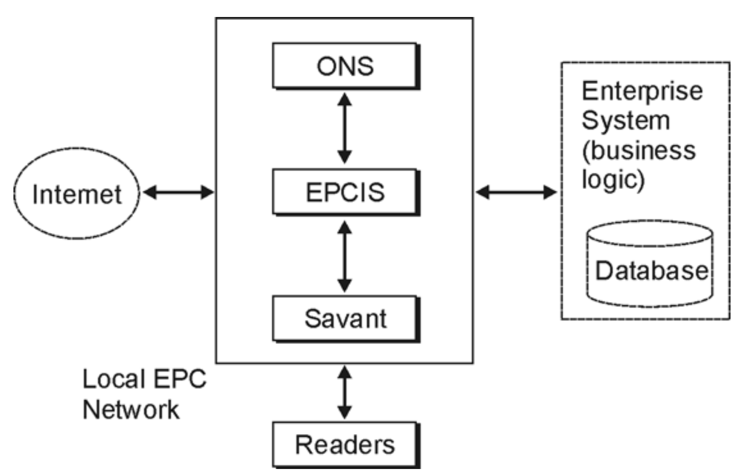

Exhibit 4 : The EPC network architecture

EPC Class	Functionality	Comments
Class 0	"RO" passive backscatter	Programmed as part of the semiconductor manufacturing process
Class 0+ (not an EPCglobal)	"WORM" passive backscatter	Programmed once by the customer then locked (practically, they can be reprogrammed; we have reprogrammed them in the lab). Gen 2 has 32 bits of memory at the discretion of user
Class 1	"WORM" passive backscatter	
Class 1 – Generation 2 (UHF Gen2 protocol ratified by EPC Global on Dec. 16, 2004)	"WORM" passive backscatter	
Class 2	"RW" passive backscatter	Can be reprogrammed many times
Class 3	"RW" Semi passive (Battery backscatter)	Can be reprogrammed many times andcan be integrated with sensors to log and transmit critical data
Class 4	"RW" Battery Transmitter, very high range	
Class 5	Tags are also Readers	

Exhibit 5: EPC RFID tag classes.

ness schools. This is a great opportunity for business faculty, in general, and those who teach and research IT, IS, and operations, in particular, to pay more attention to the integration of these technologies not just to the RFID in isolation.

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