The Impact of Automatic Identification on Supply Chain Operations

Duncan McFarlane
Research Director
Auto ID Center-Cambridge Laboratory
Institute for Manufacturing
Cambridge University Engineering Department

And

Yossi Sheffi
Professor of Engineering Systems
Professor of Civil and Environmental Engineering
Co-director, MIT Center for Transportation and Logistics
Massachusetts Institute of Technology

Author Biographies

Duncan McFarlane is a Senior Lecturer in Manufacturing Engineering in the Cambridge University Engineering Department and head of the Centre for Distributed Automation and Control within the Institute for Manufacturing at Cambridge. Since, 2000 he has also been the European Research Director of the Auto-ID Center which is a collaborative project involving MIT, University of Adelaide, Fudan University, M Lab, Keio University and 85 industrial partners (www.autoidcenter.org). In addition to his academic work, Dr McFarlane spent 14 years working in the Australian steel industry. Dr McFarlane's work is focused in the areas of response and agility strategies for manufacturing businesses, distributed supply chain automation and control, and integration of manufacturing information systems.

Yossi Sheffi is a Professor of Engineering at the Massachusetts Institute of Technology where he leads the School of Engineering's Center for Transportation and Logistics as well as the newly launched Masters in Logistics Engineering program. He received his Ph.D. from MIT and is an expert on logistics and supply chain management, carrier management, and electronic commerce. Dr. Sheffi is the author of a textbook and over 50 technical publications. He also founded several successful software, logistics and electronic commerce companies. In 1997, Dr. Sheffi was awarded the Council of Logistics Management's Distinguished Service Award.

The Impact of Automatic Identification on Supply Chain Operations

Abstract

Automated Identification (Auto ID) applications can provide corporate information systems with the identity of each a physical item in the supply chain in an automated and timely manner. The real time availability of item identity allows other information, related to the item, to be drawn on in order to assess both the current state of the product and future actions required. In the context of supply chain operations, widespread introduction of such systems represents a major opportunity to overhaul and improve tracking and tracing systems, process control and inventory management. In the longer term, it is possible that Auto ID systems may enable a complete re-engineering of the supply chain, by removing a number of the constraints that limit today's supply chain structures. This paper reviews some key challenges in supply chain operations today and introduces the main elements of an Auto ID system. Using a simple categorization of supply chain operations, areas for short term deployment of Auto ID are identified and opportunities for longer term re-engineering of different sections of the supply chain are highlighted.

1 Introduction

Computers are used to process, analyze and display information about many processes involving moving "things." Entering the information about the status of moving things requires repeated data entry which is cumbersome, expensive and error-prone. Consequently, many automated systems have been developed to perform this data entry task. Together these systems are referred to as automatic identification ("Auto ID") systems. Example application areas include product identification in consumer goods industries, swipe card access systems and GPS/on board computer systems used in trucking. The availability of such data entry systems has provided the impetus for development of more sophisticated decision support and control systems. Thus, while bar codes speed checkout counters [1] as well as shipping and receiving processes, powerful software uses these data for dynamic pricing and inventory control. And while simple RF tags allow anybody to follow a runner in the Boston marathon on the Internet, powerful decision support system help optimize the dispatching of large truck fleets [2] or locomotives [3].

The focus of this paper is on logistics operations in the supply chain. We examine the potential of very low cost automatic identification ("AutoID") for both improving today's supply chain operations -- "playing the current game better," and enabling new services to customers of all kind -- "facilitating new games." We are motivated by an ongoing research effort involving several academic centers around the world, including the Massachusetts Institute of Technology and Cambridge University. The project aims to develop standards and infrastructure for a low cost, advanced tag and reader system as well as a standard electronic product code (ePC) that can replace the current bar code. The effort is funded solely be industry and involves over 90 manufacturers, retailers, information technology providers, communications companies and system integrators.

The paper is organized as follows: Section 2 introduces supply chain operations, looking at current trends and challenges, positioning AutoID and its role in logistics operations with the supply chain. Section 3 describes a simple product information model and introduces AutoID technology relevant to supply chain management, including product identity codes, radio frequency identification (RFID) tags and readers, and supporting software. As a means of supporting our analysis, Section 4 then establishes a classification for examining the way in which Auto ID can be deployed in different supply chain configurations, which are then used in Section 5 to examine possible improvements to existing operations and in section 6 to look at possible new products and services that the AutoID may enable. Section 7 discusses implementation issues and the challenges facing the technology. Section 8 concludes our exposition.

2 Supply Chain Trends and Challenges

The term "supply chain" refers to the series of players and activities that take part in the movement and transformation of raw material "in the earth" into finished goods at the consumers' hands. Many analysts also include reverse flows (returns, disposals, recycling) in the definition of the supply chain. Clearly, the term "chain" is a simplification of the complex web of suppliers, sub-assemblers, manufacturers, distributors and logistics providers who are the primary actors in managing the physical flows "from womb to tomb." For a detailed overview of supply chain management the reader is referred to one of the current text books such as Chopra and Meindl [4], Christopher [5], Shapiro [6] or Simchi-Levi *et al* [7]. We use the term supply chain management here in keeping with the definitions established in that literature.

The management of supply chains can be summed up in two challenges: (i) being able to optimize entire systems, rather than subsystems and (ii) managing the variability inherent in supply chain operations. The first challenge stems from the restricted view of managers who are constrained by corporate boundaries, limited responsibilities and lack of supply chain-wide visibility. Thus, the best they can do in most cases is to sub-optimize. While this is an over-arching theme of this paper, we focus on the second challenge, that of managing variability. Variability management has always been important but is increasingly critical due to several current trends:

- *Globalization* – Requiring longer and more complicated supply lines, inventory systems and distribution networks.
- *Outsourcing* – Involving more entities in the supply chain.
- *SKU Proliferation* – Resulting in demand desegregation with the resulting increased coefficient of variation. (For example, the Mercedes E Class has 3.9 trillion possible configurations [8].)
- *Shorter product lifecycles*. Resulting in lack of historical data, reducing organizations' forecasting ability.

In addition, the whole external environment has become less predictable. The rate of technological change is high, competition is intense, and new risks, such as terrorism and the government actions designed to fight, it introduce new costs and uncertainty. In trying to understand the ways in which variability is dealt with we distinguish between two types of variability that might influence a supply chain operation:

- *External variability* brought about by unexpected demand or supply fluctuations,
- *Internal variability* brought about by imperfect internal process control.

Traditionally, demand uncertainty is managed by using a forecast, coupled with fixed *level-of-service guidelines*, to set operational parameters (such as inventory reorder levels and shipping schedules). Supply uncertainties are handled by using a yield forecast to inflate manufacturing requirements or set inbound buffer inventory.

Naturally, both demand and supply are random variables whose various possible realizations are best characterized by a probability distribution, while the control systems which guide supply chain operations require specific numbers in order to act. Consequently, all forecasts tend to be "wrong" and the resulting mismatch can be handles either by using buffer inventory or by building into the system a degree of *ad hoc* responsiveness, or agility.

Sources of internal variability typically include errors in determining the amount and location of inventory, errors in process yield or errors in predicting effort and time required for different operations. In addition to affecting stock holding and operational costs, these errors also hinder the ability to accurately determine whether demand can be genuinely satisfied, limiting the proactive capabilities of the organization. The impact of *internal variability* on the ability to manage *demand fluctuations* is significant, and it is the combination of these two factors that is addressed by Auto ID systems.

Many companies have realized that the key to success in environments with significant variability is to complement *predictive* capabilities (that is, forecasting and estimates of consumption and operational times) with a highly *reactive* capability as part of a single strategy for variability management [9]. In order to be most effective, however, such a response capability must be reflected throughout the supply chain [10] [11].

One of the most important tenants of responsiveness is the ability to detect a variation, recognize its cause and act accordingly [12]. Clearly, the earlier a problem is detected the more time there is to recognize its nature and formulate an action plan. In fact, this is the promise of a relatively new type of supply chain management software tools dealing with event management.

Supply chain event management tools evolved from process control and are an outgrowth of supply chain visibility software tools. Visibility software flags deviations from plan (late shipment, missing components, lower-than-expected inventory, etc) so that logistics operations managers can act on it. Supply chain event management tools have added some capability for intelligent and (sometimes) automated response.

The Achilles' heel of all such systems is the data acquisition – event management processes are completely dependent on the availability of accurate and timely data from suppliers and service providers as to where shipments are, what the current inventory level is, and where is it located. This is where AutoID can add crucial value to supply chain operations. AutoID can improve the data acquisition process, make sure that deviations are captured earlier and that the data are more complete and accurate – thereby giving supply chain managers more time to recognize a problem, assess its potential impact and take corrective action. Note that this is not only an issue of human reaction time. Early detection means that more variables can be manipulated and more options are open for a systemic response. For example, early notification of a delay of a shipment on the railroad may mean that it can still make its deadline by trucking it, while a later detection of the problem means that a critical part may have to be air-lifted.

3 Automated Identification: Concepts and Systems

The previous section identified the accurate and timely availability of information relating to components and products as the "Achilles Heel" of supply chain management systems. This section introduces a technological approach to rapidly and accurately delivering product data into supply chain operations. The core to the approach is the decoupling of the physical item from the information representing it (as is the case with bar codes). In particular, digital identity is the only piece of product data that must be directly located on the product itself. All the other information in can be stored elsewhere, with the identity providing a unique code to access it.

3.1 Auto ID System Architecture

Definition: *Automated identification (Auto ID) involves the automated extraction of the identity of an object*

The Auto ID system described in this paper draws heavily on past and current developments in the area of Radio Frequency Identification (RFID) – see Finkenzeller [13] for an overview. RFID provides a simple means of automatically obtaining the unique identity of an item, at increasingly low cost. These low cost RFID systems can then be coupled with networked databases which enable access to additional product data. Clearly, much of this functionality is already provided by bar code systems and so the discussion in the next section focuses on a comparison with bar codes.

An RFID-based Auto ID system generally comprises the following elements (see Fig. Figure 1 and also Sarma [14]):

1. A unique identification number which is assigned to a particular item
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.
3. Networked RFID readers and data processing systems which are capable of collecting signals from multiple tags at high speed (100s per second) and of preprocessing this data in order to eliminate duplications and misreads.
4. One or more networked data bases that store the product information.

The particular Auto ID system specifications being developed by the Auto ID Center [15] follow this general approach, but have some particular aims in mind:

- Establishing specifications for very low cost tags and readers
- Providing global standards for an identity numbering scheme and product information specification
- Developing open, global network specification to enable the interchange of product data in a seamless manner.

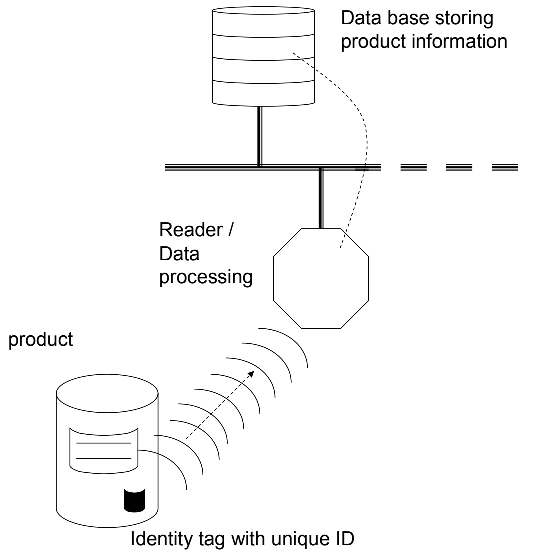

Figure 1 Simple Schematic of an Auto ID System

For these reasons, the following features are specifically associated with the automated identification systems being developed initially by the AutoID Center:

- Reference specifications for write-once, read many (WORM) times RFID tags which contain *only* a unique product identity number – all other information about the product is held in networked data bases. The implementation, in fact, need not follow this approach if costs permit greater *on-tag* information storage
- a unique Electronic Product Code (ePC) which represents an extension to the bar code naming conventions in that it includes unique product identity
- an Object Naming Service (ONS) which provides a reverse-directory style look up to enable ePCs to be linked to database information held anywhere on the internet
- a Physical Markup Language (PML), which provides a common language and structure for holding product information in a web style server.

With this approach, the cost of installing and maintaining such systems can be spread across several organizations while each is able to extract its own specific benefits from having uniquely identified items moving in, through and out of the organization's operations.

3.2 RFID Based Auto ID Systems vs. Bar Code Based Systems

The system described above is a logical extension to today's barcode-based systems that have been so successfully applied throughout supply chains. Barcodes identify products at transition points such as shipping, receiving, and checkout. The technology exists, it is inexpensive, ubiquitous and, in principle, very accurate. Thus, one should think about the benefits of Auto ID systems emanating from replacing today's barcode-based systems. While we note that the barcode is not incompatible with the architecture provided in

Figure 1, we note that an identity collection system based on RFID tags has two advantages over conventional bar code systems:

1. Bar codes have to be scanned deliberately by a person in a process that is difficult to automate. RFID tags, on the other hand, can be readily scanned automatically without human involvement.

   This characteristic of AutoID implies several benefits:

   - The data can be obtained continuously and thus they are more up-to-date then data obtained only at specific intervals (like inventory counts) and specific points in the supply chain (like shipping or receiving)
   - Not involving a human in the process means that the readings can be less expensive and generally more accurate – incremental readings are virtually cost-free once the system has been set. It also means that there may be fewer misreads.

2. Bar codes require line-of-sight to read, while RFID tags can be read in any orientations as long as they are within the reader's range.

   The implications of this characteristic, in combination with the previous one are the following:

   - Speed – many tags can be read simultaneously into a computer, rather than reading a single tag at a time
   - The content of various conveyances (such as trailers, cases, pallets, shopping carts) can be read automatically without opening and sorting the conveyance
   - Bar codes do not work well when exposed to weather elements, when dirty, or if damaged in any way that interferes with clear line-of-sight reading.
   - Location – RFID readers can provide rough location information, particularly when the goods being scanned are moving relative to the reader.

Although not explicitly a feature of a bar code or an RFID system, we add here a further issue relevant to the Auto ID system proposed by the Auto ID Center:

3. The numbering systems used on today's bar codes are generally limited to manufacturer and product type identities and cannot include a unique identifier or serial number for specific items (see Figure 2). Without a unique identity it is not possible to associate information with a specific physical product.

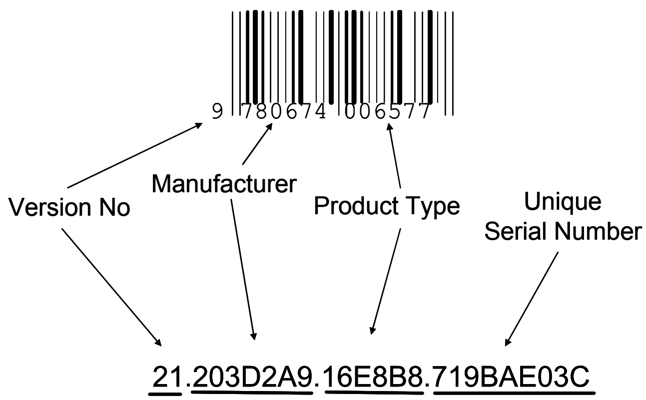

Figure 2 Conventional Bar Code and ePC Numbering

There remains a number of short term challenges associated with ubiquitous RFID adoption in an Auto ID environment – e.g., cost/benefit for some applications and interference issues for complex metallic products. Thus it is most likely that bar codes and RFID systems will coexist. We return to this question in Section 7.

4 An Elemental Supply Chain Model

Before assessing the potential impact of AutoID on supply chain operations, this section outlines a simple, generic supply chain building-block. This building block is then used to discuss the potential impact of Auto ID on supply chain operations without being restricted to particular configurations or contexts.

4.1 The Elemental Building Block – A Ship/Receive Pair

Not only are supply chains different across industries and companies, many companies operate multiple supply chains. For example, retailers may carry tens of thousand of SKUs in every store, supplied by hundreds of vendors/ manufacturers. Each family of products has its own supply chain, all of which can be aggregated into the retailer's supply chain. Similarly, manufacturers transform many different products in the same factory and on the same lines, requiring many supply chain and distribution networks.

All of these supply chains, in all industries and regardless of the structure of the chain are based on a single common element: a ship/receive (S/R) pair. In the "classical" supply chain view an S/R pair consist of a shipper (seller) entity and a receiver (buyer) entity, connected by several links. These links include the physical flow between the entities, as well as the two-way information flow and the cash flow between them. Figure 3 depicts an S/R pair with a particular emphasis on the physical material flows between the shipper and receiver.

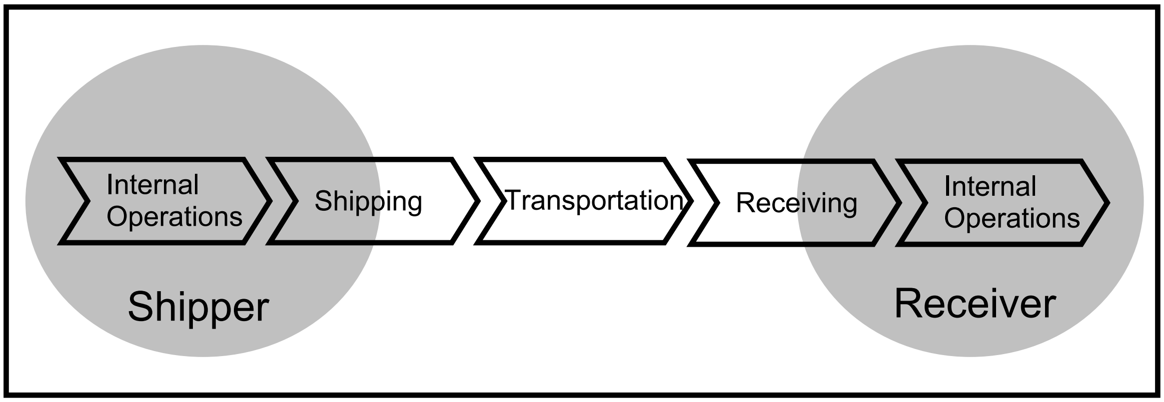

Figure 3 Physical Flow Processes of an S/R Pair

Naturally, the definiton of the elemental R/S pair does not impose any supply chain structure. The same structure can be used to examine both intra and inter organisational supply networks which will influence the nature of *cash* flow and the levels of information sharing between nodes.

4.2 Extending the Definition – Modeling Internal Supply Chains

The definition of the elemental supply chain components can be readily extended from the inter-enterprise view presented above to intra-enterprise movements between locations with their associated information and cash flows. Clearly any intra-enterprise material movement will be associated with intra-enterprise information flows. In general, however, there will be no cash flows as such. In some cases there will be specific internal charges associated with the internal accounting system as value is added and funds expended along the internal chain. Thus, we refer both to inter-enterprise supply chain and intra-enterprise supply chain where our meaning should be obvious from the context. We basically consider a movement of items of some sort from one operation to the next. Hence, such a definition also includes the movement within a transportation network or within a manufacturing plant from one work station or work cell to another. The movement of finished goods from a manufacturing plant to a warehouse or a distribution center can be interpreted as an S/R pair regardless of whether the same enterprise owns both operations involved or whether – for example - the manufacturer is using a common carrier and a warehouse owned by a logistics company.

By examining the sources of variability in the context of the key functions of these S/R pairs we can begin to determine where Auto ID systems can impact logistics oprations in the supply chain.

4.3 Functions of the S/R Pairs

The process associated with the flow of items across an S/R pair includes the following:

- **Shipping process**: - Includinf shipment consolidation, contract compliance, routing optimization, tendering and other transportation management functions associated with getting shipments out the door.
- **Transportation process** – Including all the processes and activites performed by the carrier, logistics company or whomever, in connection with the transportation process.
- **Receiving process** – Including verification, acknowledgement, pairing and put-away activities associated with receiving shipments at the buyer location.
- **Internal processes** – Include all the processes taking place within the buyer's facility. These may include transformation in a factory, storage in a warehouse, display in a store and all the processes around these activities.

These processes are depicted in Figure 3. The specific activities in each of these functions will differ depending on the specific S/R pair considered, the industry and supply chain involved, but most of the processes described are generic.

4.4 Examining Supply Chain Auto ID Benefits

In the next section the S/R model will be used to examine benefits to be achieved from Auto ID introduction into the supply chain. In Section 2 it was noted that *internal variability management* was a key rationale for Auto ID systems, and here we briefly provide example sources of internal variability for each of the S/R pair functions

- **Shipping -** late orders, emergency shipments, lack of transportation capacity, lack of inventory visibility for order completion, misplaced and mis-picked items, etc.
- **Transportation -** delays, misrouted packages in terminal operations, last minute diversion of conveyances,[1] dynamic trucking operations, wrong drop-off and pick-up operations, pilfrage during transit, spoilage, etc.
- **Receiving -** item shortages, wrong items, wrong quantities, deliveries to the wrong location (or receiving door within a location), put-away in wrong locations, wrong data entry, etc.
- **Internal Operations -** errors in determining product state during processing, quality problems, raw material stockouts, inventory mismatches, unknown location of product within the facilty, etc.

5 Improving the Existing Game

As mentioned in section 3, the potential value of deploying AutoID systems should be analyzed by a comparison with the value already available through existing systems based on barcode technology [16]. Also as discussed earlier, bar coding technology itself could also be integrated into an Auto ID framework and Auto ID network software could be phased in through an existing bar code-based scanning environment as part of an implementation strategy.

[1] For example, many vessels can be diverted several times *en-route* as their cargo is being traded on the commodities exchanges of the world.

This section looks first at the four S/R processes, examining the applications and benefits of Auto ID as a means of dealing with sources of variability. The last part of this section looks at supply chain-wide applications which cut across the four functions characterizing each S/R pair. In each analysis we assume the availability of not only product identity but also – via a networked database - information about the product which might influence the way it is handled, including order information, product state and specification. Unless explicitly stated, the Auto ID approach we are considering is the specific model developed by the Auto ID Center as described in Section 3.1.

5.1 Shipping

The shipping process involves several decisions from the time a product is ready to leave the facility (factory, warehouse, terminal or retail backroom) until it gets on the conveyance to its destination. These include decisions on which mode of transportation to use, how to economically consolidate and load shipments and when and how to exchange information with the carrier and the consignee.

Shipment consolidation
To see the opportunities for better shipment consolidation, consider, for example a typical situation in which a shipper needs to transport a number of less-than-truckload shipments, ranging in size from 1,000 lbs. to 10,000 lbs, to several consignee facilities.

The shipper can tender each one of the shipments to an LTL carrier who will consolidate it with shipments from other shippers and move the shipments to the various destinations through its terminal network. Alternatively, it can combine shipments destined to the same location and tender them to a TL carrier who will go directly to the drop-off point at much lower cost - if there is enough freight. Another alternative is to combine shipments going to several different locations and construct a multi-stop tour for the truck.

To consider all available options, a shipper typically looks at the shipments "on hand" – i.e. on the loading dock and ready to ship. The more shipments are taken into account, however, the better are the consolidation opportunities. With an Auto ID system in place, the shipper has greatly extended visibility, in that it is possible to assess the status of shipments that are still in the production or picking processes when making the decision. The shipper can also look at trailers already loaded and waiting in the shipper's yard for the carrier to pick them up. With Auto ID the content of the trailer can be read *through the trailer's walls*. While currently, no shipper will open a trailer and take off a shipment or to add one, Auto ID will allow shippers to do just that—exchange content across trailers to optimize the ever changing transportation requirements.

Conveyance loading
In some cases, such as truckload shipping, the mode decisions are obvious. The challenge in this case is not to decide what to load on each outbound trailer but rather speed and efficiency. The advantage of RFID in this process is the efficiency of the loading process – shipments can be scanned while driven out of the inbound trailer and into the outbound trailer through the loading doors, eliminating the manual task of reading each shipment or

pallet. This is an environment where bar code readers may not always perform well since it is open to the elements. The savings here are labor and accuracy related.

5.2 Transportation

As shipments move from terminal to terminal through the carrier network or as they change hands when moving from one mode to the next, they are moving through a series of S/R pairs with receiving, in-terminal operations and shipping. The benefits of Auto ID during the transportation process itself involve the tracking of the carrier's conveyances, sub-conveyances and shipments.

Conveyance Tracking
One area where automated identification – in its most general sense - has already made tremendous strides is the automatic identification of trucks in movement. Here the Auto ID system – which is implemented via satellite communication and GPS rather than an RFID based system – enables the carrier headquarters to know not only the location of every truck in their fleet in real time, but also the status of several operational parameters regarding the truck. Clearly, just having this information allows dispatchers to exert better control of their truck fleets. The quantum leap in performance, especially in the truckload sector, however, came with the development of sophisticated optimization tools which utilize these data. Such applications include the following:

<u>Automatic dispatching</u> – The challenge is to assign each truck to the right load. This process was enhanced significantly with AutoID since it is a system problem – knowing which truck to assign where, depends on the location as well as current and future activity of the rest of the fleet.

<u>Local operations and trailer swapping</u> – As trucks move throughout the country, changing requirements mean that Auto ID systems can be utilized to divert trucks in real time, change schedules and swap trailers. The use of automatic dispatching and trailer swapping algorithms has led to significant measurable improvements in customer service, costs, and driver satisfaction. (For example, the 1993 annual report [17] of JB Hunt, the second largest truckload carrier in the US claims a reduction of 10% in empty miles driven and a reduction of 20% in driver turnover as a result of using such optimization models coupled with a satellite-based communication system.)

<u>Fuel optimization</u> – As trucks movements are tracked through the country, sophisticated algorithms check the fuel price in real time along the future route of the truck. Fuel represents about 20% - 25% of a trucking company's costs and such algorithms have shown to reduce fuel expenditure by 6% - 8%, leading to 1% - 2% overall cost reduction.

While the applications discussed here do not involve RFID tags but rather expensive satellite transceivers and GPS, it is important to realize that many of these sophisticated applications are dependent on getting real time data and were developed, or enhanced only once the data stream became available in real time.

Sub-conveyance Tracking
Operations of transportation carriers involve tracking many conveyances and sub-conveyances. The last section looked at tracking the power equipment (trucks, locomotives, etc). This equipment is expensive and manned, thus it is worth tracking with satellite communications. Sub-conveyances, however, are harder to account for since there are many more of them, and they spend time in their usage cycle outside the control of the carrier. Such sub-conveyances include trailers, containers, pallets, racks, air igloos etc. The management of these sub-conveyances is where the impact of RFID based systems can be felt immediately. Being able to automatically and accurately track individual pallets would enable material handling companies to reduce the number of pallets in circulation, charge customers appropriately for their use on an individual pallet basis and maintain the pallets better. Similarly, delivery logistics companies will be able to track returnable containers and racks thereby improve their utilization. Other examples of current use of Auto ID in sub conveyance tracking include the following [11]:

- Scottish Courage Brewing tracks a UK inventory of 10 million beer kegs with Auto ID, reducing shrinkage, improving operations (shipping, receiving, payments, etc.) and providing an immediate audit trail.

- Marks & Spencer, the UK retailer is using RFID to track food trays and rolling cages, cutting down the time required to read and identify these sub-conveyances by a factor of five.

In addition, automatic identification of larger sub-conveyances, such as trailers and containers is already improving their utilization, especially in port operations, which involve loading, storing, and moving thousands of containers at a time.

Shipment & Item Tracking
With RFID, transportation carriers will be able not only to track individual shipments but the components of individual shipments. This means that carriers will know immediately what they picked up – something that many carriers do not know until a claim is submitted for shortage or damaged goods. Naturally, this can trigger the early warning at the consignee before a problem shipment arrives.

By the virtue of the majority of their items fitting a standard model, courier firms such as UPS, USPS and Federal Express are already capable of performing extensive tracking using sophisticated bar code-based systems. RFID tags, however, can speed the reading process allowing all loading, unloading and terminal operations to be speeded up reducing costs and time. More irregular shipments, such as those carried by LTL carriers are harder to scan automatically and Auto ID can provide significant benefits there.

The culmination of these different tracking applications is the combination of the different data types as illustrated in Figure 4. Hence a shipper with access to carrier location information, and RFID scanned items information, is able to provide its customer with location information or temperature of specific items en route to delivery.

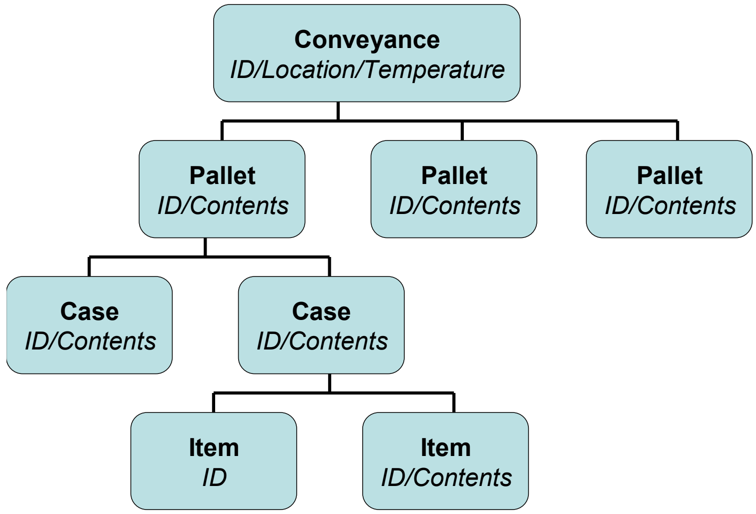

Figure 4 Hierarchy of Identified Objects

5.3 Receiving

The receiving processes include a host of verification activities, followed by "put away" functions.

Verification

Receiving processes are time consuming since they involve a verification of what was actually delivered. With complete use of RFID the manual verification aspect of the receiving process may be eliminated. When the carrier picks up the shipment, its *content* can be immediately transmitted to the consignee for verification.

"One Touch" approaches to receipt of goods are becoming increasingly popular with large. The intention is to stock shelves directly from the carrier. In "one touch" environments, timely and accurate verification is critical.

Verification processes are a source of continuing tension and wasted efforts on the part of customers and suppliers. Many retailers have a schedule of deductions when receiving merchandise – each infraction in the contract terms (late delivery, shortage, wrong shipments, etc.) involves a "fine" to the supplier. These deductions are a source of contention between the parties. Many of these and similar points can be eliminated by careful tracking of what was delivered and when.

Storage

As material, parts, or finished goods come into a facility, computer based acknowledgement is required to recognize their presence and provide the carrier with a proof of delivery. That process can be simplified substantially by installing RFID readers at the unloading docks, detecting the presence of incoming material as it flows through the receiving docks, resulting in a more accurate count and less expensive process.

In October 2001 the Auto ID Center initiated a large scale field test, in which tagged pallets of Bounty paper towels sent from a P&G factory in Cape Giradeau, Missouri, were read as they left the factory and on receipt as they arrived in Wal-Mart's Sam's Club in Tulsa, Oklahoma. Over the following months, pallets of goods from other vendors, including Gillette and Unilever were added. In February 2002, Phase Two of the field test involved putting tags on cases. It included Unilever, Procter & Gamble, Kraft, Coca-Cola, Gillette, Wal-Mart, and Johnson & Johnson who shipped tagged cases to and from selected distribution centers and retail store in eight US states.

In addition to receipt acknowledgement, knowing which reader in a warehouse or a stock room has identified a particular item can give inventory managers the location where each item is stored.

5.4 Internal Logistics Processes

Some of the biggest impacts of Auto ID systems may be in operations within facilities. Since facilities are so different, we will discuss here some of the possible applications by facility type: manufacturing plants, warehouses, distribution centers and terminals, retail outlets, homes and disposal/recycling centers.

Manufacturing plant
Auto ID systems can help manufacturers track material throughout a plant, providing administrative process savings. In many cases bar codes are read several times as materials move through the plant.

In a UK consumer electronics plant, several customization items are put into one box which is then put into trolleys with racks. The trolleys are then moved from the location where the box is built to the line where it joins the main device. Throughout this process workers have to read the trolley bar code, the rack bar code (there are about 50 racks on each trolley) and the item bar code. This happens with every item manufactured by the plant both when the trolleys are loaded and when they are positioned next to the production line. Auto ID systems using RFID technology would simplify this process considerably, increasing both efficiency and accuracy.

In addition to tracking, Auto ID systems can make significant contribution to quality control and reworking processes, and the management of raw material and work-in-progress items in a manufacturing environment.

Warehouse
Possible benefits of Auto ID in warehousing operations include the following:

- Efficiency - The central functions of a warehouse are to put items away and then retrieve them efficiently. One of the immediate benefits of Auto ID systems in the warehouse will be the tracking of constant inventory levels in real time, or "always on" inventory count, leading to more efficient and accurate picking and packing operations.

- Reach - Auto ID information can enable by "virtual inventory networks" in which inventory can be retained and accessed anywhere that is convenient – in storage, on the move, in stock rooms, etc. While many order fulfillment systems use this capability already – querying other warehouses if an ordered item is not available locally – this capability would become more seamless, and be extended to querying all locations such as other outlets or transportation links.

- Productivity - Some systems, such as "pick to light," try to get workers' attention to where the items are and direct their search centrally. With Auto ID workers can find where items are via a message on a local device, such as a personal digital assistant. Using such system, workers can manage their tasks individually, allowing real time events to influence their own work and re-optimize it without impeding others.

- Accuracy – More and more warehouses are operated like distribution centers where the flow in and out is continuous. In many cases such facilities are used for cross-dock operations, where shipments from manufacturers are broken down and reassembled into shipments into individual stores. Auto ID systems can ensure that the right shipments get routed from the inbound to the outbound facilities, performing the necessary checks regarding shipment content *automatically* and *continuously*.

Retail store

Some of the biggest impacts of the Auto ID systems may be felt in retail stores. A retail store can be thought of as a chaotic warehouse where non-employees (consumers) are allowed -- in fact, even encouraged -- to roam the isles and perform picking and packing operations. The continuous inventory system afforded by Auto ID systems can mean the following:

- Less out-of-stock (OOS) situations due to the continuous checking of the shelves, coupled with automatically triggered replenishment. The exact magnitude of OOS situations and the resulting losses to retailers and manufacturers cannot be easily measured since the phenomenon is not recorded; only actual purchases are. Many studies have tried to estimate the magnitude of OOS; for example the GMA/FMA [18] estimates 8.2% out of stock situations, costing retailers about 4% of sales, with a quarter of these incidents resulting from items in the store but not on the shelf.

- Labor costs can be reduced through automating the checkout counters, reading the content of a whole shopping cart at a time. In the short term, replacing bar code scanning systems with RFID based system can lead to more accurate and speedy checking out processes. In the longer term, by using "smart" shopping carts consumers can have a running total of their purchases, going through checkout procedures with no queuing.

- Pilferage can be reduced by monitoring the content of shelves and alerting store personnel for unusual purchases of certain items. Gillette Inc. and Tesco in the UK have recently announced the trial implementation of an in-store theft detection system, focusing on razor blades [19]. The system is based on a "smart shelf detecting how many blades were taken and alerting in-store personnel to unusual patterns." In January 2003, Gillette ordered 500 million tags from Alien technology Inc. [11].

- Phantom stock problems happen when consumers put away items on the wrong shelf, creating a mismatch between the virtual inventory in the computerized database and the actual inventory in the store. By some estimates this so called "phantom inventory" phenomenon accounts for up to 40% of the inventory in book stores. Auto ID can virtually eliminate the problem.

5.5 Cross Supply Chain Applications

Some possible applications of Auto ID are relevant to any location throughout the supply chain and affect more than one of the S/R pairs. Such applications include, for example:

- Easier recall campaign - using the knowledge of where specific items, which were manufactured at specific times in specific plant, are in the supply chain.

- Piracy and diversion detection – tagging would allow a new level of security verification of authenticity.

  In Italy, the entire pharmaceuticals supply chain has been grappling with the government's mandate of unique item level labeling. Current efforts involve scanning of pallet and case labels coupled with centralized recording of each transaction as a means of ensuring authenticity from drug production to patient dosing. Pharmaceutical wholesaler, Felletti Spadazzi S.p.A. , has run a series of trials in conjunction with AstraZenecca and GlaxoSmithKline testing the feasibility of RFID solutions in this environment [20]. The global network infrastructure of the Auto ID Center's solution is also being examined as a means of managing data between the different stages of the supply chain

- Standardization. The vision of the Auto ID Center is that the items' data will reside on shared data bases which can be shared by all supply chain partners.

> A major global computer systems producer identified more than ten different item identification systems across the design, manufacturing and usage phases of its products' lifecycles. Each system maintains its own database and in only one instance are the databases linked. This results in frequent inaccuracies in reporting faulty items in service and lack of ability to replace these items with the correct parts. A common information architecture linked to a real time identification system would reduce many of the complexities of managing the reverse logistics process associated with company's service management [21].

6. New games

In addition to offering improvements in many existing processes, Auto ID systems can enable new customer service offerings which may have widespread ramifications. Since our discussion here is speculative, we simply provide a few examples of possible "game changing" applications of Auto ID in order to encourage readers to think further. This section describes two categories of applications: the first includes new designs of facilities and the second is focused on more dynamic operations.

6.1 New Facility Designs and Operations

The strategic impact of AutoID may include smaller warehouses and smaller stores, allowing new supply network designs

Store of the Future
Continuous shelf inventory checking and more frequent replenishments mean that shelf space for each item can be reduced substantially while increasing level of service and avoiding OOS. The result may be smaller supermarkets and other retail outlets while the number of SKUs offered remains constant. Thus, the trend towards suburban large malls may be reversed by offering all the variety of suburban supermarkets in a corner store. The supermarket of the future may also enable many local ad hoc networks in which the addition of inert objects to a wireless LAN means that shoppers can find out what's in the store by passing next to it, or examine the ingredients in a box of serial on the supermarket shelf on their PDA, as they get near it.

Procter and Gamble in Ohio, Phillip Morris in New York State and most recently MGI (Metro) of Germany have opened Future Stores as a means of demonstrating the type of facilities that might be expected in an Auto ID-enhanced retail outlet. Applications range from smart – anti theft – shelves, to wireless and automated ordering systems, to intelligent trolleys which scan items as they are collected and update an electronic shopping list accordingly. Personalized advertising systems have also been tried.

Future Warehousing
Garcia *et al* [22] describe possible reductions in warehouse space by the removal of recursive buffering zones used to ensure transfer cars can always unload. Faster

information enables the transfer car to directly load into a warehouse zone capable of dealing with that item (see Fig.5).

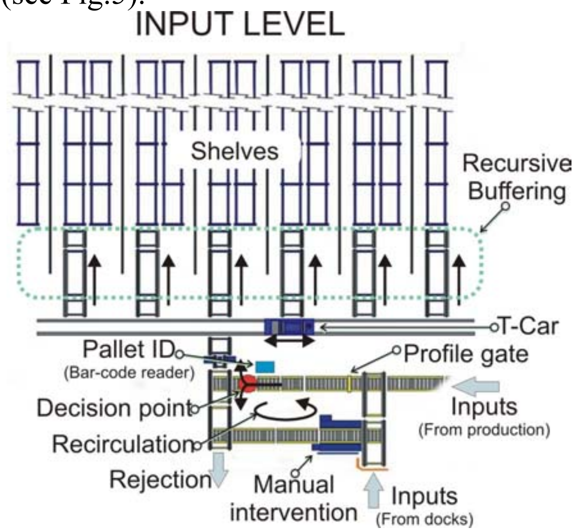

Figure 5 Potential Reduction in Warehouse Space (Garcia et al, 2003)

Smaller warehouse space means that warehouses can be put closer to urban areas for faster service of retail outlets, especially when those outlets are automated and "inform" the warehouses on the shelf and stock room inventory level continuously.

Another possible benefit of Auto ID is the complete redesign of warehousing operations. Currently both put away and pick up operations as well as storage strategies are geared to human sensing. With Auto ID systems put away locations can be determined by new, optimized trade-offs using criteria such as efficiency of put-away, picking, space, or a combination of these criteria. Under any of these scenarios, the typical warehouse design will change drastically, looking very chaotic to the naked eye but totally in control through the electronic sensors and readers and the underlying information system.

Smarter Homes

As mentioned above, one of the first applications in the home may be continuous inventory. RFID, however, may give a new generation of home appliances the ability to know their content and act on it. Such actions may include cooking (in case of a microwave oven reading imbedded instructions on a package); a refrigerator and a cupboard ordering automatically from a store when the inventory level reaches a predetermined reorder point; and a refrigerator or medicine cabinet letting the owner know about the expiration date of content.

Given the right permission, one can also imagine one home system interrogating the inventory in a neighbor's system in real time -- to complete a recipe, for example – managing a cross-neighborhood borrowing or barter system. Naturally, one can simultaneously interrogate digitally the corner store and find out what is the store availability of missing items in real time.

6.2 Toward More Agile Operations

The premise of Auto ID is that by having more accurate, continuous and real-time information, supply networks can operate in a more responsive and agile fashion. We look at two aspects of this: flexible manufacturing and disposal/recycling management.

Customization in Manufacturing

Auto ID is an important step in tracking and identifying individual items and components in an automated manner and in linking them to order priority and 'product recipe' information. Such abilities are critical enablers for highly customized manufacturing operations in which order sizes of one will become as simple to monitor and adjust as today's high volume orders.

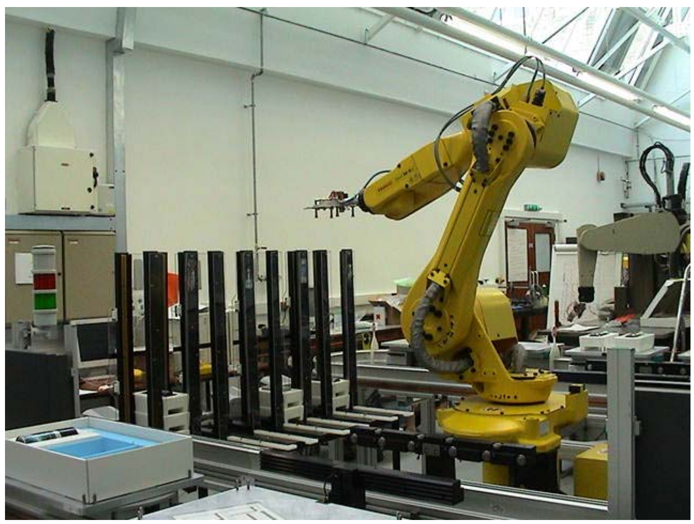

Figure 6 Customized Packaging Demonstration System

One of the first fully Auto ID-compliant systems has been demonstrated in the Auto ID Center's Cambridge Laboratory in England. The system in Fig. 6 constructs seasonal gift boxes comprising a range of retail items. The empty boxes to be filled are tagged and these are aligned with a customer order – *which may change at any time* before of after packing. The Auto ID tag is read at entry to a loading station and at that point the robot-driven packing system interprets the order "recipe" and proceeds to locate the required set of items for the gift box. See Hodges et al, [23] and Brusey et al, [24].

Extending the Visibility

Today the supply chain for retail goods effectively ends at point of sale. Auto ID can enable applications in the usage phase (e.g. in the home) and at the end-of-life phase (e.g. disposal/recycling/reuse application) through information preservation. Keeping product information by continuing the Auto ID infrastructure through the usage and disposal processes means that information about the item is known throughout their lifecycle. Figure 7 is derived from Thomas *et al* [25], illustrating the current typical information profile of items as they go through a supply chain. (See also Parlikad et al [26].) The Auto ID-enhanced case is shown by the dashed line in Figure 7

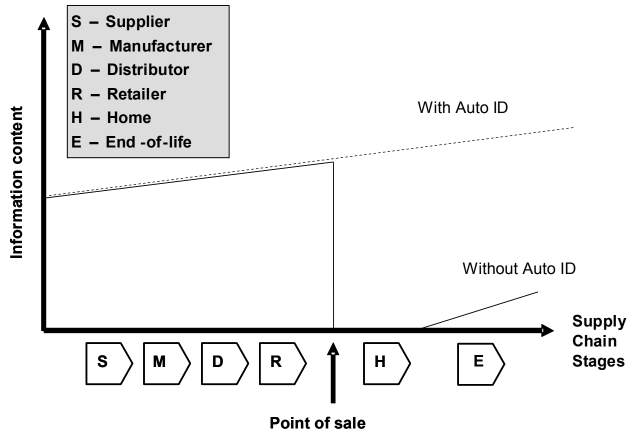

Figure 7 Product Information Content along the Supply Chain

The benefits of the extension of the visibility beyond the home are in more efficient and agile end-of-life operations. Being able to detect which parts are contained, for example, in a discarded appliance and how that appliance was used at home, can aid in the decision of where to send it for processing, allowing recycling centers to specialize. In the recycling centers RFID information can help automate the sorting process, which is the Achilles' heel of most recycling processes. It can help decide what parts to recycle, what can be used in remanufacturing and what should be discarded and where.

7. Moving Forward

This section highlights some implementation issues and some of the challenges that are still facing the technology and early adopters.

7.1 Implementation Strategy

The first adopters of Auto ID technology on a large scale are likely to be those companies who have a single application which on its own provides a financial justification for the cost of infrastructure and tagging systems. An example is Gillette which, as mentioned in section 5, is using the technology to reduce theft of its expensive razors. Similarly, the UK's "Chipping of Goods" initiative [27] has specifically addressed the issue of crime and the use of RFID systems

Similarly, UK retailer Argos in conjunction with Integrated Product Intelligence (IPI) is developing an electronic tag-based system for the tracking and tracing of jewellery and other high value products from a central distribution point to a number of retail stores in the UK and Ireland. The current method of distribution requires the use of specialist carriers with high security vehicles. This is not only costly but does not offer shippers visibility and control. The demonstration project will use RFID technology on individual transit packs and roll cages. These will be read at every point where products are handled, from when they are picked in the central warehouse to when they are received at the retail store. The same process will be applied to all products on the reverse journey from retail stores to the warehouse. This system will be able to alert shippers in near-real-time the ability to pinpoint where and when items are removed unlawfully from the supply chain.

Initially, bar code readers and RFID readers are likely to coexist. Auto ID data may be stored in special databases and then fed to current systems in batch mode. Later, as the Auto ID infrastructure develops, bar codes can be used to provide limited automated identification information within the global Auto ID network infrastructure.

As enterprises start contemplating the implementation of AutoID system the benefit/cost ratio of adopting the technology should be examined carefully. Unlike the development of the bar code and the uniform product code that enabled it, the hurdle now is much higher – the new system is required to be demonstratively better than the bar code.

Byrnes *et al* [28] propose that it makes sense to convert distribution centers and warehouses to the AutoID first and to convert retail outlets in a second phase. The reason is that the former requires tagging of only pallets and cases rather than individual items and it means that only warehouse systems need be modified, including warehouse management systems (WMS) and transportation management systems (TMS). Another reason is that it may be relatively simple to convert the transportation system to AutoID. The benefit to transportation carriers, especially LTL motor carrier is large and it is likely that such enterprises will invest in the systems.

In general, RFID-based AutoID systems are unlikely to be implemented for all products during the initial period of its commercialization and bar code based systems will continue to have a role for a long time.

7.2 Challenges

While the focus of this paper was on the possible benefits of the technologies, one should balance this presentation with a consideration of the possible challenges and hurdles that still face widespread adoption. This section distinguishes between technological and organizational challenges.

Technological challenges include the following:

- Data storage and access – tracking every object at the individual item level will generate enormous amount of data that will have to be stored (probably using distributed data bases) and accessed quickly. The Auto ID Center has developed migration strategies but at present this can be accomplished only at the cost of reducing the fidelity of the data.

- Accuracy – As operations and their underlying information systems grow to rely more and more on real time, automated product identity data, the specifications placed on the identification system will tend towards absolute accuracy. This will place new challenges on the engineering and production of the tags and readers.

- Interference – with the proliferation of wireless devices (phones, PDAs, radio, etc.), there is the potential for electromagnetic interference with large scale Auto ID networks. This maybe particularly important since RFID does not have its own licensed frequency but rather uses several available frequencies.

In addition to these technical challenges, organizational challenges include the following:

- Information sharing – Once the data is shared across the supply chain, there is a question of ownership of the data. The manufacturer may endow the tag with initial data; many players along the supply chain may update the tag data; and the consumer who buys the item may feel that they buy the data with the tag. When one of the parties derives benefits based on another party's work (updating or reading), how are the right parties compensated?

- Security – This is not a new question in as much as database security is concerned. A new element, however, may be introduced when writing into the tag is possible, since wrong information can be written onto the tag accidentally or maliciously. (We note that initial tag specifications from the Auto ID Center are specifically *Read Only* for this and other reasons.)

A continuing challenge will, naturally, be the cost of the system. Current tag costs are at US 5 c when produced in very high volume. This may or may not be low enough for widespread application, but it is already feasible for high-end goods or cases and cost reduction pressures are sure to continue.

8 Summary

This paper focused on the application of Auto ID to improve four basic logistics processes: shipping, transportation, receiving and in-facility operations. The greatest potential initially is probably in improving in-facility operations within retail stores, warehouses and distribution centers. Auto ID systems should mean that many operations which require identification can be performed automatically, more accurately and faster, leading to reduced costs and increased timeliness. Beyond the cost cutting and improve processes offered by Auto ID, it can facilitate strategic improvements in store and warehouse operations and in network-wide agility.

Earlier in this paper we stated that global optimization is one of the key challenges for tomorrow's supply chain. Although we have not discussed this issue directly in this paper, Auto ID systems provide a likely catalyst for the development of a new generation of decision support system. Such systems will be supported by more real time information and thus keep pushing the use of optimization systems to the operational level, where the greatest benefits may lie.

9. References

[1] Brown, S, (1997), **Revolution at the Check Out Counter,** Harvard Publishing

[2] Powell, W., Sheffi, Y., Nickerson, K., Butterbaugh, K., Atherton, S. (1988) *Maximizing profits for truckload carriers: a new framework for pricing and operations*. **Interfaces,** 18(1) pp 21-42, Jan-Feb 1988

[3] Smith, S. and Sheffi (1990), Y., *Locomotive scheduling under uncertain demand*. **Transportation Research Record,** 1251 pp 45-54, June 1990.

[4] Chopra, S. and P. Meindl (2000) **Supply Chain Management: Strategy, Planning and Operations**, Prentice Hall

[5] Christopher, M. (1998) **Logistics and Supply Chain Management: Strategies for Reducing Cost and Improving Service** (2nd Edition), Financial Times Prentice Hall

[6] Shapiro, J. (2000) **Modeling the Supply Chain,** Duxbury Press

[7] Simchi-Levi D., P. Kaminski and E. Simchi-Levi **(1999), Designing and Managing the Supply Chain: Concepts, Strategies, and Cases,** McGraw Hill

[8] Pil, F. and M. Holweg (2003) *Mitigating Product Variety on the Supply Chain*, **Working Paper, MIT Center for Technology, Policy and Industrial Development**.

[9] Kritchanchai, D., and MacCarthy, B.L., (1999) "Responsiveness of the order fulfillment process", **International of Journal of Operations and Production Management**, Vol 19, No. 8, pp 812-833

[10] Shaw, A, D.C. McFarlane, Y.S. Chang, P.J.G. Noury**, (2003)** ***Measuring Response Capabilities in the Order Fulfillment Process*****,** Proceedings of EUROMA, Como, Italy.

[11] Ericson, J. (2003) *RFID Rising*, **Line56**, February 13th, 2003.

[12] Matson J.B., and McFarlane, D.C., (1999). *Assessing the responsiveness of existing production operation*, **International Journal of Operations and Production Management.** 19 (8), pp 765-784

[13] Finkenzeller, (1999), RFID Handbook, John Wiley & Sons.

[14] Sarma, S, (2002), Towards the 5c Tag, **Auto ID Center White Paper,** CAM-AUTOID-WH01, www.autoidcenter.org.

[15] Auto ID Center - www.autoidcenter.org

[16] Habermann, A, ed (1999), **Twenty-Five Years Behind Bars: The Proceedings of the Twenty-Fifth Anniversary of the U.P.C. at the Smithsonian Institution, September 30, 1999,** Wertheim Publications in Industrial Relations

[17] J.B.Hunt (1994) **1993 Annual Report to Shareholders**. J.B.Hunt, Arkansas.

[18] GMA/FMA (2000), **Retail Out of Stock: A Worldwide Examination of Extent, Causes and Consumer Responses**, Grocery manufacturers of America and the Food Marketing Institute study. (see: http://www.fmi.org/supply/)

[19] BBC, (2003), **Supermarket Tries Out Smart Tagging,** BBC News, www.bbc.co.uk, 16 January

[20] IFPW (2002), **Felletti Spedazzi Part of RFID Test**, International Federation of Pharmaceutical Wholesalers Journal, v9, n7

[21] Hewett, P, (2002), **Auto ID and Product Life Cycle Management**, Master's Thesis, Manufacturing Engineering Tripos, University of Cambridge.

[22] Garcia, A, McFarlane, D, Thorne, A, Fletcher, M (2003), Auto ID in Materials Handling, **Auto ID Center White Paper,** CAM-AUTOID-WH017, www.autoidcenter.org.

[23] Hodges,S, Thorne, A, Garcia, A, Chirn, J, Harrison, M, McFarlane, D (2002), Auto-ID Based Control Demonstration Phase 1: Pick and Place Packing with Conventional Control, **Auto ID Center White Paper,** CAM-AUTOID-WH06, www.autoidcenter.org.

[24] Brusey, J, Fletcher, M, Harrison, M, Thorne, A, Hodges, S, McFarlane, D, (2003), Auto-ID Based Control Demonstration Phase 2: Pick and Place Packing with Holonic Control, **Auto ID Center White Paper,** CAM-AUTOID-WH011, www.autoidcenter.org.

[25] Thomas, V, Neckel, W.; Wagner, S., (1999) Information technology and product lifecycle management, **Proceedings of the 1999 IEEE International Symposium on Electronics and the Environment**, pp 54 -57.

[26] Parlikad, A, McFarlane, D, Fleisch, E, Gross, S, (2003), The Role of Product Identity in End of Life Decision Making, **Auto ID Center White Paper,** CAM-AUTOID-WH017, www.autoidcenter.org.

[27] See www.crimereduction.gov.uk

[28] Byrnes, J., Y. Sheffi and J. Wass, (2002), AutoID: *Selective or Comprehensive System*, **AutoID Brief, MIT**