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AUTO-ID CENTRE

WHITE PAPER

The Intelligent Product Driven Supply Chain

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ABSTRACT

Establishing connectivity of products with real-time information about themselves can at one level provide accurate data, and at another, allow products to assess and influence their own destiny. In this way, the specification for an **intelligent product** is being built – one whose information content is permanently bound to its material content. This paper explores the impact of such development on supply chains, contrasting between simple and complex product supply chains. The Auto-ID project will enable such connectivity between products and information using a single, open-standard, data repository for storage and retrieval of product information. The potential impact on the design and management of supply chains is immense. This paper provides an introduction to some of these changes, demonstrating that by enabling intelligent products, Auto-ID systems will be instrumental in driving future supply chains. The paper also identifies specific application areas for this technology in the product supply chain.

WHITE PAPER

The Intelligent Product Driven Supply Chain

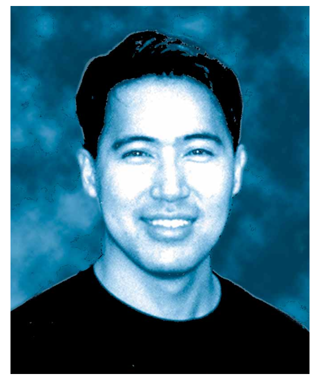
Biography

Duncan McFarlane
Research Director Europe

Duncan McFarlane is a Senior Lecturer in Manufacturing Engineering in the Cambridge University Engineering Department. He has been involved in the design and operation of manufacturing and control systems for over fifteen years. He completed a Bachelor of Engineering degree at Melbourne University in 1984, a PhD in the control system design at Cambridge in 1988, and worked industrially with BHP Australia in engineering and research positions between 1980 and 1994. Dr McFarlane joined the Department of Engineering at Cambridge in 1995 where his work is focused in the areas of response and agility strategies for manufacturing businesses, distributed (holonic) factory automation and control, and integration of manufacturing information systems. He is particularly interested in the interface between production automation systems and manufacturing business processes.

Robin Koh
Doctoral Candidate, Research Assistant

Robin T. Koh is currently completing his Masters in Engineering at the Massachusetts Institute of Technology. He obtained his undergraduate degree in Industrial Engineering and Operations Research from the University of Massachusetts at Amherst and has a Masters in Business Administration from Dartmouth College. He has worked for over 15 years – the last 11 of which have been in the field of logistics and supply chain management. He has held operational, tactical and strategic supply chain positions at Hewlett-Packard, Pepsi-Cola International and Arrow Electronics.



Yun Y. Kang
PhD Candidate

Yun Kang's doctoral research at the Auto-ID Center involves design and control of supply chain management, with particular focus on the impact of automatic identification technology on today's supply chain. He has also closely worked with the sponsors in identifying the applications of automatic identification and developing business cases. Prior to joining the Auto-ID Center, Yun studied design theory for product and process development and its application in semiconductor photolithography machines. Yun received his Bachelors from The Cooper Union and Masters from MIT, both in mechanical engineering. He also has research experience in mathematical modeling, applied superconductivity, and automatic control systems.

Biography

Alia Ahmad Zaharudin
Research Assistant

Alia completed her Bachelors of Arts (Honours) and Masters in Engineering, both in Manufacturing Engineering, at Cambridge University in June 2001. Alia is at the Auto-ID Center for a brief stint as a research assistant. The main project scope is to look at new product-driven supply chain models, enabled by the advent of Intelligent Products and to a lesser degree, Internet Communication Technologies. Her analysis aims to cover both technical and organizational issues, including altered competitive position. In her spare time, Alia enjoys reading, listening to music and sampling exotic cuisine from various parts of the globe, preferably all at once.

Chien Yaw, Wong
PhD Candidate & Research Assistant

Chien Yaw is reading for his PhD at Cambridge University. He completed a Master of Manufacturing Engineering Degree at Cambridge University in July 2001. He has been involved with several automation control projects including Holonic Manufacturing System (HMS) and PLC programming. With the close collaboration between MIT and Cambridge University, he aims to integrate Auto-ID technology with HMS to enable a paradigm shift in the way things are manufactured in the future. He is also heavily involved in evaluating and analysing the benefit of adopting e-Manufacturing. In his free time, Chien Yaw enjoys playing the piano and listening to funky jazz.

Vivek Agarwal
Masters Candidate & Research Assistant

Vivek Agarwal completed a Bachelors and Masters in Manufacturing Engineering, graduating in June 2001. Vivek lives in India and did his primary schooling there from St.Xavier's, Calcutta and Mayo College, Ajmer. He then went to England for his A Levels and University education. As part of his studies at Cambridge, Vivek under took a 7-week long Project with the Auto-ID Center at MIT and has continued with the centre since graduation. His aim is to analyse the potential costs and benefits of Auto-ID for manufacturing companies in the consumer goods industry, and will be focusing on Unilever. In his free time Vivek enjoys playing sports such as Squash and Cricket.

WHITE PAPER

The Intelligent Product Driven Supply Chain

Contents

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1. INTRODUCTION

Supply chains are often beset with problems caused by the mismatch between material and information flow. The lack of timely and accurate information relating to order status, inventory levels or delivery times for example can introduce uncertainty and variability in a supply chain. One approach which is helping to alleviate such issues is the development being driven by the Auto-ID Centre[1] in establishing direct network connectivity between a physical product and its supporting information. The Auto-ID Centre is developing standards and network infrastructure enabling tagged products to be connected to real time product information over the Internet. Establishing such connectivity, and by coupling this information into existing business information systems, can immediately help to address inventory management issues such as stock outs, by reducing the amount of uncertainty around product and resource availability.

[1] www.autoidcenter.org

Extending this a step further, one of the keys to effective supply chain management is supply chain integration. A complete seamless integration of the supply chain enables real-time visibility of useful, digestible data in a collaborative manner, all across the supply chain. Approaches such as VMI, CRP, FRM, JIT, ECR, EDI, VAN or even CPFR are all methodologies for integrating aspects of the supply chain – enabling a company to work more closely with partners to identify improvements and address inefficiencies. By providing timely, accurate and complete item level data, Auto-ID technologies can provide critical support for complete supply chain integration.

However, equally or perhaps more importantly, Auto-ID systems provide the basic infrastructure for reconsideration of, and possibly alterations to, the supply chain. This is based on the observation that a physical product connected to a network – which itself links different aspects of the supply chain – can potentially assess and influence its own functions. That is, through this network connection, a product (or a set of products) can interact indirectly with those operations that it comes in contact with. We refer in this document to such products being **'intelligent'** in a loose sense and in this paper we introduce the concept of an **intelligent product** and consider its potential impact on the entire supply chain – i.e. the life-cycle of the product. In Section 2, by way of background, we overview the typical product life cycles of both a simple product and a more complex product, highlighting important issues and distinctions in their supply chains. The concept of an intelligent product is then proposed in Section 3, and it is argued that developments in the Auto-ID field and in the field of so called **software agents** provide a means for constructing intelligent products. Sections 4 and 5 then examine the types of supply chain functionalities and applications that might be developed using intelligent products as a basis. In this way, a range of potential application areas for Auto-ID systems in the product supply chain are identified.

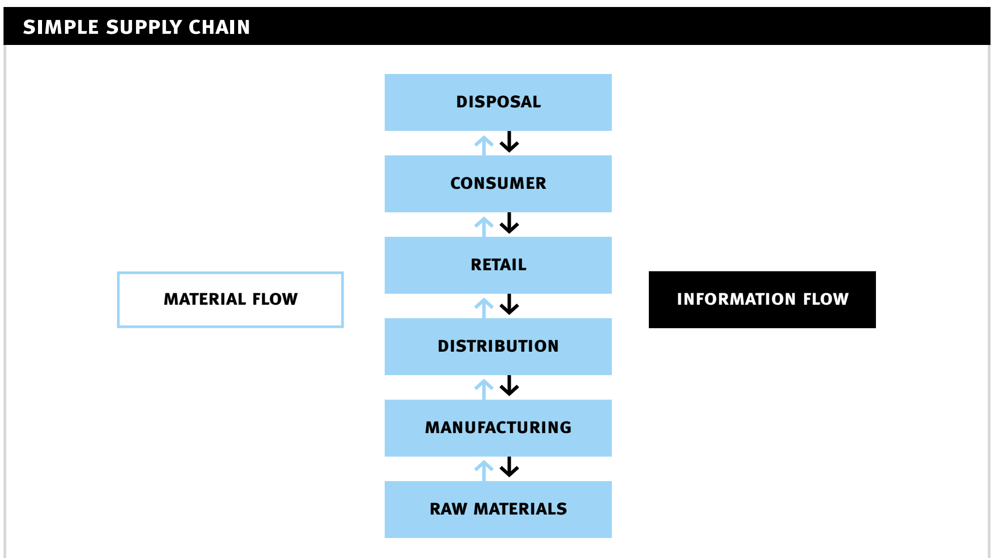
2. SIMPLE AND COMPLEX PRODUCT LIFECYCLES

This section models the typical product lifecycles (raw material to finished product to disposal) for a simple product and a complex product in order to understand conventional material flows and the information networks that support them. We do this in order to be able to distinguish between the type of Auto-ID applications each is likely to attract. In each case some of the current problems in managing the product flow are also identified, focusing in particular on areas where timely, accurate information is important.

2.1. Simple Product Lifecycle

A **simple** product in this paper is defined as one that has only a few constituent parts, with relatively straightforward processes for production, packaging and logistics, and with simple information and material flows. Typical examples include a jar of pasta sauce or a can of soft drink. The key issue here is management of the high volumes. As the products become more commoditised with time, the focus is on efficient replenishment and high resource utilisation (production lines, haulage trucks, warehouse storage space, retail shelf space) at each echelon.

Figure 1: Modelled simple product supply chain



Most demand information is sequential and linear along the simple product supply chain. Products are made-to-stock, with production volumes driven by demand forecasts, incorporating customer orders massaged with company sales targets. Retailers' orders are usually based on past consumer purchases and seasonality factors. They are also based on the amount of inventory on the shelves, in the back-of-store area and in their distribution centres. Poor visibility of inventory levels can lead to over- or under-ordering, both of which are detrimental in their own way. This situation is repeated upstream, between manufacturers and their suppliers.

Distribution is normally triggered by customer orders, based on inventory levels left in the warehouse or in the retail outlet, and expected sales levels. Planning and control for procurement, production and distribution functions are centralised within manufacture and retail echelons for 'global' i.e. echelon-wide optimisation.

Common practices necessary for tracking orders and inventory in the current environment include the following:

a. Retail level
– Electronic point-of-sale (EPOS) data as substitute for actual end consumer demand.
– Physical stock counts daily/ weekly to synchronise physical and perpetual inventory levels.

b. Warehouse level
– Systems checks at the pick-face introduced in sophisticated, automated warehouses, to increase the accuracy of systems.
– Physical stock counts monthly/ annually to synchronise physical and perpetual inventory levels.

c. Plant level
– Material consumption measured by back flushing MRP or ERP system. No visibility into WIP [2].
– Finished goods tracked at case/ pallet level only.

[2] Work-in-Progress

2.2. Complex Product Lifecycle

A complex product is meant to be one that has many constituent parts, each part manufactured to high precision backed-up by a level of research and development – for example a computer server, sports car, refrigerator, etc. These products are normally innovative products with less predictable demand. Material flow is complicated by the potential backward flow of material, due to product returns, reuse, etc.

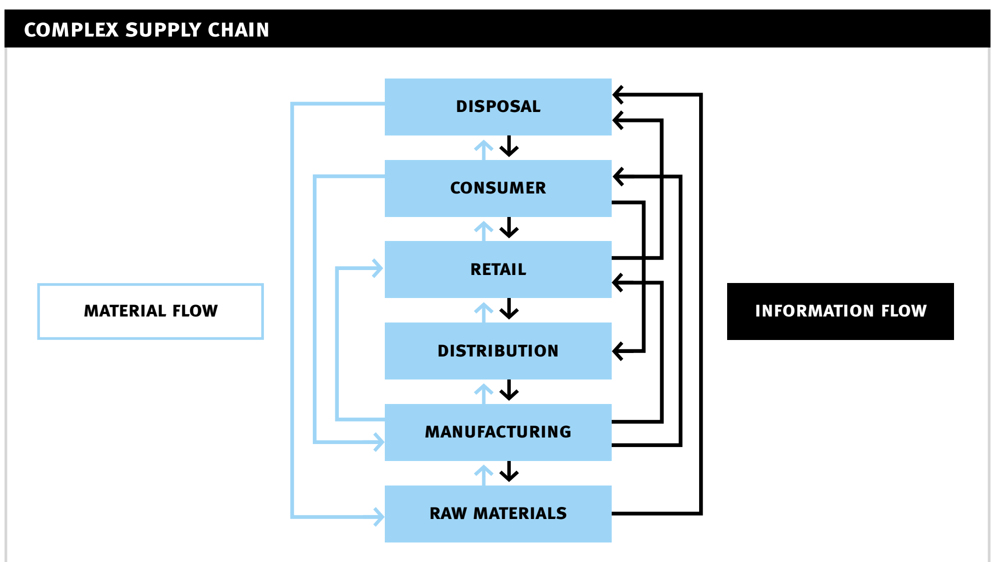


Figure 2: Modelled complex product supply chain

Information and product flow is more complex (less sequential) than for a simple product. The need for accurate and easily accessible databases at all echelons is extremely important. Consumer information is recorded and maintained, as it is vital to service levels. Note that this is not the case for simple products, where the end consumer is invisible to the manufacturer. Products are mostly made-to-order. Product allocation is carefully monitored, for which customer orders are entered into a central database to be allocated against a finished product, WIP or to trigger assembly.

Due to the expensive and performance critical nature of some components used in the end product, several components are bar-coded with SKU information, allowing these components to be traced. However, this information

– normally resides on multiple systems within and across echelons,
– is rarely updated across echelons, and
– is redundant once a component forms part of an end product.

Typically, a finished product will have a serial number giving it unique identity. However, information about this 'unique' product is not updated over the life of the product. At present, having a single data repository of product information within a company and across the supply chain is uncommon. Gathering information on a product is a long and tedious process. The product lifecycle is still open-looped in that:

– No record of components that form the end product is kept
– Products cannot be easily traced to customer (customer information changes, or product changes hands)
– Servicing of product requires information gathering across multiple systems
– Products rarely collected back for refurbishment and resale, or dismantled for part reuse or even disposal. No detailed material mix information for recycling.

3. INTELLIGENT PRODUCTS AND SUPPORTING TECHNOLOGIES

In this section we introduce the concept of an intelligent product as a key output from the Auto-ID system developments, and describe how it can be supported using the Auto-ID infrastructure developed to date in conjunction with so called **software agent** technologies. We note that much of this section has already appeared in other Auto-ID White Papers [3] but we include it here for completeness.

[3] The Intelligent Product concept is introduced in more detail in McFarlane, D, Auto-ID based Control – An Overview, Auto-ID Center White Paper, January, 2002

3.1. Intelligent Product

We use the concept of an intelligent product in this document to encapsulate the set of capabilities associated with a commercial product which is equipped with an Auto-ID system and some advanced software. The proposed definition of an intelligent product is one that has part or all of the following five characteristics:

1. Possesses a unique identity
2. Is capable of communicating effectively with its environment
3. Can retain or store data about itself
4. Deploys a language to display its features, production requirements etc.
5. Is capable of participating in or making decisions relevant to its own destiny

In the remainder of this paper, two clearly defined levels of product "intelligence" are proposed:

Level 1 product intelligence allows a product to communicate its status (form, composition, location, key features), i.e. it is information oriented. Level 1 essentially covers points 1 to 3 of the intelligent product definition above.

Level 2 product intelligence allows a product to assess and influence its function (e.g. self-distributing inventory and self-manufacturing inventory) in addition to communicating its status, i.e. it is decision oriented. Level 2 therefore covers points 1 through to 5 of the intelligent product definition above.

Implementing a Level 1 intelligent product is the current focus of the Auto-ID Project, and has the potential to bring benefits in the short-term (2 – 5 years), while there are numerous research challenges still to demonstrate that a Level 2 intelligent product is viable and hence the implementation of these systems may only be seen in the longer-term (5 – 10 years).

3.2. Auto-ID Technology

The Auto-ID project [4] is essentially improving the bridge between information networks (bits) and material flows (atoms) to form a seamless, synchronous network functioning as a product data repository. In order to achieve this, the project is developing

[4] www.autoidcenter.org

A Unique product identity described by an EPC (Electronic Product Code)
The EPC is currently a 96-bit numerical code embedded on memory chips – 'smart tags' that are attached to individual products and physical objects. Each individual product or object has a unique EPC., as shown in Figure 4.

Smart Tags and Flexible Readers
Each smart tag is scanned by a radio frequency 'reader', which transmits the product's embedded identity code to the Internet, where the real product information is kept. The tags itself do not retain any information other than the EPC. This minimises cost while not compromising on functionality.

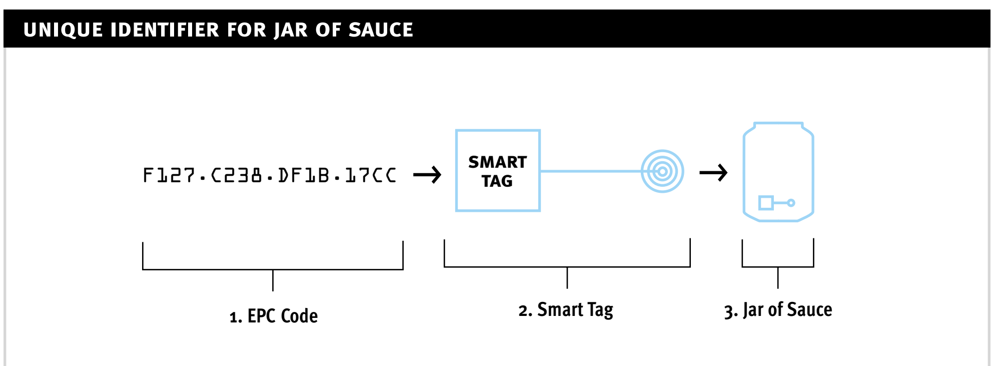


Figure 4: EPC as unique product identity

1. EPC Code
Unique Number 96 bits long

2. Smart Tag
Made from a microchip w/antenna – transmitting EPC code

3. Jar of Sauce
Typical Object becomes unique because of "Smart Tag"

A name server which directs queries to information linked to an EPC
The EPC acts as a pointer to a specific location on the Internet where product data is stored – it is analogous to a web address. An Object Naming Service routes queries to information about an object that carries an EPC code. The ONS is based in part on the Internet's existing Domain Naming Service (DNS), which routes 'addresses' to appropriate websites. This is shown in Figure 5.

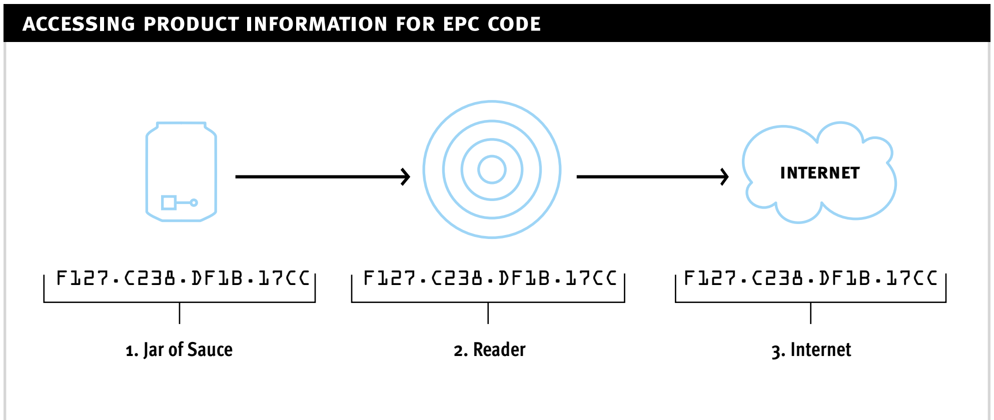
A Mark Up Language to describe Product features
Physical mark-up language (PML), is a new standard language for describing the Form, Fit and Function of Goods and Services to the Internet in the same way that Extensible Mark-Up Language (XML) is a language to describe data fields for Internet sites.

Figure 5: Accessing product information for EPC code

1. Jar of Sauce
Transmits EPC Code from embedded "Smart Tag" on side of jar.

2. Reader
Could be found in shelving, appliances, etc. Transmits EPC to internet

3. Internet
Translates EPC Code into useful information



Auto-ID technology will allow the Internet to extend to everyday objects, providing connectivity between product and information. The 96-bit numerical code has the capability of accounting for over 268 million manufacturers, each with over one million individual products. It is envisaged that the information will not be stored on the product to minimise tag costs. Rather, product information is stored on the Internet making it openly accessible by supply chain users at any point rather than only when scanning the tag.

The Auto-ID project promotes the concept of a single data source allowing access to information from any point in the supply chain, regardless of the system used. It leads toward the creation of a centralised system allowing information sharing. The utilisation of shared information can help in reducing the bullwhip effect by increasing trust levels, and can provide the network backbone for an integrated supply chain. This is discussed further in Section 6 of this paper.

In addition to the radio frequency identification methods (RFID) being pursued initially within the Auto-ID project, some alternative (line of sight) approaches are being developed for real-time data mining and access based on so called 2-D barcodes and UDEX [5]. 2-D barcodes provide higher data capacity than traditional barcodes, but product attributes are not described uniformly across or within echelons. UDEX and Auto-ID both provide a uniform description of product attributes. The additional functionality provided by Auto-ID is that tags do not require line-of-sight reading, have higher data capacity and the data can be updated (i.e. information is not static).

[5] www.udex.com – A single, Internet-based data repository for common product attributes, using bar-coding technology

3.3. Software Agents

A software agent is an interactive decision-making software module. The ability to make automated decisions has been developed by the intelligent agent research community. Software agent developments are more than fifteen years old, initiating from the artificial intelligence sections of computer science. Predominantly, they have been developed for programming parallel tasks in purely software environments as an alternative to a single problem solver – e.g. optimisation problems.

A suitable formal definition for a software agent is:

A distinct software process, which can reason independently, and can react to change induced upon it by other agents and its environment, and is able to cooperate with other agents.

Software agents provide the ability to address features 4 and 5 of the intelligent product definition discussed previously. Using the example of the jar of sauce, the tagged jar, through a local or remote network connection, is linked both to information stored about itself (in PML format) and to a software agent acting on its behalf, as shown in Figure 6[6].

[6] A clarification on Software agents and SCM applications: To avoid confusion for readers we emphasise that there is a distinction between software agents and supply chain management (SCM) software. Software agents are a programming tool, much like object oriented programming. SCM software represents solutions developed to solve particular applications. Software agents could potentially be used in future as a tool for developing SCM software. In the same way that many of today's SCM solutions are based on object-oriented methods, tomorrow's may be based on agent-oriented methods.

INTELLIGENT JAR OF SPAGHETTI SAUCE

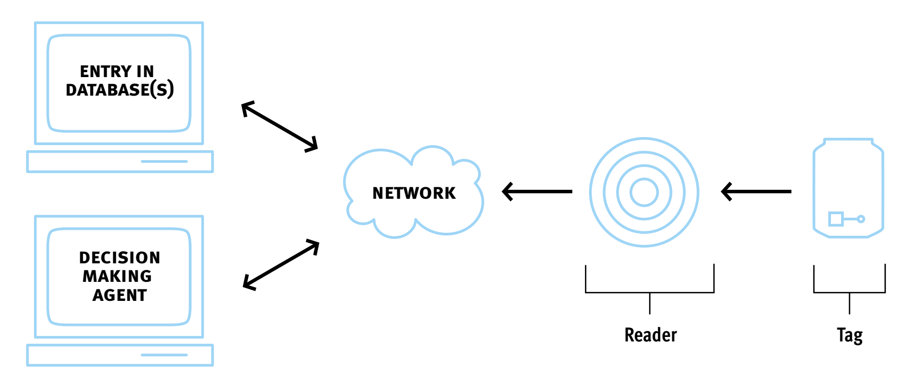


Figure 6: Intelligent jar of spaghetti sauce

Existing research in software agents has led to the development of expressive languages and algorithms for distributed decision making which will be applied in the context of embedding intelligent product capabilities into supply chain applications.

3.4. The Intelligent Product in the Supply Chain

The concept of an intelligent product is an extension of the basic Auto-ID concept. Coupled with software agents and control algorithms, an intelligent product is able to make automated decisions, providing a mechanism for delivering automated, distributed supply chain control. It is intended that such developments can lead to a more flexible supply chain environment, in which information can be aligned specifically with a set of products (i.e. a customer order) rather than with information systems of the particular organisation dealing with that order. This type of information structure supports outsourcing, the exploitation of dynamic distribution channels, non conventional approaches to storage and inventory management and numerous other response oriented ways of operating.

In the next two sections we begin to identify the type of functionality and typical applications that might be achieved with the intelligent product capability being afforded by the Auto-ID Center developments. We divide the analysis into applications for the two levels of product intelligence defined in Section 1, and hence in Section 4, we examine Auto-ID applications which are predominantly information oriented while in Section 5 we examine applications in which enhanced or changed decision making occurs via the introduction of intelligent products.

4. INFORMATION ORIENTED APPLICATIONS FOR INTELLIGENT PRODUCTS

In this section we examine the way in which the deployment of Auto-ID systems can enhance information collection and analysis across the supply chains of both simple and complex products. We are essentially considering the deployment of Level 1 Intelligent Products introduced in Section 1 and we now formally define this in the next section.

4.1. Definition – Level 1 Intelligent Product

A **level 1 intelligent product** is information oriented. It satisfies three characteristics, namely that the product

1. Possesses a unique identity
2. Is capable of communicating effectively with its environment
3. Can retain or store data about itself.

These capabilities can support functionalities such as product status updates (form, composition, location, key features), real time product tracking, and product history record. The development of a Level 1 intelligent product is already underway, is being tested in the field trials and has the potential to bring benefits in the short-term (2 – 5 years). This functionality is fully supported by the current developments in the Auto-ID project, although we note the need to understand the way in which this data can be best integrated into business information systems.

4.2. Functionality

Level 1 intelligent products, using Auto-ID technologies, can provide the functionalities as shown in Table 1. Each of these functions is purely an information enhancement function – improving information quality or timeliness compared with existing systems. The aim of the table is to provide a classification for potential functionalities – the method of deployment described in each case is indicative only.

Table 1: Functionalities of Intelligent Product (Level 1)

Continued next page

PRODUCTION	METHOD OF DEPLOYMENT	POTENTIAL APPLICATION
PRODUCT STATUS	Tagged product passes through reader. PML data repository for specific product EPC accessed. Reader can record and store information [7] about product in PML data files. Alternatively, PML data repository can be manually accessed and modified by authorised user.	– Automated, undisputable proof-of delivery visible across all echelons – Record of ingredient mix in food products for health warnings – Product costing at each stage along supply chain
PRODUCT TRACKING	Readers placed at start and end of a production line, on a distribution truck, on a storage shelf in warehouse etc. As an object enters, resides or exits the location, its timestamp [8] can be recorded by scanning the product.	– High-resolution product recall – Delivery lead time prediction in real time – Identification of bottlenecks and congestions

[7] Includes time, date, location and temperature at scanning; Ingredient/ Component mix and the corresponding EPCs; Packaging material information; Cost breakdown

[8] Part of the PML protocols that includes information such as time, date and location.

Continuation of Table 1

PRODUCTION	METHOD OF DEPLOYMENT	POTENTIAL APPLICATION
PRODUCT TRACKING	The object's progression through the supply chain can thus be mapped from the PML database. Locating the product right up to and including consumers is potentially feasible.	
PRODUCT HISTORY ACCESS	A user remotely keys in specific object EPC or scans product tag. PML database of the product can retrieve required historical information in a digestible format. Alternatively, a user can key in a product attribute (e.g. locate all objects that contain a specific batch of components). The product database is able to retrieve EPCs of products fitting the criteria and provide current product location.	– Product-based accounting where the product cost differs according to production/distribution routes – High resolution product recall – Authentication of product returns – Ability to adjust product warranty terms based on product usage – Accurate material information for product and component recycling/reuse

4.3. Lifecycle Applications

In Section 2 we outlined the different stages of the product life-cycle for both simple and complex products. An indication of the lifecycle applications of information oriented (level 1) intelligent products is given in Table 2, divided between simple and complex products. Two key differences to consider are a) the complexity involved in the manufacture of the complex product and the associated difficulties with quality control and b) the fact that the usage phase for complex products is significantly more demanding, where service support for some or all of the product life cycle is likely.

Table 2: Lifecycle Applications of Information Oriented (Level 1) Intelligent Products

Continued over

SUPPLY CHAIN ECHELONS	SIMPLE PRODUCT	COMPLEX PRODUCT
CONSUMER	– Detailed information about a product can be retrieved at a store or from home (through the Internet) – Advice or health warnings about usage of the product, potentially catered to individual profile – Accurate product recall information, if necessary	– Proof-of-purchase is on the product itself, along with any product warranty information – All data, including service information, is consolidated for better customer service and remote maintenance
RETAIL	– Improves on-shelf availability by triggering replenishment systems – High security enabled by product tracking; ability to predict theft by detecting sharp volume drop on shelf	– EPC data on returned product with tagged sub-components could be used to verify with original data – Unique customisation of product or service offering – Accurate tracking of any order in the supply chain, boosting customer confidence on service

Continuation of Table 2

SUPPLY CHAIN ECHELONS	SIMPLE PRODUCT	COMPLEX PRODUCT
RETAIL	– Product returns can be authenticated – Elimination of periodic physical stock counts as real-time accurate visibility of products	
DISTRIBUTION CENTRE/ WAREHOUSE	– Automated proof of delivery; no need for invoice adjustments – Improved accuracy of on-hand inventory due to automation – Locating a particular product could be done quickly with high precision – Extending FRM[9] to mass customisation with multiple retail clients each with different price tags	– Customised product with the same exterior appearance can be easily identified and sorted – Embedded tags are physically more robust in the hostile distribution environment – Lower insurance premium as anti-theft security is high[10]
MANU-FACTURER	– Identification of real-time bottlenecks to enhance high volume production – Visibility will provide the optimum configuration to move closer to JIT[11] production	– Quality check by reading EPC of sub-components within a product – Quality assurance levels can be traced back to the assembly line and specific assembly workers – WIP can be traced down to component level
END-OF-LIFE	– Product sorting based on product composition and history of use	– Full product history provides accountability when trying to meet increasingly strict legislation – Product refurbishment and part replacement are recorded, potentially improving resale value

9 Floor-Ready-Merchandise: Practice of delivering products straight to the store's shelf with security tagging and other accessories ready. Usually price tags are left out due to inaccessible retail IT system

10 Products entering or exiting entrance can be read, and products can be tracked

11 Just-In-Time

5. DECISION ORIENTED APPLICATIONS FOR INTELLIGENT PRODUCTS

In this section we examine the way in which the deployment of Auto-ID systems can enhance not only information collection but also the nature of decision making systems across the supply chains of both simple and complex products. We are now considering the deployment of Level 2 Intelligent Products introduced in Section 1 and we now formally define this in the next section.

5.1. Definition – Level 2 Intelligent Product

A level 2 intelligent product is decision oriented. It satisfies the full set of characteristics of the intelligent product, namely that the product

1. Possesses a unique identity
2. Is capable of communicating effectively with its environment

3. Can retain or store data about itself
4. Deploys a language to display its features, production requirements etc.
5. Is capable of participating in or making decisions relevant to its own destiny

It allows a product to assess, influence and possibly drive the operations it is involved in (e.g. self-distributing inventory, self-organising manufacturing operations, automated alarming systems). The full development and supply chain wide deployment of a Level 2 intelligent product will only be seen in the longer term (5 – 10 years), and requiring a radical change to supply chain configurations. This functionality needs to be supported by software agents in addition to the Auto-ID project.

5.2. Functionalities

The extension of an intelligent product to include decision-making capabilities can provide the functionalities of instructing resources. Table 3 provides classes of functionalities for an intelligent product directly involved in the decision making process, and indicates how these functionalities can be deployed and possible applications. Note that the functionalities listed are not exhaustive and are intended to highlight possible uses in the supply chain.

Table 3: Functionalities of Intelligent Product (Level 2)

Continued over

CLASS OF FUNCTIONALITY	METHOD OF DEPLOYMENT	POTENTIAL APPLICATION
PRODUCT STATUS	In the previous section, information updates were not used to adjust a product's **objectives**[12]. In this scenario, a product may itself adapt its objectives based on updates from its environment. For example, a carton of milk passing through a reader 'acquires' temperature information from the reader. In case of higher than optimal storage temperature, the carton of milk may bring forward its due-by-date.	– Dynamic pricing based on product lifecycle – Dynamic picking process for stock rotation – Dynamic product costing for rushed or reworked orders
OPTION ASSESSMENT AND NEGOTIATIONS	A resource being used to perform an operation on a product (e.g. picking machine, production line, delivery van, supermarket rollcage) can also be viewed as an intelligent product which is in its **usage** phase. Hence a product requiring transformation may negotiate with a resource via their respective software agents, where the product can choose a production and distribution 'route' that meets its criteria. In this context, a 'route' would cover process steps, beyond purely geographical routes.[13]	– Real-time delivery planning based on less congested traffic routes – Real-time delivery allocation in the event of a system disturbance (e.g. delay, breakdown)

[12] Due-by-date; Due delivery date; Product cost; Customer Prioritisation

[13] This is described in significantly more detail in McFarlane, D, **Auto-ID based Control – An Overview**, Auto-ID Center White Paper, January, 2002

Continuation of Table 3

[14] Vehicle delivering to stores/warehouses is then loaded with other products on the return journey

[15] Products are delivered straight to customers after being sorted in the distribution centre, bypassing warehouses.

CLASS OF FUNCTIONALITY	METHOD OF DEPLOYMENT	POTENTIAL APPLICATION
RESOURCE INSTRUCTIONS 1. Make	Product recipes specifying materials to be used and processing steps are stored over the network. This recipe can be downloaded straight to the PLC of a machining cell and production executed immediately. This allows parallel execution of customer order processing, designing, production planning and production.	– Flexible manufacturing capabilities can potentially reduce the cost and time barrier for mass customisation – Late changes to customer order can be more easily accommodated, improving customer service
2. Source	A product can trigger its replenishment based on pre-determined minimum inventory levels or even real-time customer demand based on accurate data information. This scenario is applicable in any supply chain echelon. For example, component re-ordering for production, or pasta sauce re-ordering by an intelligent refrigerator in the home.	– Self-maintained 'kanban' system in production/warehouse/retail/household environment – Different customers may 'bid' for the same product
3. Storage	Based on product status and product tracking, picking plan can be dynamically adjusted based on order prioritisation by the product. Dynamic adjustments may be necessary due to late in-coming delivery to the warehouse resulting in incomplete outgoing deliveries. An extension of that would be a picking sequence based on dynamic product due-by-date, a picking budget based on dynamic product costing.	– Self-organising inventory can adapt better to system disturbances – Self-organising inventory can lead to more accurate fulfilment of customer requirements
4. Distribute	Collaborative inventory management between different distribution centres and warehouses can provide visibility to optimise truckload on delivery. In the event of a delayed delivery, trucks may be rerouted in real-time (by the products transported) to a different set of customers, based on overall order prioritisation. This allows deliveries to meet sections of customers' orders rather than miss whole orders for some customers.	– Dynamic delivery allocation can reduce the number of late deliveries to reduce customer stockouts – Dynamic and optimisation of back-hauling [14] and cross-docking [15]

Continuation of Table 3

CLASS OF FUNCTIONALITY	METHOD OF DEPLOYMENT	POTENTIAL APPLICATION
RESOURCE INSTRUCTIONS 5. End-of-life	Detailed information about the constituent parts of an object can be obtained and downloaded to a sorting machine in a recycle/ reuse facility.	– Potential retrieval of reusable components, lowering material cost for new item.

5.3. Lifecycle Applications

Analogously to Section 4.3, we now provide an indication of the lifecycle applications of decision oriented (level 2) intelligent products, divided between simple and complex products.

Table 4: Lifecycle Applications of Decision Oriented (Level 2) Intelligent Products

Continued over

SUPPLY CHAIN ECHELONS	SIMPLE PRODUCT	COMPLEX PRODUCT
CONSUMER	– Automated cooking according to cooking requirements downloaded from PML database – Automatic re-ordering of products triggered by due-by-dates or low product counts (from the fridge, example)	– Consumer order can activate inventory search for desired product, triggering finished product movement, or make-to-order production – Possible remote prognosis and diagnosis of unique products (assuming self – monitoring capabilities) before a maintenance visit
RETAIL	– Advanced back-of-store or in-store replenishment system based on criteria such as shelf life, space etc. – Stock rotation based on dynamic due by-dates rather than LIFO[16] or FIFO[17] basis	– Better demand management possible through better marketing instruments[18] based on timely, accurate data – Synchronization between demand and production capability will maintain manufacturing OE[19] at the peak
DISTRIBUTION CENTRE/WARE HOUSE	– Automated updates on inventory systems – Optimisation based on physical space instead of product item number – Manual or automated mixed palleting is much easier	– Self-organizing distribution schedules – Small scale assembly hubs near customers will reduce customer waiting time, pushing the push-pull boundary[20]
MANU-FACTURER	– Improve outsourcing capability using readily usable manufacturing recipes that can be shared with partners – WIP products diverted to another production line can be manufactured quickly according to their product status, reducing system shocks	– Customer orders are exploded into its BOM and components are sourced on a real-time basis with the aim of minimising safety stock at buffer areas

16 Last-In-First-Out basis

17 First-In-First-Out basis

18 Pricing, promotion, placement

19 Operating Efficiencies

20 Boundary between assemble-to-stock and assemble-to-order

21 Bill-Of-Materials

Continuation of Table 4

SUPPLY CHAIN ECHELONS	SIMPLE PRODUCT	COMPLEX PRODUCT
MANU-FACTURER		– With connectivity to the marketing and design departments, quick changes based on customer response are possible, reducing stock loss during NPI [22] – Self-organizing production schedules
END-OF-LIFE	– Dismantling products into its core components with traceability and accountability all the way back to its manufacturer	– Product approaching its end-of-life can potentially trigger collection of itself – Disposal or refurbishment costs can be automatically allocated and debited to component manufacturers

[22] New Product Introduction

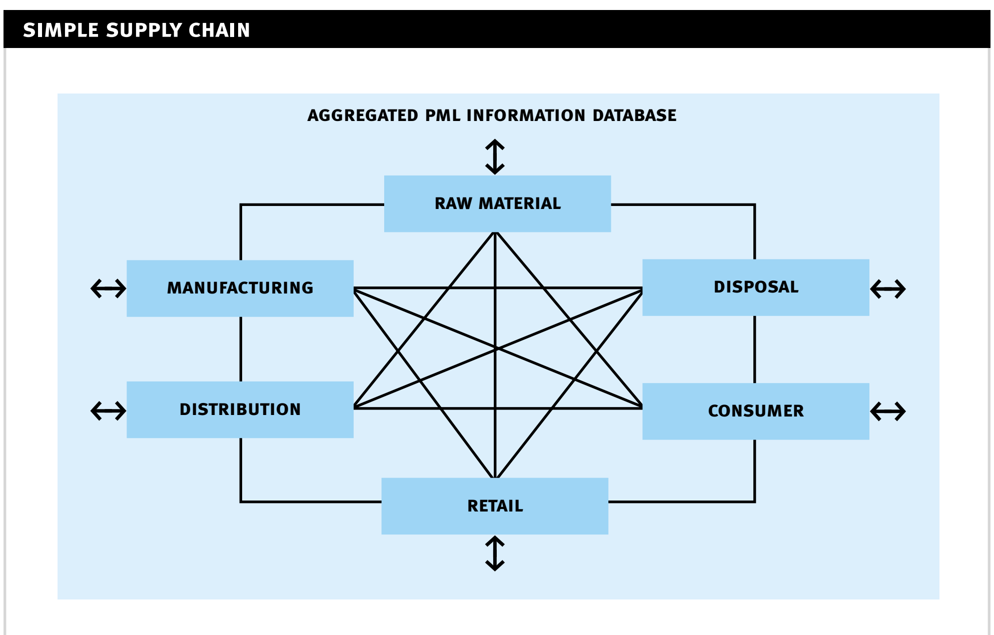
6. STRATEGIC REDESIGN OF SUPPLY CHAINS

The previous two sections have outlined how intelligent products at two levels (information oriented and decision oriented) can be deployed, and what potential applications they have in driving future supply chains. However, they have concentrated more on the operational and tactical levels of the supply chain. This section aims to introduce a more strategic flavour, motivating the reader to imagine the paradigm shift in future supply chains that is enabled by the concept of intelligent products.

Firstly, consider the creation of a single, open-standard, real-time data repository of product information. The result is a fully integrated supply chain as seen in Figure 8.

Figure 8: Fully Integrated Supply Chain

→ Information Flow
— Material Flow



Such a supply network enables the possibility of material flows across all echelons, supported by the relevant product information. As the aggregated PML information database is accessible by all the partners in the chain, product movement in all directions can be easily tracked, updated and processed appropriately. Such a highly distributed, Internet-based data management system could be quite successful. Having such an ideal, but realistically obtainable supply chain model has major implications towards the business model.

[23] Refer to D McFarlane, M Gregory, A Thorne, E Manufacturing in Japan, DTI OSTEMs Report, May, 2001

First, it enables a company to shift from selling a product to offering a service. Japan has been considering such a possibility for some time and clearly understood the implications and potential benefits [23]. Essentially, this development **extends** the effective supply chain to include service and maintenance of manufactured products. With such an extension, products no longer need to be sold individually, but are offered as monthly/ yearly (service) packages that include such services. The implications of such a business model on the information management system are huge, demanding multiple layers of processed information down to the information granularity of a unique single component within a unique product.

Secondly, it allows products to give up their static and inanimate image, becoming more dynamic and resourceful, collaborating with other products across different echelons. In much the same way that machines are getting smarter, so too can products. The intellectual property associated with a product – from design through its entire life cycle – also has a value and this is emphasised in the intelligent product model. Depending on the intelligence and global objectives of the supporting software agents, these intelligent products can create a pool of knowledge, teaching each other about what they have learnt. For example, a product downstream in the supply chain can share usage information, triggering requests by other products in the production stage to change their existing attributes. This could enable an effective NPI process that can quickly phase out product lines that are not gaining popularity. Similarly, a product experiencing traffic congestion during transportation could discourage other products from taking the same transport route. Intelligent products can create their own community to achieve local as well as global optimisation. System shocks and disturbances may not in future require panic-struck, slow and costly manual intervention.

Thirdly, it allows improved chances of success for any strategic collaboration between two organisations or business units. There are numerous examples of collaboration failures resulting from incompatibility between information technology systems. Current information technology systems do not have a common standard for data storage and data retrieval, not allowing “plug n play” capability. However, with Auto-ID technologies, this may change. It may allow improved collaboration and openness between organisations that do not pose a competitive threat to each other.

Fourthly, it allows incorporation of end-of-life handling of products – an issue of growing strategic importance. Recent legislations in Japan and some Scandinavian countries require strict controls over the disposal and recycling of manufactured products at the end of their useful life[23]. End-of-life consideration needs to be further incorporated into the design and production stages. Additionally, proper identification of components/ products is required to extract the information necessary for disposal. A central source of information, as enabled here, allows an accurate record of the full history of the component/ product to be maintained, together with necessary disposal information.

A fifth scenario is to minimise the physical material flow but maximise information flow from the order to the delivery cycle. By meeting customer demand with minimum physical material flow, inventory in the supply chain is minimal. The contribution to immediate cost savings is apparent, but there is more. What this does is reduce the level of the water, exposing the rocks beneath the surface. In less metaphoric terms, problems across the supply chain can be identified and corrected, which until now were hidden due to excess inventory acting as a safety buffer. By more closely matching actual demand to supply, the bullwhip effect could also be alleviated.

Although a supply chain can be very lean and efficient, if it is passive and unable to find an alternative route of delivery quickly, it will be susceptible to system shocks and disturbances. High amount of costly manual interventions are needed to pacify such events and yet finding the right solution is slow. With intelligent products however, a dynamic form of temporary supply route may exists for all or even part of the products life forming **product driven supply threads**. With the relevant authorisation, such intelligent products can communicate with other transportation supply routes, negotiate delivery costs based upon various possible mechanisms[24], and arrange for pick-up and delivery with minimal or at best no manual intervention. This is possible as trucks location can be monitored in real-time using satellite tracking. Information on truck space availability, products on hand, products routes and so forth can be obtained from PML database linked to the system. Such an IT platform can be developed, overarching Auto-ID technologies serving as base components. It will have a major impact on contemporary cross docking or backhauling practices by allowing multiple sources connection coupled with the availability of very accurate real time data. Possible characteristics for the success of such IT platform are ubiquitous, distributed software agents forming a system that are capable of collaboration and decision-making.

These were just a few ways in which the design and management of supply chains could be strategically altered in the future. It is important to note that these are not comprehensive. Fresh ideas are regularly conceptualised, and even some operational or tactical changes to supply chains could motivate strategic redesign.

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