WHITE PAPER SERIES / EDITION 1

AUTO-ID LABS

BUSINESS PROCESSES & APPLICATIONS
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AUTOIDLABS-WP-BIZAPPS-015

RFID Data Capture and its Impact on Shelf Replenishment

Chien Yaw Wong & Duncan McFarlane

Cambridge Auto-ID Lab, Centre for Distributed Automation and Control, Institute for Manufacturing, Cambridge University, UK

dcm@eng.cam.ac.uk
www.autoidlabs.org

Abstract

The final few metres of a retail supply chain can be the most critical. No matter how efficient the supply chain is in delivering to the retail store, inefficient backroom to shelf replenishment will lower the total supply chain performance. This paper provides a systematic means for describing different shelf replenishment policies and in particular, investigates the role of readily available product information in improving shelf replenishment performance. The motivation for such an investigation comes from the observation that there are emerging automated identification technologies that may be used in the retail environment to enhance product information capture. In particular, Radio Frequency Identification (RFID) can provide accurate and timely unique item level information to influence current shelf replenishment operations. Based on literature and a series of retail case studies, this paper examines current replenishment policies and discusses factors that influence the effectiveness of these policies. Specifically the issue of timeliness of information, decision and operations is assessed in order to determine the potential impact of RFID technology on shelf replenishment policies.

1. Introduction

The deployment of low cost Radio Frequency Identification (RFID) technology in the retail supply chain has received much attention in the last few years. This can be attributed, in part, to the work of the Auto-ID Center which has driven the adoption of standardised, low cost RFID tagging and the establishment of suitable network connections (Auto ID Center 2001). The adoption of this technology seems imminent given announcements by major retailers, for example Wal-Mart (RFID Journal 2003a) and Tesco (RFID Journal 2003b), and numerous on-going field trials (Ailling 2004). The initial focus of this adoption is on pallet and case level rather than item level tagging which is most relevant to the main focus of this paper. However, in the longer term, low cost RFID technology can provide accurate, timely and unique item level information that is capable of influencing decisions and subsequently physical operations throughout the supply chains (Soga 1999). This paper seeks to explore the impact of having such a facility at the final few metres of the supply chain – that is, in the retail store. We will consider RFID as one of several different data capture approaches and demonstrate how these technologies influence the effectiveness of product replenishment from the backroom to the retail shelves.

We note that there is little consistency in the definitions of supply chain management (Bechtel & Jayaram 1997) and such inconsistency can influence the extent to which the processes within the retail stores are viewed as part of the whole supply chain. Using definitions by Cooper et al (1997), supply chain management is “the integration of business process” in such a way that it “adds value for customers”. A similar view by Christopher (1992) suggests that it involves “process and activities that produce value in the form of products and services in the hands of the ultimate consumer”. Thus, the integration of processes and activities within a retail store forms part of the supply chain. Most of the time, the retail store is the only point of interface between final consumers with the whole supply chain and therefore any inefficiencies or errors will propagate down the whole supply chain. In this paper, we limit our scope to processes within the retail store, noting that limited research has been conducted in this area, particularly with respect to the use of information technology such as electronic point of sale (EPOS) to improve in-store processes (Stone & Hollier 2000).

The rationale for limiting the research scope to within the confines of the retail store is motivated by both business and academic relevance. In the real world, the final few metres of the supply chain may be most critical as no matter how efficient the backend of the supply chain is, inefficient shelf replenishment will lower the total supply chain performance. A recent finding by ECR Europe (Roland Berger Strategy Consultants 2003) suggests that the availability of products deteriorates along the supply chain from the manufacturer to the retailer in the manner shown in Figure 1 — the service level within the retail store is significantly lower than the stages before. A different survey by Accenture (2003) found that almost a third of off-sales items could be found in the backroom of the retail store. The focus of this research on replenishment from backroom to the shelf is therefore important in order to understand the cause behind the problem. We therefore define shelf replenishment as the process of restocking shelves by moving products from the backroom of the retail store. Similarly, store replenishment is therefore defined as the process of restocking inventory in the retail store from the warehouse, distribution centre, manufacturer or supplier. With these definitions, we could now examine the occurrence of out-of-stock as temporarily unavailability of products in the retail store while off-sales as the temporarily unavailability of products on the retailer's shelves.

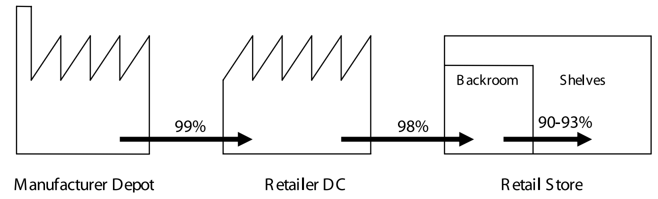

Fig. 1: Service Level along the Supply Chain

In academic inventory control literature, retail supply chains are often examined at the echelons level (Beamon et al 2001; Chen 1998; Clark & Scarf 1960) with the assumption that once the retail stores are replenished from the distribution centres, all the products will be automatically displayed on the retail shelves (Urban 2001). In other words, the internal operations of the retail store are viewed essentially as a black box and the occurrence of *off-sales* products (not on the shelf) is treated to be the same as out-of-stock products (not in the store at all). Although not specially targeted at shelf management, here have been various previous studies on the impact of inventory accuracy (Raman et al 2001; Wayman 1995; Brown et al 2001) and time delays (Forrester 1969; Lee 1997; Chen 1999) on effective supply chain performance and their approaches are also useful in examining the shelf replenishment process within the retail store. To limit the scope of this research into shelf replenishment policies, we will focus specifically on the impact of time delays on the policies and hence the benefits to be achieved by removing them. . This focus was chosen with the realisation that even with an accurate inventory system, the timeliness of information, decision and operation will significantly affect shelf replenishment performance. The examination of the impact of accuracy on product replenishment processes has been the subject of a separate study by the Auto ID Labs (Kang 2004). In the next section, we will examine a number of automated identification approaches and demonstrate their relevance to retail store processes. Drawing on both the literature and findings from retailer case visits, we will then examine current shelf replenishment policies and identify various factors that influence the effectiveness of these policies. Next, section 4 discusses the impact of having Auto-ID technologies in the retail store on current shelf replenishment. An alternative shelf replenishment policy will also be presented as a mean of best exploiting a comprehensive RFID deployment within a retail store.

2. Data Capture Strategies

The use of Automated Replenishment Programmes (ARP), as a means to replenish inventory based upon actual product usage and stock level information, is gaining popularity especially when the effectiveness of ARP was empirically examined to be positively influencing cost and service-related effectiveness (Daugherty 1999). The effectiveness of ARP is clearly dependent on the information provided by data capturing system as it forms the basis for further analysis and decision-making process. Different data capture strategies, manual or automated, have different capabilities and limitations that impact on the type of information obtained.

Lindau (1997) defined an *automated* data capture system as "a system that can read data automatically, decode the data and manage data in a computer". For any inventory control systems, their *effectiveness* is dependent on accurate and timely information from the data capture system (Lindau 1999). Clearly, the accuracy of the system is dependent on how exact the captured information is with respect to the real-world. Hence, in this context, we define an effective data capture strategy as one that will accurately translate actual physical events (or non-event static environment) in a complete, accurate and timely manner into a representation (electronic or non-electronic) in formats that are readily available for further processing and decision-making process. The ability to perform such translation will be determined by the choice of product identification technologies and hence in this section, we will discuss issues surrounding the use of conventional manual approach versus barcode and RFID based approaches.

2.1 Manual Based Data Capture

Traditionally, data capture was conducted using pen and paper approach. This cumbersome approach relies heavily on the ability of manual workers to consistently identify the correct product at the right location and to count them accurately. Before the availability of barcode technology, product type differentiations were difficult and products of the same family range could easily be incorrectly identified. Coupled with the fact that retail customer transactions are usually in the form of paper receipts, it is difficult, if not impossible, to perform any up-to-date analysis on actual inventory holding in the store in a timely manner.

A recent study of six retailers (Wong and McFarlane 2004) has indicated that data capture approaches that rely heavily on human intervention are still a common practice at most retail stores, with the range of responsibility primarily focussed on shelf replenishment. Visual inspections are regularly conducted to determine the level of inventory on the shelf and in the backroom. However, the frequency of these inspections is highly dependent on the availability of manual workers to perform such tasks. Normally, the manual workers that perform visual inspections will record their information on the paper and this information is usually not shared with others. In other words, those performing visual inspections are also responsible to replenish the appropriate products from the backroom. The decoupling of visual inspections and the actual replenishment is difficult unless an electronic system is used to share and delegate tasks to other workers in a simple and timely manner.

2.2 Barcode Based Data Capture

The proliferation of barcode technology in the retail industry drove the adoption of product type identification standards throughout the world, mainly the UPC and EAN standards (Brown 1997; Haberman 1999). The availability of barcode technology provided not just the opportunity for identification of products, but also for inventory control purposes. One of the most common barcode-based data capture applications in the retail supply chain is the integration of barcode reading with so called Electronic Point-Of-Sales (EPOS) systems to provide an electronic record of customer purchases. For a comprehensive literature review on the history, benefits and data utilisation of EPOS, refer to Stone & Hollier (2000). In addition to EPOS deployment, the barcode is also used for identification of incoming goods at the retailer backdoor and in some retail stores, for identifying products on the shelf (Yao and Carlson 1999). Barcode technology provided a clear operational advantage over manual methods to retailers. Within the retail stores, incoming goods could be verified against the order and the data reads from barcode readers or EPOS could be used to update inventory book-stocks (Yao and Carlson 1999). However, Page 4 of 22 there are several subtle but potentially important characteristics about barcode reading that limits its capability as an electronic data capture method. Firstly, barcode reading requires line-of-sight between tag and the barcode reader. This means that a barcode reader cannot be used for example to read items within a box or a case. As long as the barcode on any item is obstructed from view, manual workers have to intervene to handle the items so that the barcode can be read.

A second limitation is that today's barcode numbering system can lead to inventory inaccuracy. This is because the most widely adopted UPC and EAN barcode standards in the retail industry do not have unique product identification — different instances of the same product type will have the same barcode number. Therefore, accidentally reading the barcode of one item twice will electronically capture two items and the occurrence of such error is possible at EPOS or in any part of the supply chain that uses barcode as the data capture technology.

The implication of the barcode limitations means that a high number of manual interventions are needed to keep inventory book-stock accurate and up-to-date. Most of the time, each and every items needs to be manually handled to provide the line-of-sight required for reads and there is no electronic measure of ensuring that the same item only appear once in the inventory counts. Perhaps more critically is the fact that in practice, inventory counts — whether in the backroom or on the shelf — are generally performed manually, supported by barcode only for product type identification.

Such a high level of manual interventions also has an impact on the timeliness of information. Barcode based data capture is always initiated by a manual worker as the automation of barcode reading is difficult due to line-of-sight requirements. Thus inventory book-stock in the retail store will only be updated when it is triggered by manual workers, and this is often on a fixed periodic basis. Further, it follows that any events not triggered by manual workers such as customer product removal from the shelf or theft go largely unnoticed until stock counting operations are performed. Finally, events initiated by manual workers but without appropriate updating of the resulting information system will also go unnoticed. An example of this is the moving of products from the backroom to the shelf without registering the amount to the inventory book-stock. Due to such event-based data capturing, the inventory level at any point in the retail store may not be reflected in the inventory book-stock in a timely manner.

2.3 RFID Based Data Capture

The concept of Radio Frequency Identification (RFID) was first invented by Stockman (1948) and the first application goes back to World War II when Britain pioneered the use of radio-wave navigation and identification of friend or foe aircraft for night operations (Landt and Catlin 2001). It is not until recently that commercial organisations started to utilise RFID technology to improve supply chain visibility by tracking products from one location to another. The basic RFID technology consists of a tag reader and a tag. Information stored on the tag could be read by the tag reader without the requirement of line-of-sight through electromagnetic waves. Therefore, it is easier to automate data capture at data collection points to provide continuous feed of data than using barcode. RFID could read multiple tags at the same time through anti-collision protocols and could also read tags within an enclosed area. For more information on RFID, please refer to Finkenzeller (1999).

RFID provided the means for automatic identification (Auto-ID), that involves automated extraction of identity of an object, and this forms the basis for the networked RFID System developed by Auto-ID Center. A networked RFID system generally comprises of several essential elements as outlined in Table 1 (also refer to Sarma 1999). With these requirements, the Auto-ID Center has developed the so called *EPC Network* to deliver a set of technologies (refer Table 1) that will enable immediate, automatic identification and sharing of networked information on items in the supply chains. In this paper we will refer to this type of networked RFID deployment as an RFID Network.

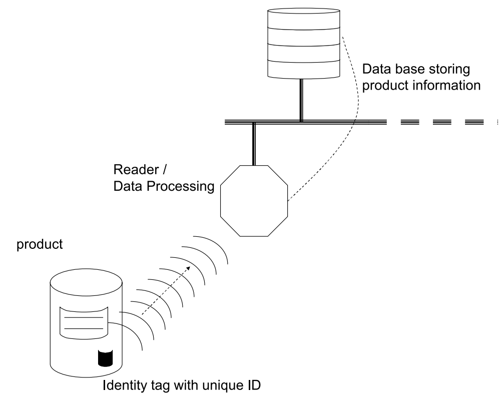

Fig. 2: RFID based Auto-ID System (McFarlane and Sheffi 2003)

	Networked RFID Requirements	EPC Network
1	A unique identification number which is assignedto a particular item	Electronic Product Code (EPC) which contains manufacturer, product type and serial number data
2	An identity tag which is attached to the item with a chip capable of storing - at a minimum - a unique identification number. The tag is capable of communicating this number electronically	Low cost reference specifications RFID tags which contain just the EPC – all other information about the product is held in networked data bases.
3	Networked RFID readers and data processing systems which are capable of collecting signals from multiple tags at high speed and of pre-processing this data in order to eliminate duplications and misreads	Low cost, passive RFID specifications for tags operating at 13.56MHz and 915MHz. Corresponding readers that provide EPC information from tag reads to a filtering and logging system (Savant^{TM}) for data processing.
4	One or more linked, networked databases that store the product information and enable queries to be made from any location in the product supply chain	An Object Naming Service (ONS) provides a reverse-directory style look up to enable EPCs to be linked to database information held anywhere on the internet while a Physical Markup Language (PML) provides a common language and structure for holding product information in a web style server.

Table 1: Networked RFID Requirements and the developed EPC Network

We emphasise that the choice of data capture technology for EPC Network is not strictly limited to RFID and could be substituted by other technology such as barcode. The RFID based EPC Network provides the EPC information system that is capable of enhanced data capture capabilities compared to barcode data capture technology. In particular, the main characteristics are as follow:

- Unique identification of products enabled by EPC numbering
- Non-line of sight reads enabled by RFID tags and tag readers
- Continuous event or non-event based data capturing without the need to rely on human interventions

The implications of such capabilities on shelf replenishment practices is potentially revolutionary as the quantity and location of inventory in the retail store can be instantaneously updated and readily made available in a format ready for further analysis and decision-making. In a store with typically 40,000 stock keeping units (SKUs) in the United States (Pollack Associates 2002), the ability to have such information in a timely manner will improve the accuracy of each and every SKUs—a prerequisite towards better inventory control.

The placement decision of RFID tag readers affects the location and range in which tags could be read (hence data could be captured). In the ideal situation, RFID tag readers could be placed everywhere in the store to capture the movement of every single item movement at every possible location. However, we note that it is very costly to do so at least in the foreseeable future (Thomas 2004). Hence, in this paper, we will examine a minimal and full RFID Network implementation determined by the possible locations for data capture, as shown in the shading in Figure 3 and summarised in Table 2. The primary focus here is on improving shelf replenishment although these data collection configurations could also be used for other purposes such as consumer marketing. The concept of "zoning" of a retail store has previously been used by Stone & Hollier (2000), although in this analysis, this division of zones are location driven rather than process driven.

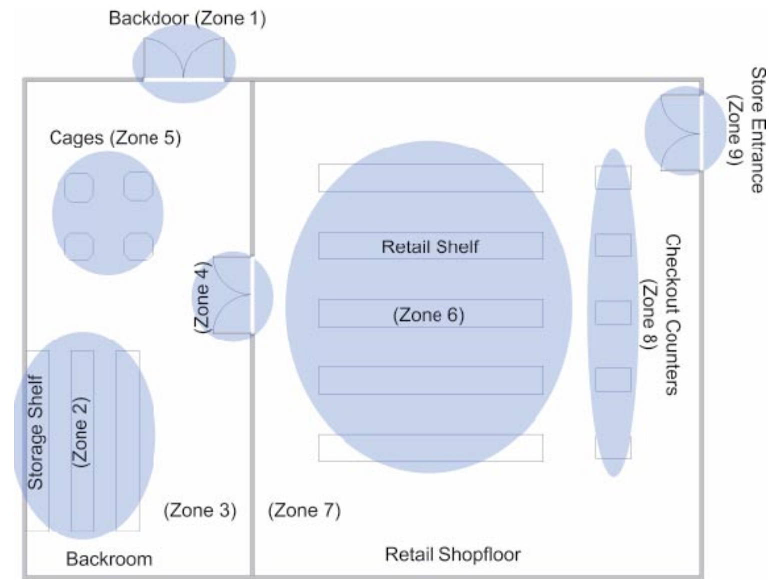

Fig. 3: A typical retail store divided by zones

To save cost, the Minimal RFID Network based approach is proposed as a mean of minimising the data collection points and therefore minimising the number of tag readers needed. Having tag readers permanently fixed to the shelf (Zone 6 and Zone 2) may be extremely costly, and hence we suggest that a handheld tag reader is used instead. The implications of this will be discussed later in the section. We also assume in this analysis that tagging at item level exists for every single item in the store, or at least every single item for a particular SKU (in which case the impact will be limited to that product type).

We note that Zone 5 is not a static in the sense that the equipment used for transporting products from the backroom to the shelf could be anywhere in the store, and the ability to detect the locations of these moving equipments (as well as the products being transported by these equipments) are considerably more technically difficult than other zones. Most retail stores have theft prevention system built in place at Zone 9 (for example Electronic Article Surveillance) using RFID technology but these tags only contain binary information (example, 0 for non-paid items and 1 for paid items) that will flip their states using read/write tag readers at the checkout counters.

Characteristics	Data Capture Technologies		
	Manual Based Approach	Barcode Based Approach	RFID Network Based Approach
Product Type Identification	X	X	X
Unique Item Identification			X
Data capture information readily available in electronic format for other processing		X	X
Accurately perform continuous direct item level inventory counts on actual physical availability			X
Ability to associate other information with each unique items			X

Table 2: Minimum, Full and Ideal RFID Network data collection points as compared to manual and barcode approach

2.4 Comparison between Data Capture Technologies

The main differences between the data capture approaches outlined in Table 2 are summarised in Table 3. "X" marks the capabilities of these data capture approach in terms of "ease" of executing these capabilities. For example, although the manual based approach could well identify the different product types, however the data captured is not readily available in electronic format for other purposes—unlike barcode based approach. However, inexperienced manual workers may have problems identifying product types in which case the use of barcode can help the identification process considerably. For example, a manual worker could use handheld barcode reader to capture the barcode number on the product and this information could be electronically processed to provide immediate descriptions about that particular product type via the handheld reader itself. Without RFID Network however, it will be difficult if not impossible for manual workers to uniquely identify all the items in the store.

Characteristics	Data Capture Technologies		
	Manual Based Approach	Barcode Based Approach	RFID Network Based Approach
Product Type Identification	X	X	X
Unique Item Identification			X
Data capture information readily available in electronic format for other processing		X	X
Accurately perform continuous direct item level inventory counts on actual physical availability			X
Ability to associate other information with each unique items			X

Table 3: Characteristics of Data Capture Technology

3. Shelf Replenishment Policies

In this section, we will propose three different types of shelf replenishment policies and discuss the impact of manual and barcode based data capture on each of them. These policies were observed through case studies with six major retailers; four of which were in the UK, one in Germany and one in Japan. A total of 17 semi-structured interviews (Yin 1994) were conducted with 20 individuals ranging from store managers to operational staffs on-site and also with staffs from headquarters. On-site *passive* observations of shelf replenishments were conducted in 7 retail stores and *participative* observation was conducted over a period of 3 days in one of the retail store.

From these case studies, two types of shelf replenishment policies naturally emerged. We differentiate between a "Pull" replenishment policy in which physical observation on product shelf level provides the basis for replenishment from the backroom to the shelf. In a "Push" policy, the physical observation begins from the products in the backroom. The main differences between the approaches are outlined in Table 4.

"Pull" Replenishment Policy	"Push" Replenishment Policy
Visual inspection starts on the shelf	Visual inspection starts in the backroom
Products are replenished according to shelf arrangements	Products are replenished according to backroom arrangements
For barcode approach, amount of product in the backroom is estimated	Amount of product on the shelf is estimated
Time to move product from the backroom to shelf is affected by the time to find the product in the backroom	Time to move product from the backroom to shelf is affected by the time to find the product on the shelf

Table 4 "Pull" and "Push" Policies

The observation point is an important distinguishing factor as currently, simultaneous direct physical observations (as opposed to inferred) on both the shelf and the backroom are not possible. Within these two main policies, there may be variations in the length of operation, frequency of operations, types of staffs involved, replenishment quantities and so on. Further, there are two variations specifically within the "Pull" replenishment policy that merit differentiations and this depend on whether the data capture approach is manual or using a barcode. We note that for "Push" replenishment policy, only barcode based data capture was observed

The concept of *"push" and "pull"* in supply chain is not new. In manufacturing literature, a "pull" strategy is often described as a *Kanban system* where the Kanban signal or card pulls material forward only when it is required by the next stage of production (Kenwood and Little, 1995). A "push" system is described as a "system of ordering in which orders are issued for completion by specified due-dates, based on estimated lead times" (BS5192 1993). In the management literature, Bowersox et al (1999) defined a traditional launch strategy as forecast driven and is based on anticipatory logistics ("push") while a lean strategy is formulated on principles of postponement and is based on response-based logistics ("pull"). Although these definitions of "pull" and "push" are not directly applicable in this research, the concept is similar. While the "push" strategy has a continuous tendency to drive the products further up the supply chain, the "pull" strategy aims to move the products only when it is triggered from upstream of the supply chain. Figure 4 shows this conceptual difference between these two strategies in the context of shelf replenishment. In the "pull" strategy, a manual worker will observe products on the shelf and if the quantity is low, shelf replenishment will be triggered based upon estimated product availability in the backroom. In the "push" strategy, the manual worker will observe product in the backroom with the intention of moving the product to the shelf if estimated shelf level indicates that there are spaces available for the product.

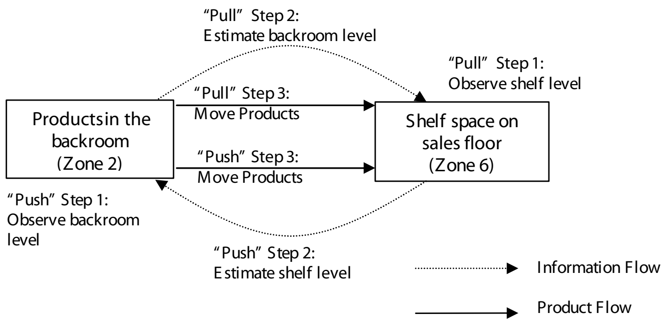

Fig. 4: "Pull" and "Push" Shelf Replenishment Concepts

Before examining the case study findings, we describe each of the pull and push policies in more detail.

3.1 The "Pull" Policy

In this section, we will first describe the manual based "Pull" policy. This policy is the most common and the most basic type of shelf replenishment observed in all the case studies conducted with the retailers. We will then describe another variation of this policy that uses barcode as the basis for data capture.

In a manual based pull policy, products on shelves are directly observed by manual workers at a periodic basis. Most of the retailers conduct their shelf replenishment twice a day—typically once before the noon time rush hour and another after that, although admittedly, this depends on whether the products are on promotion, the availability of manual workers, day of the week etc. During the visual inspection, the quantities estimated for each product types on the shelf are compared against the maximum allocated shelf space set for that particular period (often via a planogram that changes every week). The allocated quantities are often displayed on the shelf edge ticket. Product types that are observed to be below the allocated quantities or below a certain threshold will need to be replenished. In most cases, the worker will determine whether a case-pack of the item would fit in the space left vacant by item sales. The dependency on case-pack replenishment is clearly not optimal as it ignores any effects of demand during the time it needs to replenish the items on the shelf (Ketzenberg 2002). The advantages of doing so is that it simplifies visual ordering, as well as simplify replenishment as case based replenishment is easier to restock than if the manual worker has to break the case. Breaking the case might also cause individual items stored temporarily in the backroom difficult to find and easily misplaced.

Once the manual worker determines the particular product type that needs to be replenished, the product will be added to a picking list. In all the retail case studies observation, this picking list started off basically as a blank sheet of paper and the list of product types will be added together with the quantity desired. Each manual worker often has their set of short-hand notations as they do not share this picking list with another worker.

With this picking list, the manual worker will try to find the products in the backroom. Note that at this point, the product listed may or may not be in the backroom. The worker will not know this until the product is found or until the worker is sufficiently confident that it is not in the backroom after several attempts to locate it. In three of the retail stores observed, products in the backroom were stored in an orderly manner but most of the retail stores exhibit some elements of chaos as the workers have to search for a particular product in several places. In one extreme case, the same product may be located in different floors in the backroom.

If the desired product is found in the backroom, it is placed in a cage and will be rolled out to shelves for restocking when the cage is full. Products that are not found will be flagged for reordering.

This way, products are as though “pulled” from the backroom triggered by direct physical observations of products on the shelves. Table 5 shows a summary of how this replenishment occurs.

Actors	Actions	Zones of Data Capture Points								
		1	2	3	4	5	6	7	8	9
Customer	1. Customer remove product from shelf									
	2. Customer walk around the store									
	3. Customer check out products at counters									
Manual Worker	1. Estimate inventory quantity on the shelf for each SKUs at a periodic basis						*			
	2. Find products in the backroom if inventory on the shelf is low		*							
	3. Move products to the shelf									

Table 5: “Pull” Replenishment Policy with Manual Based Data Capture

More automated variation to this “Pull” policy arises from the use of barcode inventory system observed in two of the retail stores. When a product type is observed to be “low” in quantity, the barcode of the product will be scanned using a handheld barcode reader. At the same time, the quantity of product on the shelf will be visually estimated and manually recorded on the handheld reader and this information will be sent to the retail inventory system. Instead of physically counting the quantity of products in the backroom, inventory system will be used to estimate the quantity of products in the backroom by keeping track of deliveries into the store and the EPOS data registered at checkout counters. If the products are estimated to be in the backroom, those products will be included in the picking list for shelf replenishment. This picking list will be printed off and the manual worker will look for the product in the backroom. Table 6 shows a summary of how this replenishment occurs.

As the electronic inventory system could perform tasks in almost near real-time, the actions that it performs are not through sequential actions (unlike customer and manual worker) and hence

Actors	Actions	Zones of Data Capture								
		1	2	3	4	5	6	7	8	9
Customer	1. Customer remove product from shelf									
	2. Customer walk around the store									
	3. Customer check out products at counters								*	
Inventory System	Update inventory book-stock with EPOS data from customer check out								*	
	Update inventory book-stock with Advanced Shipping Notice or when the inventory registers at the backdoor	*								
	Provide estimate of product when requested by manual workers									
	Update inventory book-stock when quantity of product on the shelf is entered by the manual worker						*			
Manual Worker	1. Observe inventory quantity on the shelf for each SKUs at a periodic basis									
	2. Input estimated quantity to inventory system if inventory on the shelf is low						*			
	3.Get an estimate of quantity of product in the backroom from inventory system		E							
	4. Find products in the backroom if product is estimated to be in the backroom									
	5. Move products to the shelf									
	6. Whenever available, make sure that inventory in the backroom is updated	*								

Table 6: “Pull” Replenishment Policy with Barcode Based Data Capture

these actions are not numbered in Table 6. Note that the two “*” marked in Zone 8 and Zone 6 indicates that both the events took place at the same time. For example, in Zone 8, when a customer checks out a product at the counters, the inventory system’s book-stock is updated with the same EPOS data. In Zone 6, when the manual worker entered the estimated quantity, the quantity is updated in the inventory book-stock at the same time. Clearly, the inventory system depends on the manual worker for data capture and updates. In Zone 1 however, in all the retail stores observed, the manual worker need not estimate the total quantity of individual items, but instead they need to verify that the quantities and product types of incoming product tallies with what was ordered. This is typically accomplished by reading the shipment barcode with the handheld barcode reader and visually estimating the number of cases to make sure that it tallies on the invoice.

The “E” in the table indicates that an estimated quantity of product is needed at Zone 2. Note that in this policy, the quantity at Zone 2 is estimated based on data capture at Zone 1 and Zone 8.

Let Q_n^E and Q_n^D be the quantity estimated and quantity detected respectively at Zone n where $n \in Z^+$ and in this case $1 \le n \le 9$. Therefore, in this pull policy,

$$Q_2^E = Q_1^D - Q_8^D - Q_6^D \tag{0.1}$$

Clearly, the quantity estimated at Zone 2 may not be accurate as direct physical inventory counts is not possible using the data capture approach. The higher the time delays of product movement between Zone 1 and Zone 8, the lower the accuracy of the estimated quantity.

If products are estimated in the backroom by the inventory system, but the manual workers fail to locate the product in the backroom, then they will reset the inventory system’s book-stock to zero.

Such practice will further decrease the accuracy of Q_2^E if the products are actually still somewhere in the backroom or misplaced on the retail shelf.

3.3 The “Push” Policy

In this policy, a manual worker will directly observe the quantity of products in the backroom. They will scan through the products in the backroom according to a sequence of arrangement using a handheld barcode reader. The inventory system will indicate if any product needs to go onto shelf by estimating the stock level on the shelf (based on EPOS data, quantity of product in the store and the number of replenishments since the start of the day) with the maximum shelf allocation (this is likely to change weekly and this value needs to be recorded into the inventory system every time it changes). The manual worker has to input the number of quantity replenished to the shelf in order for the inventory system to update the inventory book-stock. This way, products are essentially “pushed” out from the backroom to the shelves. Refer to Table 7 for a summary of this policy.

When this “Push” policy is compared with the policies shown in Table 5 and Table 6, note that the trigger for shelf replenishment begins from the backroom instead of the retail floor. This eliminates the walking time from the retail floor to the backroom as well as the time to find a specific product type, but the sequence of product replenishment is that of the sequence of arrangement in the backroom, and not according to the product types that are “low” on the shelf.

Actors	Actions	Zones of Data Capture								
		1	2	3	4	5	6	7	8	9
Customer	1. Customer remove product from shelf									
	2. Customer walk around the store									
	3. Customer check out products at counters								*	
Inventory System	Update inventory book-stock with EPOS data from customer check out								*	
	Update inventory book-stock with Advanced Shipping Notice or when the inventory passes through the backdoor	*								
	Provide estimate of product when requested by manual workers									
	Update inventory book-stock when quantity of product to be replenished to the shelf is entered by the manual worker		*							
Manual Worker	1. Observe inventory in the backroom for each SKUs at a periodic basis									
	2. Get an estimate of quantity of product on the shelf from the inventory system						E			
	3. Input quantity of product to be moved from the backroom to the shelf		*							
	4. Move products to the shelf									
	5. Whenever available, make sure that inventory in the backroom is updated	*								

Table 7: “Push” Replenishment Policy with Barcode Based Data Capture

In this policy,

$$Q_6^E = Q_1^D - Q_8^D - Q_2^D \tag{0.2}$$

Note that in this case, the estimated quantity needed on the shelf (Zone 6) is based on data captured at Zone 8, Zone 2 and Zone 1. After removing the product from the backroom storage area (Zone 2) but if products are actually in other zones before the shelf (i.e. Zone 3, 4, or 5), then the estimated quantity in Zone 6 will be inaccurate. Even assuming that the manual worker have completed the tasks without error by moving products from the backroom to the shelf in the right quantity, the estimated quantity in Zone 6 may still be inaccurate depending on the quantity of products with the customers (Zone 7) and also the quantity of product misplaced on the shelf (Zone 6).

3.4 Factors Influencing the Effectiveness of Current Policies

Any effective automated information system depends on accurate and timely input data to execute the appropriate decisions (DeLone and McLean 1992; Ballou et al 1998). There are various factors that influence the performance of shelf replenishment policies and in this section, we will examine these factors in isolation.

- *Observation delay.* In the "Pull" policy, *observation delay* depends on the frequency in which the quantity of product on the shelf is observed to determine whether that particular product type is low in quantity or off-sales. Hence, this delay is essentially the time between inspections. In the "Push" policy, this observation delay is defined as the time interval between product scanning in the backroom. Whether it is "Pull" or "Push", *observation delay* is the trigger for current shelf replenishment policies and therefore the frequency of observations affect the frequency of shelf replenishments. Less frequent observations may result in lower on-shelf-availability of products.
- Checkout delay. Checkout delay is the time it takes from the moment a product is removed from the shelf until it is registered as paid at the counter. This delay includes customer walking time (which may be significant if the size of the store is large) and customer queuing time (which may be long during peak hours). When the product is finally registered at the checkout counter, it will be recorded in the EPOS data to update the inventory book-stock. Barcode based data capture feeds the EPOS information into the inventory system in order to update the inventory book-stock. This information is then used to infer the quantity of product on the shelf. Naturally, the longer the checkout delay, the more inaccurate the estimates will be.
- *Delays in picking list preparation.* A paper-based picking list, whether generated off from inventory system or recorded manually by the staff workers, records the quantity to be replenished from the backroom to the shelf. This picking list is important because it is the output from the shelf observation that later forms the "instructions" for the manual workers on the type of product and quantity to be replenished. This picking list may take a long time to prepare if executed manually using pen and paper approach. With a handheld barcode reader, this process is simplified as product is automatically identified and only the number of items on the shelf needs to be recorded. However, if the execution of subsequent shelf replenishment processes takes a long time, this picking list may be obsolete especially if the product removal rate from the shelf is high. Most retailers in the case studies were observed to replenish twice throughout the day but uses the same picking lists generated early in the morning and early afternoon respectively.

- *Delays in locating products in backroom or on shelf.* The ability to locate different product types in the retail store is necessary for a quick and efficient shelf replenishment process. This task may seem trivial on the retail shop floor (although multiple shelf displays on different locations may confuse manual staffs) but in an often cluttered backroom, it can be a non-trivial, time-consuming task. Even with an accurate inventory system, manual workers that are working under time pressure could "write-off" unobserved or misplaced products by setting the inventory level for that product type to zero. Experienced staffs often rely on their memory or their experience to locate products quickly. A timely execution of shelf replenishment process depends on the ability to find product locations anywhere within the store in a fast and efficient manner and this task is not trivial with manual or barcode based data capture approach as instantaneous product location will not be readily available.
- *Delays in moving products from backroom to shelf.* Once the product to be replenished is located in the backroom, it will be put into a cage or dollies. Depending on the picking list, there may be various other product types that need to be put into the cage before the cage could be rolled out. The correct amount of quantity should be replenished over a single replenishment process to avoid double handling. The layout of the retail store hence will determine this delay. For example, backrooms that are large or separated into multiple floors will potentially experience significant delay.
- *Time invested in filling shelf up to the maximum allocation.* Maximum shelf allocation is the maximum number of product quantity allocated on the shelf. The allocation of product quantity is usually based on previous sales pattern according to marketing forecasts and it usually changes by the week. High shelf allocation will increase the time spent on product presentations as well as the number of products that needs to be replenished at any one time from the backroom. Products that are small in sizes or products that are heavy and bulky are difficult to be arranged neatly on the shelves.
- *Product removal pattern impacting on replenishment.* Product removal pattern is the rate in which products are removed from the shelf by the customers and is differentiated from the demand pattern. When a customer pays for a product during checkout, that transaction influences the demand pattern. However, before the transaction occurs, products are first removed from the shelf and this influences the product removal pattern. As such, the demand pattern is a function of the removal pattern, customer walking time, customer queuing time at checkout counters and possibly theft after removal. Product removal pattern also depends on the characteristics of product. Demanding categories such as detergents, spirits, carbonated soft drinks, ice cream, confectionery and fresh ready meals have higher off-sales level. Impulse driven products like confectionary are another prime candidate for off-sales. Promoted products were also surveyed to have higher off-sales (Roland Berger Strategy Consultants 2003). While there is no specific delay in this factor, if the product removal rate is high, shelf needs to be replenished within a shorter period of time to maintain the same onshelf- availability. In both the "Pull" and "Push" policies, product removal pattern cannot be continuously monitored but could only be done on a periodic basis by the manual workers.

3.5 Case Study Findings

A summary of case study findings are shown in Table 8. All of the retail stores observed have implemented "Pull" replenishment

AUTO-ID LABS

policy with manual based data capture. This is expected as it is the most basic shelf replenishment without relying on any technology. Out of the six retailers, two also implemented a different variation of “Pull” policy with barcode based data capture. Note that both of these policies are not performed at the same time on the same product type as it may cause inaccurate estimates using the barcode approach (Imagine a scenario whereby a manual worker has removed products from the backroom for shelf replenishment, and at the same time another worker is just beginning to replenish shelf by observing products on the shelf. Then, the estimated product in the backroom will be inaccurate as the inventory system assumes that products are still in the backroom). Of all the six retailers, “Push” policy was observed in only one of the retail store.

Country	Retailer	“Pull” Replenishment Policy with Manual Based Data Capture	“Pull” Replenishment Policy with Barcode Based Data Capture	“Push” Replenishment Policy with Barcode Based Data Capture
UK	Retailer A	X		
	Retailer B	X		
	Retailer C	X	X	
	Retailer D	X		X
Germany	Retailer E	X	X	
Japan	Retailer F	X		

Table 8: Summary of Findings

There are growing trends in various innovative store replenishment such as Direct-To-Store (Guptil & Wilkins 2001) or One-Touch-Replenishment (David & Clarke 2002) that replenishes directly onto the shelf and thereby reducing the role of the backroom and thereby shelf replenishment. However, there are various reasons why backrooms may still be an integral part of retail stores. Theoretically, the backroom should be more space and cost effective than retail shelves. In backrooms, products could be stacked higher than on the shelf space of retail shop floor, and the width of the aisles between storage compartments in the backroom are generally smaller than those between retail shelves. Hence, increasing utilization of the backroom for temporary storage means that there will be more shelf space available on the sales floor without increasing the size of the store. This is important especially when the number of products competing for limited retail shelf space has increased sharply over the years. An example quoted by (Ketzenberg 2002) showed that in the grocery industry the average supermarket can stocks approximately 40,000 stock keeping units (SKUs) but suppliers have listed a few hundred thousands SKUs for consideration. Increasing category and product variety will be more attractive for customers as it could offer better opportunity for one-stop shopping (Messenger and Narasimhan 1995). The backroom also forms an important buffer to cope with delivery uncertainties especially when the transportation lead time is long. Bulky and high velocity product lines may need a large shelf space allocation and hence it may not be economical to allocate all of these products on shelves. Backrooms are also used as buffers to cope with imperfect deliveries such as when the quantity delivered is higher than the maximum shelf space allocated.

4. The Impact of Networked RFID Systems on Current Shelf Replenishment

We will now examine the impact of having a minimal and full RFID deployment on current “Pull” and “Push” shelf replenishments. We will not discuss the impact of manual based data capture as there is little basis for comparisons. Instead we will focus on the difference between barcode based data capture with that of RFID based approaches.

4.1 Impact of Minimal RFID deployment on Current Policies

In this section, we assume a minimal RFID deployment (as specified in Table 2). This configuration is based on a demonstration by one of the retailers in the case study. Specifically, the areas where tag readers might be deployed to read tagged products are:

- Backroom entrance (Zone 1) — Products that arrive from distribution centres will be detected and recorded automatically on the inventory system
- Entrance to sales floor from the backroom (Zone 4) — With the ability to read tagged products in this area, we could determine which products are being physically moved from the backroom to the shelves after they are placed on the cages.

As mentioned earlier, we also assume the availability of a handheld tag reader of tag readers to read products on the shelf (Zone 6) instead of using tag readers permanently fixed to the shelf. With a handheld tag reader, products on retail shelves could be detected and counted automatically by “swiping” the tag reader across the products on the shelf. The EPCs read will be updated in the inventory system. Besides saving costs, having a handheld tag reader will automatically identify and count the number of products on the shelf – this as opposed to a barcode tag reader that only identifies the object and requires manual intervention to estimate the quantity on the shelf. Hence, using a handheld tag reader may significantly reduce the observation delays. The downside is that the unavailability of permanent tag readers on the shelf means that continuous stream of data capture is not possible and hence data capture using handheld tag readers could only occur at a periodic basis depending on the manual worker.

Actors	Actions	Zones of Data Capture								
		1	2	3	4	5	6	7	8	9
Customer	1. Customer remove product from shelf									
	2. Customer walk around the store									
	3. Customer check out products at counters									
Inventory System	Update inventory book-stock when tagged products are detected at these zones	*			*					
	Provide estimate of product when requested by manual workers									
	Update inventory book-stock when EPCs are read by the tag readers swiped across the shelf						*			
Manual Worker	1. Swipe tag readers across the shelf for data capture and obtain an estimate of product in the backroom from inventory system		E				*			
	2. Obtain a list of products to be replenished via a handheld reader or printouts									
	3. Find products in the backroom if product is estimated to be in the backroom									
	4. Move products to the shelf									

Table 9: The Impact of Minimal

Table 9 shows how the “Pull” policy will change with RFID deployment. Note that with this minimal configuration of the RFID system, the dependency on the manual workers for data capture has reduced from three zones to one zone (compare this with Table 6).

In this policy:

$$Q_2^E = Q_1^D - Q_4^D \tag{0.3}$$

The estimated product in the backroom within the boundary of data capture is reduced from Zone 1 to Zone 8 as shown by equation (0.2) to in between Zone 1 and Zone 4 as shown above thereby improving the accuracy of the estimation. The handheld tag readers required at Zone 6 merely serves as a trigger for shelf replenishment rather than for estimation.

With this minimal RFID deployment, a “Push” policy could also be implemented if we adapt this RFID based approach deployment to include barcode data capture at the checkout counter (refer Table 10).

Actors	Actions	Zones of Data Capture								
		1	2	3	4	5	6	7	8	9
Customer	1. Customer remove product from shelf									
	2. Customer walk around the store									
	3. Customer check out products at counters								*	
Inventory System	Update inventory book-stock with EPOS data from customer check out								*	
	Update inventory book-stock when tagged products are detected at these zones	*			*					
	Provide estimate of product when requested by manual workers									
Manual Worker	1. Observe inventory in the backroom for each SKUs at a periodic basis									
	2. Get an estimate of quantity of product on the shelf						E			
	5. Move products to the shelf									

Table 10: The Impact of Minimal RFID Network on "Push" Policy Supported by Barcode at Checkout

In this case,

$$Q_6^E = Q_4^D - Q_8^D \tag{0.4}$$

Comparing this with equation (0.2), the boundary has decreased from Zone 1 and 8 to just Zone 4 and 8. Note that in this case, any products that are moved from the backroom to the shelf will be recorded automatically at Zone 4 and hence the manual worker does not need to input the quantity of products moved into the inventory system.

Even with just minimal RFID deployment in the retail store, inventory location determination and therefore estimated quantity can improve considerably. Having the RFID data collection at Zone 1 and Zone 4 essentially provide a convenient inventory partition between backroom and sales floor. The amount of inventory within the backroom could be accurately estimated due to data capture points incoming and outgoing at each backroom entrance.

Table 11 summarises some of the key impacts of a minimal RFID deployment on current "Pull" and "Push" policies.

FACTORS	IMPACT ON CURRENT POLICIES
Observation Delay	This delay will be reduced with the ability to automatically count the quantity of products on the shelf by simply moving the handheld tag readers around the shelf. Unlike barcode tag reader, manual workers do not need to visually estimate the quantity of product for each product types and input the quantity individually into the handheld reader. Furthermore, quantity of products on the shelf could be estimated and recorded into the inventory system for all the product types, instead of just products that are "low" in quantity.
Checkout Delay	For "Pull" policy, checkout delay no longer affects the estimated quantity due to the "enclosed" data capture of incoming and outgoing products in the backroom.
Delays in picking list preparation	A manual picking list or generated printouts may not be necessary. Instead, a picking list shown on the mobile handheld reader could be used to provide a much more real-time product quantity in the store by taking into account of incoming deliveries and product movement within the store.
Delays in locating products in backroom or on shelf	There is no tag readers permanently fixed to the storage shelf in the backroom and item level product location cannot be determined. However, with tag readers in Zone 1 and Zone 4, the manual worker can be confident that the products are indeed in the backroom if notified by the inventory system. Without this RFID based system , the manual workers will not know whether the product is somewhere in the sales floor (with customers, misplaced or on the cage in the sales floor).

Table 11: Impact of Minimal RFID deployment on current policies

4.2 Impact of Full RFID Network on Current Policies

In this section, we now discuss implications of having a full RFID Network deployment in the retail store. We assume that RFID Network could be deployed in the manner as specified by Table 2. Specifically, these "extended" deployment areas compared to a minimal RFID deployment are:

- *Backroom Storage Shelf (Zone 2)* — Products that are stored on storage shelf in the backroom could be identified automatically to obtain information about product type and its associated quantity
- *Retail shelf (Zone 6)* – Permanent RFID tag readers will be fixed to the shelf. Products that are added or removed from the shelf will be updated instantaneously in the inventory system.
- *Checkout Counters (Zone 8)* –Products that are bought by the customers could be uniquely identified, recorded and updated in the inventory system. The availability of RFID systems at

the checkout counter will increase the accuracy and speed of checkouts.

- *Entrance/Exits to the retail store (Zone 9)* — Products that have not been bought by the customers will trigger an alarm indicating possible theft. The awareness of theft is important because theft will decrease the total inventory in the store.

The main difference between this and other policies is that it is no longer necessary to estimate products on the shelf or in the backroom. Continuous stream of data captures could be obtained from all the RFID enabled zones. Such direct sensing or observability of products will provide faster closedloop replenishment control to meet the desired target (McFarlane, 2002).

Actors	Actions	Zones of Data Capture								
		1	2	3	4	5	6	7	8	9
Customer	1. Customer remove product from shelf									
	2. Customer walk around the store									
	3. Customer check out products at counters								*	
Inventory System	Update inventory book-stock when tagged products are detected at these zones	*	*		*		*		*	*
	Algorithm to decide when to trigger shelf replenishment and send alert to manual worker									
Manual Worker	1. Wait for shelf replenishment trigger from inventory system									
	2. Obtain a list of products to be replenished via a handheld reader or printouts									
	3. Find products in the backroom									
	4. Move products to the shelf									

Table 12: The Impact of Full RFID Network on "Pull" and "Push" Policies

Comparing this policy with other replenishment policies, a distinct difference is that the trigger for shelf replenishment is not the frequency of observation but rather a decision by the inventory system based on the product removal pattern. In this way, we have moved away from periodic observationbased shelf replenishment policies to instantaneous shelf-level based replenishment policy.

The decisions about when, what and how much to replenish will be controlled by the inventory system instead of relying on manual decision making process.

The manual worker could be anywhere in the store when a shelf replenishment is triggered by the inventory system. Whether the policy is "Pull" or "Push" all depends on the algorithm that decides how the shelf should be replenished. For example, priority could be given to replenish according to the arrangements on the shelf ("Pull") or it could be replenished according to storage arrangements in the backroom ("Push"). Table 13 summarises the impact of full RFID Network deployment on each factor that influences shelf replenishments.

FACTORS	IMPACT ON SHELF REPLENISHMENT POLICIES
Observation Delay	With the ability to obtain information about products on the shelf directly via tag readers, physical observation by manual workers will not be necessary. The time between observations will essentially be the same as the refresh rates of tag readers on the shelves which may be near real-time. Tagged products on the shelf will be directly read to obtain unique product information such as quantity, product type as well as product due-dates.
Checkout Delay	With tag readers on the shelf, inventory system will be able to obtain quantity information for each product types on the shelf without inferring from POS data. Hence, checkout delay will not affect shelf replenishment decisions.
Delays in Picking List Preparation	As described in Table 11.
Delays in Locating Products in Backroom or on Shelves	With tag readers on all the shelves in the backroom, finding the current product location is almost effortless. Inexperienced staffs need not need to rely on familiarity and memory to locate products in the backroom. With visibility to what is actually in the backroom, inventory system will only include products that are actually in the backroom into the picking list, instead of listing all the possible product types that may be in the backroom.
Delays in Moving Products from Backroom to Shelf	Having full deployment of RFID Network on the shelf will not affect the actual time to move products from the backroom to shelves. To reduce this time, the layout of retail stores must be changed.
Time invested in filling shelf up to the maximum allocation	With timely information of actual product levels on the shelf, total inventory in the store as well as in the supply chain may be able to alter the maximum shelf allocation from a periodic basis to almost real-time based on events for better shelf space management while possibly reducing the time spent filling the shelf.
Product Removal Pattern Impacting on Replenishment	Product removal patterns may no longer be inferred from POS data which is subjected to checkout delay. It will be "observed" directly through tag readers. This information will be used to provide faster response to shelf and store replenishments and to also predict future behaviours.

Table 13: Impact of Full RFID Network Deployment on shelf replenishments

5. Towards New Shelf Replenishment Policies

The limitation of the full RFID Network system described in the previous sections is its inability to detect tagged products in non-storage areas in the backroom (Zone 3) and in non-shelf space areas on the sales floor (Zone 7). Adding the ability to accurately determine product location in these two zones will increase costs significantly (as more tag readers will be required) — unless one is willing to sacrifice location precisions. The ability to identify products in these zones will provide complete transparency to product movement in the store. Hence, any products that are misplaced, accidentally fell out of shelves etc can be detected. Having this information will also enhance theft detection capability as the routes of products within the retail store can be traced, therefore decreasing the reliance on just a single point of detection at the exit or on the shelf. Having such total product visibility also provide an effective way of evaluating shelf replenishment and retail store layout efficiencies.

More importantly, all the products in cages, dollies or any other transportation equipments (Zone 5) must ideally be identified by the RFID Network. The ability to read tagged products on these equipments will provide information about what products are being replenished at that time and that will provide useful information for near real-time, collaborative replenishment scheduling.

When all the zones are RFID enabled, the truly ideal RFID Network deployment in the store could underpin better shelf replenishment policies. Shelf replenishment decisions could be based not only on quantities, but could also consider the price and cost of products, cost of replenishment activities, expiration dates etc. In this way, shelf replenishment could be triggered and managed based on different operating strategies, such as:

- "Remove one, Replenish one" policy
- Priority-based replenishment for different product types
- Minimizing replenishment distance for each replenishment
- Variable replenishment quantity based on dynamic maximum shelf allocations
- Auction-based shelf replenishment based on bidding of retailers shelf space by manufacturers

A summary of the way in which product data capture approaches might enable new features in shelf replenishment operations is given in Table 14. What is clear is that RFID deployment is required to effectively implement almost all of the features described.

	Product Type Identification	Unique Item Identification	Data capture information readily available in electronic format for other processing	Accurately perform continuous direct item level inventory counts on actual physical availability	Ability to associate other information with each unique items
Data Capture Technology					
Manual Based Approach	X				
Barcode Based Approach	X		X		
RFID Network Based Approach	X	X	X	X	X
Possible Tasks and Applications					
Demand at checkout updated immediately to inventory book-stock	*		*		
Continuously monitoring quantity of inventory on the shelf	*	*		*	
Alert when inventory on the shelf reach a certain threshold	*	*	*	*	
Detect misplaced products on the shelf	*	*		*	
Quickly locate products in the backroom	*	*		*	
Products being moved from the backroom to the sales floor and vice versa are immediately recorded without manual counts	*	*		*	
Automatically adjust due-by-dates according to other sensor information	*	*	*		*
Automatic store reordering based on inventory on the shelf or backroom rather than total inventory in the store	*	*	*	*	
Shelf replenishment based on other criteria (such as profit margin) other than quantity on the shelf	*	*	*	*	*
Automatically verify incoming goods through the backdoor with advanced shipping notice (ASN)	*	*	*	*	*
Real-time manual workers shelf replenishment scheduling based on real-time inventory in the store	*	*	*	*	*

X – This data capture technology shows these characteristics

* – This characteristic is prerequisite to enabling these tasks and applications

Table 14: Characteristics of Data Capture Technology and Impact on Tasks and Application

6. Conclusion and future work

This paper has described the main characteristics of manual, barcode and RFID data capture strategies and its relation to the effectiveness of shelf replenishment policies. The use of RFID in retail stores will provide a new level of product visibility currently not possible using manual or barcode data capture approach. The availability of timely and accurate item level information will not only improve current shelf replenishments policies but more importantly, it will provide a basis for altering shelf replenishment processes for incremental and possibly step-change improvements.

Research is still on-going at Cambridge Auto-ID Lab to model, simulate and evaluate the impact of RFID information on shelf replenishment policies. There will also be a greater focus on the role of backroom and maximum shelf allocation that may directly impact on the effectiveness of these policies. This research will ultimately provide a guideline for retailers to adopt the appropriate shelf replenishment policy based on different operating environment and product characteristics.

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