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WHITE PAPER

Auto-ID in Materials Handling

Andrés García, Duncan McFarlane, Martyn Fletcher, Alan Thorne

AUTO-ID CENTRE INSTITUTE FOR MANUFACTURING, UNIVERSITY OF CAMBRIDGE, MILL LANE, CAMBRIDGE, CB2 1RX, UNITED KINGDOM

ABSTRACT

Materials Handling Systems (MHS) can be defined as "the set of all pieces of equipment that make possible the physical movement within the distribution chain – including the production chain and the warehouse – of raw material, work in progress and finished goods". Therefore, MATERIALS HANDLING SYSTEMS perform a wide range of activities. In general, Materials Handling refers to the necessary tasks to be performed in order to move a load around the factory floor as well as to store and freight it. Materials Handling takes place one way or another along all the links of the supply chain including production, distribution, storage and retail functions.

Auto-ID will open the way for new strategies, methods and solutions in Materials Handling. This paper highlights the impact that the introduction of this technology will have in various industrial Materials Handling Systems. The current limitations in Material Handling Systems are analyzed and some examples are presented to outline the ways in which Auto-ID can help tackling them.

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Biography

Andy Garcia
Senior Research Associate

Andy H. Garcia received his Ph.D. from the Polytechnic Univ. of Madrid as well as an MSc in Electronics and Automation Engineering. He also has an MSc in Mechanical Engineering from Cordoba Univ. (Spain). He has been an Assistant Professor at the Polytechnic Univ. of Madrid, where he also worked in close collaboration with companies such as: Dragados y Construcciones (one year based at one of their sites), Iberdrola, Menasa and more. He continued these collaborations while an Assistant Professor at Carlos III Univ., also in Madrid. After that he became a Projects Engineer at Thyssen Automation, setting up automated warehouses in Spain, South America and the UK, until he joined Castilla La Mancha Univ. (Spain) as Lecturer-Senior Lecturer in Industrial Engineering.

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.

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Biography

Alan Thorne
Laboratory Manager

Alan Thorne is the Program Manager for the Auto-ID Centre Lab at Cambridge University. Mr. Thorne graduated from Anglia Polytechnic University in Electronics and Control Systems and has a varied background in the field of Automation and Control. He has been involved in British Aerospace/IBM research projects as a systems engineer investigating flexible manufacturing systems on civil and military aircraft production. He has most recently been involved in projects relating to the development of novel AI-based control strategies.

Martyn Fletcher
Applications Specialist

Martyn Fletcher works as an Applications Specialist at the Cambridge Laboratory of Agent Oriented Software Ltd. He graduated from Liverpool University in 1991 and obtained his Ph.D. from Keele University in 1997 with a thesis on the application of software agents in telecommunications for increased flexibility. He has four years post-doctoral experience in the research and design of intelligent agent systems for holonic manufacturing. Dr Fletcher is responsible for both implementing JACK in systems at Cambridge University's IfM, and consulting on agent/holonic technology to manufacturing and defence projects. His research focuses on problems related to multi-agent and holonic systems, production planning/ scheduling, and inventory management.

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Auto-ID in Materials Handling

Contents

1. MATERIALS HANDLING SYSTEMS IN THE MANUFACTURING SUPPLY CHAIN

This paper reviews the current state of the art in industrial materials handling systems and examines the role that Auto-ID systems might take in addressing some of the current shortcomings. We will examine both near term, incremental improvements and some more revolutionary changes that will be enabled by ubiquitous Auto-ID systems. We begin by examining the scope of materials handling operations covered within this white paper. Materials Handling Systems (MHS) can be defined as "the set of all pieces of equipment that make possible the physical movement within the distribution chain – including the production chain and the warehouse – of raw material, work in progress and finished goods". Therefore MHS perform a wide range of activities. In general, Materials Handling refers to the necessary tasks to be performed in order to move a load around the factory floor as well as to store and freight it. It may be considered that Materials Handling takes place one way or another along all the links of the supply chain and of the production chain.

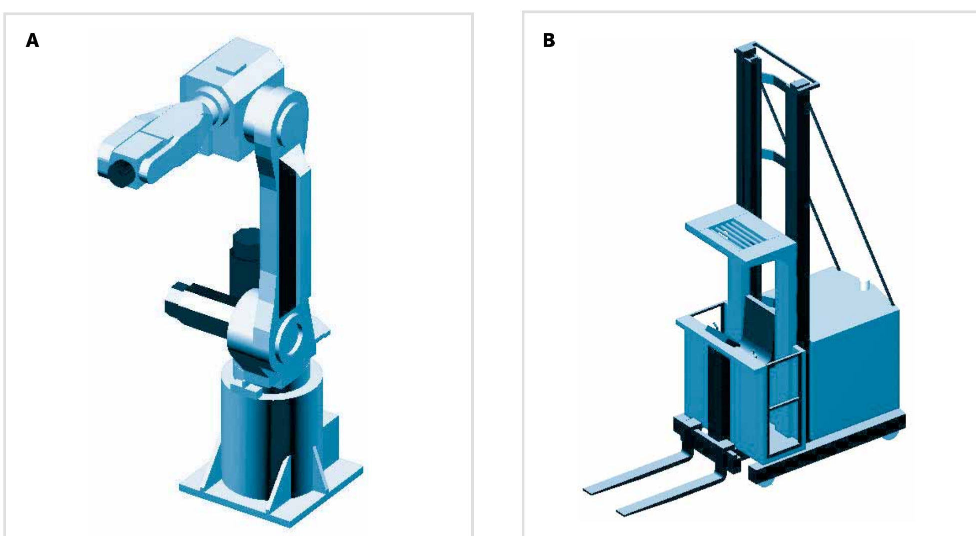
1.1. Key Physical Elements in Materials Handling

There are many elements and devices whose function can be referred to as 'handling'. The most representative categories in which they can be grouped can be listed as follows:

Transfer systems: there are different methods of transferring a load around the factory floor. These are typically relatively static devices like conveyor belts, rollers or chain tables. Transfer systems usually require the load to be placed on some kind of container (pallets/trays/touts), they require loading and unloading and can just move the load along fixed routes. For systems that generate movement, these are especially safe and reliable.

Cranes, Manipulators and Robots: (Figure 1a) these elements are characterised by their flexibility. This flexibility may be expressed in the area they can reach and/or the range of movements they can perform. They do not just take materials, products or tools from one place to another, but can also position them. They can also perform a wide range of operations such as the loading or unloading of transfer systems, vehicles and machines, as well as packing, picking and assembly. Along with their safety features, their complexity and price are often considered their more notable disadvantages.

Figure 1a & b: Handling Equipment



Vehicles: these go from Automatically Guided Vehicles (AGV's) to fork-lift trucks (Figure 1b). Vehicles in general are often used to carry a load long distance within a factory, and fork lift trucks are most common in dock areas. Their main advantage is the flexibility of their routes, and their main problems most often are safety, space limitations, traffic congestion and location error.

In today's fast changing industry, new materials handling technology is essential. However, it is sometimes hard to update the systems when they are heavily used, and it is not uncommon to find MHS that are not appropriate or that are not working in the conditions for which they were designed.

1.2. Key Issues for MHS

We now raise some specific issues of interest to help focus the problems that MHS are facing.

Maximising the productivity of the MHS solution selected
Maximum productivity is obtained in material handling through minimizing the number and complexity of handling operations. It is also desirable for all the movements to be as simple and automated as possible (e.g. using gravity whenever possible).

Matching MHS design Material Flow
It is important to carry out a detailed analysis in the design phase to decide:
- Between continuous or discrete flow of materials.
- Routing for all the moving elements, from materials to tools and equipment.
- Layout of the production cells.
- Production stages that avoid products moving between cells against the flow.

Handling affects the performance of the whole plant and it therefore has to be introduced into the cost calculation for alternative sequences and routings in production.

Reducing Handling equipment Investment
This equipment is usually expensive; it is important, therefore, to check alternative utilization possibilities for existing equipment before making new investments. An important drawback in the use of handling equipment is its setting up and the difficulty of utilization. However, it is possible to find easy-to-use handling equipment, provided that this requirement is specified in the design phase. Finally, emergency procedures need to be defined.

Greater Integration of MHS and Other Hardware and Software
To take advantage of all the possibilities that handling systems can offer, the systems need to incorporate information about their physical environment and the process in which they are instrumental. MHS need to be connected to sensing devices providing essential information for handling such as location or status of the cell in which they are integrated. This requirement is basic and is always met, but the importance of connecting handling equipment to a broader network and the plant management system has not traditionally been fully acknowledged. Data can be transferred using this link which can improve the efficiency of MHS, such as picking information, grasping points or even different sequences of tasks to be performed for movement of a specific product.

1.3. Trends in MHS

Developments in MHS are today leading to automated equipment and systems that move faster, accommodate greater throughput, and require less maintenance than those described above. Automated storage and retrieval systems (AS/RS), vertical lift modules and high-density storage systems all offer new twists on the storage/staging and order-picking productivity equation. So called, **Pick-to-light** systems, already widely used in the U.S. but not in Europe, are being implemented in unprecedented numbers. At the same time, high-speed sorting systems are becoming common.

There are also new developments in equipment and systems for moving inventory in both factories and Distribution Centres. Inductive-powered monorails that eliminate electrical contacts, reducing maintenance without sacrificing efficiency, are easy to find. Meanwhile, many of the world's largest lift truck suppliers make their case for improving efficiencies with AC-power.

New Warehouse Management Systems (WMS) are continuously appearing in the market, showing the high degree of requirement that modern warehouses are facing. MHS are beginning to give a response to the increasing need for bigger integration levels in this area.

2. PRODUCT IDENTIFICATION CHALLENGE FOR TODAY'S MHS

As stated before, integration is one of the key issues for modern MHS. It is possible to divide the current limitations that Material Handling Systems are facing in this field into two categories: physical restrictions and information visibility (Table 1). The first issue refers to problems that are associated with the hardware being used in Materials Handling Systems and to the identification technologies at hand. The second category has to do with the access to information from different points of the supply chain and, more specifically, by Materials Handling Systems. It also deals with the presence of relevant information for handling in the information system.

Table 1: Concerns in MHS

CONCERN AREAS IN MHS RELATED TO PRODUCT IDENTIFICATION	
PHYSICAL RESTRICTIONS ⟷	**INFORMATION VISIBILITY**
– Line of Sight	– Plant Management to upper level
– Accessibility	– Plant Management to MHS
– Speed	– Plant Management to Working Cell
– Reliability	– MHS – Working Cell

2.1. Physical Restrictions

The physical restrictions that are associated with the identification technologies being used are currently a major drawback for the automation of Materials Handling Systems. We focus specifically here on limitations associated with bar code reading as it is the dominant identification approach used today in MHS.

The barcode labels that identify a product can only be read when they are well placed in front of a reader; this becomes a very big problem for many applications. Conveyor belts and other transfer systems are strongly limited by this fact because:

– The bar code labels must always be at the side of the product where they can be read. This may mean in some cases that the product has to be rotated to put it into the right position for identification.
– The speed of conveyors is sometimes limited by the speed at which bar codes can be read.

It is also common to have similar problems with trolleys, cranes and lift trucks. If the label of a product is placed in such a way that it can be read when the product sits at its storage location, then it will probably become hidden when it is retrieved by any of these systems as the label will now face the inside of the vehicle.

In order to reduce the problem of location of the label it is frequent to find cases in which the products are multiply-labelled. This is convenient as it gives more flexibility to the way in which the product and the readers can be located. However, multiple labelling of products carries with it the big problem of introducing the possibility of mismatch between the different labels.

However, mismatches can happen everywhere. A big problem lies in the fact that the identification technologies used vary frequently between factories even within the same company. In any case, the only effective way to identify products as they come into a factory is by sticking a bar code label onto them at arrival, and this process is done manually in almost every case.

The identification technologies currently in practice are useful within a factory for many purposes but are rarely linked to the production processes.

It is common nowadays for a theoretically flexible production line to be dedicated to products that are all similar size and shapes. This is primarily because the different operations within the line will need intensive re-programming at many points as the product dimensions change. This is complex because there is no efficient way in which the individual operations can access specific and well structured information, regarding the way in which the different products have to be handled.

At this point, the information flow of the type that could be useful for Materials Handling Systems (e.g. grasping points for a product or its exact location within a pallet) is completely inexistent between factories. This leads to the second category of limitations of Materials Handling Systems.

2.2. Information Visibility

The increasing demand for real-time information at all stages of the supply chain has a huge limitation on the control systems that are being used in materials handling operations. These pragmatic requirements have been identified by a number of researchers (see Trebilcock, 2002 for an overview of the data requirements in modern MHS).

It will no longer be enough having control systems and software in place to direct the automated materials handling equipment, that move inventory through a facility. Just as important will be the ability to manage in real-time all information about the status of each item at all times.

Something similar is already happening in the area of supply chain management. Here, companies are beginning to integrate their business processes with those of their trading partners to take time, inventory and unpredictability out of the supply chain.

However, the movement of goods through the supply chain begins on the factory and warehouse floor. Warehouse management systems (WMS) already track steps in the process as they are completed.
The next step is tracking inventory between the steps within the facility, which in turn means monitoring the movement of inventory at the level of the conveyors, sorters, and palletizers (Forger, 2002).

The term that is being used for this new level of information and management is: **information-driven materials handling systems**. In the broadest sense, the term defines a seamless control and management system which is integrated from the machines to the WMS and transportation management system, and back to the enterprise information systems if necessary.

The three critical levels of a typical information-driven materials handling system are:

1. **Warehouse management systems** which receive orders from the enterprise and direct activities of associates and transporters;

2. **Materials handling control systems (MHCS)**, also known as warehouse control systems (WCS), which are execution software systems that direct the activities of powered materials handling equipment, and;

3. **Machine Control systems** such as programmable logic controllers (PLC) and PC-based controls at the machine level run motors, conveyor rollers, diverters, and switches.

What is critically different in the emerging systems is the role assumed by these components, and the level of integration between them. Today's systems are loosely coupled, resulting in information delays. In the future, they will have to be seamlessly integrated in real time.

Integration of the three levels of an information-driven materials handling system is a key to visibility. Although industry standards are in development, they remain a work in progress. Many providers still offer proprietary systems that require extensive customisation, in order to integrate with equipment, software and controls from competing vendors.

3. AUTO-ID SYSTEMS IN MHS

Auto-ID is an emerging technology that will change the world by merging bits and atoms together to form one seamless network that interacts with the real world in real time (Sarma et al., 2000). All the required information about specific products is stored in files written in Physical Mark-up Language (PML) that are kept in Internet Servers. An Electronic Product Code™ (EPC™) is embedded onto individual products and physical objects, on memory chips known as "smart tags", and this code allows the system to find the desired PML file over the internet.

It is important to highlight the impact that the introduction of Auto-ID technology will have in Materials Handling Systems. This study leads to a general and broad range of research topics with specific applications that cover every industrial sector. The research is done keeping in mind the most important areas in which Materials Handling Systems are especially relevant. Good examples of this are the Distribution Centres (big industrial warehouses) whose configuration and structure strongly affect the whole supply chain, and whose performance reaches back to the production line. This is even more true as they also take up the Work In Progress (WIP) buffers (which otherwise would lead to duplicate material handling technologies).

Besides those Distribution Centres, Materials Handling clearly covers all of the processes associated with the changes of location involved in moving the products around the production lines, and taking them to and from the storage places and the docks. Figure 2 shows the ways in which some areas within the supply chain interact with each other and highlights the importance of Auto-ID for enhancing that interaction.

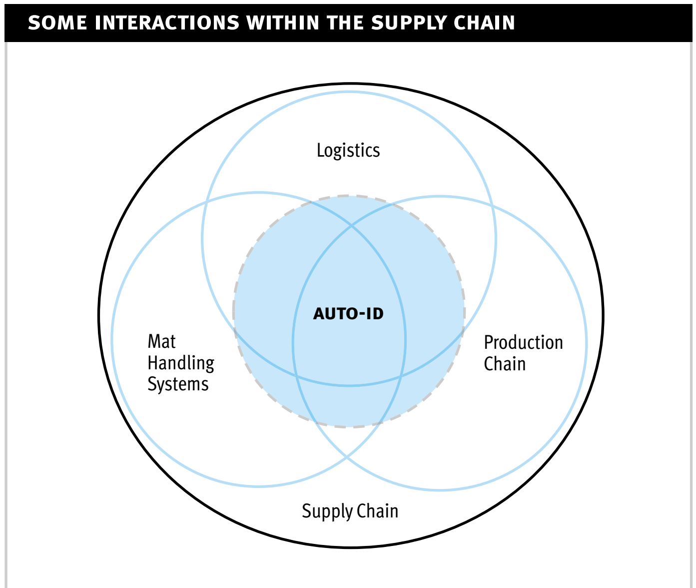


Figure 2

3.1. Addressing Integration Via Auto-ID

This section is dedicated to examining the way in which new possibilities for data collection and analysis due to the deployment of Auto-ID systems can enhance the performance of Materials Handling Systems (MHS). Figure 3 illustrates the evolution in Manufacturing that will happen due to the introduction of Auto-ID. The business case for deploying Auto-ID has been discussed (Alexander, et al., 2002).

The direct impact that such deployment of the basic Auto-ID technology will have in existing materials handling systems will be discussed below. After that, the concept of "Intelligent Products" will be introduced to analyze how it can combine with Auto-ID technology to generate a powerful new line of solutions for different aspects of MHS as well as for WMS and AS/RS.

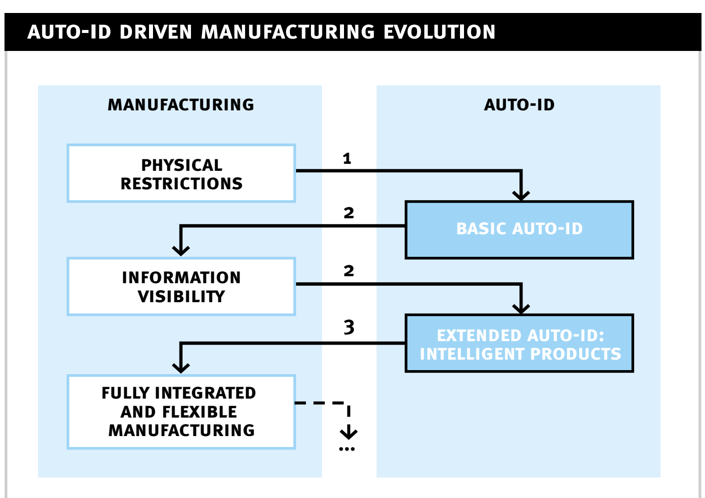


Figure 3: Evolution in Manufacturing due to the introduction of Auto-ID.

1. – Simultaneous reading
   – Reading range
   – No line of sight
2. – Simple and standardised database access/update
   – Unique identification
3. – Self organised operations
   – Distributed control

3.2. Basic Auto-ID Level (Level 1)

By Basic Auto-ID (Level 1) – see Wong et al, 2002 – we refer to the deployment of a suitable product identification approach in conjunction with PML based information relating to the identified product. We consider the impact of this type of system on MHS.

The ultimate objective of any MHS integrated into the supply chain is to meet customers' demand for guaranteed delivery of high quality, low cost, customized products with minimal lead-time.

To achieve this objective, companies need to have visibility into the entire supply chain of transaction and planning systems – of its own plans as well as those of its suppliers and customers. Also, the company should be flexible enough so that it can adjust, rebuild and re-optimize plans in real-time, to take care of unexpected events taking place in the supply chain. Such effective management of the supply chain as a whole, as well as within each participating supply chain company, depends on timely, reliable and accurate information, accompanying product and merchandise as it is sorted, stored, picked, transported and kept secure.

A point was made before about the ubiquity of MHS along the supply chain. Therefore, as Auto-ID technology will have a huge impact on all systems that help manage and plan supply chain operations, it will also affect specific MHS.

RFID tag based access to PML files will enable a continuous, accurate and real time information on products, providing an unprecedented level of visibility in the supply chain. Tags are also the keys that will provide access to the specific information on products, that is needed to handle them as this information will also have a place in the PML files.

Two of the most important issues that triggered the development of Auto-ID technology, are the ordering process and the backroom-to-shelf replenishment process. These processes are similar to those that can be found in every single manufacturing, storage, picking and packing cell, as all those cells need to be served and are in their turn serving others.

The ability to provide the necessary solutions lies in the ability to capture the behaviour of each SKU (Stock Keeping Unit) at each location through the use of Auto-ID technology. Readers can provide accurate data on shelf and backroom availability, as well as timing and location of incoming deliveries. Auto-ID based systems can then trigger an alarm to inform the store/plant personnel or automated systems of a re-ordering or replenishment that needs to take place.

In addition, the typical problem of "stock verification" has to be tackled. Products can simply be passed through tag readers and the stock verification can be automated, speeding up the process and eliminating manual effort. Automated operation also eliminates errors in scanning and labelling. The activity of taking stock checks can be eliminated, as the system can give continuous, accurate and real-time information on what you have, how much of it you have, and where you have it. The effort behind internal audits can be drastically reduced. The picking activity in warehouses could also be simplified through tagging, as pickers would not have to spend time specifying what they have picked. This becomes more relevant as more instances of the picking process can be automated due to the availability of more information, such as the exact location of each product within the pallet that can be stored in the PML files.

3.3. Extended Auto-ID: Intelligent Products (Level 2)

The deployment of Auto-ID technology can enhance not only information collection but also the nature of decision making systems. In Wong et al, 2002 and McFarlane, 2002 the concept of product intelligence was introduced, which couples the Auto-ID infrastructure (as per Level 1) with an intelligent software environment in order to support such decision making.

By connecting machines over a high-speed network and giving them access to databases with information on products, a two-way street of information between devices and products gets established. In that scenario, powered materials handling equipment like automated storage and retrieval systems (AS/RS), automatic guided vehicles (AGV's), robots and conveyors are no longer passively connected to a bus-bar or similar device awaiting instructions from another system as they are today. Instead they may potentially communicate peer-to-peer, or machine-to-machine, with the other automated devices in the facility. That means decision making can take place at the point where the work is occurring.

Consideration of that environment gives rise to the idea of "Intelligent Products". An Intelligent Product is decision-oriented and satisfies the following full set of characteristics, that the product (McFarlane, 2002):

– Possesses a unique identity.
– Is capable of communicating effectively with its environment.
– Can retain or store data about itself.
– Deploys a language to display its features, production requirements, etc.
– Is capable of participating in or making decisions relevant to its destiny. For instance, (Wong, et al., 2002) narrated how intelligent products could interact with service providers to ensure a smooth and timely movement of goods through the supply chain.

As described by (Overby, 2002), Auto-ID 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 picking operations).

4. THE IMPACT OF AUTO-ID ON SUPPLY CHAIN MHS

In this section some more examples are presented on what the deployment of Auto-ID technology might mean in some specific environments within the supply chain.

Production cells can benefit from the new and more powerful ways to identify products and access significant information in an automated way. MHS in warehouses and distribution centres, can easily enhance their performance by taking advantage of the new, standardised and more powerful methods for storing and accessing information on products.

Several reports have been written on how companies can benefit from the use of Auto-ID, as an enabling technology to support more intelligent automation, and control both in the factory and across their supply chains. For instance, (McFarlane, et al., 2001) discussed how flow shops can be adapted by intelligent software agents making distributed decisions. Meanwhile (Macchiaroli, et al., 2002) describes how agents (controlling factory resources in a job shop), can co-operatively schedule their activities. The information needed to make such decisions needs to be accurate, timely and structured in a suitable fashion – Auto-ID provides an infrastructure that supports these knowledge processing requirements in a scaleable and seamless manner.

4.1. Impact of Auto-ID Enhanced MHS in Production

The physical limitations of some production systems due to the specific needs of bar code identification have already been discussed here. With the new Auto-ID technology, the location of the tag within the pallet or product will not have any impact on the layout of the production cells. Also, bolting/turning of products in conveyors will not be required in order to identify them. In addition, there will be no need for multiple tags on a product and it will not be necessary to segregate products that are physically different due to barcode reading problems.

However, automated production cells will also have access to more relevant information for handling; these cells will become truly flexible, as they will automatically reprogram themselves to handle different products through the use of information, such as the size and shape of the product, grasping points and specific tasks to be performed in them. PML files can also contain pointers to specific programs for the different pieces of equipment in the cell. Therefore, those devices can automatically download the required program, on being notified by the Auto-ID software of the nature of the incoming product.

In linking Auto-ID with the concept of intelligent products, we get a most powerful tool for controlling production. A production cell in need of material can now contact the holon that is associated with that material/product, so that it will decide on how and from where the material can be obtained (Fletcher, et al., 2002). For example, as all the loading cells are busy, the resource holon will decide to acquire and transport a specific box of bolts to the cell, using a suitable AGV. The way in which that holon works is directly influenced by the information associated to each box of bolts – in PML format – that it gathers from the PML server and to the structure of that information.

Also, an order from a customer can be associated with one or more product holons, that will interact with the different resources within the factory, in order to fulfil that order in the most efficient way. And those orders can also be managed through PML files, which will allow automatic updating.

When it comes to assembly operations it will not be necessary to re-tag the aggregated product. It may well be possible in the future, to de-activate a tag so that the finished product will already have a unique tag. In any case it is quite easy to update the existing PML files associated with the tag or tags to reflect such aggregation.

4.2. Impact of Auto-ID Enhanced MHS in Warehouse/Distribution

With the use of Auto-ID technology, it will not be necessary to re-tag a product in order to reflect the specific needs of a warehouse or distribution centre; just the updating of the PML file associated with the existing tag, will be required. Therefore, all the handling operations required for re-tagging will be spared.

It will be possible to have information on the structure and content of a pallet reflected in the PML file associated with it. In this way, a palletising cell will be updating that same PML file as it is building the pallet. As a result, when it comes to unpacking, there will be a big reduction in the complexity of the automated localisation/identification systems, hence mixed pallets will become far easier to handle.

Intelligent sorting will become possible as much more information will be available on the existing products, their storage parameters and their locations.

Simple and handy ideas, such as to make sure that damaged containers are not reused (Tompkins, 1997), will become easy to implement. Stock-Check will become far easier and more reliable. For example, it will be possible to develop new solutions such as adding a “super-tag” to the pallets, that have a reader to check what is sitting on them, and power it so that it can retransmit all the information at a longer distance.

This leads to something very important: by tagging pallets it is possible to make tags and barcodes easily co-exist and co-operate.

With the push for smaller, more frequent deliveries, full-pallet shipments are almost non-existent for retailers, and the number of manufacturers using them (currently 40–60% of total cases shipped for customer products and less than 5% for retailers) is dwindling. Case level picking is fast becoming the method of necessity. So far this process is being performed manually in most cases, but picking will be one of the operations to benefit most from Auto-ID technology, as it will help identify the products to pick while eliminating errors and shrinkage. MHS can take advantage of all this to become more efficient, and be able to offer a fast and reliable way of performing picking.

At the docks, the habitual mistakes in loading and unloading trucks will be eliminated, while these tasks will also be dramatically speeded up.

4.3. Impact of Auto-ID Enhanced MHS in Retail

Retailers are engaged in a two-pronged strategy that is focused on their asset base. Firstly, they want to more closely align their products to the needs of their consumers. For stores, this increasingly means customising the product to suit every individual location. Secondly, retailers want to squeeze operating costs and inventory levels at all points in the value chain, to help drive their bottom line and overall competitiveness. High product availability at the retail shelf is critical to this part of the strategy, and is an important “heath check” to its effectiveness.

In order to achieve both points in this strategy, retailers are becoming more aware of the need for mixed pallets and last stage mass customisation. At present, they do not care how this is achieved by the distribution centres that supply them, but they are clearly driving those centres to make their MHS more flexible and dynamic (Park, et al., 2002).

So far, the introduction of automated MHS has not been a big concern for retailers. However, the ease with which mixed pallets and varied products can be handled, using Auto-ID in operations such as picking, sorting and packing, will most probably change this, as will the opportunity to have automated invoicing and verification when goods enter the store’s delivery area.

5. TOWARDS INTELLIGENT DISTRIBUTION

Auto-ID improves the transfer of information between systems, products and devices to a level yet unknown in the industry. The new and outstanding ease of communication combines with distributed systems, to generate an industrial environment in which the different elements can be understood as separate units. All these separate units will work together in a seamlessly integrated whole. This new approach will become essential, in a world with an exponential increase in complexity, coupled with a drive towards greater customisation.

5.1. From Mass Production to Mass Customisation

New marketing techniques, together with the progressive introduction of e-commerce, are generating a significant demand for customisation of product types and mixes, while delivery times need to be shortened. At the same time, it is becoming evident that the expected reduction in inventory levels due to the introduction of JIT (just in time) techniques, is not really happening.

While enhancements in the flexibility, and speed of the supply chain lead to significant stock reductions, companies are using this extra capacity to increase the range of their products. Hence there is an ongoing pressure to increase efficiency in storage, while still maintaining flexibility in the MHS feeding it.

5.2. Material Handling Systems at the Distribution Centre

Having more products with less stock of each one, puts a big strain in the manufacturing chain as well as in the warehouses, and as the range of products increases, as does the need to perform last minute changes. These changes may go from mixed pallets/packing, to product finishing with the introduction of the concept of generic products. Thus the operations to be performed at the warehouse are steadily increasing, while the product turn-round time experiences a big fall (Tompkins, 1997).

The only way to cope with this problem in the long term, will be to automate as many material handling operations as possible. Products will have to be automatically routed from storage to the finishing, picking and packing cells as well as to and from the docks. In the increasingly common situation in which the warehouse also takes work in progress and raw material, the problems of material handling automation and routing of the products in the distribution centre will become even more challenging.

5.3. Warehouse Management Systems (WMS)

Companies are now storing fewer products of each type but have more types of products to store. They require faster warehouses that can perform more operations. All this, together with the resulting expansion and complexity of the offer; means that storage becomes a bigger problem than ever. Proof of this is the fast expansion of companies that provide storage and logistics to others, the so called **"Third Part Logistics"**. The big success of this model in recent years, can be justified by the increasing level of complexity of the required Warehouse Management Systems needed.

The complexity of the operations to be performed at the distribution centre means that this model of third part logistics is not always enough. However, the market is already given an answer to this new situation, and some companies are now offering a model that is beginning to be known as **"Fourth Part Logistics"**. In this new model, and due to the complexity of the demand, companies provide not only storage and distribution capabilities, but also some tasks that have always been part of the production chain like packing, and even some finishing operations related to late customisation.

The most advanced examples of automated Materials Handling, can be found in many fully automated warehouses that are already, due to a lack of space in Europe, very common. However even in these environments, routing problems are common, and simple problems such as traffic jams and collisions between forklift trucks, can affect the most well organised of facilities.

5.4. "Holonic" Control at the Warehouse

Centralised solutions for controlling inventory within the scope of such agile environments, do not work since they are slow to react, impose operational bottlenecks and are a critical point of failure. The flexibility needed by the inventory management system must be tackled with a distributed control and so called distributed, intelligent – holonic – control solutions (introduced in the Auto-ID context in McFarlane, 2002) provide an approach that can support the requirements of systems as demanding as these.

The context for pragmatic investigation in this area is that a physical environment is provided, by the integration of a variety of factories with different attributes, which share some common functionalities. For example the multi-cell holonic demonstrator (Hodges, et al., 2002), being developed at the University of Cambridge's Institute for Manufacturing, provides a machining and assembly environment. Further applications in warehouse management have been suggested in Fletcher et al 2002. In the next section we consider the (hypothetical) application of holonic control, in conjunction with Auto-ID system in a warehouse environment.

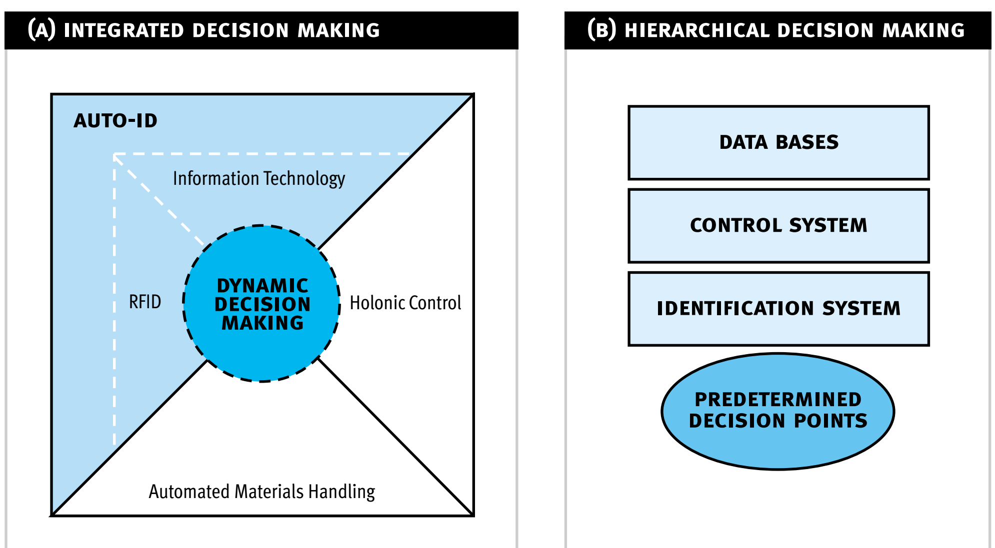
5.5. The Warehouse Routing Problem

The ultimate limitations of conventional control, and the lack of an adequate level of integration between physical and information systems in warehousing, can be seen in the specification of so called "routing decision points". At these points, the products/cases/pallets/touts are identified, and the data transferred to the control system that makes the appropriate decisions on the future location of the item. There is of course a powerful reason for the existence of these points, namely the accessibility, as manual intervention may be required when the identification technology is not completely reliable.

The existence of decision points is a serious drawback, because the status of the resources involved can change while the load is in transit (e.g. breakdowns and rush orders). The usual way of getting around this problem is adding extra buffers that can take the load routed, to a resource no longer available. But buffers, usually on conveyors, are a very inefficient way of storing goods.

However Auto-ID technology can be used in combination with a holonic control system to produce completely flexible, local, and efficient decision making (Figure 4). In the resulting **"Smart Warehouse"**, tracking is no longer necessary and the products are taken – rather than "routed" – from one point to another in the best way available at every instant. Less buffering is needed and the transfer systems can be shortened and simplified.

Figure 4: Control models for the warehouse (A) Auto-ID technologies combines with Holonic Control and Automated Materials Handling to provide integrated and powerful dynamic decision making; (B) Standard technologies rely on predetermined decision points.



Example:
An example to clarify the existence of concurrent buffering associated with decision points, can be seen in the inputs to automated warehouses. Figure 5 shows the input area to the shelves of a warehouse, with six corridors served by automated cranes. The incoming pallet is routed by a circuit of roller/chain tables that take it through a profile gate, to then be identified by a bar code reader. After that the pallet arrives to the decision point from where it is assigned to a specific location at a certain corridor. But if the pallet has not been properly identified, it is sent to a re-circulation loop where it can be rejected or the problem solved by manual intervention. Therefore, it is this loop that justifies having the decision point there.

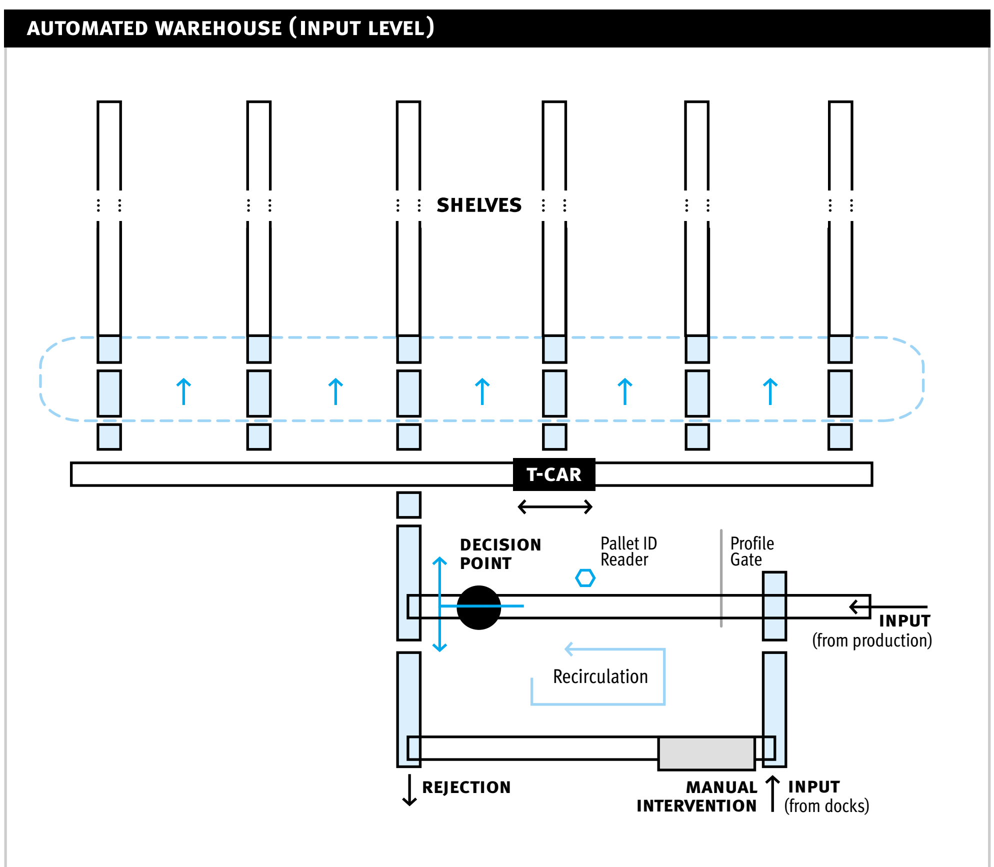
Once the pallet has been given a destination, it goes onto a T-Car (transfer car) that takes it to the incoming buffer for the specified corridor. The T-Car cannot have any problem or delay in downloading the pallet otherwise the whole system will get stuck. This is why there are buffers before each corridor.

Now, with a more reliable identification technology, the decisions can be taken when the pallet is already on the T-Car, and the actual status of each corridor can be considered on assigning the pallet location. With this simple solution, all the area taken by the buffers can be used to extend the shelves. For this example in which the shelves have the height for fifteen pallets, this simple solution would increase the capacity of the warehouse in:

$$Ec = Bs*C*S*H = 3*6*2*15 = 540 \text{ (pallets of extended capacity)}$$

where Ec stands for the extended capacity, Bs for the buffer size in pallets, C for the number of corridors, S for the sides in each corridor and H for the height of the shelves in pallet locations.

Figure 5: Example of the inputs area to an automated warehouse



6. CONCLUSIONS

Auto-ID represents a truly transformational technology with the ability to improve and potentially revolutionise materials handling system and their role in the supply chain.

MHS will have to adapt to these new technologies, and the increasing need for information visibility will compel them to do so even more. But there is no reason why MHS need just report information on what they are doing; this new world of available information endows MHS with that which they are most in need of: structured information.

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