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WHITE PAPER

Auto-ID Based Control

An Overview

Duncan McFarlane

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

ABSTRACT

The Auto-ID Center has to date focused on developing the essential infrastructure for dynamically extracting, networking and storing product data. These developments will help to revolutionise the accuracy, quality and timeliness of data acquired by Business Information Systems and should lead to major cost savings and performance improvements as a result. This white paper introduces an additional phase of Auto-ID research and development in which the nature of operational and business decisions is reconsidered in the light of the availability of ubiquitous, unique, item-level information. We refer to the decision making processes and the subsequent execution of these decisions as control systems. The white paper will motivate the reasons for a **control systems** research activity within the Auto-ID Project and will:

1. Indicate WHY the availability of ubiquitous, unique, item-level data can enable enhanced, and fundamentally different, control approaches and highlight potential benefits from control systems incorporating this Auto-ID data

2. Demonstrate WHAT is required to develop control systems based around the availability of Auto-ID data, and illustrate this using the example of a manufacturing control system

3. Outline the research challenges in determining HOW such systems will be developed

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Auto-ID Based Control

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Biography

by 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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Contents

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1. WHY CLOSE THE AUTO-ID LOOP?

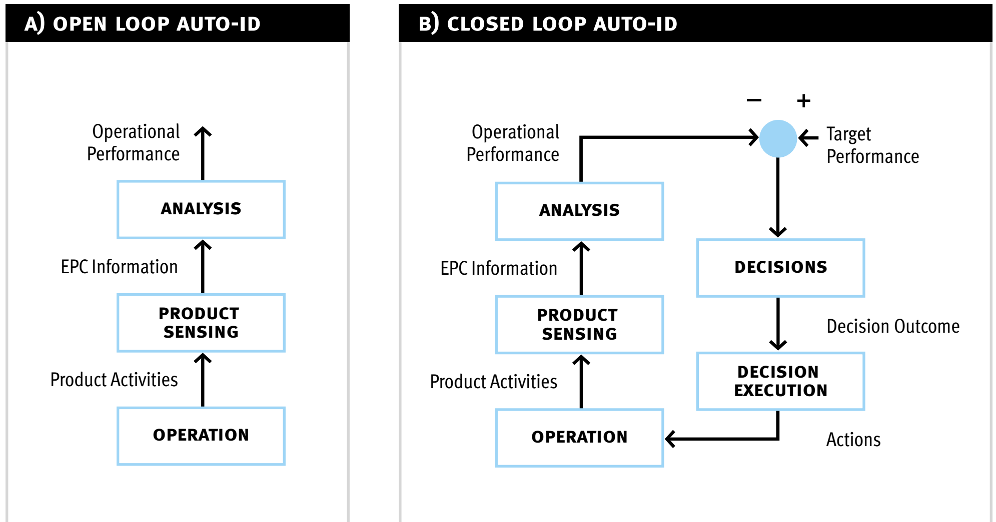
The aim of this white paper is to motivate the role of control systems in Auto-ID developments and to introduce a new control systems research activity in the Auto-ID project. In particular, we will contrast **information-oriented** (“open-loop”) Auto-ID based processes with control or **decision-oriented** (“closed-loop”) Auto-ID based processes. Requirements for the developments of the latter will be outlined and using the example of manufacturing control we will show that the availability of Auto-ID data can enable enhanced and fundamentally different ways of controlling production operations.

1.1. Motivation

Research at the Auto-ID Center has to date predominantly focused on building an infrastructure for the extraction, networking and storage of product data made available during the production, distribution, retail, usage or disposal of that product. We refer to the facility this provides as an “open loop” system (see Figure 1a) as Auto-ID information flowing from an operation is not used to influence the operation directly. In contrast, we provide the basis here for research into “closed loop” Auto-ID systems or Auto-ID based **control systems** – which considers decision making and actions taken on the basis of the availability of accurate, timely, unique item-level data – see Figure 1b.

The fundamental difference between the two diagrams is that implementing **open-loop** Auto-ID systems will provide benefits because of the increased accuracy, quality and timeliness of data within existing information management systems, while **closed-loop** Auto-ID systems implies changed decision making processes enabled by the availability of this accurate, timely, unique item-level data.

Figure 1: Open and Closed Loop Auto-ID Systems



In Table 1 we identify some typical open and closed loop applications for Auto-ID data that arise across a product life cycle (i.e. production, distribution, retail, usage or disposal). Note the difference between the information-oriented nature of the open-loop applications and the decision-oriented nature of the closed-loop ones.

Table 1: Typical Open and Closed Loop Applications of Auto-ID systems

	PRODUCTION	DISTRIBUTION	RETAIL	DOMESTIC
OPEN LOOP	Direct Tracking of items for multiple customer orders, quality monitoring	Monitoring of condition of produce, predicting order delivery time	Product sales monitoring, product condition monitoring – dynamic sell by dates, stock taking	Access to product instructions, home inventory, disposal sorting
CLOSED LOOP	Alteration of production sequence, product customisation, late order changes	Optimised truck utilisation, delivery of complex mix of products and customers	More accurate and predictive theft detection, higher levels of automated surveillance possible	Automated cooking of more complex food products, adaptive washing, cleaning, cooling operations

To further clarify the nature of the control systems we will be discussing in this paper, Table 2 then uses a number of typical applications to illustrate the key elements in the closed-loop Auto-ID diagram in Figure 1b.[1]

[1] For further details on potential applications of both open and closed loop Auto-ID systems across the supply chain see Zaharudin et al, Intelligent Product Driven Supply Chain, Auto-ID Center White Paper, January, (2002)

Table 2: Key Elements of Typical Closed-Loop Auto-ID Systems

	PRODUCTION	DISTRIBUTION	RETAIL	DOMESTIC
OPERATION	Control of assembly operation	Optimise distribution fleet	Theft management system	Synchronised appliance management
RESOURCES	Robots Machine tools Conveyors	Trucks	"Smart" shelves alarm systems Security services Surveillance cameras	Oven Microwave Fridge
PRODUCTS	Auto component	Consumer goods	Razor blades, perfume, batteries	Semi-prepared meal with several parts
PERFORMANCE GOALS	Low cost, on time production to order in small batches	Mixed pallet delivery of >70% of "use by" dates at lowest cost within delivery windows	100% detection, location and stop of item removal	Cook meal to required specification independent of starting conditions (temp, use by) and available resources
CONTROL DECISIONS	Frequency, sequences, timing, resources used	Truck fill, delivery schedule, routing	Removal rates, false alarm levels, theft diagnostic patterns, response mode	Resources needed, heating levels and timing, coordination of multiple components
CONTROL ACTIONS	Coordinate material flow with equipment	Load/Drive/Unload to specified sequence adjusting for conditions	Instigate in store response actions: alarms, security alerts, police notify, store shutdown	Instructions to person, execution of sequences on individual devices

We will define the way in which closed-loop Auto-ID systems work more closely in Section 2, but first we will briefly review the Auto-ID systems developed to date.

1.2. Background – Auto-ID Infrastructure Research

An overview of the ongoing research work in building a cost effective infrastructure for collecting Auto-ID data has been previously presented in Sarma[2] (2000) and on **www.autoidcenter.org** the key requirements for developing this infrastructure were outlined and important research challenges identified. Hence a brief summary only is provided here.

[2] S Sarma, (2000), Auto-ID Center Research Plan, Auto-ID Center White Paper, July, (2000)

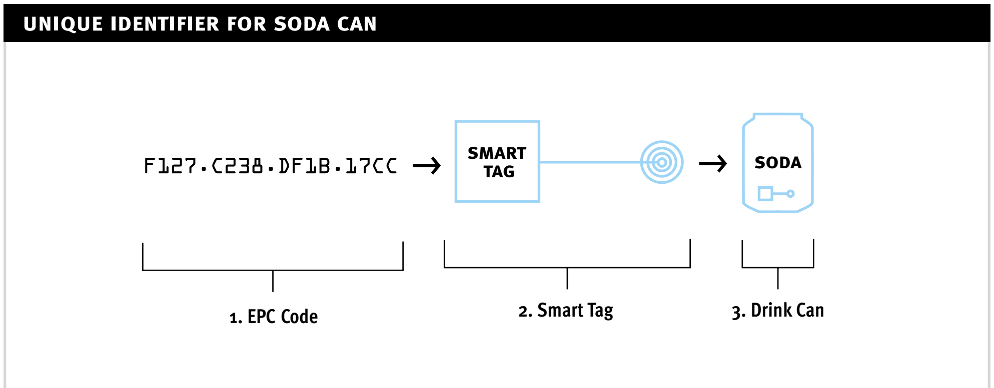
A 96-bit code of numbers called an **Electronic Product Code** (EPC) is embedded in a memory chip (smart tag) on individual products. Each smart tag is scanned by a wireless radio frequency "reader," which transmits the product's embedded identity code to the Internet using a software intermediary referred to as a **Savant**, where the "real" information on the product is kept. That information is then communicated back from the relevant data repository to provide whatever information is needed about that product.

Figure 2: Unique Identifier for Soda Can

1. EPC Code
Unique Number 96 bits long

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

3. Drink Can
Typical Object becomes unique because of "Smart Tag"



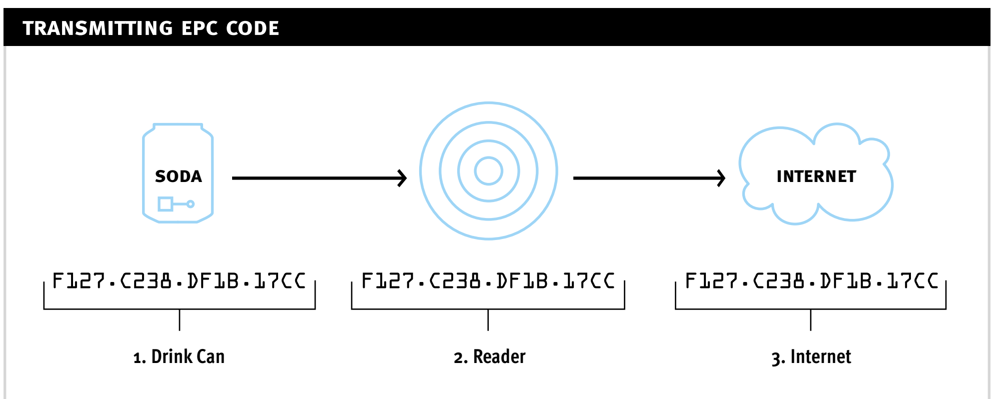
The EPC works together with a **Product Markup Language** (PML) and an **Object Naming Service** (ONS). PML is a new standard "language" for describing physical objects to the Internet in the same way that HyperText Markup Language (HTML) is the common language on which most Internet web sites are based. The ONS tells computer systems where to find information about any object that carries an EPC code, or smart tag. ONS is based in part on the Internet's existing Domain Name System (DNS), which routes information to appropriate web sites. The ONS will likely be many times larger than the DNS, serving as a lightening fast "post office" that locates data for every single one of trillions of objects carrying an EPC code.

Figure 3: Network Connection for Tagged Product

1. Drink Can
Transmits EPC Code from embedded "Smart Tag" on side of can

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

3. Internet
Translates EPC Code into useful information



1.3. Overview of the White Paper

Armed with these developments, we now have access to unique item level information in an accurate and timely manner. In the remainder of the paper we will introduce the concept of Auto-ID based control systems, in which this Auto-ID data can be used to enhance the way in which automated decisions are made and executed. An example from the manufacturing control domain will be used to illustrate the way in which Auto-ID information can enhance a control operation. A plan for Auto-ID based control research is presented in the final section.

2. WHAT IS AUTO-ID BASED CONTROL?

2.1. What is a Control System?

Before examining the role of Auto-ID in enhancing control systems, we will briefly explain what is meant by a control system and its scope in the context of this white paper.

A control system can be defined as:

> The process of adjusting appropriate variables in order to direct the performance of an operation towards a target level

A control system for a particular operation comprises the following basic features:

Sensing – measurement of information about the state of the operation (e.g. location, temperature, condition...)

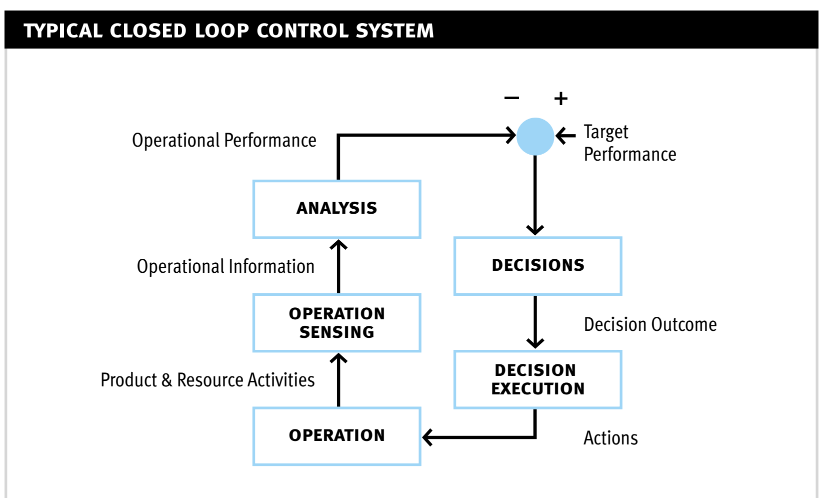
Decision – a process for determining suitable instructions for improving performance based on performance targets and current operational state

Action – the carrying out of the above instructions in a suitable manner

For example, a well known control system is a thermostatically controlled heating system, in which the a temperature **sensor** compares actual room temperature with the preset target temperature, and makes an automated **decision** as to how to adjust boiler gas flow, and the **action** of adjusting gas flow is performed via an automated valve.

Figure 4 provides a simple schematic for a typical control system which is referred to as **closed loop** because there is direct feedback of performance onto future decisions and their execution.

Figure 4: Typical (Closed Loop) Control System



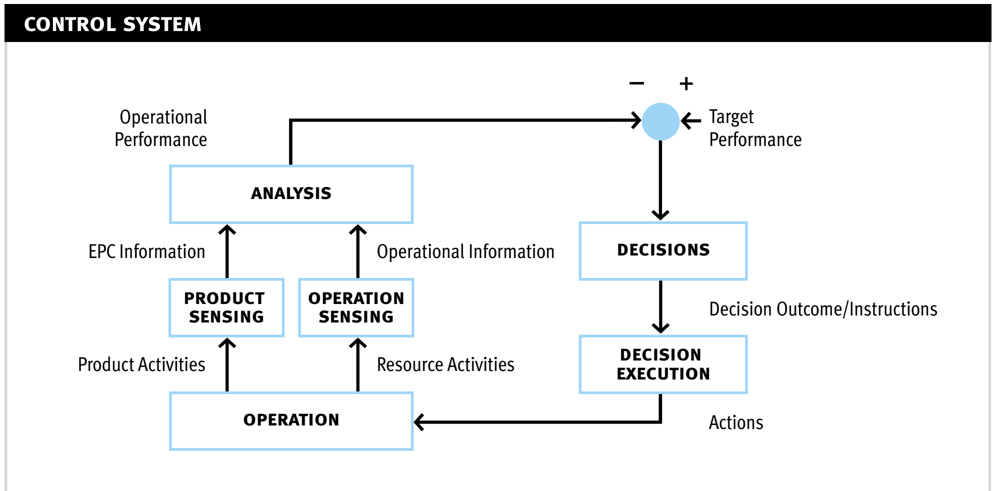
This description is broad and can cover a range of control situations of differing complexity and from different stages of the product supply chain. This closed loop diagram is equally valid, for example, in describing the long term production and stock building planning process for a consumer goods manufacturer or the temperature control of a domestic washing machine.

2.2. A Model for Auto-ID based Control Systems

In a conventional control system, sensed information is gathered from the different resources (machines, people, computing hardware) used to carry out the particular operation. Ideally this is automated and in most industrial situations, data is gathered through network connections between individual devices and computer systems. Auto-ID introduces the concept of a **networked product** as a **compliment** to these **networked resources** which enables ID information relating to each individual part or product involved in the operation to be gathered at the same time as other sensed data. Combining features of Figure 1a and Figure 4, Figure 5 depicts the way in which these different information sources might be combined in a closed loop control system [3].

[3] We note that prior to the development of Auto-ID systems it has only been possible to obtain product ID information through either complex automated tracking systems using inferred data or through manual recording. Neither are reliable, cost effective or scalable.

Figure 5: Control System Incorporating Product and Operational Data



In the following discussion, we will consider two distinct strategies for Closed Loop Auto-ID systems:

1. Conventional Control Enhanced by Auto-ID Data
– in which product ID data is used to simply improve the accuracy, timeliness, and hence quality of decisions and their effective execution.

2. Auto-ID Driven Control
– in which the availability of Auto-ID information forms the basis of a radically changed control approach

Each of these approaches will be examined separately in the following sections.

2.3. Conventional Control Enhanced by Auto-ID Data

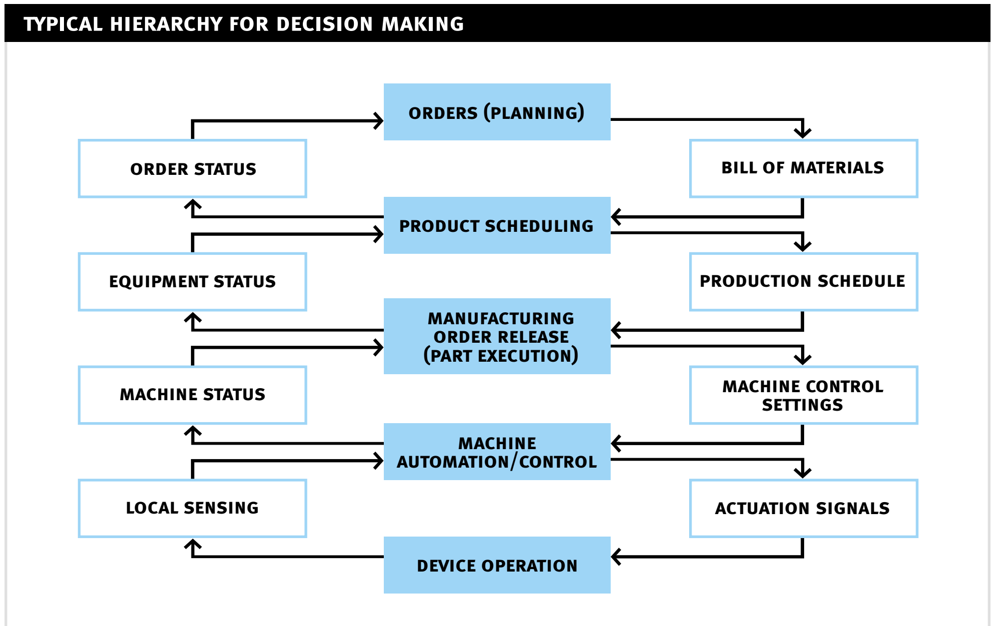
This approach is conceptually simple in that it predominantly involves the linking of Auto-ID data with **existing** commercial information and control systems [4]. It is likely that early inclusions of Auto-ID data into control systems will follow this approach. Unique, item-level data in individual or aggregate form provides an automated means of determining product presence and movement. Auto-ID data is therefore a **supplement** to existing sensed information provided directly from the operations. By way of illustration we next discuss the way in which Auto-ID data can enhance manufacturing control operations.

[4] Some typical commerical information and control systems are Enterprise Requirements Planning, Materials Requirements Planning, Manufacturing Execution Systems, Shop Floor Control Systems, Advanced Planning and Scheduling Systems and Supply Chain Management Systems.

Example – Auto-ID Enhanced Manufacturing Control

Figure 6 illustrates a typical hierarchy for decision making in a manufacturing control system. There are four successive control loops, each of which contains decision making, actions, operations and sensing. For example, in the top loop planning decisions lead to **actions** in terms of a bill of materials being generated, which drives the factory scheduling **operation** whose progress is **sensed** or monitored via order status information.

Figure 6: Conventional Manufacturing Control Hierarchy



In the planning and scheduling loops, the sensing is primarily intended as a means of approximately determining the status of a particular batch of products and a customer order respectively. **Order status** information is typically collected intermittently by manual or indirect means, and this sensing operation might be entirely replaced by the collection and analysis of **Auto-ID data from completed products**. **Equipment status** is only at best an indirect indicator of whether operations – and hence customer orders – are keeping to schedule or not, and such monitoring would be greatly improved by the availability of **product status information** which would unambiguously indicate successful completion of production batches. The introduction of timely, accurate and unique item-level information into these loops would greatly enhance the effectiveness of the current planning and scheduling functions. Additionally, Auto-ID information would significantly impact on the order release stage, for example, reducing unexpected delays due to unavailable parts and minimising the risk of incorrect order processing.

Because, this strategy is predominantly intended to work with existing control systems, the primary challenge for this approach is in determining exactly how to build the interfaces between existing information and control systems and an Auto-ID reader network with the supporting PML files for products that are read.

Simple Auto-ID enhancements of conventional control systems are likely to also provide a migration path for the more fundamental developments described next.

2.4. Auto-ID Driven Control

More profoundly, the availability of Auto-ID data provides an opportunity for a complete re-engineering of the way in which control systems are designed and operate. **We will define a class of control systems that can only operate effectively if and only if Auto-ID data is available.** In particular, the introduction of an Auto-ID system can radically alter the role of a product from a purely **passive** one to one in which a product – representing a section of a customer order – can **actively** influence its own production, distribution, storage, retail etc. We refer to this as an **intelligent product**, and we formalise the concept of an intelligent product with the following working definition:

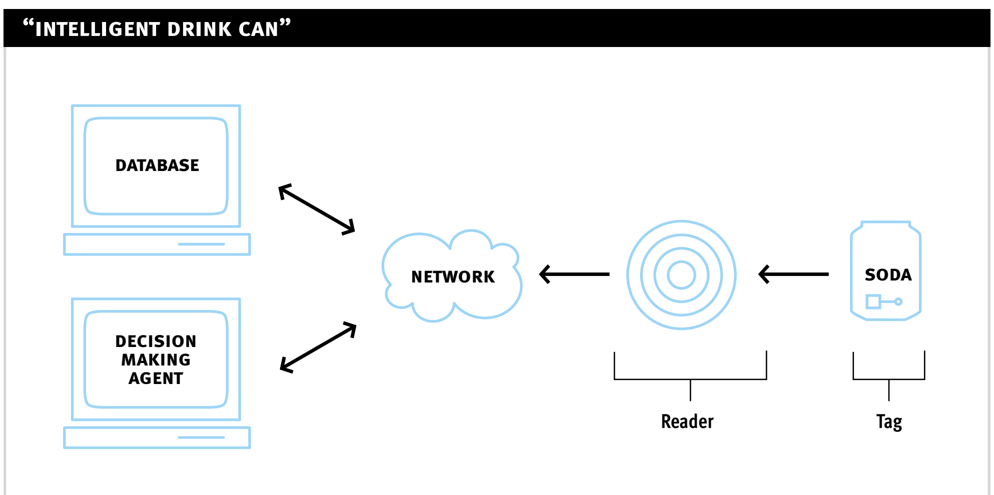
An intelligent product is a physical and information based representation of an item for retail which:

1. possesses a unique identification
2. is capable of communicating effectively with its environment
3. can retain or store data about itself
4. deploys a language which can articulate its features, production, usage, disposal requirements etc…
5. is capable of participating in or making decisions relevant to its own destiny on a continuous basis.

The corresponding **intelligent** product for a drink can is illustrated in Figure 7 in which the soda can is connected to a network and thus to both information stored about it and also to a **decision making (software) agent** acting on its behalf. The concept of a software agent is important to the following discussion and is defined as:

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.

Figure 7: "Intelligent Drink Can"!



Clearly the features of an intelligent product are an extension of the Auto-ID system outlined in Section 1b. Item (1) is provided by the EPC, Item (2) through appropriate tag, reader and network connections and Item (3) through the ability to store both current and historical data in PML format. In addition, to satisfy (4) the intelligent product must be equipped with suitable approaches for presenting information for describing itself and expressing its requirements (i.e. **recipes**). It must also be capable of managing automated decision processes that it may be involved in (5). Software agents as defined above provide one means of doing this.

The intelligent product forms the central construct for the approach to Auto-ID driven control system research under investigation [5], in which we are investigating a class of control systems in which the product to be made, delivered, sold or used – can influence – or even direct – the operations performed on it through **direct** interaction with the different resources available to carry out the operation [6].

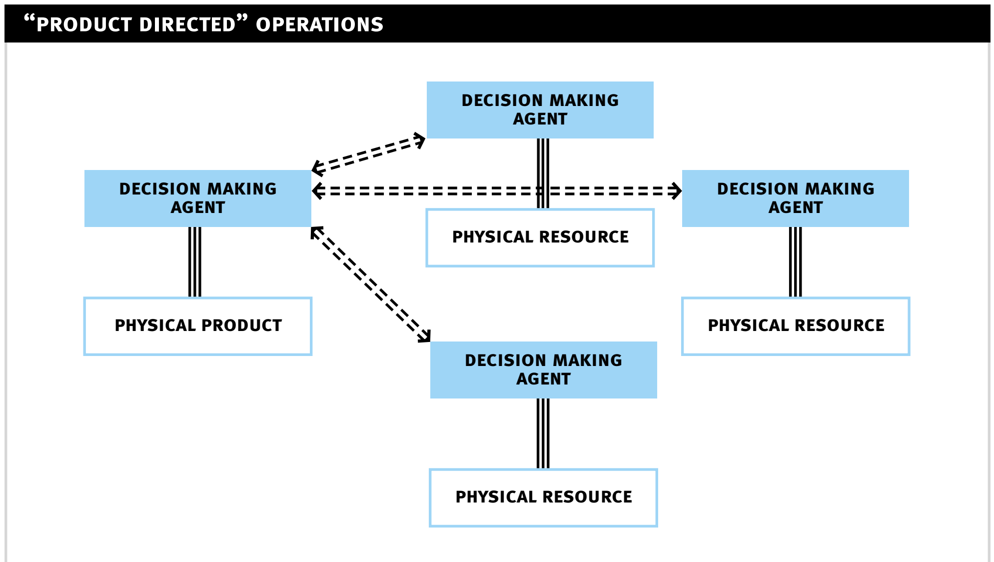
In these control systems, the physical resources – as well as products – are also connected to software agents, via a suitable communications network. These systems are generally referred to as **distributed, intelligent** control systems. They are **distributed**, because there is no single, central management of the decision making process driving the closed loop control and **intelligent**, because each of the distributed software agents is capable of interacting with other agents, reasoning and forming decisions. Hence the software agents representing a number of products communicate their requirements to the software agents representing the available resources, and – as per Figure 8 – a set of operations is negotiated, agreed on, then executed [7].

[5] It is worth emphasising that only through the availability of an Auto-ID system does an intelligent product become a reality.

[6] Although a slightly abstract notion, we note that the intelligent product is potentially capable of representing the customer's interest in whichever operation is being carried out. The software agent, can be thought of as an escort for the physical product.

[7] An important feature is that there is a one-to-one relationship between the decision-making elements and the physical systems carrying out the operations – much the same way as if a group of humans were negotiating and executing tasks.

Figure 8: "Product Directed" Operations



This class of control systems has the potential to provide for increased adaptability in the face of operation disruptions or reorganisations and promises to support the agile production, storage, distribution, retail and usage of rapidly customised products.

We next illustrate the role of Auto-ID driven control in the context of a manufacturing assembly operation:

Example – Auto-ID Driven Control of an Assembly Operation [8]

To illustrate the way in which an intelligent product driven manufacturing control system might operate, an assembly cell system has been adapted to reflect how Auto-ID capabilities might be integrated. The job of the robot assembly cell illustrated in Figure 9 is to complete the assembly of a simple electrical meter box. A robot arm is used to pick and place parts. A rotary table equipped with two jigs turns through 180 degrees swapping the position of each jig. A robot with screwdriver assembles together two separate parts in the jig. A flipper unit is utilised to hold a part and then flip it upside-down. Also, a software agent exists for each individual resource.

[8] For further details see J-L Chirn, D C. McFarlane, Building Holonic Systems in Today's Factories: A Migration Strategy, **JASS Special Issue on Holonic and Multi Agent Systems**, (2001) or D McFarlane, S Sarma, J-L Chirn, C Y Wong, K Ashton, The Intelligent Product In Manufacturing Control And Management, To Appear, **IFAC World Congress**, Barcelona, September, 2002.

LAYOUT OF SIMPLE ASSEMBLY OPERATION

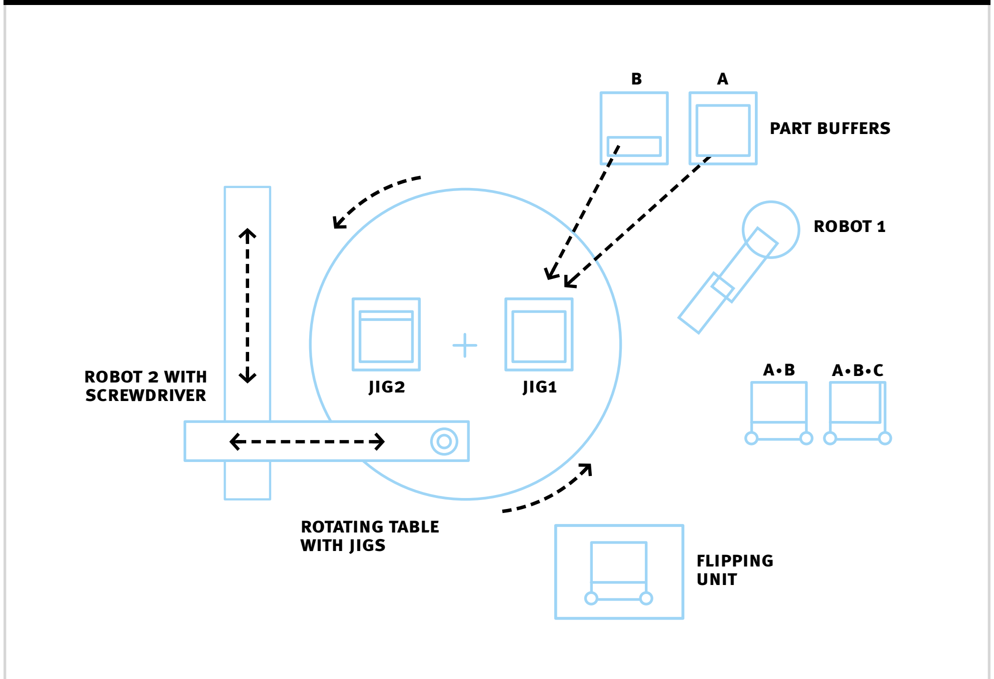


Figure 9: Layout of Simple Assembly Operation

Three kinds of components – Parts A, B, and C – are used to assemble the two kinds of products. One is **Product AB**, which is assembled from Parts A and B. Part A is the main housing of the meter box. Part B is a small access cover. Product AB is assembled by putting part B on top of part A and screwing B into A. The other product, referred to as **Product ABC**, is assembled by attaching a transparent plate to product AB. The screws attaching the transparent plate are fed in from the opposite side of the box to the single screw attaching the access cover. For this reason, it is necessary to flip Product AB during assembly using the flipper unit. Hence the two products require a different set of resources to perform their respective assembly needs.

We note that these two products can be considered to be **intelligent products** as through RF tagged components, each is able to access an information repository holding parametric data about the product and its production sequence. Additionally, a software agent resident on a networked PC exists for each product type, and in fact for each individual entity produced.

We emphasise that in carrying out assembly operations here, there is no predetermined schedule or control for this cell. In the Auto-ID enhanced environment, the customer order forms one or more intelligent products to manage the operation, which in turn generates product specification/recipe software, and in addition, tagged components required for the assembly are scanned and automatically synchronise with the intelligent product software which updates during production. Hence the components effectively **belong** to the customer from this point on.

Next, the product effectively drives its own manufacturing sequence via negotiation with production resources. Because of the Auto-ID system in place it is possible to track the product (and its sub components) through the different stages of assembly which makes reorganisation of production simple both in terms of the information & control systems and also the physical operations. In trials, the system has been shown to readily handle the following scenarios:

Multiple simultaneous orders – orders for two customers were produced simultaneously with near identical parts without any ambiguity in component identification or assignment

Quality error – a semi completed product was erroneously placed on the incoming components conveyor. The Auto-ID system detects from the order history that the product is part complete and rejects it from production

Real time customisation – a late order interrupt is received requesting a customisation to an AB product (adding Part C). The order profile is updated and the product holon negotiates additional resources to complete the revised assembly.

These simple descriptions illustrate the potential benefits of combining Auto-ID technology with advanced manufacturing control systems, and will fform the basis for the first closed-loop Auto-ID demonstrations under development.

3. HOW WILL AUTO-ID BASED CONTROL SYSTEMS BE DEVELOPED?

In this final section we will overview the proposed research activities in Auto-ID based control systems research. The aim of the control system research activity is to demonstrate, facilitate and encourage the development of control systems which directly benefit from the deployment of Auto-ID data. Although demonstration systems and position papers will be developed by the research team in the Auto-ID Center, it is important that partners in the Auto-ID project and members of the academic alliance also involve themselves in the area and that more generally the broader industrial and academic communities be aware of the potential impact of Auto-ID data on control systems.

3.1. Research Challenges

A number of clear research challenges must be addressed in the next 24 months in order to provide a clear path for the development and adoption of Auto-ID based control. We briefly overview some of these next:

Conventional Control Enhanced by Auto-ID Data

A core challenge for the Auto-ID control activity is that of obtaining product location information **simultaneously** with identification information. While open-loop (information oriented) approaches generally do not require specific location details, position data is vital to any closed loop control operation.

The remainder of the challenges in this category relate to the integration of Auto-ID systems with existing commercial information and control systems:

- Determining compatibility of data formats, data types, update frequencies etc with legacy environments (migration)
- Identifying hardware/software implications for existing commercial information and control systems wishing to adapt to include Auto-ID data
- Developing and implementing meaningful demonstrations which show the benefits that Auto-ID based control can provide

Auto-ID Driven Control

We divide the challenges associated with this strategy into 3 parts:

RECIPES/MACHINE INSTRUCTIONS
Here, we are seeking to specify one or more methods for describing the way in which recipes or machine instructions associated with individual products can be embedded within the existing Auto-ID system designs (e.g. within a PML based environment) while being readily accessible by control systems that are "Auto-ID friendly". Issues to be addressed include:

- Determining to what extent it is practical to specify generic recipe/machine instruction structures and formation
- Establishing compatibility with existing industrial recipe standards – such as the S88 standard in the process industries, or ensuring Rosetta Net compliance in electronics industries and with existing standards for data exchange such as STEP (Standard for the Exchange of Product Data).
- Ensuring that any developments are in line with existing PML specifications where possible
- Managing the interface between general product specifications (recipes) and instructions for specific machines.

AUTO-ID ENHANCED DECISION MAKING
Distributed, intelligent control systems have been developed academically over a number of years. The key challenges associated with delivering distributed decision making in an Auto-ID environment are:

- Determining appropriate decision making rules, and decision solving protocols for distributed decision making in an Auto-ID environment
- Developing guidelines for the effective embedding of Auto-ID information into a distributed control system
- Assessing the likely stability and performance of systems developed in this way

EXECUTION OF AUTO-ID ENHANCED DECISIONS
The execution of these decisions requires careful consideration of the best way to implement both control systems hardware and software and the physical operations themselves.
Effort is required in the following areas:

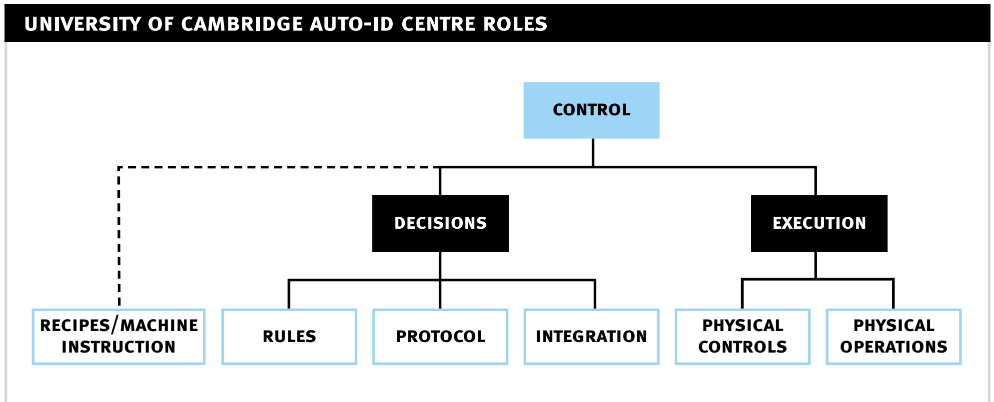
- Development of suitable demonstration environments which enable options for control systems hardware and software and different physical operations to be assessed
- Development of guidelines for specifying and implementing control systems hardware and software

In addition, there are a number of research issues specific to different application domains, such as those associated with the development of Auto-ID based manufacturing systems, routing systems for distribution, diagnostic systems (for maintenance, theft detection etc,) warehouse management solutions and domestic appliance control.

3.2. Research Structure

The control systems research activity within the Auto-ID project, reflects the nature of the research challenges, and will initially be structured as in Figure 10 although it is expected that this structure will be revised from time to time. (Recall that the Auto-ID Center currently has 5 such research activities: Hardware, Software, Languages, Control Systems and Applications.) The Recipes/Machine Instructions section is in fact part of the Languages Research activity, but we include it here for completeness as it is also integral to control systems research.

Figure 10: Auto-ID Control Systems Research Structure



The activities listed in Figure 10 are as defined as follows:

- **Recipes/Machine Instructions** – the specification of a set of parameters, tasks, sequences, decision points which describes a transformation of one of more products

- **Decisions** – the generation and resolution of issues encountered by auto-id based products in their manufacture, distribution, retail, use and disposal
  - **Rules** – Underlying criteria used to guide and resolve automated decisions which use Auto-ID and other information
  - **Protocol** – Mechanisms for managing distributed communications such that application of the rules can provide a distributed solution.
  - **Integration** – Alignment of auto-id based information with industrial decision making and information systems

- **Execution** – methodologies for the carrying out of auto-id based decision outcomes e.g. execution of schedules, inv. Management, distribution policies
  - **Physical Control** – Guidelines for the development and implementation of Auto-ID Driven Control System Hardware/Software, coupled with suitable demonstration.
  - **Physical Operations** – Guidelines for the design and operation of physical systems so that they best exploit advantages provided by auto-id capabilities

As a means of illustrating the results of these developments, A 3 phased demonstration system will also be developed within the Cambridge Laboratory:
- **Phase 1:** Simple Auto-ID driven packing and storage (conventional control)
- **Phase 2:** Intelligent Auto-ID driven packing and storage (enhanced control)
- **Phase 3:** Intelligent Auto-ID driven mini supply chain (enhanced control)

3.3. Deliverable & Timing

A provisional set of deliverable for the control research activity has been developed. Those to November 2002 should be seen as firm deliverable, while those beyond that date represent the current targets for development and outputs. These should be firmed during quarter 1, 2002.

The set of deliverable below have also been recorded in the European Auto-ID Centre Business Plan for 2002–2003 [9]. Figure – indicates the timing for these deliverables.

[9] H Duce, Executive Briefing: The University of Cambridge Auto-ID Centre from 2001–2003 – Going Global, Auto-ID Centre Report, February, 2002

Control Systems
a) A white paper scoping and rationalizing control systems will be presented in February 2002
b) A white paper on the Intelligent product driven supply chain will be presented in February 2002

Recipes/Machine Instructions
A white paper and software demonstration will be developed

Decisions – Rules & Protocol
A white paper and software demonstration will be developed (the latter to be incorporated into demonstration environment)

Decision – Integration
A White paper on methodologies for Integrating Auto-ID data into Information Systems is due in October 2002

Execution – Physical Control
A guideline white paper and software demonstration will be developed (the latter to be incorporated into demonstration environment)

Execution – Physical Operations
A guideline white paper and software demonstration will be developed (the latter to be incorporated into demonstration environment)

Demonstration
The 3 phased demonstration is timed for June 2002, November 2002 and June 2003 respectively.

In addition to these main deliverable, it is intended that separate documents internal to the Auto-ID Centre will be developed in 2002 [10] outlining more detailed plans for research in:

- Integrating Auto-ID data into business information and control systems
- Developing Auto-ID based control demonstrations
- Specifying appropriate recipe environments
- Determining appropriate decision making strategies

[10] These will be available to any sponsor on demand.

Figure 11: Control Systems Deliverable Plan – Including Demonstrations

WP: White Paper

	Q102	Q202	Q302	Q402	Q103	Q203
CONTROL SYSTEMS	Control Research WP Supply Chain WP					
RECIPES/ MACHINE INSTRUCTIONS			WP			
DECISIONS: RULES & PROTOCOL		WP		Software Specification		
DECISIONS: INTEGRATION				WP		
EXECUTION: PHYSICAL CONTROL						Guidelines WP
EXECUTION: PHYSICAL OPERATIONS:						Guidelines WP
DEMO PHASE 1	Simulation	Demo		WP		
DEMO PHASE 2			Simulation	Demo	WP	
DEMO PHASE 3				Simulation	Demo	WP

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