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WHITE PAPER

The Impact of Product Identity on Industrial Control
Part 1: "See More, Do More..."

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ABSTRACT

Sensing of the specific identity of products moving through the manufacturing supply chain is generally indirect. Typically such information is inferred from local proximity sensor readings coupled with appropriate computer based tracking models, which align these readings to the last known point of identity recognition. **Automated Identification** systems promise to address some of the limitations of these approaches by providing automated, item level, product identity information at any point in the supply chain. Technically speaking, the impact of product identity is to enhance the visibility or **observability** of the state of a production, storage, transportation and retail processes that a product is subject to during its life cycle. Enhanced observability means more accurate, timelier data and ultimately a greater scope for optimisation and customisation of the operation concerned. Hence the title **"See More, Do More..."** This paper examines the notion of observability, illustrates what it means for physical operations and outlines practical implications for industrial control systems. A materials handling example is used as an illustration. A second white paper will examine product identity and its impact on customisation.

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The Impact of Product Identity on Industrial Control Part 1: “See More, Do More...”

Biography

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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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1. INTRODUCTION

Direct product sensing is often replaced in industrial applications with inferred information, about product state derived indirectly from process conditions, and a suitable control strategy is executed on the basis of this information. Temperature, location and pressure are commonly used process indicators used to infer product properties.

The focus of this paper is to introduce the notion of the direct sensing of product identity within the manufacturing supply chain. Direct product identity sensing (or **automated identification**) involves the automated, timely recording of an identity record for a particular product. Coupled with suitable location information, this record can enable actions to be taken which are specifically relevant to the item in question. The specific aim of the paper is to examine the impact of product identity information, on the observability of the underlying processing operation and in particular, the improvement of the fidelity of observations made, and the subsequent control actions taken. In the case of an automotive plant for example, automated identification enables individual cars to be tracked throughout their production life, and for production control actions to be made specific to their individual order requirement. This white paper provides a conceptual overview to the issue of observability and its uses. It is noted that a more theoretical development of these issues is given in McFarlane, (2002).

In the next section, the concept of automated identification is defined formally and the main features of Auto-ID systems are overviewed. In the following section, the link between Auto-ID Systems and industrial control systems is examined and we illustrate **where** Auto-ID can enhance typical sensing arrangements in these systems. Then, in order to understand **how** Auto-ID information can enhance sensing in industrial control systems, we then define what is meant by observability and then use a simple example to demonstrate the way in which Auto-ID information can enhance a processes observability. Finally, we discuss the benefits of increased observability and comment on the way in which such information can be used in the design and operation of industrial systems.

2. AUTOMATED IDENTIFICATION (AUTO-ID) SYSTEMS

2.1. Introduction

Monitoring of the specific identity of products moving through the manufacturing supply chain is typically indirect. Such information is inferred from local proximity data, coupled with appropriate computer based tracking models which align this data to the last known point of identity recognition. Often this identity recognition process involves a manual inspection or a bar code scan – also often manually taken. The limitations in using such systems, as a means of tracking individual items during their life cycle are:

- There are significant inaccuracies associated with the initial product identification process, which become exacerbated as the product evolves over time.
- The identification processes are cumbersome and difficult to fully automate in a timely manner.
- Typically, the identification processes identify – at best – product type but not in fact the unique identity of the product in question.

This leads to the concept of so called **automated identification** systems which for the purposes of this paper can be defined:

Definition [Automated Identification]
Automated identification involves the automated extraction of the identity of an object.

We note that this definition is entirely independent of the method used to extract the identity from the object. The discussions in this paper primarily centre on the assumption that product identity is available. We will also implicitly make the assumption that some form of product location information is also concurrently available, so that the location of the uniquely identified object can be determined. (This is in fact the subject of another ongoing research programme at the Auto-ID Centre and is discussed in Haller, 2002)

2.2. Auto-ID Systems

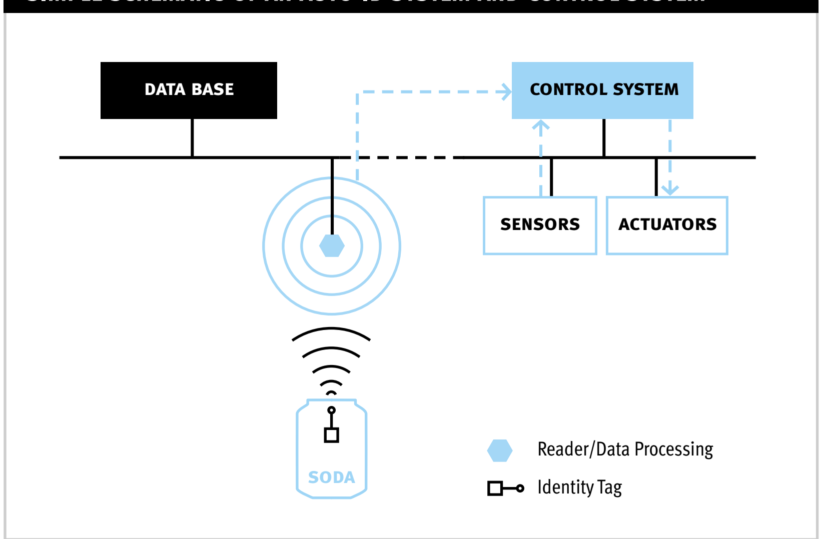
Automated identification systems have been used industrially for almost twenty years. More recently the aim of the work of the Auto-ID Centre – see **www.autoidcenter.org** – has been to develop standards and network infrastructure, for enabling unique, item level identity and related product information, to be uniformly available to enhance production, distribution, storage and retail processes in the supply chain (Sarma, 1999). The Centre is also helping to bring the price of the automated identification process down so that it becomes feasible to consider the automated identification of everyday retail items. The initial systems being developed draw heavily on past and current developments in the area of Radio Frequency Identification (RFID) – see (Finkenzeller, 1999) and the references therein. RFID provides a simple means of obtaining unique, item level identity data, increasingly at a reasonably low cost. (Sarma, 2002) These systems can be coupled to networked data bases which enable additional data to be held about the item.

A simple overview of a typical Auto-ID system is now provided. The intention here is not to provide a definitive description (the reader is referred to Sarma, 1999). Referring to left hand side of Figure 1 we note the following features:

1. An identity tag attached to a product with a chip capable of storing a unique identification number and communicating this number via an RFID communication system.
2. Networked RFID readers and data processing system capable of collecting signals from multiple tags at high speed (100s per second) and of pre-processing this data in order to eliminate duplications and misreads.
3. One or more networked data bases storing information related to the product (basic product data, tracking history, processing instructions) whose entries are uniquely bound to the product identification number.

Figure 1

SIMPLE SCHEMATIC OF AN AUTO-ID SYSTEM AND CONTROL SYSTEM



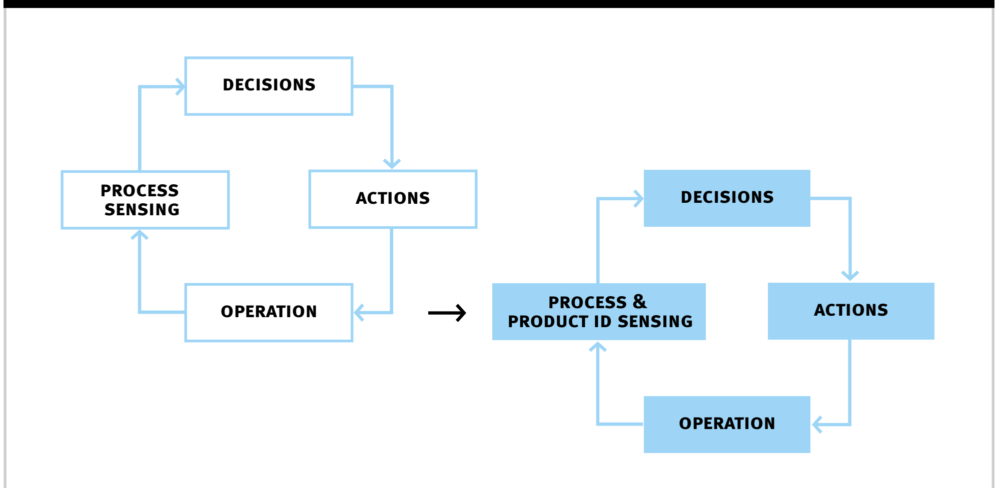
3. AUTO-ID AND INDUSTRIAL CONTROL

3.1. Auto-ID and Closed Loop Control

In Figure 1 we also include a networked control system, which has direct access to the identity information, generated in addition to other sensed information from the operating environment. On the basis of sensed information, the control system makes decisions and initiates actions based on the process and product identity information through appropriate commands to the actuators. Figure 2 illustrates the simple feedback loop of a control system and demonstrates the role automated identification has in enhancing this loop. The issue of introducing data from automated identification systems into closed loop control environments, and thereby enabling a greater customisation of control action, has previously been introduced in McFarlane (2002) where a range of different application areas across the supply chain were identified.

Figure 2

GENERAL IMPACT OF AUTO-ID ON CLOSED LOOP CONTROL



3.2. Auto-ID in Today's Industrial Control Systems

Initially, the simplest benefits from the deployment of Auto-ID systems in the manufacturing supply chain will be to improve tracking and hence a product's visibility and traceability. Many enhancements to existing materials, handling, and storage solutions based on this increased accuracy of data, have been proposed – we refer the interested reader to the numerous business case reports on **www.autoidcenter.org** or to papers on manufacturing applications (McFarlane et al, 2002), supply chain management (Wong et al, 2002b), retail (Sydalio, 2002) and product life cycle management (Bajic, 2002). These changes, while significantly enhancing the sensing part of the underlying control system, make little fundamental alteration to the overall control system itself. This is illustrated in Figure 3 for the case of a manufacturing control system. A manufacturing control system (Figure 3a) consists of a hierarchy of nested control loops of the form in Figure 2 in which higher level decisions (e.g. order planning) are broken down into a series of smaller, shorter term decisions (e.g. machine setting determination). Requirements flow down the right hand side and sensing/reporting in increasingly aggregated forms flows up the left side. Figure 3b then shows the impact of product identity information on this control system hierarchy. Rather than have the order status determined solely from equipment derived information, the status of the products themselves is used to provide a more representative indication of order status. Note however, that the "decision" and "action" sections at the right hand side of Figure 3b are not changed.

Figure 3a: Impact of the introduction of product sensing on an industrial control system

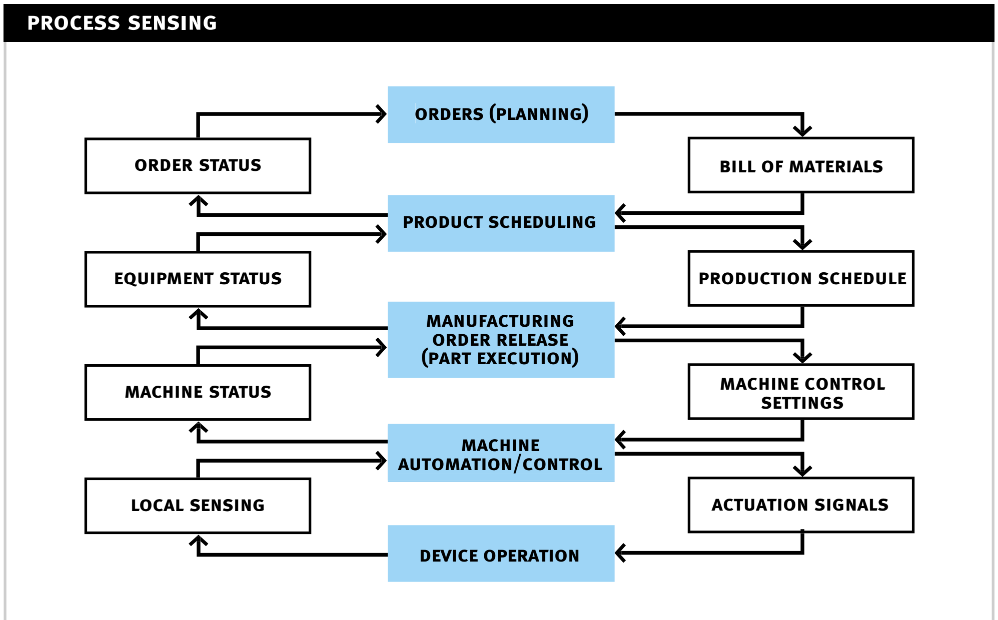
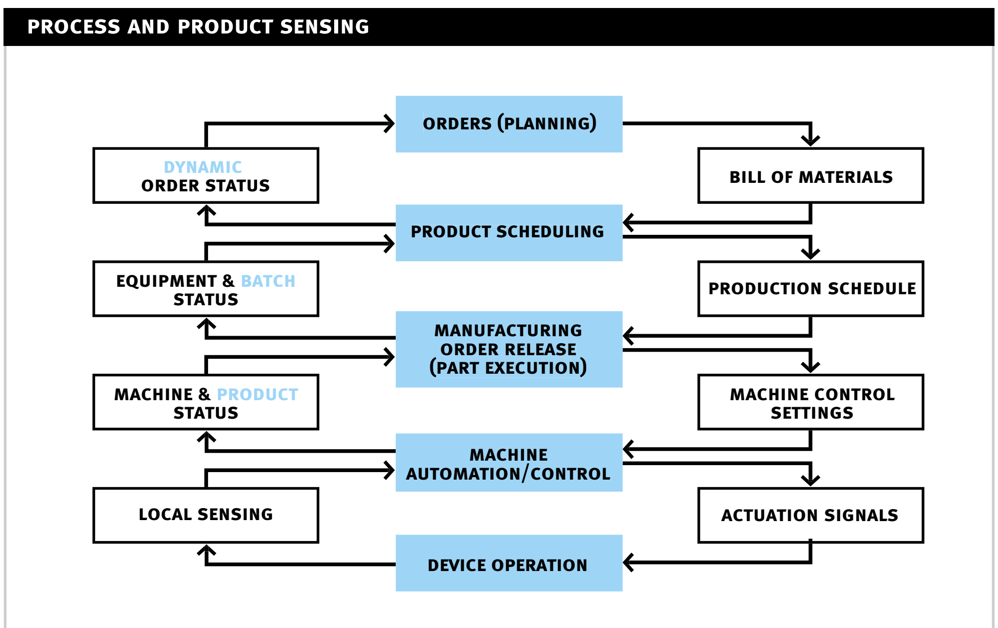


Figure 3b: Impact of the introduction of product sensing on an industrial control system



We note however, that the impact of product identity data can be even more fundamental for industrial control – enabling new, more flexible and adaptive control structures. (We will discuss this more in McFarlane, 2003). It is the fact that collection of product identity data can be automated, and used to uniquely identify a specific item in real time, that is of most benefit when considering fundamental changes that automated identification might result in. It is this last characteristic that the remainder of the paper focuses on.

4. THE OBSERVABILITY OF INDUSTRIAL OPERATIONS

In this section we introduce the idea of **observability** as a means of more rigorously describing the idea of product or order **visibility** which is so central to the rationale behind the Auto-ID Centre's work. By more clearly specifying these concepts, we hope it will be simpler to understand and quantify the generic implications of the large scale deployment of Auto-ID systems.

4.1. A Simple Representation of Industrial Operations

To begin it is necessary to provide a generic way of describing different supply chain processes – essentially any operation involving a flow and/or storage of products. We do so by introducing two terms – **states** and **transitions**.

Definition [State]
The states of a system, are the sets of variable quantities, which can completely describe the system at a given point in time.

Definition [State Value]
The allowable values that a state can take are referred to as state values.

Definition [Events]
Events define the way in which a system moves from one set of state values to another.

Hence an industrial operation can be simply described as a set of states which can take on a number of values with a defined set of events between each.

For example – consider a simple filling and emptying of a box. The box has a single state representing the `BOX CONTENTS`. The allowable state values are either `"FULL"` or `"EMPTY"` or more conventionally `1` or `0`. The events that can occur are `"FILLING"` or `"EMPTYING"`. Note that at this point we do not differentiate between the different types of contents that may be placed in the box or for that matter the unique identity of each item that may be placed in the box. This leads us to some additional definitions of state types that can occur in a supply chain context:

Definition [Operational States]
The set of variable quantities which can completely describe the status of an operation at a given point in time.

Definition [Product Type States]
The set of variable quantities which can completely describe the type of products in an operation at a given point in time.

Definition [Unique ID States]
The set of variable quantities which can completely describe the range of individual items in an operation at a given point in time.

Returning to the box example, we can now see that in order to completely know the current fill status of the box in full detail, we require information about all three state types – this has clear implications for the type of sensing used in an automated environment to check the box status.

4.2. Product Identity and Observability

Based on the above descriptions, one interpretation of the impact of the product identity data in a supply chain context is that **without it**, there is a reduced **observability** of the states of the system – where the system might for example represent the production, storage, transportation and retail processes to which a product is subject to during its life cycle.

We define observability (loosely) in the following way:

Definition [Observability]
The ability to completely determine the value of all of the states of a system at any given time given available measurements.

Based on this general definition and the definitions of states in the previous section we then make three further definitions which are specific to operations in the supply chain.

Definition [Operational Observability]
The ability to completely determine the value of all of the operational states of a system at any given time given available measurements.

Definition [Product Type Observability]
The ability to completely determine the value of all of the product type states of a system for any at any given time given available measurements.

Definition [Unique Item Observability]
The ability to completely determine the value of all of the unique item states of a system for any at any given time given available measurements.

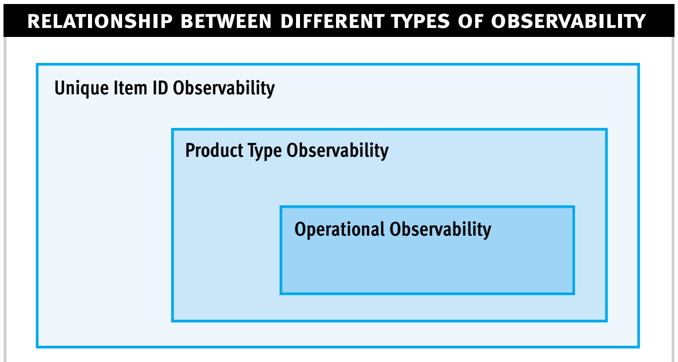
The critical issues resulting from these definitions are the following:

1. As discussed above, the level of observability can be directly related to the type of product sensing being used. Operational observability can be achieved through simple, appropriate proximity sensing, product type observability requires a sensing system that includes the sensing of product type, and unique item observability requires a sensing system capable of capturing the unique ID of a product at appropriate points in the system.

2. Unique Item Level Observability is a more stringent requirement than Product Type Observability, which in turn is more stringent than Operational Observability. (This is illustrated in Figure 4.)

Figure 4

RELATIONSHIP BETWEEN DIFFERENT TYPES OF OBSERVABILITY



Returning to the box example yet again, it is clear that with a proximity sensor alone monitoring the contents of the box, it does not have complete Product Type or Item Level Observability. Informally, we say that this system is only **partially observable** with respect to Product Type or Item Level.

We conclude this section by noting that – despite the comments made above – Product Identity on its own is in fact rarely sufficient to fully observe the states of an operation. The requirement for true observability is rather more subtle. Many automated product identity sensing devices – such as RFID systems – are **directionally agnostic** in that they sense information within a read-range without actually sensing the direction it comes from. In order to truly observe the state space defined by both process operations and product types, it is in fact necessary to determine both location and identity information in a coordinated manner.

5. ILLUSTRATIVE EXAMPLE – AN INDUSTRIAL STORAGE BUFFER

5.1. Overview

By way of example, we now consider storage of products within a prototype customised packing cell, that has been developed in the Institute for Manufacturing at Cambridge University, Engineering Department, as a demonstration system for the Auto-ID Centre and its industrial sponsors. The cell in Figure 5 shows individual retail items arriving in a random sequence on the left conveyor, being identified then stored, or directly packed into a customised "gift box" whose identity is linked to a set of instructions which directly drive the control operation. This system is described in significant detail in Hodges et al, 2002.

Figure 5

SCHEMATIC OF PROTOTYPE CUSTOMISED PACKING CELL

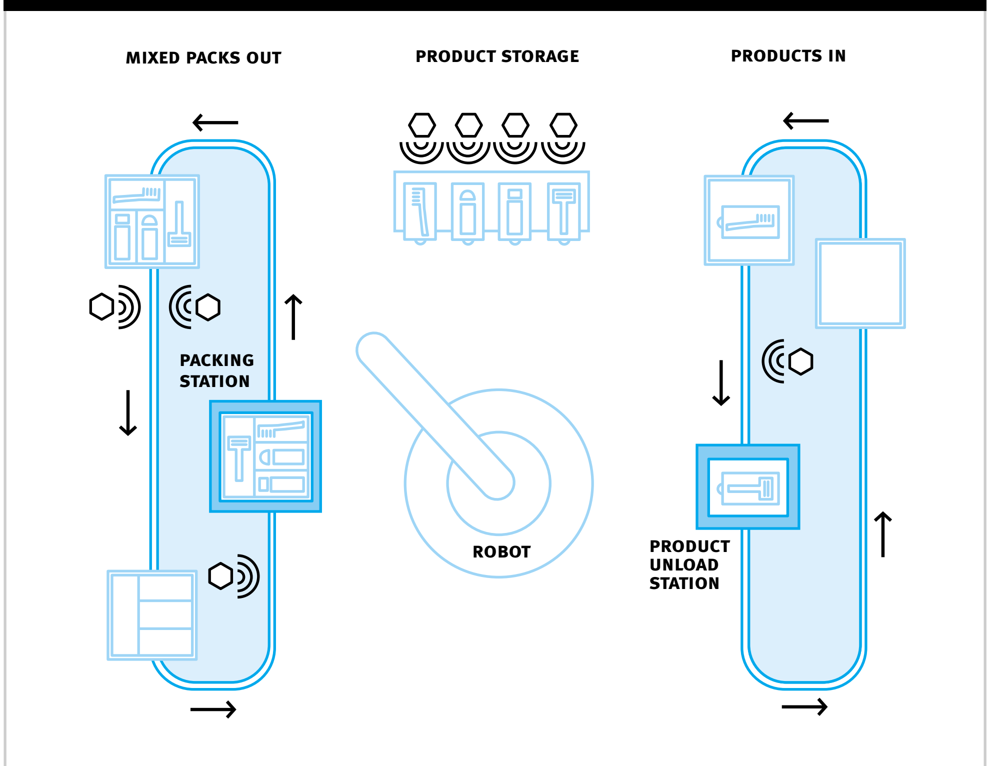
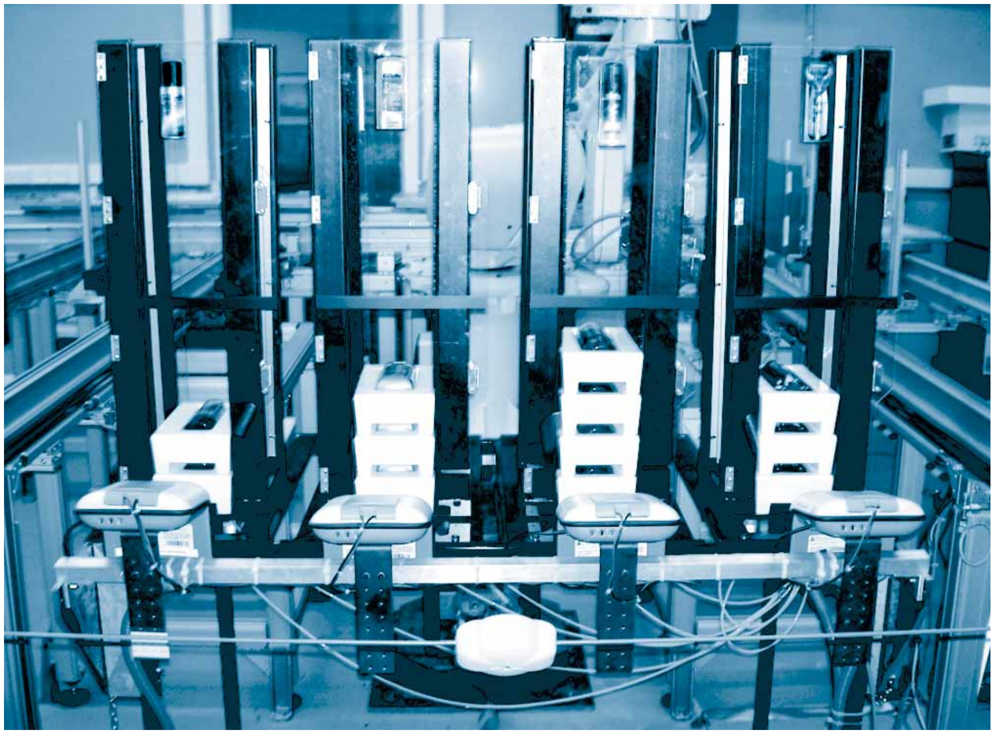


Figure 6: Product Storage System in Prototype Customised Packing System



This example focuses specifically on the simple addition to and removal of items from the product storage zone, which is illustrated in Figure 6. We note that the exit from each first-input, first-output (FIFO) storage "stack" is viewed by an RFID reader and in addition, any item entering any one of the stacks is also read by an additional RFID reader (not shown). We also note that due to gravity, the stacks always fill from the bottom up.

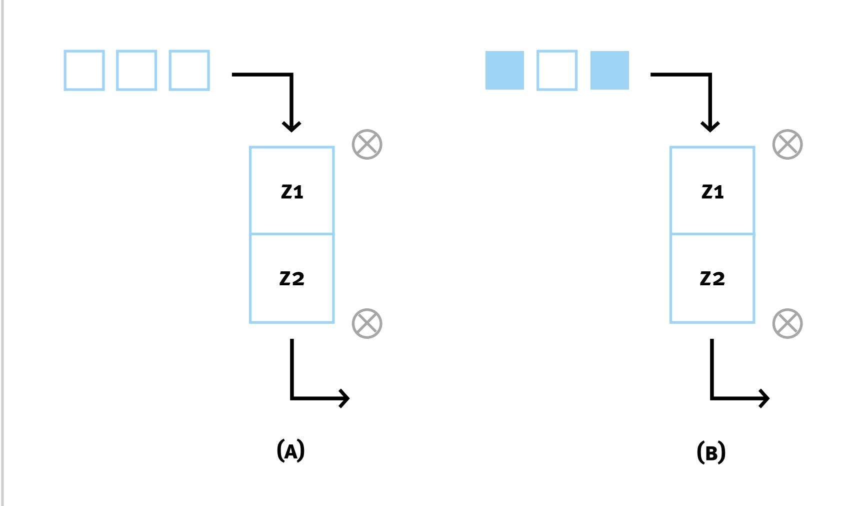
5.2. Modelling and Analysis

We simply aim here to show the impact product identity information has on the observability of the state of any one of the product stacks. Referring to Figure 7, it can be seen that the system has two states denoted Z_1, Z_2 corresponding to the available storage spaces. In this example we only compare Operational Observability and Product Type Observability but the results extend and are in fact more profound for the Unique Item case.

Initially, consider Figure 5 (a) in which there is only one type of product being loaded and unloaded and where there is a proximity sensor at both input and output. Then this system is both Operationally Observable and Product Type Observable simply by using the proximity sensors, as there is no variability in product type requiring detection. However, in the case of Figure 7 (b) in which there are now two products types arriving to be stored, the simple proximity sensor is insufficient to ensure Product Type Observability. Full observability could be restored by the replacement of the proximity sensors with a suitable product type sensor. The extension of this example to unique item level identification can be achieved by considering every new product arriving to be of its own unique product type – i.e. we are considering a batch size of one under all circumstances! Under such conditions only an automated identification system can achieve full Unique Item level Observability for this system.

Figure 7

SCHEMATICS OF PRODUCT STORAGE STACK



6. OBSERVABILITY AND CUSTOMISED INDUSTRIAL CONTROL

Although not discussed in detail in this paper, the implications of the addition of product identity sensing on the control of supply chain operations are immediately clear and quite far reaching. The ability to customise production or materials handling operations is known to be directly linked to the flexibilities of the corresponding equipment required to carry out the task. Less well understood yet equally important is the issue dealt with in this paper. Namely, without product identity sensing it is immaterial whether flexible equipment is available or not!

In the case of the single product stack described in the previous section, the use of Auto-ID sensors is perhaps excessive given the FIFO nature of the storage device – i.e. there is insufficient flexibility in the equipment to warrant the fidelity of sensing. However, when four stacks are used simultaneously there is sufficient cause for such sensing. This relationship between this behaviour and supervisory control performance will be the subject of a further paper (McFarlane, 2003) which will address the issue of the improved fidelity of industrial control brought about by automated identification.

7. ACKNOWLEDGEMENTS

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