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Is it the End of Barcodes in Supply Chain Management?

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Barcode is a mature automatic identification (auto-ID) technology that has been used in supply chain management (SCM) for several decades. Such has been the domination of the auto-ID technique that it has pervaded all facets of SCM, from item-level identification to transportation applications. It has enjoyed free reign especially in the retail sector. However, recently radio-frequency identification (RFID) has been considered a rival technology, more superior in terms of its power to store and update information instantaneously, and non-line of sight (nLoS) ability to be read. Yet RFID is more costly and for the present barcode is still the most widely used and accepted standard worldwide. This paper makes use of document analysis and interviews as sources to support the premise that while RFID may be looming, the need for barcode in the supply chain will never really disappear. What is being observed rather is a pattern of convergence, suggesting a need for both technologies to be integrated into the supply chain, each serving toward a common goal.

Keywords
Bar Codes, Radio-frequency Identification (RFID), Convergence, Co-existence, Supply Chain, Supply Chain Management, Selection Environment

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Is it the End of Barcodes in Supply Chain Management?

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Abstract

Barcode is a mature automatic identification (auto-ID) technology that has been used in supply chain management (SCM) for several decades. Such has been the domination of the auto-ID technique that it has pervaded all facets of SCM, from item-level identification to transportation applications. It has enjoyed free reign especially in the retail sector. However, recently radio-frequency identification (RFID) has been considered a rival technology, more superior in terms of its power to store and update information instantaneously, and non-line of sight (nLoS) ability to be read. Yet RFID is more costly and for the present barcode is still the most widely used and accepted standard worldwide. This paper makes use of document analysis and interviews as sources to support the premise that while RFID may be looming, the need for barcode in the supply chain will never really disappear. What is being observed rather is a pattern of convergence, suggesting a need for both technologies to be integrated into the supply chain, each serving toward a common goal.

1. INTRODUCTION

Supply Chain Management (SCM) is the "management and control of all materials and information in the logistics process from acquisition of raw materials to delivery to the end user" (CSX, 2001). An investigation of the barcode's rise to popularity in supply chain management (SCM) and its advantages and disadvantages will be the core theme of this paper. While there has been much written on the topic of radio-frequency identification (RFID) in SCM, there is a gap in understanding what role barcode will play in the future. With the current publicity surrounding RFID, one would not be mistaken for believing that the end of barcode in SCM was imminent. However, the evidence given in this paper acknowledges that while barcodes have some limiting factors, their widespread adoption and pervasiveness means that companies should not be abandoning the auto-ID technique just yet. If RFID is to dominate in the future, it

must at least go through the same product lifecycle as barcode, and for now, despite the technology's age, it is still in its infancy. The absence of standards, the lack of regulatory requirement, and numerous unknowns about form and function in diverse conditions and settings, are among the factors acting against RFIDs proliferation.

2. METHODOLOGY

The primary method of data collection involved document analysis. Given that barcode is a well-established technology there were many company case studies from differing vertical sectors available online. Resources accessible for download from vendor web sites included customer testimonials, barcode examples by industry and application, standards documentation, technical equipment specifications, whitepapers and press releases. The online sources were complemented by hardcopy documentation including books and academic papers on barcode. Recent academic papers on barcode, while few, are preoccupied by research on new configurations and symbologies that are revitalizing the technology's future prospects. There is a distinct narrative approach taken in the paper which is complemented by the use of a conceptual framework based around the systems of innovation dimensions founded in evolutionary theory (Edquist, 1997). The narrative tells the story of the barcodes inception into the marketplace beginning with a technical discussion on the barriers and drivers to entry. It continues by giving evidence as to the maturation of barcode from proprietary to open standards, i.e. its institutionalization into the marketplace. Thereafter a discussion on its organizational advantages and disadvantages is provided, ending with its economical factors which have made the technology affordable by even the smallest of merchants. Two semi-structured interviews were also used to supplement and further validate the findings of the document analysis. Participant 1 is an employee of a leading barcode supplier, and Participant 2 is an end-user of barcode in one of the world's largest oil refineries. This paper is both descriptive and interpretive.

3. TECHNICAL ISSUES

The road to success for any emerging technology starts with quantifiable advancements in terms of technical capabilities. The early developments made in barcode technology included their ease of use, reliability and line-of-sight (LoS) properties. This technological progression sparked interest from organizations in the technology and was the beginning of its rise to prominence.

3.1 Affordability

The simplicity of barcodes is one of their most appealing aspects. Since their inception, typical barcode printing costs have dropped to less than a cent per barcode (Thompson, 2003). As the two core ingredients used to produce a barcode are ink and paper, they will remain relatively inexpensive compared to alternative technologies in the foreseeable future, such as RFID that makes use of silicon chips (exhibit 1). Barcode labels can produce significant media savings for

organisations, as traditional paper forms are much larger than barcode labels. For companies with a developed barcode infrastructure, the cost of printing barcodes is almost nothing (Lai, 2004). As barcode technology has reached a state of maturity, it has become much more affordable making it suitable for even small-scale niche applications. Participant 2 works for a large organisation that uses a simple barcode system comprising of a small database, barcode software and several barcode scanners to monitor tool usage and noted that the "system is a very useful and low cost solution".

Continual improvements in barcode have ensured cost reduction in the technique itself and its peripheral components. An example of this is the development of linerless barcode labelling. This can decrease media costs by ten to twenty-five percent while increasing the number of barcodes on each roll, resulting in no leftover waste in the form of discarded label backings, leading to lower production costs per barcode (MMH, 1996).

Exhibit 1. RFID Tags, Transponders

3.2 Usability

The barcode technology's ease of use is a significant factor in its success. Barcode labels can easily be printed *on-the-fly* offering a great deal of automation and reducing human interference wherever possible. When the right infrastructure, software and hardware, is in place, the "automation provided by a barcode system greatly simplifies information collection, processing and tracking" (Zebra, 2004b). Automation has brought companies like Procter & Gamble double-digit productivity gains (Varchaver, 2004). The data collected can be easily distributed throughout an enterprise and even to an organisation's partners with the use of advanced management systems. Furthermore, the user interaction with barcodes is very simple (Stephenson, 1998). Most modern systems and scanners provide users with wireless remote data capture and a graphical user interface to assist in usability and end-user training (exhibit 2). As barcodes are easy to use, the technology has the ability to be implemented seamlessly into many business applications. This has helped pave the way for a number of other advantages to be realised, such as better inventory management and quality control.

Exhibit 2. Wireless Barcode Reader

3.3 Continual Improvements and Innovations

Barcode technology continues to evolve, reinventing itself to solve a wide array of business problems and challenges. Until the 1990s most barcode systems were capable of reading only one symbology (given storage limitations on scanners and computer hardware), creating a problem when more than one symbology was used by a particular organisation. At that time an organisation had to be equipped with multiple sets of scanners, each with the ability to read their respective symbology. Today however, most barcode scanners can typically read a large number of symbologies, the act of which is known as *autodiscrimination*. All of the barcode

scanners produced by Participant 1's employer, for instance, read all symbologies where possible.

Recently Nextel Communications, Motorola and Symbol Technologies announced the first barcode scanner, the PSM20i to be attached to mobile phones. This recognises the trend of barcode technology, in particular the growth in popularity of remote data capture scanners using wireless technology. Wal-Mart has deployed over 300,000 wireless barcode scanners (Varchaver, 2004) While remote data capture scanners are limited to the range of their wireless network, the range of mobile phone barcode scanner attachments is considerably less limiting. Their range would allow employees to scan items in the supply chain regardless of their location and update the information in real-time, whether they are onsite at a client's warehouse or out in the field (Symbol, 2004).

Vernon (2003) acknowledges, "there is no shortage of innovative new applications", citing the development of the "mobi-ticket" system developed by Mobiqa. The system allows customers to purchase tickets online and receive a barcode image on their phone as a multimedia messaging service (MMS). This 'virtual barcode' message can be read with a standard scanner to gain entry to an event, averting the need to mail out tickets. In this way, mobi-ticket helps organisations to manage events and reduce processing costs. It also allows vendors to attach promotional material to the 'virtual ticket'. It is quite ironic that at the RFID Australasia 2005 Exhibition (17-18th August), barcodes were used for delegate registration (exhibit 3). The first step in the process required delegates to pre-register online. After the pre-register stage the delegate received an automated email with a barcode. And on day of the exhibition, the delegate could self-scan their invitation and print out their badge at a collection station before entering the Exhibition Centre in Sydney. Ongoing developments in symbology standards are also paving the way for new standards that hold substantially more information than more traditional symbologies.

Exhibit 3. Barcodes Used for Delegate Registration at RFID Australasia 2005

3.4 Reliability and Accuracy

There is no doubt that barcode scanning is more reliable than manual data collection, yielding vastly higher accuracy rates at high speeds. Accuracy in the supply chain, particularly in the manufacturing stage is paramount. Zebra Technologies (2002) claim that read error rates are approximately one error in one million characters or greater than 99.99% accuracy. Cohen (1994), Brewin (2004), Kevan (2004) and Participant 1 and 2 support the notion of high accuracy read rates for barcodes. In contrast to this, Delta airlines has only achieved read rates of 80% to 85%, however such poor read rates are not common and may be due to environmental constraints (Brewin, 2003). There is no doubt that trained data

entry operators using manual key entry are less accurate and much slower than barcode scanning, making approximately one error for every 300 characters entered (Long et al., 1989). Singer (2003) noted that although barcode accuracy rates are near perfect, they typically have one weakness in that they require people to perform the scan which can often lead to mistakes.

With many barcodes being manually readable, they hold a distinct advantage over alternative technologies such as RFID. This is a feature San Francisco International Airport found important when barcoding luggage. Should a scanner be unable to read a barcode, the barcode contains enough printed information to allow airport staff to manually route the luggage (Foster, 2004). An organisation using barcodes to monitor the use of tools found that barcodes would often come back damaged. To counter this problem, the organisation engraved the barcode number into each tool so the information could be read manually in case of damage. This allowed the operator to correctly identify the tool and replace the damaged barcode with the appropriate code. Such a unique benefit has some believing that RFID will not replace barcodes with human readable information, paving the way for barcodes and RFID to be used in conjunction. It is important to note, that despite widespread global computerisation, manual ID techniques are still necessary to counter potential systems failure.

3.5 Optical Scanning Implications

Barcode readers uses direct 'line-of-sight' when scanning a barcode, requiring each item to be manipulated one at a time (Atock, 2003). This is because the optical nature of barcodes necessitates labels to be seen by lasers and typically requires close range scanning, often making the technology difficult and impractical in many industrial environments (Want, 2004; Sarma et al., 2001). This characteristic often results in human error, as barcodes often have to be scanned by hand. For example, a warehouse receiving goods of varying dimensions cannot easily automate the scanning of incoming goods, making this a manual process (Donoghue, 2004). Motorola has had to deal with the LoS issue in its manufacturing operations. It found that small barcode labels were difficult to scan and apply to transceiver boards with endeavours to use a label applicator machine failing. Subsequently, labels were scanned and applied by hand, making the procedure one of Motorola's few manufacturing processes that was not automated (Heng, 1998). Line-of-sight barcode properties have significant consequences especially when systems are operating in harsh environments.

3.6 Information and Data Properties

Ordinary barcodes store only a small amount of static information, typically around 20 characters (D'Hont, n.d.). Once the barcode is printed, the static information it contains cannot be changed, updated or reprogrammed as the product moves through the supply chain. Such limited data capacity means that barcodes can generally only identify what type of product a good is, for example a can of Coke, not each individual item. This issue has been partially alleviated by linking barcodes to databases that contain more detailed and dynamic information. Improvements to barcode symbologies have lead to the development of two-dimensional barcodes, which are capable of storing millions of bytes of information. Swartz (1999) comments, "2D [two-dimensional] portable data files fill a conceptual gap, which can redefine the working relationship between people,

computers, and documents". 2D barcodes do not depend on links to larger databases, acting as a kind of mini-database themselves, including the ability to encrypt information.

3.7 Environmental Effects

As barcodes require line of sight technology, products must have barcode labels that are clearly visible to make scanning easy. This leads to an inherent hindrance as barcodes are susceptible to damage. To prevent damage, barcodes must be relatively clean, be handled gently in abrasion free environments, and not be exposed to extreme temperatures and harsh surroundings (SAP, 2002). This can poise a significant problem throughout the supply chain, where goods are often handled roughly and exposed to damaging environments. Barcode readers must also have clean and clear optics to achieve effective scan rates. Harsh environmental conditions such as fog, dirt and rain are considered to be the *downfall* of traditional barcodes (Gerdeman, 1995). Participant 1 outlined a common environment consideration when they stated that many manufacturers and distribution centres run continuously. As barcodes rely on reflective light for reading, sunshine can often hamper barcode scanner read rates and reliability when it is directed at barcode labels.

The oil refinery Participant 2 is employed by uses barcodes to monitor the use of their fire retardant clothing. However, it is common for these barcodes, which are printed onto clothing to become damaged through general use and washing. When this happens, the refinery has to pay their laundry company to attach a new barcode. This process is an additional cost to the system and requires accurate communication between the refinery and the laundry company, as the new barcode has to be updated on the system. The refinery is looking into the use of RFID tags to solve this problem. 2D barcode technology has partially overcome this intrinsic problem. Should they become damaged the barcode label may still contain useful information and can be read by scanners. This is an important feature when goods are subject to tough operating environments. Testament to this is the fact that the U.S. Marine Corps uses this technology to help manage inventory en-route to conflict zones and once it is on the ground (Vernon, 2003).

4. INSTITUTIONAL STANDARDS

For the successful deployment of any emerging technology, established standards are essential, especially as they relate to regulations. The progression of barcode standards was to move from proprietary to globally accepted open standards. This played a pivotal role in encouraging uptake of the technology, which caused a subsequent ripple effect throughout global supply chains. Companies like Wal-Mart, for example, who had been grappling with how to lower back-office overheads, leveraged barcode standards, and at the same time convinced their suppliers to adopt the technique as well.

4.1 Established Quality Standards

The success of barcodes can be largely attributed to the standardisation of symbologies within the industry, with many becoming widely accepted barcode standards. Although the first patent for a barcode was in 1949, it was not until the 1970s that industrial and supply chain applications were fully operational. A symbology defines "how the information is encoded into the physical attributes of bars and spaces" on the barcode itself (Palmer, 1995). There are many different kinds of symbologies, each with its own intended industry and characteristics. Standards that have been ratified by major institutional bodies help organisations decide which symbology to adopt.

The two most widely used standards are the Universal Product Code (UPC), developed by the Uniform Code Council (UCC) and the European Article Numbering (EAN), developed by the International Article Numbering Association, specifically for the retail sector. The prevalence of these two standards lead to the foundation of the EAN.UCC system of barcode and electronic commerce standards. The "UPC/EAN is the dominant standard in retail" and is used by more than a million companies in 141 nations, primarily for retail applications (New Jersey, 2004). Industrial codes play an important role in streamlining SCM practices. As industrial codes do not have a single application focus, unlike the EAN and the UPC for the retail industry, a special group called the Automatic Identification Manufacturers (AIM) manages these standards (Collins & Whipple, 1994). Consistency of symbologies is an important consideration for all organisations as this ensures that when they adopt a standard the information is universally understood and accepted by all the parties concerned. This allows the organisation's partners to reuse the barcode information throughout the supply chain, adding further value to their products.

4.2 Continual Improvements in Standards

The continual improvement of barcode symbology standards has kept barcodes at the forefront of auto-ID in the supply chain. In 1995, there were over 200 catalogued barcode configurations and a great deal more that were developed by organisations for internal use (LaMoreaux, 1998). Formidable industry groups such as the Automotive Industry Action Group (AIAG), Electronic Industries Alliance (EIA), and the Health Industry Business Communications Council (HIBCC) have developed many specific industry standards. These standards allow for universal compliance within industries, permitting "identification of product shipments among trading partners in the supply chain" and ensure that dangerous materials are handled in the appropriate manner, increasing workplace safety (Zebra, 2003a).

The success of the UPC caused some concern over the possibility that the code could run out of numerical spaces if too many manufacturers registered for use of the UPC for the identification of their goods. One of the inherent limitations of barcodes is their inability to hold large quantities of information. Barcode symbologies generally contain only a small string of numeric or alphanumeric characters. Standards organisations have ensured that barcode standards have kept pace with the needs of the supply chain industry, through the ongoing introduction of new standards. 2D barcodes are a prime example of this, as the symbology can store millions of bytes of data with a one inch by two-inch 2D barcode being able to store the entire U.S. constitution (Zebra, 2004b).

Scanners can read the symbology quickly, efficiently, and error free thanks to inbuilt error checking, error detection, data reconstruction and redundancy characteristics (Swartz, 1999). Participant 1 also expects to see a surge in the Reduced Space Symbology (RSS) code. They noted that RSS involved "taking one UPC barcode, shrinking it down and placing another one on top of it", allowing for the identification of individual items.

The development of 2D barcodes has facilitated General Motors to not only record goods coming in via the receiving dock, but also to provide employees with enough information to direct them to specific put-away locations or even straight to the production line. This improves productivity within the receiving phase and lowers raw material storage space requirements and handling costs. In addition, the more detailed information on each part lets General Motors to track specific parts with more accuracy as they move along the supply chain. This could result in significant goodwill and cost savings as it enables them to take a more specific approach should they have to undertake a general recall of certain parts (Zebra, 2003b).

5. ORGANISATIONAL FACTORS

Once the technical and institutional dimensions of barcode technology were established, organisations began turning to barcodes in an effort to improve efficiency and control of their SCM systems. This is evident when examining the causative factors for Wal-Mart and other retailers pushing their suppliers to adopt barcode technology in the 1970s. These factors included ongoing attempts to maximise SCM efficiency, to lower expenses, and gain a competitive edge over rival organisations. Other returns to organisations included the ability to better utilise assets and increase quality control processes. In addition to this, organisations could yield higher returns with superior inventory management capabilities.

5.1 Asset Tracking

Many organisations turned to barcoding in an effort to help manage their resources. Barcode labels that contain serial numbers are often used as nameplate identification and help organisations with asset tracking operations. The use of barcodes to track specialty tools, manufacturing equipment, computer hardware and office equipment is commonplace in many companies. These barcodes can be linked to a database maintained by the organisation to hold additional information about assets such as cost, maintenance schedules, physical condition and features. Participant 2's organisation uses a barcode system to monitor their tools. Prior to the systems implementation, the company had no control over tool borrowing. If a tool went missing, the company had no way of tracing which tradesperson or contractor had borrowed it. This resulted in the company having to pay for the replacement of many tools and as a number of specialist tools cost in excess of $35,000 this was a significant expense. Upon the implementation of a barcode system to manage tool usage, the number of tools going missing dropped and the company had the ability to charge tradespeople and contractors if they borrowed a tool and did not return it.

Numerous goods require special reusable packaging containers as they move through the supply chain. Such packaging items include track pallets, milk cartons, trays and other returnable items. Using barcodes to track these objects "can provide a strong return on investment by lowering operating expenses" (Zebra, 2004a). When these items are not effectively managed, they can often become lost at customer facilities and not be returned promptly. According to Zebra Technologies, this results in companies purchasing additional "returnable containers to ensure they have an adequate supply, creating excess capacity and locking capital to fixed assets". Barcodes empower companies to permanently identify these items, and to scan them to record information and location details as they move in and out of sites.

5.2 Inventory Tracking

Barcodes provide organisations with an "effective tool for basic inventory tracking" (Intermec, 2002). The advent of barcoding inventory has yielded numerous advantages to organisations allowing them to accurately manage inventory levels. Zebra (2004a) cites an example of a baking company reducing its inventory and distribution costs by US$3 million in the first year after implementing an inventory tracking system. Monitoring and capturing more information on their products allowed the company to "gain an accurate, timely view of inventory and to increase the average number of pallets per shipment from 47 to 61", about a 30% improvement.

5.3 Inventory Management and Traceability

Enhanced inventory management is made possible through item level inventory tracking with barcodes. Participant 1 believes that in terms of barcode technology in SCM, "the big thing is inventory control". At a high level, barcodes allow organisations to have inventory details at all times, including information on location and quantity. This permits companies to minimise product search times, improve inventory control, and ensure they have enough inventories on hand to meet demand, while enhancing productivity and efficiencies of scale (Zebra, 2002). Organisations are also better equipped to monitor order fulfilment processes and quickly meet order demands even as they reduce labour costs by eliminating manual steps. With the prevalence of just-in-time (JIT) inventory management and build-to-order (BTO) SCM practices, the need for immediate and accurate reporting is paramount. Barcodes offer the means for companies to meet these requirements. Barcodes also aid organisations in reducing operational inventory levels and increasing working capital.

Hau Lee, a professor at Stanford's business school thinks that when it comes to barcodes and inventory management, "Wal-Mart is certainly the champion". Enhanced inventory management practices throughout their supply chain has allowed Wal-Mart to keep both costs and prices down by using barcode systems, which benefits both the company and the consumer (exhibit 4). Wal-Mart stores use wireless scanners, allowing staff to make price changes, place orders and view sales histories of products. This in turn means that stores can be flexible, adjusting prices on a popular item which is a crucial capability for a

Exhibit 4. ALDI Point-of-Sale

worldwide supply chain. This ensures that companies do not run out of stock for a particular item, as systems can alert staff when specific product quantities are running low. Australian retailer, David Jones, uses a similar system that allows staff to use wireless barcode scanners. David Jones has found the system particularly useful when employees are doing inventory stocktakes. The system has been very successful and the retailer is investigating the possibility of expanding it to include wireless point-of-sale (POS) terminals (Crowe, 2004). In contrast, the Singaporean convenience supermarket chain, Cheers, still relies on manual stocktakes for its in-store inventory count. Personnel count and record the number of remaining items of a particular good, and use paper taped to shelving to identify the quantity that needs to be ordered. Zebra Technologies note that for companies "with millions of parts to identify, locate and move in and out of inventory, barcoding is essential". Warehouse management systems (WMS) linked with barcode systems can help route workers directly to optimise put-away locations depending on a good's shelf-life, size and predicted consumption schedule. A baker and snack food producer with national distribution requirements was able to achieve improved tracking over work-in-progress and finished goods, reducing inventory distribution costs by 30% (Zebra, 2003b).

5.4 Quality Control and Recall Management

Sound and thorough inventory management practices also lead to more advanced lot management and quality control capabilities. Long et al. (1998) note, as companies begin to "automate and to use Just-In-Time (JIT), Total Quality Control (TQC) and Computer Integrated Manufacturing (CIM) in the management of their operations, then bar coding will become the veins and arteries which carry that information". When used for quality and control purposes, barcodes contain such internal information as completion dates, serial numbers, materials used and miscellaneous quality control information. Organisations can scan these barcodes as items leave their shipping department and record exact details of products to record information, such as destination, in real-time. Motorola uses "tiny barcodes as part of its quality assurance in its manufacturing process to correctly identify assemblies" (Heng, 1998).

The cost of a product recall is determined by the degree of traceability that organisations have on their products. "The amount of information included on unit-of-use packaging can make the difference between a general, mass recall with notices going out in newspapers and TV news, and a highly targeted, limited recall where customers may receive notification by a phone call from their supplier" (Zebra, 2004a). First class quality controls have contributed significantly to decreasing the likelihood of a product recall. Enabling barcodes to track items at lot level throughout the supply chain means that specific quantities and shipment lots can be recalled should there be a problem. Returned goods can be easily checked with a barcode scan, limiting the burden on staff in the advent of a recall. "This degree of traceability limits the logistics handling costs and administrative burden, so recalls can be resolved more quickly" and creates an audit trail that would "limit liability exposure and prevent lawsuits from unaffected individuals" (Zebra, 2004a). General Motors have saved millions in costs and damage to its reputation through higher level tracking with its two dimensional shipping labels.

6. ECONOMICAL CONSIDERATIONS

One of the later realisations in the barcode diffusion cycle was the economical saving. Once the deployment of barcodes in SCM approached critical mass, large savings could be achieved in numerous ways including reduced error levels, increased visibility and labour reduction.

6.1 Timely Information and a Reduction in Errors

There is no doubt that barcode technology is faster than manual keyboard data entry, which depends on human operators, and is slow, inaccurate and expensive. Information can be read from a barcode in less than a second, giving an organization immediate information on a products lot number, invoice data order number and other information attributed to the barcode. Zebra Technologies (2004a) note that gathering information manually "is time consuming, because the information first must be recorded at the point of activity, then later transcribed and entered into the computer system", every additional stage increasing the already high chance of error.

The real-time information provided by barcodes allows organisations to base their decisions on current, accurate and concrete information. Such information can provide companies with a competitive advantage through their supply chain management practices. For example, if a company receives timely and accurate information they may be able to operate with a greater warehouse capacity or lower inventory on hand through employing JIT inventory practices. JIT allows companies to predict precisely when they will run out of stock and place orders with suppliers to replenish stock levels. Although this can be risky, when properly implemented it can yield enormous savings. This means the company can keep stock levels at a minimum. JIT helps to reduce "inventory levels and overall inventory carrying costs", maximising working capital for a business to invest in other areas (Zebra, 2003c).

6.2 Efficiency Benefits

The key motivations for organisations to utilise barcoding are generally the same across organisations; to improve data management, accessibility and reduce costs. It is estimated that in the domestic retail industry of the U.S., barcodes save over US$17 billion annually (New Jersey, 2004). There is a plethora of literature, mainly in whitepapers, with case studies of organisations saving significant amounts of money and improving efficiency through the utilisation of barcode technology (Vernon, 2003). Improved labour efficiencies are a significant contributor to overall cost savings delivered through barcodes. The automation of processes can dramatically increase speed and efficiency throughout the supply chain without risking accuracy. Testament to this is the fact that around 80%-90% of Fortune 500 companies have automated their warehouses with barcode systems (Varchaver, 2004). Automation of formerly manual tasks enables personnel to be more productive in other areas of an organisation's operations.

An example of an efficiency gain through barcode technology can be demonstrated by examining United Postal Service (UPS). The company predicts that they will save US$600 million a year when their barcode system is fully operational in 2007. These savings are largely delivered through enhanced automation and employee utilisation. General Motors have used barcodes in the

assembly line of some of their plants, successfully reducing errors, such as installing the wrong parts, from 15% to 0%. Other examples include Procter & Gamble, who realised double-digit productivity improvements through automation, and Kimberly-Clark who reduced shipping errors by more than 50% with barcode technology (Varchaver, 2004). After implementing a barcode system for shipping operations DePuy Orthopaedics have saved several hundred thousand dollars (Zebra, 2003b).

6.3 Proven Technology with Existing Infrastructure

Since the inception of barcodes more than 30 years ago, the technology has been turned to by many industries and applied throughout the supply chain. In fact, barcodes have evolved to meet demands throughout the enterprise including warehousing, package delivery, accounting and customer service functions. Singer comments that "bar coding is a proven, well-established technology", as evidenced by the fact that worldwide, barcodes are scanned over 10 billion times a day (Singer, 2003). Many organisations, in particular most mid-to-large sized distribution intensive operations, have adopted barcoding technology and invested considerable amounts of capital in infrastructure and related systems. Such organisations would need to thoroughly assess the benefits of any other auto-ID technology before being able to justify investment in an alternative technology.

6.4 Proven Technology with Existing Infrastructure

It takes less than a second to scan a barcode, making barcode scanning faster than manual collection, improving labour productivity and reducing labour costs. However, with barcode technology commonplace in the supply chain and the popularity of manual data fading, there is more focus on the labour requirements required by the physical nature of barcode scanning. This is due to the technical line-of-sight attribute of barcodes and the increasing popularity of radio frequency identification (RFID) technology (exhibit 5) that is not bound by the limitations of optical line-of-sight (Sanford, 2003). Jimmy Burk, a FedEx information technology vice president recalls when the company had "people specially trained to memorize about 300 routes in [their] hubs, to know the zip codes and the cities so that they could put them on these special conveyors, because there was no automation" (Varchaver, 2004). Barcodes have empowered such organisations to automate sorting processes. However, as IBM (2004) has stated supply chains are "constrained by barcode scanning, which requires line-of-sight visibility and manual intervention that can limit timely access to data". This physically demanding process of scanning many barcodes means that manufacturers, retailers and logistic transport organisations often spend

Exhibit 5. nLoS with RFID for Scanning

innumerable days "physically checking pallets and cases of products as they move through the supply chain".

6.5 Labour Considerations

Barcode scanning eliminates manual data entry to provide near perfect identification of objects. This makes the technology far superior for entering data into a system than manual word processing or manual record keeping with paper forms and pen, as noted by Participant 1, "it [barcodes] destroys human error". In the medical industry, human error in managing the supply chain of medicine distribution can have devastating consequences in the advent of human error. The industry has turned to barcode technology to address this issue. According to the Institute of Medicine and other experts, "thousands of deaths and millions of hospitalizations result from medication errors". The annual benefit from preventing these errors is the equivalent to saving US$3.9 billion (USA, 2003). By barcoding a patient's information and medicines it is predicted that facilities could reduce errors by around 65% to 86%, a significant benefit to all stakeholders (Heinen, 2003).

There is however, one common weakness with manual scanning in that it requires the operator to actually perform the scan. Singer (2003) notes that even with barcode systems in place, inventory still gets lost and incorrect shipments are still made because "a warehouse associate performed an inventory move without performing the corresponding scan transaction". A delivery company in the UK, Online Express Parcels, attributes human error for the reason parcels are often misrouted or left behind. Online Express Parcels have taken advantage of barcodes to reduce the risk of human error, through more accurate barcode information management practices. The company has employed a barcode system to help stem this problem; however, it too is subject to human error (Vernon, 2003). Further weight is given to this notion with Zebra Technologies (2004) acknowledging that barcode "shipment verification requires operators to scan each label, raising the possibility that items could be missed and unaccounted for".

7. FINDINGS

In this section a high-level summary of the advantages and disadvantages of barcode and RFID will be provided as well as a comparative matrix of characteristics. The findings will also identify how barcode and RFID are being used in different phases of the supply chain and offer insights into how both auto-ID techniques will be used in the future.

7.1 The Advantages and Disadvantages of Barcode and RFID in SCM

It is difficult to compare an established and mature automatic identification (auto-ID) technology such as barcodes to an emerging one like RFID. This disparity means that the two technologies are not on level ground, one has had extensive testing in a commercial environment, and the other has limited commercial exposure. Despite this inherent limitation, diagram 1 lists many of the intrinsic advantages and disadvantages of barcodes and RFID. It should be noted that the diagram offers no weighting to any particular attribute and is not exhaustive; the

factors listed have been given the most space in common industry papers and forums. Furthermore, some attributes could be listed as an advantage or disadvantage for both technologies. Where one technology offers a distinct edge over the other, the diagram will list that trait for only the dominant technology. An example of this is asset tracking, which both technologies offer; however, as RFID is superior to barcodes for this purpose, asset tracking is only listed under RFID. The diagram shows that RFID has a greater number of drivers and inhibitors when compared to barcodes. This can most likely be attributed to the fact that RFID is an emerging technology and has inherent qualities which may hamper its diffusion. As a result, there is a greater degree of uncertainty surrounding RFID technology. As RFID becomes more widely accepted and deployed, some factors will abate and others will materialise. On the other hand, barcodes have been in use for more than 30 years. This has resulted in a high degree of knowledge and certainty about barcodes. The diagram does show that although RFID has numerous disadvantages, the potential windfall for organisations is superior to that offered by barcodes.

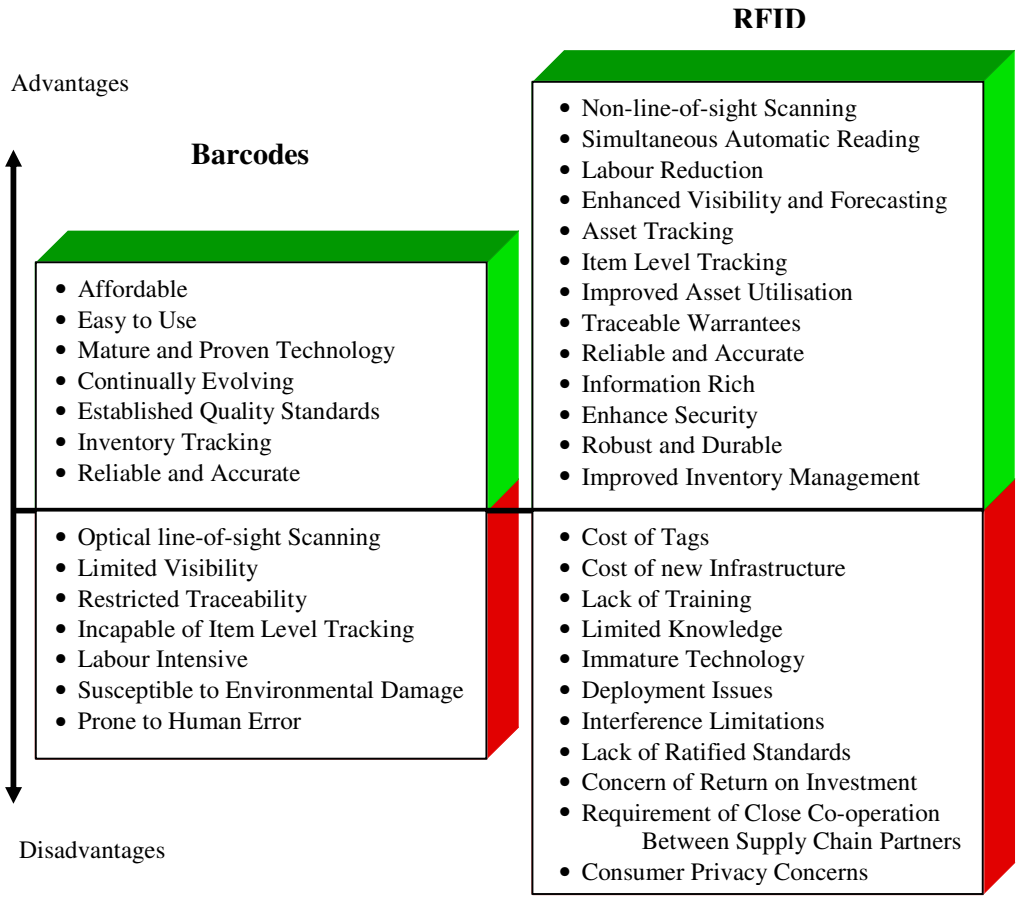

Diagram 1. The Advantages and Disadvantages of Barcodes vs RFID

Table 1 illustrates the three key phases of the supply chain, to show what barcode and RFID technology each offer. The phases examined are manufacturing, distribution and retailing. Representative company cases that have adopted barcode or RFID are also listed in each phase. The table reveals that RFID offers a larger array of benefits, over and above that of barcode for all phases of the supply

chain. It also illustrates the importance that supply chains have placed on the automatic identification of goods. It is important, at this point, to remember the momentum for auto-ID in the supply chain begun with the introduction of barcodes. Barcodes have been the catalyst surrounding the discovery of many new business processes and to some degree this automation has been tailored to the capabilities of barcode. An adoption of a new technology such as RFID would have major process implications as well.

Table 1. Barcodes and RFID in Supply Chain Management

	Manufacturer	**Distribution**	**Retailer**
Barcodes	• Affordable • Accurate and reliable • Generic quality control • Asset tracking • Reduced shrinkage • Subject to environmental factors • Labour intensive manual scanning • Non-specific recalls	• Accurate inventory information • Limited visibility • Affordable • Accurate and reliable • Partial employment of JIT • Labour intensive • Prone to human error • Susceptible to environmental damage • Better asset management • Time consuming manual scanning	• Inventory management • Reliable • Labour intensive • Limited visibility • Manual stocktakes • Subject to human scanning errors • Slow scanning of incoming shipments
RFID	• Traceable warrantees • Targeted recalls • Better quality control • Enhanced visibility • Security and counterfeiting protection • Increased asset utilization • Increased labor productivity • Superior WMS • Utilization of JIT • Better sequencing of WIP materials • Asset tracking • Reduced shrinkage	• Automatic ID of product and pallet contents • Improved order accuracy • Higher order fulfillment • Enhanced labor productivity • Enhanced visibility • Express item picking • Faster put-away times • Theft prevention and enhanced security • Fewer misdirected shipments • Better un/loading times • Superior WMS • Utilization of JIT • Reduced shrinkage • High-level of automation • Audit trails and route tracking • Asset reduction • Better management of reusable assets • Improved forecasting and planning	• Inventory visibility • Reduced incidence of out-of-stocks • Fewer expired products • Increased labor productivity • Improved customer service • JIT inventory management • Enhanced forecasting • Increased sales • Optimized recalls • Faster unloading times • Increased shipping accuracy • Smart-shelves • Self-checkout • Theft and security enhancement
Representative Examples	• Kimberly-Clark • General Motors • Procter & Gamble • DePuy Orthopaedics • Amcor Fibre Packaging • Colourpoint • MidAmerican Growers • Boeing • Chrysler • Gillette • Pierrel-Ospedali	• FedEx • United Postal Service (UPS) • Collex • Online Express Parcels • Delta Airlines • San Francisco International Airport • TrenStar	• Wal-Mart • Benetton • David Jones • Target • Albertsons

7.2 The Future of Barcodes in the Supply Chain

While it is impossible to be certain about the future of barcode and RFID technology, examining trends, both past and present, can help to more accurately predict what will happen. It is important that organisations have an insight into how the barcode and RFID relationship will evolve, as there is a considerable amount at stake. Organisations have invested heavily in barcode systems and early adopters of RFID risk wasting large amounts of capital to become RFID compliant if the technology fails to be widely accepted. There is no doubt that RFID will play a more dominant role in SCM than it presently does. However it should be noted that barcodes and RFID share many similar advantages and disadvantages. The similarities of the two auto-ID techniques enable the technologies to be used in conjunction.

As a result, organisations are in the favourable position of being able to use both of the technologies simultaneously, utilising the inherent advantages of each technology to yield the best result. This approach will lead to convergence where barcodes and RFID will co-exist within SCM for quite some time into the future (exhibit 6). A similar pattern of migration was predicted between the magnetic-stripe card and the smart card, the end result of which was a standardised multi-technology card with a magnetic-stripe on the back and an integrated circuit on the front of a credit-card.

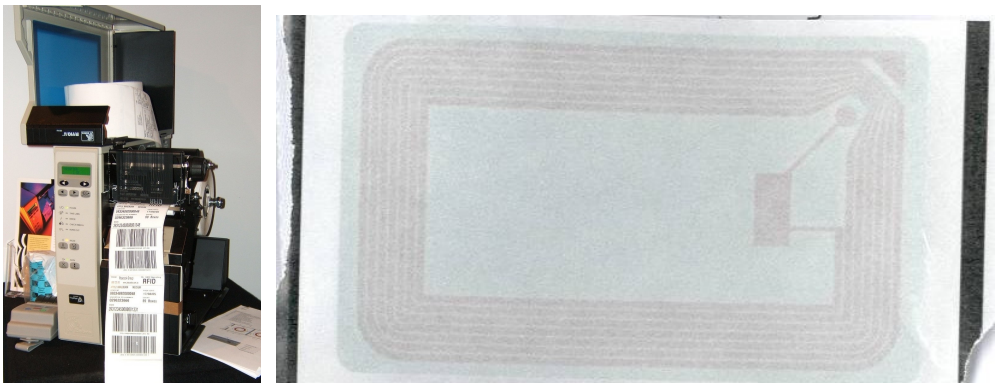

Exhibit 6. The Reality- Barcode and RFID Coexistence. Dual barcode and RFID printer (left); Passive RFID label ready for barcoding (right).

8. CONCLUSION

There will always be a diverse range of auto-ID technologies for organisations to choose from with respect to SCM. Barcodes will continue to play a significant role, whether it is helping a supplier streamline their inventory management practices or at the checkout of a supermarket. However, due to the inherent advantages of RFID technology, such as not requiring line-of-sight and the ability to track products in real-time, RFID will be increasingly utilised in SCM. It is predicted that this will lead to a co-existence of barcode and RFID where they will play a complementary role to one another. Organisations will be able to leverage the power of barcodes and RFID to achieve new levels of efficiency both internally and with partners. Pressure from retailers is leading to a 'push and pull'

effect whereby retailers force suppliers to adopt RFID, with the technology being pulled back up the supply chain, from manufacturers, logistics, distribution centres and retailers. Organisations will increasingly integrate RFID into their supply chain to primarily meet mandated requirements. The emergence of RFID standards such as the Electronic Product Code (EPC) will facilitate this process. Furthermore, there is a relationship between the cost of RFID and the technology's level of usage, whereby as the cost of RFID decreases, its level of usage throughout the supply chain will gather momentum. This paper has shown however, that barcode is still a significant force to be reckoned with, especially due to its large-scale deployment globally. The technology is far from obsolete, in fact, barcode is embedded in SCM practices and is not about to go away any time soon.

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