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RFID for Better Supply-Chain Management through Enhanced Information Visibility

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ABSTRACT

Mostly fueled by mandates, adoption and implementation of the RFID technology in the retail industry is growing rapidly. At these early stages of adoption, one puzzling issue for retailers and suppliers is the compelling business case for RFID. In order to explore the potential business case for RFID, we conducted a case study using actual RFID data collected by a major retailer for the cases shipped by one of its major suppliers. We show the physical layout of the RFID readers on a partial supply-chain covering product movement from distribution centers to retail stores. In the analysis phase, first, we identify several performance metrics that can be computed from the RFID readings. Next, using this RFID data, we compute the values of those performance metrics. These values represent mean time between movements at different locations. Then, we discuss how these measures can assist in improving logistical performance at a micro supply chain level of operations between a distribution center and a retail store. We present how such information can be valuable to both the retail store operator and the supplier. We also discuss the initial lessons learned from actual RFID data collected in the field, in terms of data quality issues.

Keywords: Radio frequency identification, RFID, retail business, supply-chain, data problems, lessons learned

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1. Introduction

With a June 2003 mandate that its top 100 suppliers place RFID tags on pallets and cases shipped to stores in the Dallas, Texas region, Wal-Mart jump-started a 50 year old technology that, until the mandate, had found limited (but successful) use in a variety of niche areas. Since that announcement, the RFID industry has blossomed. The Department of Defense soon followed with its own mandate; Target, Albertson's, and Best Buy, among others, quickly followed suit. Initial efforts focused on the largest suppliers in the retail supply chain (e.g., Procter & Gamble/Gillette, Kraft), but have now spread to include smaller retail suppliers—Wal-Mart's next 200 suppliers began shipping tagged products in January 2006 and its next 300 suppliers are scheduled to begin in January 2007.

Mandates by major retailers may have rejuvenated the technology, but a recent survey of 510 companies by Frost & Sullivan found that the number one reason for planned deployment of RFID is "improved process efficiencies" – not mandates. Thus, companies are expecting RFID to serve as a business process enabler, but without clear answers as to how it can help (Ware, 2004). The answers, ultimately, have to be found in the data produced from an RFID-enabled environment. The objective of this paper is to illustrate, via actual RFID data collected by a major retailer covering one of its largest suppliers' product movement from distribution centers to retail stores in the US, the visibility provided by RFID and discuss the potential value of this visibility to supply chain constituents. In essence, we report on initial lessons learned to provide insight into the question of "what business value can be gained from RFID data?"

In this paper, we demonstrate that RFID data can provide information visibility at a granularity never before possible. In the analysis phase, we identify several performance metrics that can be computed from the RFID observations, and discuss how these measures can assist in improving logistical performance at a micro supply chain level of operations between distribution centers and retail stores. We discuss how such information can be valuable to both the retailer and the supplier.

The paper is organized as follows. The next section provides a brief background on the importance of information visibility in the supply chain and gives an overview of RFID technology. Section 3 describes the use of RFID in a distribution center-to-store component of a supply chain. Section 4 presents the performance metrics possible through RFID data for this supply chain component, and illustrates these metrics on an example case. Section 5 discusses the business value of RFID and describes projected future uses of RFID in the retail supply chains. The last section presents the lessons learned from the case study (especially with respect to the RFID data) and concludes the paper with a discussion of future research issues.

2 Background and Brief Overview of RFID

2.1 Supply chain visibility

The motivation behind supply chain management is to eliminate the barriers by enabling the synchronization and sharing of valuable information among trading partners. The success of a supply chain system depends on the level (and the timeliness) of visibility it has on the materials from suppliers to the customers (Joshi, 2000). The most important benefits of such improved information visibility are realized in inventory management and in asset utilization. Some of the recent literature reports on studies that measure the impact of information visibility on supply chain operations both quantitatively and qualitatively. For instance, Doerr et al (2006) report on an analysis of the qualitative benefits of using RFID technology for the management of ordnance inventory. Combining a multi-criteria valuation approach with a Monte-Carlo simulation, they measure the impact of qualitative and financial factors. According to their results, the qualitative factors account for over half of the anticipated total benefits of RFID technology. In a quantitative study, Joshi (2000) developed a system dynamics-based simulation model to study the impact of information visibility on supply chain dynamics. He simulated a beer distribution network with a retailer, wholesaler, distributor and factory. The performance measures were inventory level in the supply chain and the orders for the beer cases. He studied different forecasting methods with information sharing (visibility) and no information sharing (no visibility). The inventory levels at the different stages in the supply chain experienced large fluctuation and pipeline inventory was high. When the assumptions about information visibility were relaxed, and each of the units was producing or handling to the true customer demand, the inventory in the pipeline reduced drastically and the fluctuations were almost eliminated thereby reducing the overall cost of the supply chain inventory. Their results showed that information visibility provided 40 to 70% reduction in inventory cost alone. Other intangible benefits included reduction in lost sales due to absence of backlogs, improved customer service due to timely delivery of orders, and more confidence in managing the supply chain due to accurate, real time knowledge of location of products moving in the supply chain.

With RFID, the information at different organizational levels (at the gates, at the shelves, point of sale, etc.) and types (backlog, inventory level, forecast, etc.) can be distributed in real time, eliminating the delay in information sharing. In a related study, Yao and Carlson (1999) explored the impact of real time data communication on inventory management in large distribution centers. A comparison between traditional batch data reporting and radio frequency based real-time data reporting was offered in the context of a very large distribution center. Their results showed that (regardless of the industry type) use of radio frequency based real-time data communication and reporting greatly improved such warehouse operations as receiving, order processing, material handling, reserve stock, order picking, and shipping. Similarly, Lee et al. (2004) explored the impact of information collected by RFID shared across the network on the supply chain dynamics. Their simulation model of a distribution network consisted of a manufacturer, warehouse/distribution center and the retailer with a backroom. RFID tags were placed at the entry and exit points at each of the unit. They analyzed the effect of inventory accuracy, inventory visibility and shelf replenishment policy at the retailer and distribution center with and without RFID. The RFID enabled models outperformed the others in all configurations.

Another comparative study of traditional means versus the radio frequency based data capture and communication in the context of inventory inaccuracies is reported by Fleisch and Tellkamp (2005). Specifically, they studied the effects of inventory inaccuracies on a retail supply chain. They simulated a three echelon supply chain with one product in which end customer demand is exchanged between the echelons. According to the reported results, in the base model where the physical inventory and information system inventory were not aligned, the inventory information became inaccurate due to low process quality, theft, and spoilage. In a modified model, where the above factors that caused the inventory inaccuracy were still present, but the physical inventory and information inventory were aligned at the end of each period, the results indicated that such elimination of inventory inaccuracy could lead to reduction in supply chain cost as well as out-of-stock levels. They proposed that the automated identification technology has the greatest potential to achieve the desired inventory accuracies.

The above mentioned studies all conclude that the information visibility (and the corresponding timeliness of information) is critical to supply chain operations. These previous studies primarily used simulation models to demonstrate the advantages of radio frequency based real-time data capture and communication for better supply chain visibility. The study presented in this paper augments and strengthens these previous studies by making similar claims based on (not a simulation study but) real world data collected from one of the earliest adopters of RFID technology in the retail industry. The results of this study also show that there is a very different level of information visibility possible with RFID.

2.2 Brief Overview of RFID

RFID is a generic technology that refers to the use of radio frequency waves to identify objects. Fundamentally, RFID is one example of a family of auto identification technologies, which also include the ubiquitous barcodes and magnetic strips. Since the mid-1970s, the retail supply chain (and many other areas) has used barcodes as the primary form of auto identification. Given the success of barcodes, the question arises 'Why move to RFID?' The answer lies in the numerous advantages of RFID relative to barcodes, as shown in Table 1 (Raza et al., 1999 and Shepard, 2005). Advantages of barcodes over RFID are also shown in Table 1.

Table 1. RFID vs. Barcode

RFID	**Barcode**
Not constrained by "line-of-sight". Hence, the location/orientation of the reader does not matter as long the tags are within the range of the reader's signal.	Requires line-of-sight.
Many tags can be read simultaneously.	Only one read at a time.
Very durable: they are resistant to heat, dirt, and solvents and hence are not physically damaged easily, making them useful in a large number of potential applications.	Low durability: easily damaged.
RFID tags can be self-powered (active tags). They can not only deliver information about location on demand but also collect information (via integrated sensors), and store them locally in itself. This dynamically stored data can be retrieved for analysis later or can be transmitted by the tag to the reader on an ad-hoc fashion under special circumstances.	Has no power source, and cannot serve beyond being a static label.
RFID tags can potentially be written multiple times, making them reusable data containers.	Not reusable as a data source.
Expensive (relative to barcodes).	Less expensive than RFID tags.
Liquids and metals cause read problems.	Can be used on or around water and metal with no performance loss.
RFID tags must be added to current production process (such as embedded in the box) or added to the unit (box, pallet, etc.) before shipping.	Can be printed before production or directly on the items.

The potential advantages of RFID have prompted many companies (led by large retailers such as Wal-Mart, Target and Albertson's) to aggressively pursue this technology as a way to improve their supply chain, and thus, reduce costs and increase sales.

How does RFID work? In its simplest form, an RFID system consists of a tag (attached to the product to be identified), an interrogator (i.e., reader), one or more antennae attached to the reader, and a computer (to control the reader and capture the data). At present, the retail supply chain has primarily been interested in using passive RFID tags. Passive tags receive energy from the electromagnetic field created by the interrogator (e.g., a reader) and backscatter information only when requested for it. The passive tag will remain energized only while it is within the interrogator's magnetic field. Unlike passive tags, active tags have a battery on board to energize the tag. Because active tags have their own power source, they don't need a reader to energize them; instead they can initiate the data transmission process. On the positive side, active tags have a longer read range, better accuracy, more complex re-writable information storage, and richer processing capabilities (Moradpour and Bhuptani, 2005). On the negative side, due to the battery, active tags have limited lifetime, are larger in size and are more expensive than passive tags. Currently, most retail applications are designed and operated with passive tags. Active tags are most frequently found in defense or military systems, yet also appear in technologies such as EZ Pass, where tags are linked to a prepaid account enabling drivers to pay tolls by driving past a reader rather than stopping to pay at a tollbooth (DoC, 2005).

2.3 RFID Data

The most commonly used data representation for RFID technology is the Electronic Product Code (EPC), which is viewed by many in the industry as the next-generation of the Universal Product Code (UPC) (most often represented by a barcode). Like the UPC, the EPC consists of a series of numbers that identifies product types and the manufacturers across the supply chain. The EPC code also includes an extra set of digits to uniquely identify items.

Currently, most RFID tags contain 96 bits of data in the form of serialized global trade identification numbers (SGTIN) for identifying cases or serialized shipping container codes (SSCC) for identifying pallets (although SGTINs can also be used to identify pallets). The complete guide to tag data standards can be found on EPCglobal's website[1]. For the purposes of this paper, we will restrict our discussion to SGTINs. As illustrated in Figure 1, tag data, in its purest form, is a series of binary digits. This set of binary digits can then be converted to the SGTIN decimal equivalent. As shown, an SGTIN is essentially a UPC (UCC-14, for shipping container identification) with a serial number. The serial number is the most important difference between the 14-digit UPC used today and the SGTIN contained on an RFID tag. With UPCs, companies can identify the product family to which a case belongs (e.g., 8-pack Charmin tissue), but they cannot distinguish one case from another. With an SGTIN, each case is uniquely identified. This provides visibility at the case level, rather than the product family level.

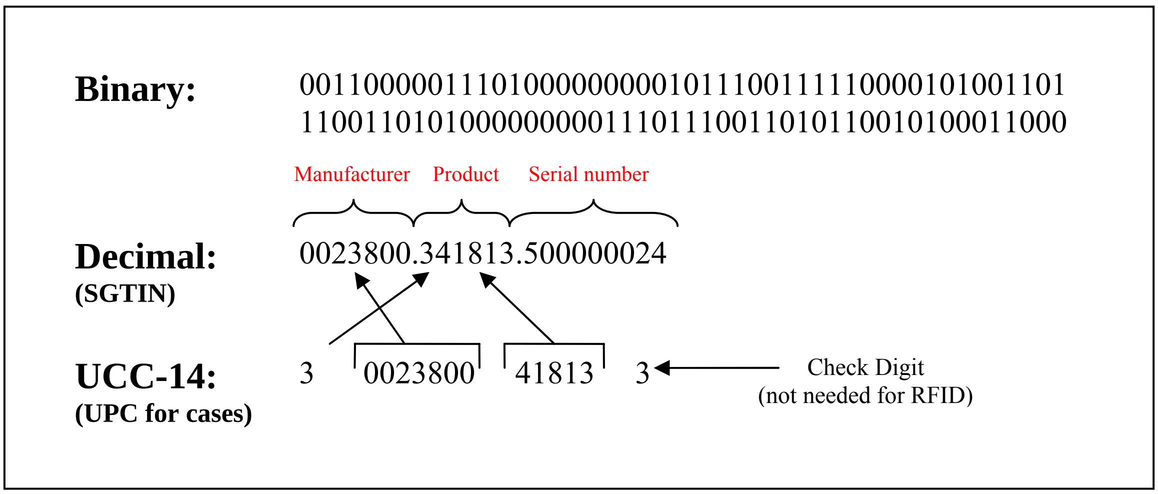

Figure 1: Tag Data

3. RFID in the Supply-Chain – A Case Study

RFID promises to overhaul the supply chain operations through information availability never before possible, thus allowing the design and implementation of new technologies to further automate supply chain operations. However, its use is still early and demonstrable benefits are slowly emerging. Based on an actual case study, this paper presents the results of how efficiency can be improved using the RFID data.

[1] EPCglobal Inc. is a subscriber-driven organization comprised of industry leaders and organizations focused on creating global standards for the Electronic Product Code™ (EPC) to support the use of Radio Frequency Identification (RFID). It can be accessed at http://www.epcglobalinc.org/.

Our case study focuses on the supply chain component between distribution centers and the retail stores. One of the most promising application areas for RFID in the retail industry is in streamlining distribution center and retail store operations, which may be considered a small-scale supply-chain. Many retailers (and other warehouse/distribution center operators) think that they can greatly improve their current processes by reducing the number of human touch points of the products in their systems (Twist, 2005). Some of the frequent touch points are at the receiving areas, putaway-picking functions and the shipping areas. These warehouse systems suffer from the inefficiency due to human errors resulting in reduced accuracy of inventory levels (e.g., miscounting received items), lower throughput and increased labor cost.

Figure 2 represents the typical functions performed in a distribution center (DC) and in a retail store with respect to the flow of materials between these supply units. In a DC, the primary functions are receiving, putaway, picking, and shipping. Receiving is the collection of all the activities related to the orderly receipt of materials/goods, inspection for quantity and quality and dispersion of the received goods to storage/putaway and/or to cross-docking for immediate shipment (Tompkins et al, 2002). Typically, the following sequence of operations happens once a truck backs into the receiving door: (1) Unloading the contents of the trailer; (2) Verification of the receipt of goods against expected delivery (purchase order); (3) Sorting of the damaged goods and documentation of the discrepancy in count and/or product type to be settled later; (4) If needed, application of labels to the pallets, cases or items so that units can be tracked inside the warehouse; and (5) Sorting of goods for putaway or cross-dock based on current demand and schedule.

Putaway is the process of placing the merchandise in either short-term (a.k.a. intermediate storage) or long-term storage. Order-picking is the process of retrieving an item/product from the shelves to meet the specific demand (Tompkins et al, 2002). Traditionally, warehouses are labor intensive and most of the labor is devoted to the picking operations. In warehouses, depending on the picking policy implemented, the order-pickers travel to the physical location of the item, scan the case/pallet load, verify the accuracy of the location and the product based on the generated pick list from the warehouse management system (WMS) and retrieve it to the forward area or to the shipping dock. Shipping includes checking order completeness, appropriate packaging, determining shipping charges, accumulating orders by outbound trailer and loading the trailers (Tompkins et al, 2002).

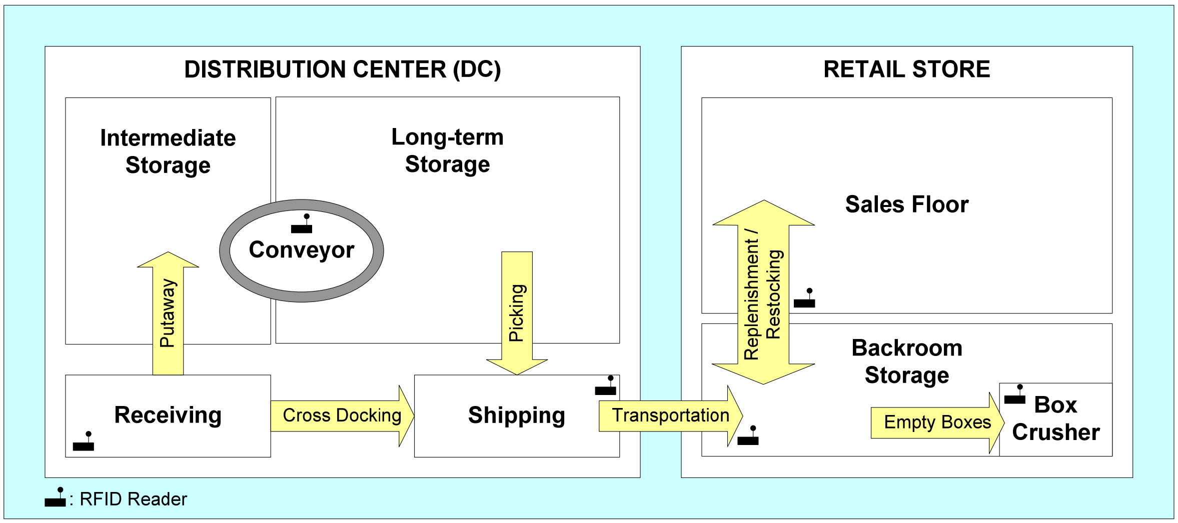

Figure 2. Operations and Related Functions of a Typical Retail System

In a store, the primary functions are receiving, putaway, picking, shelf replenishment, and container disposal. Products are received at the store from the DC either palletized or 'floor loaded' (i.e., single cases stacked from floor to ceiling but not on pallets). Products are unloaded from the truck and are either taken directly to the sales floor for shelf replenishment or putaway in the back room for future use. For these items, picklists, created by store associates when shelves become empty or near empty, are used to guide retrieval of product from the backroom for shelf replenishment. Finally, empty boxes are returned from the sales floor and placed in the box crusher for final disposition.

As a product moves from the supplier, to the retail DC, and then on to the retail outlet[2], it passes through a number of RFID read locations. Readers capture and record the case's tag data as it passes through these points. The key read points in a generic distribution

[2] Currently, most suppliers take a 'slap and ship' approach to RFID which means they put a tag on the product as it leaves their facility. Thus, RFID is operating in an abbreviated (i.e., small-scale) supply chain from the point of departure from the supplier's facility through the backroom of a retail outlet.

center are indicated on Figure 2. As product is delivered to the distribution center, read portals (created by stationary readers and antennae on each side of the delivery door) capture the pallet and case data.[3] The product is stored in the distribution center for an indeterminate amount of time, then individual cases are moved through the distribution center (e.g., put on a conveyor system for sorting or cross-docked in full pallet format) to the proper shipping doors which contain read portals similar to the receiving doors. The actual reads for a single case may vary depending on the type of product (e.g., bagged pet foods are not placed on conveyors) and the type of DC it enters (refrigerated/grocery DCs are different from general merchandise; e.g., grocery DCs have stretch wrap machines where readers can be placed, but do not have conveyors) (Alexander et al. 2003). Often, a case may not even follow the prescribed route.

At the store level, the readers are confined to the backroom area – no readers are on the sales floor (see Figure 2). Receiving doors have read portals similar to those found at the DC dock doors and capture reads from the individual cases as they are unloaded from the truck. Sales floor door readers identify the cases moving from the backroom to the sales floor and also capture the movement of these boxes as they return from the sales floor to the backroom. The final read point is the box crusher.

As a representative example, Table 2 traces the actual movements of a single case of product[4] (SGTIN: 0023800.341813.500000024) from its arrival at the distribution center to its end of life at the box crusher. This particular case of product arrived at distribution center 123 on August 4, was put on the conveyor system[5] on August 9, and departed shortly thereafter. It arrived at store 987 about 12 hours after leaving the DC, went almost immediately to the sales floor, returned from the sales floor about 5 hours later and was put in the backroom where it stayed until the following day where it once again went to the sales floor, returned about 45 minutes later, and then went to the box crusher

[3] At this point, Wal-Mart and other retailers do not expect to see 100% of the individual cases on a pallet. Rather, they expect to read a pallet tag and several of the cases. They do expect to read 100% of the cases after they are depalletized (Hardgrave and Miller, 2006).
[4] DC and store numbers are fictitious.
[5] Note: not all products would be put on the conveyor system; thus, this read may not be available for all products

for ultimate disposal. This product mostly follows the prescribed route,[6] but veers off course toward the end as it goes out the sales floor and back again on two separate occasions.

What can the snippet of data from Table 2 tell us (as one simple instance of RFID data)? If we examine the data closely, it offers up several insights.

Table 2. Sample RFID Data

Location	EPC	Date/time	Reader
DC 123	0023800.341813.500000024	08-04-05 23:15	inbound
DC 123	0023800.341813.500000024	08-09-05 7:54	conveyor
DC 123	0023800.341813.500000024	08-09-05 8:23	outbound
ST 987	0023800.341813.500000024	08-09-05 20:31	inbound
ST 987	0023800.341813.500000024	08-09-05 20:54	sales floor
ST 987	0023800.341813.500000024	08-10-05 1:10	sales floor
ST 987	0023800.341813.500000024	08-10-05 1:12	backroom
ST 987	0023800.341813.500000024	08-11-05 15:01	sales floor
ST 987	0023800.341813.500000024	08-11-05 15:47	sales floor
ST 987	0023800.341813.500000024	08-11-05 15:49	box crusher

First, knowing the dates/times of movement is important for ensuring such things as freshness of the product, tracking recalls, or getting products to the stores in a timely manner (especially for time sensitive products). For example, consider the situation faced by companies offering promotions on their products. Advertising (local, national) is generally launched to promote the products, and the fate of the product is determined in the first few days after the promotion begins. If the product is not on the shelf in a timely manner, sales may suffer. Gillette has used RFID to determine whether stores have stocked their shelves with particular items for a particular promotion. They found that in those stores that used RFID to move a product from the backroom to the shelf before a promotion started, sales were 48% higher than those that did not move the product in a timely manner (Evans, 2005) – RFID provided the data, and the insight, needed.

[6] For readability, only one read per portal per event is shown; duplicate reads at a single portal were removed.

Second, the data provides insight into the backroom process of moving freight to the sales floor. In the example provided in Table 2, we see that the product moved to the sales floor twice. Perhaps the first time it was taken out, it did not fit on the shelf and was returned to the backroom. The second time it went out, it fit on the shelf. This 'unnecessary case cycle' raises several questions. Moving the product out to the sales floor and back unnecessarily wastes precious human resources, and, the more times a product is handled, the higher the chances are that it will be damaged. Also, why did the product make two trips to the sales floor? If the product was not needed until August 11 (the day it fit on the shelf), why was it delivered to the store on August 10? This could signal a problem with the forecasting and replenishment system. Or, perhaps a worker placed a manual order for the product when it wasn't needed. If so, why was the manual order placed? It could be that the product was in the backroom, but was not visible or easy to find. Rather than taking the time to look for it, the worker manually ordered the product. While the product was in transit, another worker found the product in the backroom and stocked the shelf. When the manually ordered product arrived, it wouldn't fit on the shelf and an unnecessary trip (for the manually ordered product) was created. How can RFID help in this situation? When a worker attempts to place a manual order, the system can check to see if a case currently exists in the backroom (as determined by a backroom read). If a case exists, the system could help the worker find the case by using a handheld or portable RFID reader.

Third, it provides a precise indication of how long it took the product to move through the supply chain and the exact time between each of the key read points – on a case by case basis! This type of insight has never before been possible. Lead times are generally estimated based upon the movement of large quantities of product families through the system. Also, visibility at the store level was not possible before RFID. This visibility is a key and is explored in more detail in the next section.

4. Better Information Visibility in the Supply Chain

Following the example presented in Table 2, another way of looking at the flow of materials is via a timeline. Figure 3 illustrates the RFID reading times as products flow through an abbreviated (small-scale) supply chain, which depicts the current operations for a large retail store chain.

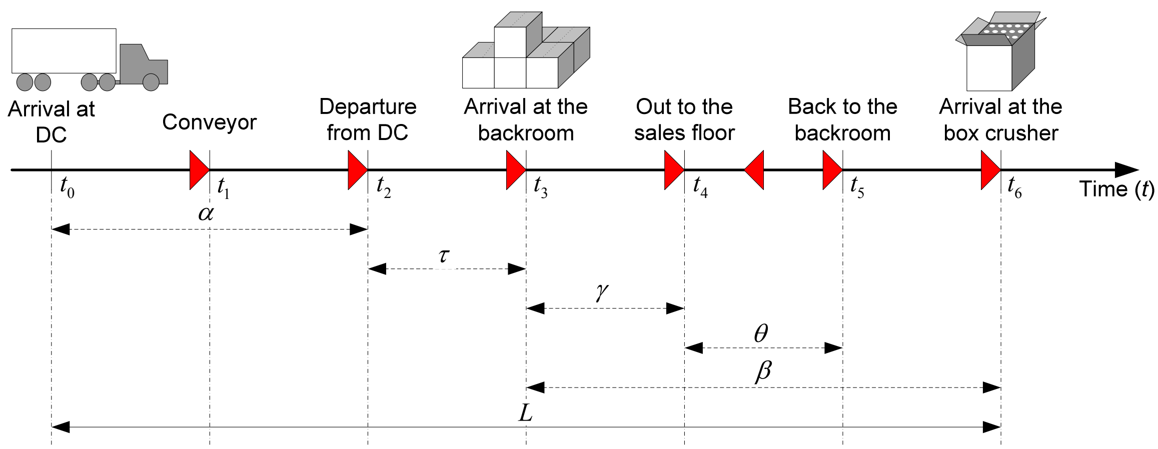

Figure 3. The timeline for a material movement reads in an abbreviated supply chain

In Figure 3, t_0 through t_6 represent RFID reads at various locations, as follows: $t_0 = \text{DC}_{\text{in}}$, $t_1 = \text{Conveyor}$, $t_2 = \text{DC}_{\text{out}}$, $t_3 = \text{Store(Backroom)}_{\text{in}}$, $t_4 = \text{SalesFloor}_{\text{in}}$, $t_5 = \text{SalesFloor}_{\text{out}}$, and $t_6 = \text{Box Crusher}$.

As shown in Figure 3, each of the discrete read points becomes a key visibility point in the movement of the products. We can identify each reading element through a label to delineate product, DC/Store location, and time.

Let i = index representing product line (or company)

j = location of the store or distribution center

k = time index (week, month, quarter, etc.)

Each reading recorded as any particular combination of product/location/time is tagged as observation l, out of N such readings.

From the RFID data read at locations in Figure 3, we can compute:

$$\alpha_{ijk} = t_{2ijk} - t_{0ijk} \tag{1}$$

$$\tau_{ijk} = t_{3ijk} - t_{2ijk} \tag{2}$$

$$\gamma_{ijk} = t_{4ijk} - t_{3ijk} \tag{3}$$

$$\theta_{ijk} = t_{5ijk} - t_{4ijk} \tag{4}$$

$$\beta_{ijk} = t_{6ijk} - t_{3ijk} \tag{5}$$

and $$L_{ijk} = \alpha_{ijk} + \tau_{ijk} + \beta_{ijk} = t_{6ijk} - t_{0ijk} \tag{6}$$

Given that these readings are taken over N observations, we can compute the means and standard deviations of all the measures proposed above. For example, for α,

$$\overline{\alpha}_{ijkl} = \frac{\sum_{l=1}^{N} \alpha_{ijkl}}{N} = \frac{\sum_{l=1}^{N} (t_{2ijkl} - t_{0ijkl})}{N} \tag{7}$$

and $$\sigma = \frac{\sum_{l=1}^{N} (\alpha_{ijkl} - \overline{\alpha}_{ijk})^2}{N-1} \tag{8}$$

Similar computations are also completed for *τ, γ*, *θ*, *β*, and *L*.

For ease of reading, we will skip the subscripts *i*, *j*, *k*, *l* in what follows. All of the performance measures proposed above measure the Mean Time Between Movements (MTBM). We also compute standard deviations of the various TBMs. Performance measure α represents the lead time at a distribution center. By a simple comparison to the projected lead times, it can be used to estimate the efficiency of the forecasting algorithm for a particular item *i* at a particular distribution center *j*. These lead times can be compared across product lines (*i*) or over time (*k*), or across different distribution centers or stores (*j*). If a particular product is spending too much time at a DC, it can raise a question with respect to the performance of the just-in-time inventory policy of the distribution center. Ideally, products should not arrive at the DC until these are ready to ship to a store.

Performance metric τ gives a measure of the transportation system's performance in delivering products from DC to a store. This can provide deeper visibility into the variability of the transportation logistics.

Performance metric γ is aimed at estimating the lead time at a store before an item is placed on the store shelves. A larger value of γ may indicate that the item is sitting in the backroom for a while before it is put on the sales floor. A store manager may wish to identify possible causes for this longer than expected MTBM from backroom to sales floor: bottlenecks in the store, inventory reordering system not performing well so as to be ordering an item too early from a DC, etc.

Performance metric θ is useful in determining the time spent by an item in the backroom before it is eventually stocked on the sales floor. Multiple readings of θ for the same case can also indicate the problem associated with sales floor cycles (as discussed earlier). Performance measure β suggests the total time spent by an item in the store until the packaging reaches the box crusher. In an efficient supply chain, that value should be as small as possible. Similarly, L measures the complete time for an item from arrival at the DC to its closure at the box crusher at the store level.

4.1 An Illustrative Analysis of Mean Time between Movements

The visibility provided by RFID into the supply chain provides the retailer and the supplier an opportunity to better understand lead times per product per specific supply chain (i.e., DC/store combination). Better understanding of lead times provides the opportunity to remove unnecessary slack and to improve forecasting. Table 3 provides a summary of two different products moving through two different DCs and four stores (see explanation at bottom of table for cell values).

Table 3. Sample measures for MTBM calculated from RFID data.

Mean Time Between Movements For: 11/1/05 – 11/08/05							
		DC in – Conveyor	**Conveyor – DC out**	**DC out – Store in**	**Store in – Sales floor out**	**Sales floor out – Backroom return**	**Backroom return – Box crusher**
Product A (for DC 128)							
Store 123 (n=232)	Mean:	15.06	0.04	1.48	0.13	0.13	0.03
	Std dev.:	4.93	.01	.46	.19	.08	.02
	Sum:	15.06	15.10	16.58	16.71	16.84	16.87
Store 125 (n=433)		12.32	0.03	0.97	1.02	0.04	0.01
		6.88	.01	.23	.86	.48	.01
		12.32	12.35	13.32	14.34	14.38	14.39
Product B (for DC 232)							
Store 201 (n=587)	Mean:	23.15	0.01	1.76	0.05	0.11	0.53
	Std dev.:	5.47	0.02	1.5	1.04	.06	.70
	Sum:	23.15	23.16	24.92	24.97	25.08	25.61
Store 264 (n=812)		19.68	0.01	1.32	0.77	0.12	0.26
		4.18	.01	.56	1.22	.23	.10
		19.68	19.69	21.01	21.78	21.90	22.16

Cell values: mean days (Mean), standard deviation in days (Std dev.), and cumulative mean (Sum) for movement between the two discrete read points indicated in each column for all products moved during the time period (indicated in the heading of the report). Number of products moved is indicated for each store (n=xxx).

The source of the data for the measures presented in Table 3 came from actual products moving through Wal-Mart's supply chain[7]. Thousands of EPC reads, from the discrete read points previously discussed, are necessary to calculate the summary statistics provided in Table 3. As shown, the lead time (from DC receipt to box crusher) for Product A is 16.87 days for DC 128 / Store 123 and 14.39 days for DC 128 / Store 125. One of the first questions that should be asked by retailers (and the supplier of Products A and B) is: how do these newly determined lead times, based on visibility never before possible, compare to the lead times currently used in the forecasts? Our early experience suggests that retailers and suppliers are often amazed at the difference between the *exact* lead time indices provided by RFID and the estimated lead times currently used. Furthermore, the precise nature of the lead time breakdown (as illustrated in Figure 3), provides a level of granularity never before possible.

[7] The actual names of the products, distribution centers and stores are scrubbed for obvious reasons.

From Table 3, let us assume that Product A is a health and beauty product; non-perishable. For DC 128 / Store 123: it took 15.06 days from receipt at the DC (DC in) before it was put on the conveyor system for store sorting. It rode the conveyor system about 1 hour (.04 days) before exiting the DC (DC out) and it took about 1.48 days to reach the store (Store in). Once at the store, it only sat in the backroom about 3 hours (.13 days) before going to the sales floor (Sales floor out) for the first time. This product then sits on the sales floor about 3 hours (.13 days) before returning to the backroom for the final time (backroom return). If the product makes multiple trips to the sales floor, then the previous metric is the difference between the first sales floor out read and the last backroom return read. As the final time interval, the product moves from the sales floor to the box crusher (.03 days; about 45 minutes). In this example, DC 128 / Store 123 appears to take their product immediately from the truck to the sales floor (movement time is only about 3 hours); stocks many shelves (boxes are on the sales floor about 3 hours) and then returns many empty boxes to the crusher (took about 45 minutes to put the boxes in the crusher). Store 125, by contrast, appears to unload the trucks and hold the product in the backroom for a while (movement time is about 1 day), and then moves them to the sales floor a few at a time (box on sales floor only about 1 hour) and crushes a few boxes at a time (about 15 minutes from return to backroom to crusher).

The snippet of data provided in Table 3 provides a powerful, albeit brief, glimpse at the potential value of the MTBM. As illustrated, one can gain insight into the exact movement times of products throughout the supply chain, how efficiently DCs operate, and the shelf stocking habits of stores (i.e., quick to sales floor / slow to sales floor; many boxes to sales floor / few boxes to sales floor at one time, etc.).

To extract further value, one could examine the MTBM data using the material movement metrics illustrated in Figure 3 and defined in Equations 1 through 6. Table 4 provides such an example, using the data from Table 3.

Table 4. Material Movement Metrics

Metric	Product A		Product B	
	DC 128 / Store 123	DC 128 / Store 125	DC 232 / Store 201	DC 232 / Store 264
$\alpha_{ijk} = t_{2ijk} - t_{0ijk}$	15.10	12.35	23.16	19.69
$\tau_{ijk} = t_{3ijk} - t_{2ijk}$	1.48	.97	1.76	1.32
$\gamma_{ijk} = t_{4ijk} - t_{3ijk}$	.13	1.02	.05	.77
$\theta_{ijk} = t_{5ijk} - t_{4ijk}$	.13	.04	.11	.12
$\beta_{ijk} = t_{6ijk} - t_{3ijk}$	.29	1.07	.69	1.15
$L_{ijk} = \alpha_{ijk} + \tau_{ijk} + \beta_{ijk} = t_{6ijk} - t_{0ijk}$	16.87	14.39	25.61	22.16

Table 4 provides a 'dashboard' of material movement metrics for a company. Although this particular example shows the metrics DC/store combination within product, many different views could be taken. One of the strengths of the metrics is the level of visibility granularity allowed, such as (1) comparing performance between DCs or between stores for all products, a subset of products, or a single product; (2) comparing performance by time period (day of week, week of year, etc.) and over time (week1 this year compared to week 1 last year, etc.); and (3) comparing actual times to expected times (i.e., those used in forecasting and replenishment models).

5 RFID Value Proposition

5.1 Current Business Value of RFID

Based on our experience with RFID technology (mostly in retail industry), we can identify three main avenues for potential business value. First, the immediate reaction to the data collected in real-time with no process changes required; second, making incremental changes to the business process; and third, enablement of new processes.

In consumer goods retail industry, the majority of products are seasonal and have only a small window of opportunity to be sold, the visibility provided by RFID can provide immediate value (with no process change required). With the insight gained from the real-time data, the products can be taken to the store where they could be sold rather than sitting in a trailer at the DC where they have no chance of being sold. Second, the retailer's forecast for the next period will be much more accurate as it will be based on product that was actually given an opportunity to be sold rather than what they thought was available for sale (Lapide, 2004).

RFID can also be used by companies to improve either the efficiency or effectiveness of various existing processes by incremental process change. For example, early evidence suggests that RFID can reduce the amount of time to receive product at a warehouse (Katz, 2006). Instead of scanning each case of product individually with a barcode scanner, RFID tagged product can be read automatically at a receiving door portal. Gillette reported a reduction in pallet receiving time at their distribution center from 20 seconds to 5 seconds due to RFID and their tag-at-source strategy (Katz, 2006). The process of receiving was not drastically changed (i.e., forklifts unloaded the product as before). The only change was eliminating the need to manually scan the product. Thus, the process became more efficient. Processes can also be made more effective (i.e., better). For example, in a widely publicized study of out of stocks, Wal-Mart found a 26% reduction in out of stocks by using RFID data to generate better lists of products to be replenished (Hardgrave et al, 2006). Herein the shelf replenishment process was not changed, but improved (made more effective) by the use of RFID. Wal-Mart has also reduced the number of unnecessary manual orders by 10%; thus, making the ordering and forecasting system more effective (Sullivan, 2005). RFID is also being used in receiving to reduce the number of errors (EPCglobal, 2006) which improves the accuracy of inventory and ultimately leads to better forecasting and replenishment.

Lastly, companies can potentially use RFID to radically change the processes by which they are either manufacturing or distributing their products. For example, should RFID get to item level tagging, then the concept of "contactless checkout" may become a reality. With contactless checkout, the shopper would place RFID tagged items into a shopping cart and walk the cart through the RFID reader at the door. The reader would read the products in the cart and automatically debit the customer's RFID-enabled credit card. If contactless checkout does come to pass, then the part of the business process that deals with checkout would be radically changed. There has also been some discussion about RFID's facilitation of pay-per-scan as a new method of inventory (whereby the retailer does not pay the supplier until the product is sold) (Sarma, 2006). Pay-per-scan would radically change existing inventory methods and relationships within the supply chain. According to McFarlane and Sheffi (2003), RFID systems has the potential and promise of enabling a complete re-engineering of the supply chain by removing a number of data and visibility related constraints that limit today's supply chain structures. While most RFID efforts to date have been focused on its use as an incremental technology, RFID does have the potential to become a radical and/or disruptive process change agent of the future.

5.2 Other Uses of RFID in the Supply Chain

Many other RFID applications in the supply chain are likely to become important. There are applications in receiving, putaway/picking, shipping, material handling, etc. For example, the receiving operation is highly time consuming, and labor intensive sometimes involving more than one level of employee and, hence, a potential source of errors. RFID can and is helpful in reducing the errors at the receiving docks. The product receipt can be automatically verified without even unloading from the truck or breaking down a mixed pallet load. New labels need not be applied to the pallets and cases, since the same RFID can be used to track the goods. This will definitely reduce the labor content at the docks. As soon as the verification is complete, the products can be sorted automatically for cross-docking or putaway increasing the throughput. Since the goods are received accurately the first time, the receiving errors do not creep into other functional areas of the warehouse causing poor inventory accuracy. This will also reduce the costly claims/returns.

Some times, order-pickers return empty handed because either the items were at the incorrect location or the inventory information is incorrect. In spite of using sophisticated technologies like voice picking to increase the picking accuracy, these operations are prone to error because 100% accuracy is not guaranteed on picking integrity. All these errors and discrepancies can be minimized or virtually eliminated with RFID implementation. Scanning and verification of products and its location can be eliminated, resulting in considerable savings in time to search and retrieve. If we know the accurate information every time about the product location, then the travel time of the order pickers will be the only productive time.

Similarly, checking the integrity of the order at the shipping dock is essential because the claims and the returns are costly to process and settle. With mixed pallet loads increasingly common in many warehouses and distribution centers, checking the output pallet for order integrity and preparing the Advanced Shipping Notices (ASN) is a lengthy and labor intensive process. Another potential error is shipping a pallet to the wrong customer because the trailers are closely arranged at the shipping dock that the same staging area could be used for multiple trailers. These difficulties can be overcome with proper implementation of RFID at the shipping gate.

RFID users have promised greater visibility to their supply chain partners. This visibility should help in reducing the supply chain inventory waste and lack of product availability caused by the Bullwhip effect. Bullwhip effect amplifies the upstream demand volatility because of safety stock accumulation at different downstream stages in the supply chain (Fleisch and Tellkamp, 2005). This will help the manufacturer produce to the distributor's demand rather than actual customer demand. A significant portion of the pipeline inventory emanates from the lack of information about the trading collaborators inventories and true customer demands.

6 Summary and Conclusions

6.1 Lessons Learned from RFID Data

In completing this project and working with actual RFID data, many data related issues came up. In this subsection, we discuss some of these concerns. As it is right now, RFID data has several problems. In fact, data related problems are considered to be "the most critical" hurdles standing in front of fast adaptation of this technology (O'Connor, 2005). The data related problems may be attributed to hardware and/or software related technologies as well as layout related issues (O'Connor, 2005). The most common problems were:

- Missing read. This may also be called false negatives, which occurs when a valid tag passes within the prescribed range of an RFID reader, but the reader fails to read the tag. This can happen for many reasons, such as (i) a case tag is buried inside a pallet, (ii) reader signals are blocked or absorbed by substances such a metal or water, (iii) a case tag is damaged, and (iv) miss-orientation of interrogator antennas. In the data that we have studied, one-third of the records did not comply with what we call regular process flow. Readings of one or more legs of the complete process were missing. For instance, according to the readings, we had cases that moved from storage location to crusher (as if they did not contain any items for the sales floor).
- Multiple reads. This may also be called false positives, which occurs when a tag accidentally passes within the range of more than one RFID reader and these additional inadvertent reads are captured. This reading error may be attributed to improper layout of the readers. In the data that we studied, we noticed readings that are a few seconds apart from each other. After investigating further, we concluded that these are multiple reads of the same container (pallets or boxes) by multiple overlapping readers. We noticed that about 18% of the total data records (readings) were erroneous multiple reads.
- In addition to incorrect reads, the magnitude of the RFID data that needs to be collected, organized, stored and used may be of concern to many. The amount of data present in an RFID tag may result in data flows that are multiple order-of-magnitude

> times greater than those delivered by bar code systems. Though most current database systems can handle this volume, servers, middleware software and lower-bandwidth networks may need added capacity. Problems with such large datasets do not end with the data flow, it continues on to the storage, maintenance and use of it. To some extent, this problem can be thought of as being similar to the click-stream data problem.

Data preprocessing should be carefully designed, modeled and automated for such systems to provide accurate information in a timely manner for decision makers. In RFID literature, this preprocessing is also called *data filtering* (O'Connor, 2005). The primary purpose of this task is to intelligently detect and resolve the issues related to false negative and false positive reads. In the case of false positive reads, the filtering mechanism should detect the incorrect reads by taking into account the flow process and the layout limitations. Similarly, in the case of false negative reads, the filtering mechanism should take into account the process flow of the pallets and cases and hence identify the missing read steps and remedy them by inserting place holders (pseudo-reads without exact times) in order to maintain the completeness of the flow process. Data filtering can be done periodically after the collection and storage of the RFID data, but before moving the data into a data warehouse (or data mart), or it can be done automatically during the data collection process by the Application Level Event (ALE) specifications created by EPCglobal (EPCglobal, 2005). In the latter case, the computer resources should be capable of handling not only the high volume of reads but also the aggregation and filtration of tag data as per the XML-based ALE specifications. Another view to the data filtering is to employ a multi step (i.e., hybrid) process where the obvious (less time consuming) filtering takes pace at the time of read and more sophisticated (more time consuming) filtering takes place after the reading. Unlike many other data mining applications, RFID provides more time-variant data on very few fields. Thus, we have more data than perhaps in other cases, but it is highly repetitive and contains only a few fields. Generating intelligence from such data is quite different than datasets where one has access to many predictive variables for perhaps a smaller set of records. Converting this data into usable information and ultimately practicable knowledge may require changes in data mining approaches. It would appear that the domain knowledge would play an even more critical role in this data mining application than before.

6.2 Conclusion

RFID is an old technology that has received a tremendous amount of attention recently. The technology has proven to be a promising alternative to barcodes. However, the key to gaining business value from RFID lies not in the technology itself; rather, the value resides ultimately in the data. The real value of these data is in leveraging this information to make better business decisions. The capability to ask new questions or discover new patterns in the data provides more intelligence to a business process, improve decision-making capabilities and help in the redesign of an entire process (Moradpour and Bhuptani, 2005). Just as quality was once the differentiator, the information from RFID could differentiate a company from its competitors. The RFID information has not only the potential to change the business process of the warehouses but also the entire supply/value chain. The example provided in this paper was only a small snippet of a single case with a limited number of reads – now, imagine the possibilities with millions of cases providing this type of data. To date, RFID systems have produced millions of records that contain countless opportunities for business value. This value will only be realized, however, if the data is understood.

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