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 is on track to 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 of 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.

Keywords: Supply Chain, Intelligent Product, Control, Auto-ID

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 (Lee et al, 1997). One approach which is helping to alleviate such issues is the developments 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.

However, equally or perhaps more importantly, Auto ID systems provide the basic infrastructure for reconsideration and possibly alterations of 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 they come 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, we define and distinguish the differences between simple and complex product, highlighting briefly 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 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. A more strategic view as a result of such Auto-ID enabled applications is discussed in Section 5 with the aim of reconsidering the conventional supply chain.

2. SIMPLE AND COMPLEX PRODUCT

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.

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.

3. INTELLIGENT PRODUCTS AND SUPPORTING TECHNOLOGIES

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

[1] www.autoidcenter.org

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. This has the potential to bring benefits in the short term (2-5 years).

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. This has the potential to bring benefits in the long term (5-10 years).

3.2 Auto-ID Technology

The Auto-ID Centre aims to improve the bridge between information networks (bits) and material flows (atoms) to form a seamless, synchronous network functioning as a product data repository.

Essentially, a unique product identity described by an Electronic Product Code (EPC) is transmitted from a tag when read by a tag reader. This EPC is used to locate information about the unique product as described in Physical Mark-up Language (PML). For more information about Auto-ID Technology, refer to Sarma et al (2000).

3.3 Software Agents

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 1.

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.

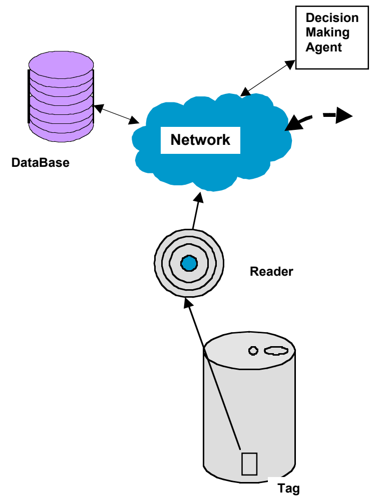

Figure 1: Intelligent jar of spaghetti sauce

Existing research in software agents has lead 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.

4. APPLICATIONS FOR INTELLIGENT PRODUCTS IN THE SUPPLY CHAIN

In this section we examine the way in which the deployment of Auto ID systems can enhance information collection and decision making systems across the supply chains of both simple and complex products. We 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 intelligent product applications discussion into *Functionalities* and *Lifecycle Applications.*

4.1 Functionalities

This section examines the different tasks or functions that the intelligent product is capable of performing. The method in which it can be deployed is then linked to potential applications.

4.1.1 Level 1 Intelligent Product

Figure 2 shows the method of deployment for each class of functionality shown. These use the availability of real-time product information as well as historical data to automate and authenticate conventional supply chain processes. For example, potential applications would include automated proof-of-delivery and process costing across all stages of the echelons, high-resolution product recall and real-time identification of bottlenecks and congestions. These applications could be extended to tie in with the financial information to enable *product-based accounting* whereby the cost of product differs according to the production and distribution routes. Accurate information about the product could also be used in component recycling and reuse. Ingredient mix in food products can be recorded for health warnings.

Class of functionality	Method of deployment
Product Status	Tagged product passes through reader. PML data repository for specific product EPC accessed. Reader can record and store information (e.g. time, date, temperature, cost) about product in PML data files.
Product tracking	Readers on 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 can be recorded by scanning the product. The object's progression through the supply chain can thus be mapped from the PML database.
Product history Access	A user remotely keys in an EPC or scans product tag. PML product database product can retrieve required historical information in a digestible format. The product database is able to retrieve EPCs of products fitting the criteria and provide product location.

Figure 2: Functionalities of Level 1 Intelligent Product

4.1.2 Level 2 Intelligent Product

This level of intelligence exploits the availability of real-time data to provide the opportunity to enable new processes and also control conventional supply chain processes in a much more effective way. The method in which it could be deployed is shown in Figure 3. Late changes to customer order can be more easily accommodated and costing for the rushed or reworked orders is possible down to the granularity of a single component. Since each product can be individually tailored to specifications, mass customization is potentially achievable. Customers could also "bid" for the same product in the supply chain creating a much more open marketplace.

Inventory can be self-organizing under disturbances and provide a more accurate fulfilment of customer requirements. Real-time planning based on traffic congestion information is also possible. Products can route itself and decide to aggregate or disaggregate with other products through cooperation or competition. Within a factory or warehouse, a self-maintained "kanban" system could trigger the appropriate human interface system by keeping track of the number of items in the tray.

Class of functionality	Method of deployment
Product Status	In this scenario, a product may itself adapt its objectives based on updates from its environment.
Option assessment and negotiations	A resource performing an operation on a product (e.g. picking machine, production line, delivery van, supermarket roll-cage) is also an intelligent product which is in its *usage* phase. Hence a product requiring transformation may negotiate 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 (McFarlane, 2002).
Resource Instructions ▪ Make	Product recipes specifying materials to be used and processing steps are stored over the network. This allows parallel execution of customer order processing, designing, production planning and production.
▪ Source	A product can trigger its replenishment based on pre-determined minimum inventory levels or even real-time customer demand.
▪ 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 various system disturbances.
▪ Distr-ibute	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.
▪ 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.

Figure 3: Functionalities of Level 2 Intelligent Product

4.2 *Lifecycle Applications*

In the previous section, discussion on the different types of functionalities can be generically applied across the supply chain. However, this section examines how intelligent product could potentially impact within each echelons of the supply chain. Within each level of intelligence, the discussion is divided into simple and complex product to distinguish between the types of Auto-ID applications that each is likely to attract.

4.2.1 Level 1 Intelligent Product

The applications of Level 1 intelligent product on simple and complex product are shown in Figure 4 and Figure 5 respectively. Essentially, whether it is simple or complex product, Level 1 intelligent product provides the opportunity for each echelon to improve its current processes.

Supply Chain Echelons	Simple 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
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 ▪ 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
Manufacturer	▪ Identification of real-time bottlenecks to enhance high volume production ▪ Visibility will provide the optimum configuration to move closer to Just-In-Time (JIT) production
End-Of-Life	▪ Product sorting based on product composition and history of use

Figure 4: Level 1 lifecycle applications for simple product

Supply Chain Echelons	Complex Product
Consumer	▪ 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	▪ 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
Distribution Centre/ Warehouse	▪ 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
Manufacturer	▪ 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	▪ Full product history provides accountability when trying to meet increasingly strict legislation ▪ Product refurbishment and part replacement are recorded, potentially improving resale value

Figure 5: Level 1 lifecycle applications for complex product

4.2.2 Level 2 Intelligent Product

The applications of Level 2 intelligent product on simple and complex product are shown in Figure 6 and Figure 7 respectively.

Supply Chain Echelons	Simple 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)
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 conventional methods
Distribution Centre/Warehouse	▪ Automated updates on inventory systems ▪ Optimisation based on physical space instead of product item number ▪ Manual or automated mixed palleting is much easier
Manufacturer	▪ 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
End-Of-Life	▪ Dismantling products into its core components with traceability and accountability all the way back to its manufacturer

Figure 6: Level 2 lifecycle applications for simple product

Level 2 intelligent product can alter conventional decision-making process to a much more sophisticated level that exploits the richness, timely and accurate product information. As the information is available real-time, decision making process at the operational level may change dynamically to optimize the system based on the most updated information.

5. STRATEGIC REDESIGN OF SUPPLY CHAINS

This section aims to introduce a more strategic flavour, extending previous operational and tactical discussion, motivating the reader to imagine the paradigm shift in future supply chains that is enabled by the concept of intelligent products. 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.

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. Having such an ideal, but realistically obtainable supply chain model has major implications towards the business model.

Supply Chain Echelons	Complex Product
Consumer	▪ 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	▪ Better demand management possible through better marketing instruments based on timely, accurate data ▪ Synchronization between demand and production capability will maintain manufacturing operating efficiency at the peak
Distribution Centre/Warehouse	▪ Self-organizing distribution schedules ▪ Small scale assembly hubs near customers will reduce customer waiting time, pushing the push-pull boundary (Boundary between assemble-to-stock and assemble-to-order)
Manufacturer	▪ Customer orders are exploded into its BOM (Bill of Materials) and components are sourced on a real-time basis with the aim of minimising safety stock at buffer areas ▪ With connectivity to the marketing and design departments, quick changes based on customer response are possible, reducing stock loss during NPI (New Product Introduction) ▪ Self-organizing production schedules
End-Of-Life	▪ 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

Figure 7: Level 2 lifecycle applications for complex product

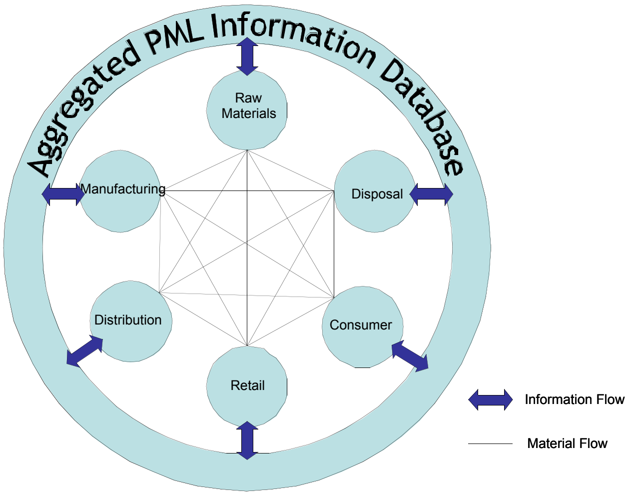

Figure 8: Fully Integrated Supply Chain

Firstly, 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. 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) package. 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. This also allows incorporation of end-of-life handling of products – an issue of growing strategic importance especially in Japan and some European countries (McFarlane et al, 2001).

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. 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 (Wong et al, 2001).

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.

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, 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.

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